Low Cost 8W Off-line LED Driver using RT8487

Abstract

RT8487 is a boundary mode constant current controller with internal high side driver, which can be used in buck and buck-boost configuration, to provide a constant output current to the (LED) load. It contains special circuitry for achieving high power factor and low input current THD, while minimizing external component count. The small SOT23-6 package keeps application footprint small, and makes RT8487 a cost effective solution for off-line LED drivers.

This application note provides details on how to design a cost effective 8W Buck LED driver with RT8487.

Contents

1. Introduction

Important requirements for low cost off-line LED drivers are high efficiency, good Power Factor with low THDi fulfilling IEC61000 class C, accurate LED current, fast start-up, and simple design using low cost standard components. The following 8W LED driver design with RT8487 in floating buck configuration fulfills all of the above.

Key specifications:

- Input range 230V +/-15% (with some alterations, the design can be extended to full range input)
- LED string 27V , I-LED = 300mA +/- 5% , P-out=8W for general retrofit lighting applications
- THDi < 20% fulfilling IEC61000 class C
- Start-up time < 300msec
- Full protections: output short-circuit, LED open circuit, over current and over temperature protection.
- Key focus on low BOM cost by using transformer-free design with standard low cost components.

2. Application Circuit

The total application of the 8W LED driver is shown below.

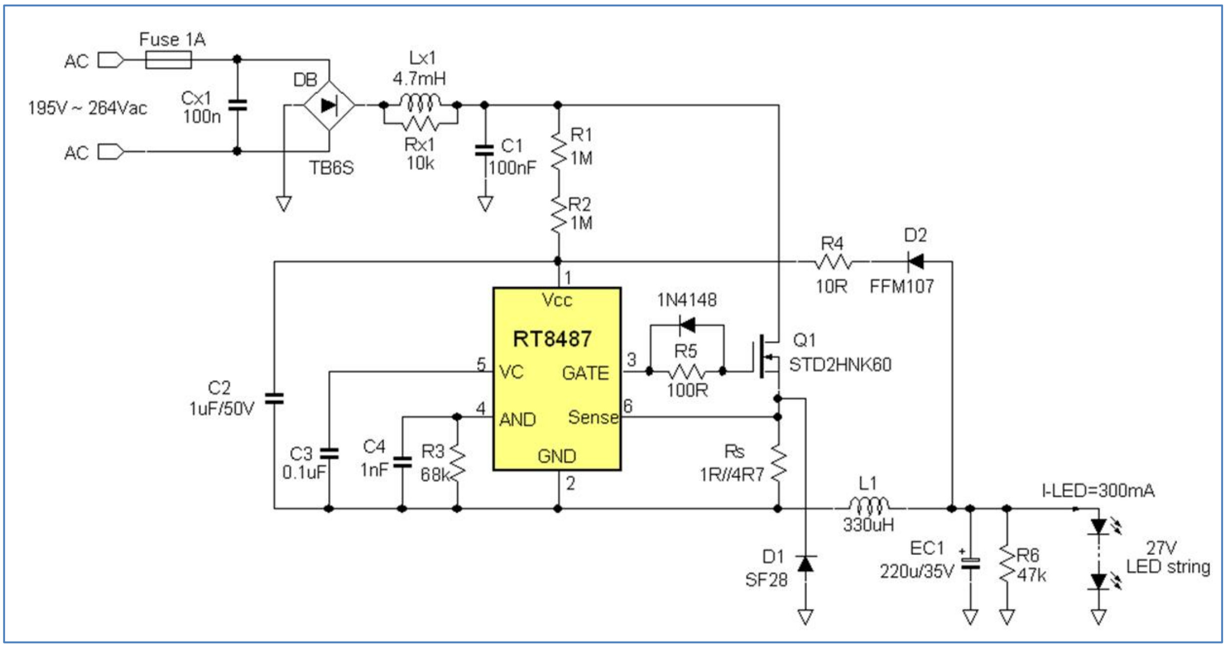

Figure 1

RT8487 is used in floating controller buck configuration. The complete application circuit is shown in figure 1. The IC controls the switch-on time of the high side MOSFET Q1, and it senses the average LED current via R_S which is in series with the buck inductor for true load current sense. Boundary conduction mode switching is obtained by sensing the zero inductor current (also via R_S). High efficient resonant switching at minimum drain-source voltage is achieved by programmable switch-on delay from zero current detection point (via R3). A smart algorithm controls the ON time to obtain high input power factor and low THDi. IC bias is provided by a simple bootstrap circuit D2 & C2, thereby eliminating the need for a separate auxiliary winding. This makes it possible to use a simple standard drum coil instead of a more expensive custom wound transformer. Low IC start-up bias current allows the use of high value start-up resistors R1 & R2 while still achieving fast start-up (typically 123msec). The total circuit can be built on a small single-sided PCB measuring 18 x 36mm.

3. Calculation of the Key Components

The following sections explain the settings of the various application parameters.

Setting Average Output Current

The average output current that flows through the LED string is set by an external resistor, R_S, which is connected between the IC GND and SENSE terminals. Since R_S is connected in series with the inductor, the average LED current can be accurately sensed via this resistor. The relationship between output current, I_{OUT}, and R_S is shown below :

$$I_{OUT} = \frac{250mV}{R_S}$$

In this application, LED current was defined as 300mA, so $R_S = \frac{250mV}{300mA} = 0.833\Omega$

We select 1Ω//4.7Ω to obtain 0.824Ω

Start-up Resistor

The start-up resistors (R1+R2) should be chosen such that the current flow through these resistors at minimum line voltage exceeds the IC start-up current. Otherwise, the RT8487 Vcc may never reach the start-up voltage. The typical IC start-up current is 25μA.

Start-up resistor should be chosen not to exceed the operating current. Otherwise, the VCC voltage may rise higher than set by the Vcc bootstrap circuit, and could trigger OVP. The typical operating current is 1mA.

The value of the start-up resistor together with the VCC capacitor C2 will determine the start-up time, which is defined by:

$$t_{start-up} = C2\frac{V_{UVLO}}{I_{start-up}}$$

where V_{UVLO} is 17V and $I_{start-up}$ can be approximated by: $\frac{V_{in}\sqrt{2}}{(R1+R2)} - 25\mu A$

For most applications, C2 can be chosen 1μF.

R1 and R2 are chosen 1MΩ each, which gives a typical start-up current of $\frac{230\sqrt{2}}{2M\Omega} - 25\mu A = 138\mu A$

The start-up time will become: $1\mu F \cdot \frac{17V}{138\mu A} = 123msec$

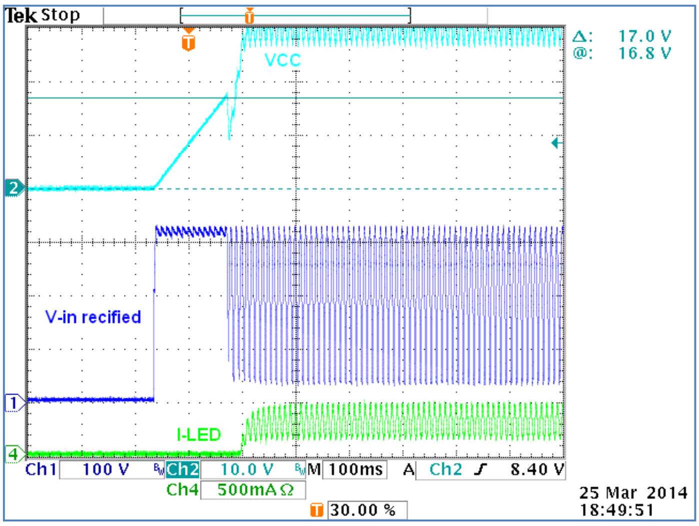

Figure 2

Figure 2 shows the IC start-up waveforms at 230V ac input.

When AC mains is applied, the current through R1 and R2 will charge C2.

When the IC VCC voltage exceeds the UVLO level, the power MOSFET starts switching, quickly charging the output.

Total measured start-up time was 150msec.

Input Capacitor Selection

For High Power Factor application, the input capacitor C1 should be sufficiently small to achieve rectified line voltage sine-wave. The voltage rating of the input filter capacitor, VCIN, should be large enough to handle the maximum input voltage. A 100nF / 500V film capacitor is a suitable choice. For reducing differential mode EMI, a pi filter can be used by means of two 47nF capacitors and a suitable inductor.

Buck Inductor Value Selection

Due to Boundary Conduction Mode switching, the buck inductance value will influence the converter switching frequency. For smaller size coil, a small inductance value could be selected, but the limitations are set by the IC minimum ON time (0.5μsec typically) and minimum OFF time (0.5μsec typically).

The maximum inductance value is limited by the IC maximum ON time (15μsec typically) and maximum OFF time (33μsec typically).

To calculate the inductance, we first need to calculate the maximum peak current (I_{peak}) at the top of the rectified sine wave (V_{peak}) :

$$I_{peak} = \frac{2P_{in}}{V_{peak} \cdot F(K(\alpha))}$$

where Pin is the converter input power, a is the ratio of LED voltage versus BUCK input voltage: $a = \frac{V_{LED}}{V_{peak}}$

and F(K(a)) is a complex function to achieve low THD for PFC buck:

$$K(a) = \frac{1-a}{a}, F(K(a)) \approx -0.411a^4 + 0.296a^3 - 0.312a^2 + 0.638a - 0.0000846, \{a \mid 0 \sim 0.7\} \quad (1)$$

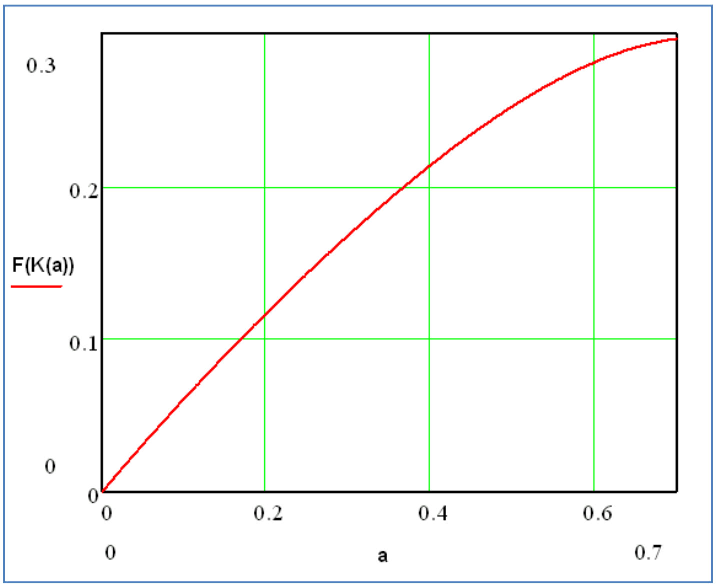

Figure 3

In the 8W application, Pin can be calculated from $\frac{P_{LED}}{\eta} = \frac{27V \cdot 0.3A}{0.86} = 9.4W$ (efficiency was estimated at 86%)

The factor a can be calculated at the peak of the rectified sine wave: $a = \frac{27V}{230\sqrt{2}} = 0.082$

From Figure 3 or formula (1) we can derive, $F(K(a)) = 0.051, so\ I_{peak} = \frac{2 \cdot 9.4}{230\sqrt{2} \cdot 0.051} = 1.12A$

The range of inductance can now be calculated from: $L = \frac{V_{LED}}{I_{peak}} T_{off}$ and $L = \frac{(V_{peak} - V_{LED})}{I_{peak}} T_{on}$

L1 was chosen 330μH with current rating 1.2A to achieve best compromise between size, cost and efficiency.

The frequency at the top of the sine wave can be calculated: $F_{SW} = \frac{1}{T_{on} + T_{off} + T_{delay}}$

(T_{delay} is determined by the resistor connected to AND pin, see next section)

Setting the switch-on delay time

After the inductor current has reached zero, a resonance will occur between the inductor and the total capacitance at the switch node, which is mainly determined by the MOSFET drain-source capacitance.

In order to minimize the MOSFET switching losses, RT8487 provides the flexibility to adjust the delay time of next switch-on cycle in order to switch-on at the maximum point of the resonance, which corresponds to the minimum drain-source voltage value.

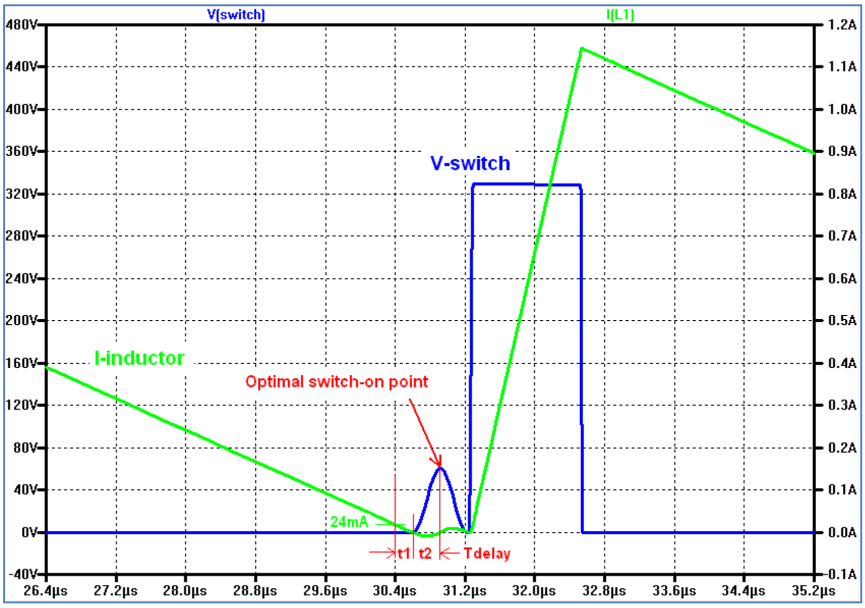

Figure 4

The delay time from zero current point to the maximum of the switch resonance (T_{delay} in figure 4) which can be calculated from: $T_{resonance} = \pi\sqrt{L1 \cdot C_{SW}}$ where C_{SW} is the capacitance at the switch node, mostly determined by the MOSFET drain-source capacitance, which in this application equals 38pF. The resonance delay becomes: $T_{resonance} = \pi\sqrt{330\mu H \cdot 38pF} = 352nsec$

The total required delay time for optimal resonant switching needs to be chosen a bit larger to include zero current detection delay (around 290nsec in this case). So total delay time becomes 270nsec + 352nsec = 622nsec.

The delay time (T_{delay}) from zero current detection point to next MOSFET switch-on cycle can be adjusted by the resistor value R3 connected between AND pin and IC GND

$$T_{delay}(\mu s) = \left(-0.6 * R3^2 + 3600 * R3 + 405200\right) * 10^{-6} \quad (2)$$

- T_{delay}= approximate total delay time in µsec
- R3 resister value in kΩ

The final value for R3 was set at 68kΩ.

Figure 5 below shows the switching waveform with optimal resonant switch-on point.

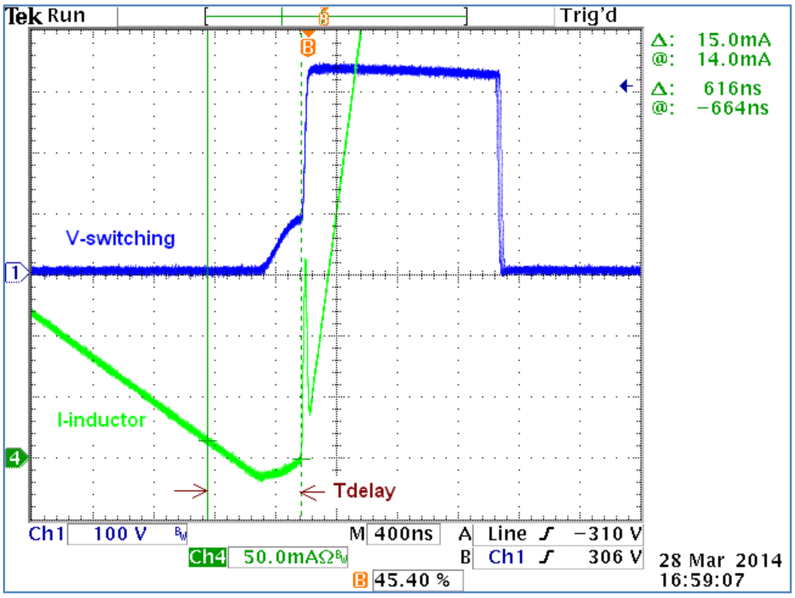

Figure 5

MOSFET Selection

The MOSFET voltage rating should be sufficient to handle the max line input voltage peak value + margin for line transients. A MOSFET with minimum 500V drain-source rating is recommended. The MOSFET current rating depends on thermal aspects. A 2A MOSFET was selected for low dissipation and better efficiency.

Forward Diode Selection

When the power MOSFET turns off, the path for the current is through the diode connected between the switch output and ground. This forward biased diode must have low forward voltage drop and fast recovery times. The reverse voltage rating of the diode is should be greater than the maximum input peak voltage + margin and the current rating should be greater than the inductor peak current. A fast 600V / 2A diode was selected for low dissipation and better efficiency.

Output Capacitor Selection

To achieve high power factor and low THDi, the inductor current contains considerable low frequency ripple. The output capacitor will filter the switching and low frequency ripple current to deliver a low ripple voltage to the LED string. The amount of output ripple voltage together with the differential resistance of the LED string will determine the ripple current through the LEDs. In this low cost design, a 220μF capacitor was chosen, which gives around 330mApp ripple current through the LED string. To reduce this ripple, a larger value output capacitor is required.

4. Key Performance Measurements

Figure 6 shows the input and output voltage and current waveforms.

Input AC waveform shows good PFC and low THD. The average output LED current is accurately set at 299mA.

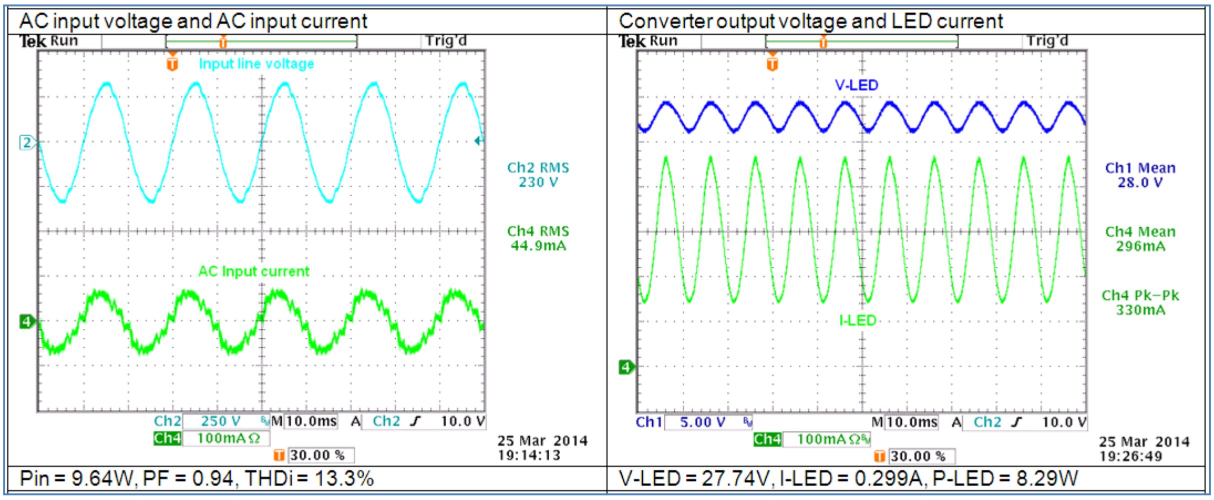

Figure 6

Figure 7 below shows the switching waveforms. To achieve low THDi, the current peak value is around 4x higher than the average current. The single switching cycle shows fully BCM switching with minimum drain-source voltage switch-on.

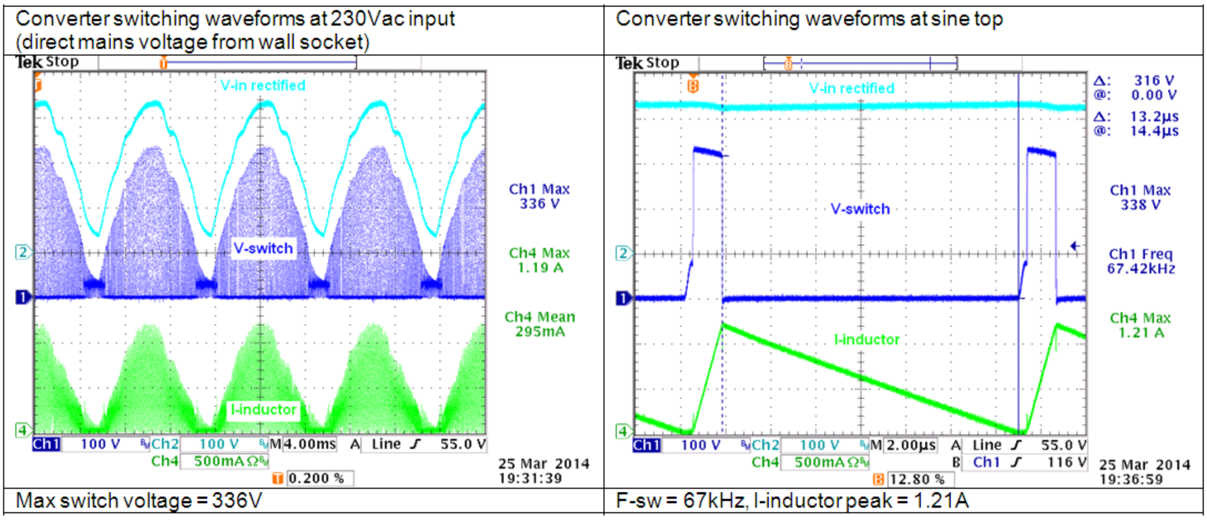

Figure 7

Below table shows the key performance parameters. Typical efficiency is 86% with excellent LED current stability over mains voltage and low THD fulfilling IEC61000 class C.

Vin ac	Pin ac	PF	THD	V-LED	I-LED	Pout	Efficiency	Ploss
195.5	9.59	0.96	11.6	27.69	0.299	8.279	86.3%	1.31
231.8	9.64	0.94	13.3	27.74	0.299	8.294	86.0%	1.35
264.2	9.68	0.90	17.7	27.68	0.300	8.304	85.8%	1.38

5. Total Bill of Materials

The total BOM of the 8W LED driver is shown below:

Item	Quantity	Reference	Part / Value	Footprint	Remark
1	1	F1	1A/250V	---	Fuse 1A
2	1	LX1	4.7mH (DR0612)	DR0612	EMI drum coil
3	1	L1	330μH (CKPK1012)	DR1012	Buck drum coil
4	1	CX1	0.1μF/275Vac	DIP	X-capacitor
5	1	C1	0.1μF/450V	DIP	MPP Cap
6	1	C2	1μF/50V	1206	
7	1	C3	0.1μF/50V	0603	
8	1	C4	1nF/50V	0603	
9	1	EC1	220μF/35V	DIP	Output E-cap
10	1	RX1	10K	1206	
11	2	R1, R2	1M	1206	
12	1	R3	6.8K	0603	
13	1	R4	10R	0805	
14	1	R5	100R	0603	
15	1	R6	47k	0805	
16	1	R_S	1R // 4R7	1206	
17	1	D1	SF28	DIP	Fast 2A/600V
18	1	D2	FFM107	SOD-123L	Fast 1A/1000V
19	1	Extra-D	1N4148	SOD-123	250mA/75V
20	1	DB	TB6S	---	600V/1A diode bridge
21	1	Q1	STD2HNK60	TO-251	2A/600V MOSFET
22	1	IC1	RT8487GJ6	TSOT23-6	LED driver controller

6. PCB Layout

The 8W LED driver application is build on a small single sided PCB. Due to the floating controller topology, the components around the IC should be compact and close to the IC, and the layout should provide sufficient creepage and clearance margin for the high voltage swing.

It should be noted that this layout is a preliminary version, and needs some further fine tuning to optimize performance: The buck inductor orientation with respect to EMI coil needs some modification: currently the stray field of L1 couples into LX1 and causes higher EMI readings.

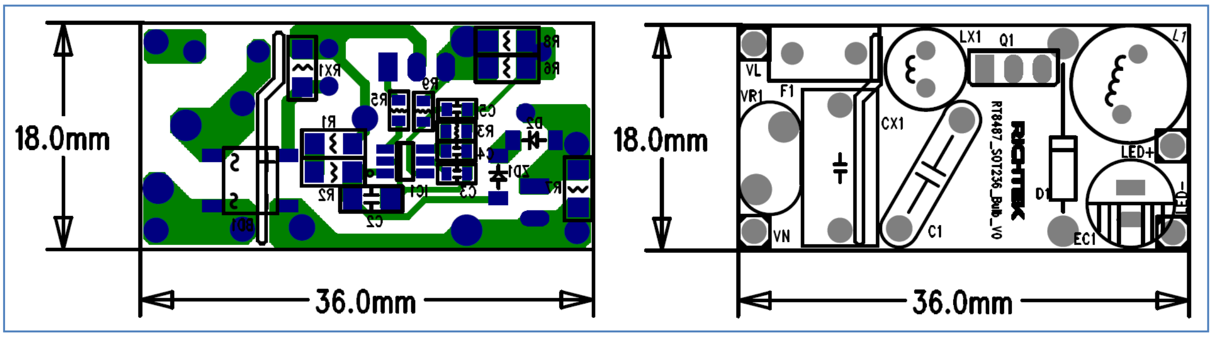

Figure 8

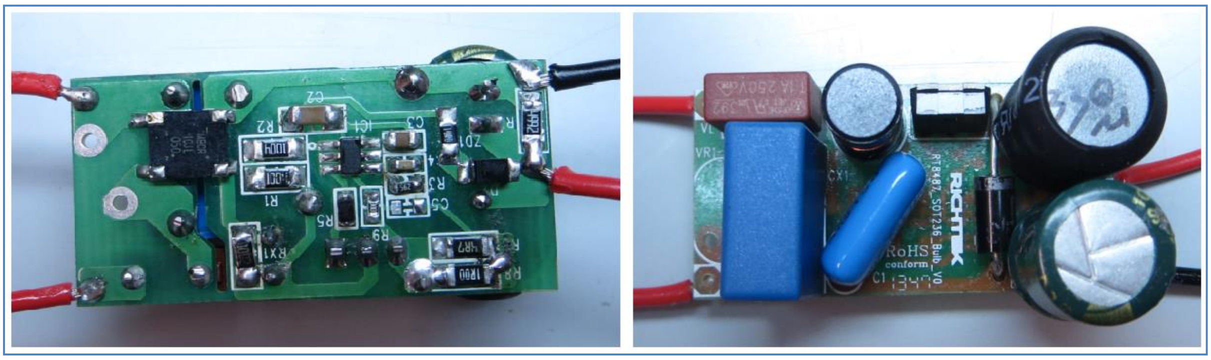

Figure 9

7. Conclusion

RT8487 makes it possible to design a very cost effective 8W LED driver which has good performance and meets the requirements of today's LED driver market.

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