Application Report

Lit. Number – Month Year

TPS92210 Single Stage PFC Flyback Design for 10W PAR30/38 LED lamp

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ABSTRACT

This document describes a reference design for PAR-38 LED lighting by using the TPS92210 to construct a single stage PFC, TRIAC dimmable Flyback converter. This driver provides 350mA to a string of nine white LEDs. It has the capability to be operated at 90~135Vac or 180~264Vac. The TPS92210 in a single stage PFC application was chosen because it offers many advantages - long life due to no high voltage aluminum electrolytic capacitors used in the design and good performance in power factor and THD. A thorough analysis of single stage PFC converter operation and performance along with design optimization guidelines are presented. Experimental results obtained on a 30V/350mA PAR-38 are provided.

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1 Introduction

The 10W LED driver reference design is a flyback converter with a single stage power factor corrector function. It provides a regulated output current nominally at 350mA with output voltages of 28V to 32V or 9 LEDs. It is designed for isolated AC-DC off-line applications, operating from an AC source of 90V ~ 264 V.

The reference design uses the TPS92210 flyback controller which integrates a low-voltage switch in the form of a 90-mΩ FET along with all associated current sensing and drive. This low voltage FET source drives a high voltage FET (HVMOSFET) to form a cascode configuration. This cascode configuration results in very fast turn-off of the HVMOSFET, which keeps MOSFET switching losses low. In addition, the cascode allows the HVMOSFET to operate as a series pass device during start-up to supply current to the bias supply capacitor at the VDD pin of the controller. Working with a TL431 it provides TRIAC dimmable function. On the secondary side, a TL103WA provides high accuracy and extra low loss current feedback and over voltage protection with easy design.

Proper precautions must be taken when working with this reference design. High voltage levels are present on the reference design, do not touch it when it is operating. The 10W LED isolated driver reference design is for reference only. It requires much more verification for any other usage besides test and measurement. Do not apply it to any end product directly.

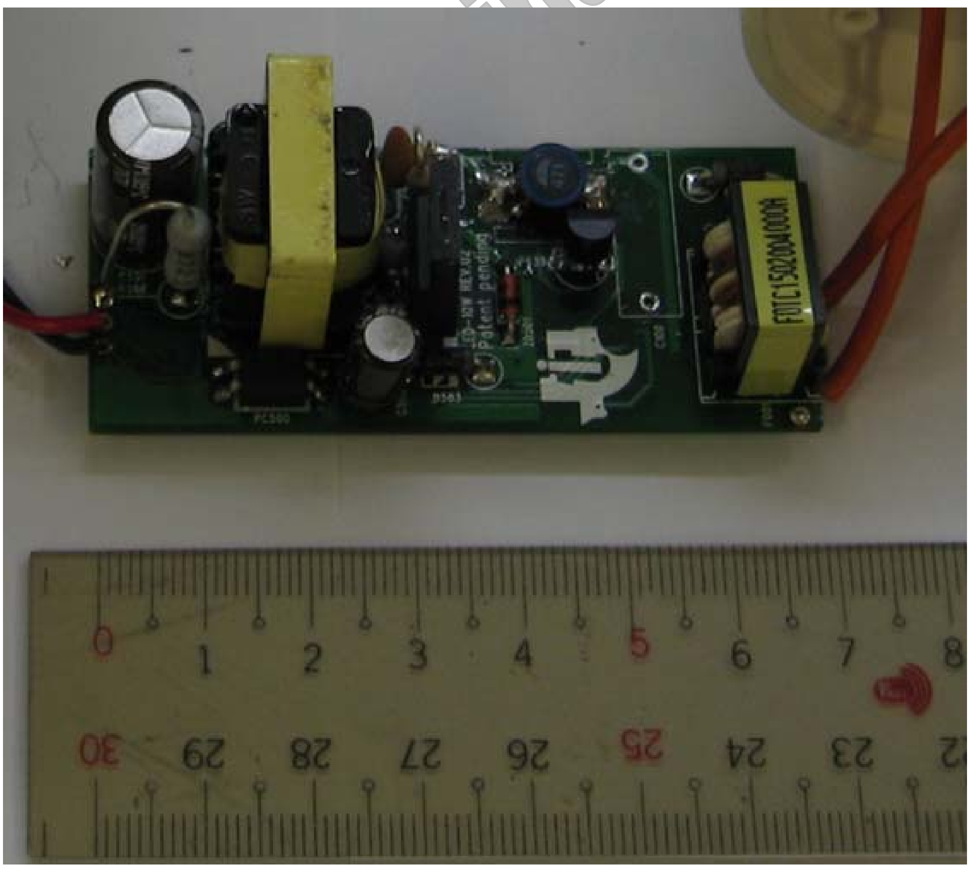

Table 1. 10W LED Driver Photograph

2 Description

2.1 Function

The 10W LED driver reference design includes the following functions. First, the TPS92210 is a cascode flyback IC that can be turned on with less loss. Second, the TL431 provides an additional current into the MOT pin to compensate high/low input voltage on time. Third, the TL103WA provides low loss and high accuracy current feedback and output voltage limited function.

2.2 Advantage

- TRIAC dimmable design
- High current accuracy
- High PF and THD lower than 10%
- No additional circuit for dimming
- Stable output when dimming eliminates LED flicker
- Low current sense loss

3 Electrical Performance

Table 2. Performance Table

Parameter	Min	Typ	Max	Units	Note
Input characteristics					
Input voltage	90		264	Vac	*1
Input frequency	47		63	Hz	
Input current			0.16	Arms	
Power Factor	0.94		1		*2
Output characteristics					
Output current	0.3	0.35	0.36	A	
Output voltage	32		28	V	
Output power		10.5		W	
System characteristics					
Efficiency		82%			*3
THD		6%	8%		
Dimming turn on level		30%			
Minimal brightness		1.00%			

1. Although the design can work normal through 90~264, it is separated into 90~135 and 180~264 design by changing R004 and R005 for better performance.
2. Over 0.98 for low line
3. Test at 120V/240V R004,R005 22 Ohm for 90V~135V 68 Ohm for 180V~264V

4 Schematic

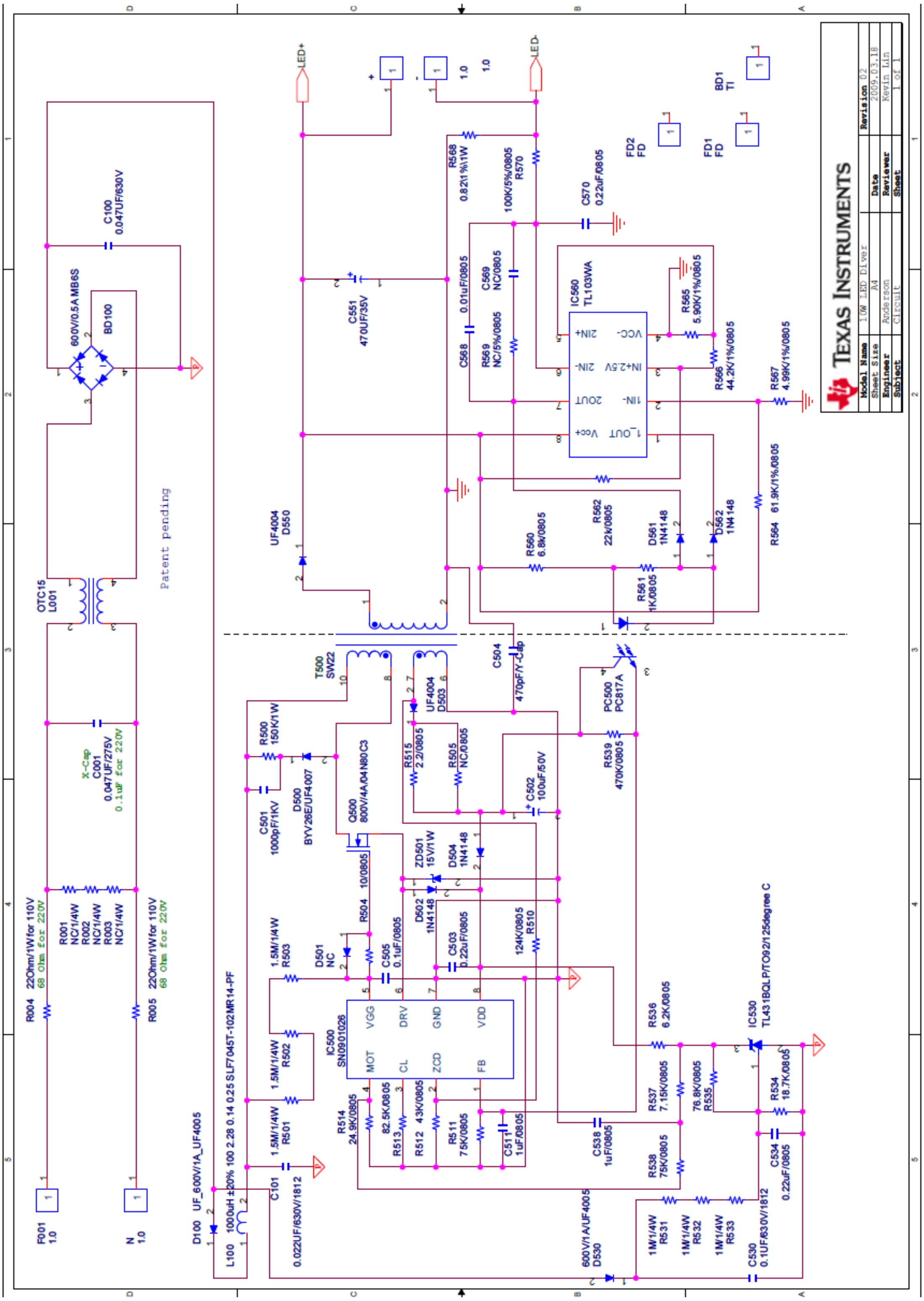

Table 3. 10W LED Driver Reference Design Schematic

5 Function Description

Figure 3 shows the LED driver's four basic function blocks. Each block is designed to help achieve the LED driver specifications. The driver is composed of an EMI filter, main controller, on time compensation and current feedback & voltage limit. The EMI filter block acts as a filter for both driver generated noise and TRIAC dimming noise. The main controller block is a cascode flyback converter based on the TPS92210. On time compensation block compensates on time relative to high/low input voltage. Current feedback & voltage limit block includes two op amps, one for current feedback the other for voltage limit.

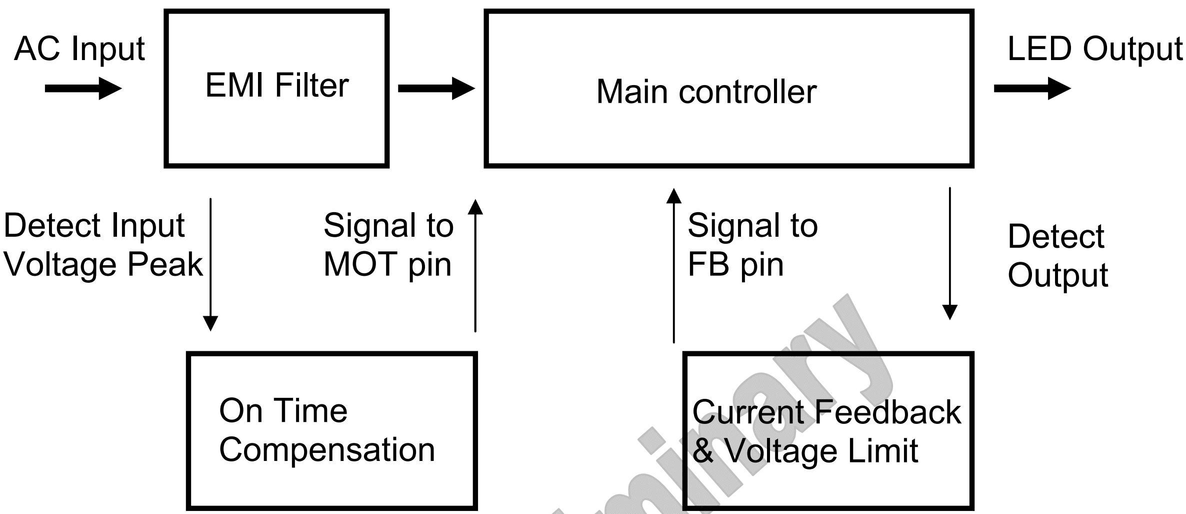

Table 4. LED Driver Function Block Diagram

5.1 EMI Filter

The EMI Filter is designed to pass CISPR 22 class B standard. It also reduces TRIAC dimming inrush current. Detail function descriptions of each key component are as following. L001 is a common mode choke to filter common mode noise and also, by using a four section bobbin to increase leakage inductance, it can help block differential noise. L100 is a differential choke; it is a key part to preventing differential noise. C001, C100 and C101 are capacitors targeting different frequency bands of EMI noise. The closer to the input, the lower its effective frequency is. C001 also works with R004 and R005 as a snubber to reduce the inrush current caused by the TRIAC. This inrush current can cause the TRIAC to shut down and results in flickering of the LED. The function of the C101 is to absorb switching frequency current to avoid extra loss in L100 and also avoid noise on the IC GND trace that might influence IC performance.

5.2 Main Controller

TPS92210 is a green-mode flyback controller for LED driver applications. The cascode flyback topology uses a fixed gate voltage and variable source voltage to drive the high voltage MOSFET. The variable source voltage is achieved by the integrated low-voltage 90-mΩ FET, which also provides primary side current sensing. The cascode configuration results in much lower loss during MOSFET current sensing. In addition, the cascode allows the HVMOSFET to be operated as a linear pass device during start-up to supply current to the bias supply capacitor at the VDD pin of the controller. The gate of the HVMOSFET is shunt regulated by the controller and requires a very low bias current supplied from the line voltage into a small bypass capacitor. This affords low stand-by losses and fast start-up of the flyback supply. Cascode also avoids having an IC pin directly connected to the high voltage input this reduces possible IC damag during a lighting surge. For more details please refer to the TPS92210 datasheet.

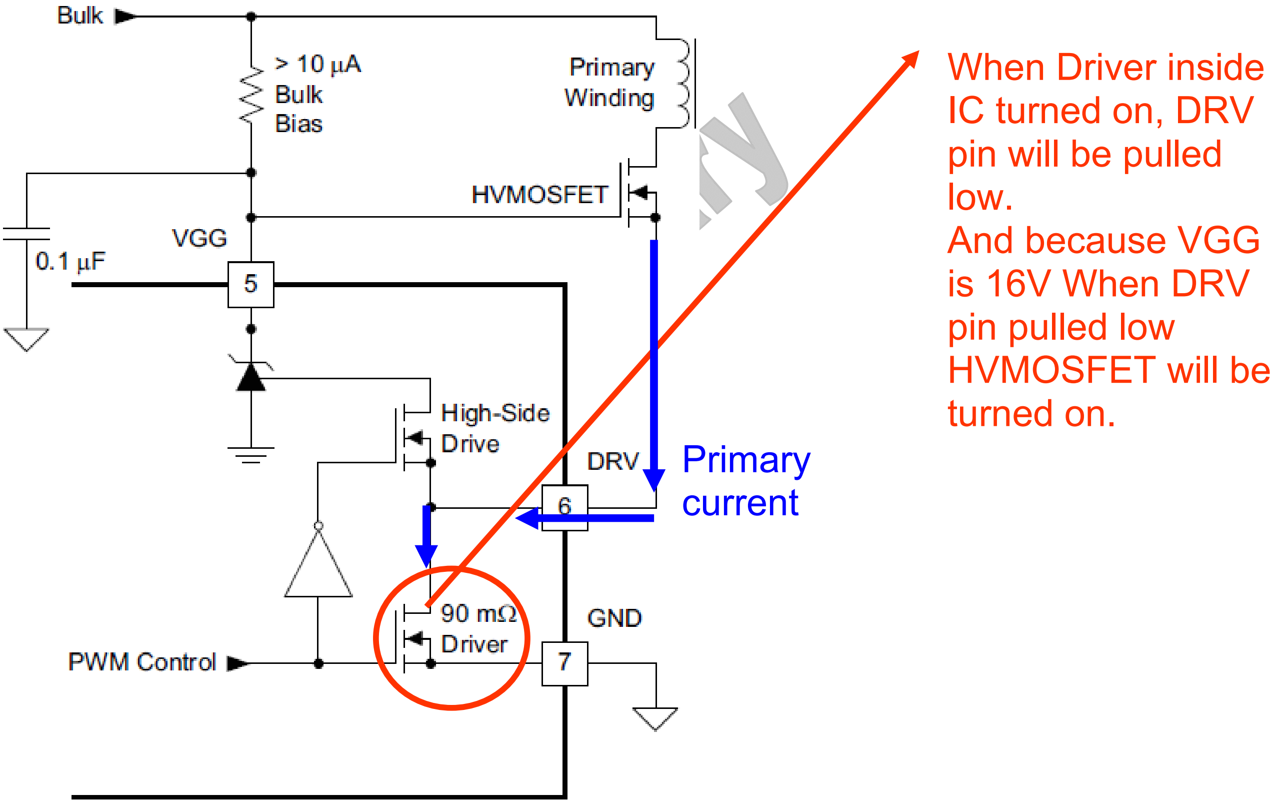

Table 5. **Theory of Cascode**

5.3 On Time Compensation

The on time compensation block uses a TL431 as an OP AMP to compensate the on time in accordance with the input peak voltage. D530 and C530 peak detect the AC input voltage through BD100+. Because the TL431 reference pin is always at 2.495V, the voltage at the cathode pin is inversely proportional to input voltage. Higher input voltage reduces the TL431 cathode pin voltage which makes the on time shorter. The circuit is set to not compensate the on time when input is equal to the maximum input voltage; in this case, the maximum input voltage is 285Vac. With this setting and with R531, R532, and R533 all equal to 1M Ohm. R534 is calculated as 18.7K. The TL431 cathode pin could be as lower as 10 V, because VDD drops during dimming, R535 is set to 76.8K. R514 is chosen as 24.9K to set the on time to 1.25us when the input is 285Vac and R538+R537 is about 82K to set the maximum on time to 5us when input is 90Vac. Circuit and detail are shown in Figure 5.

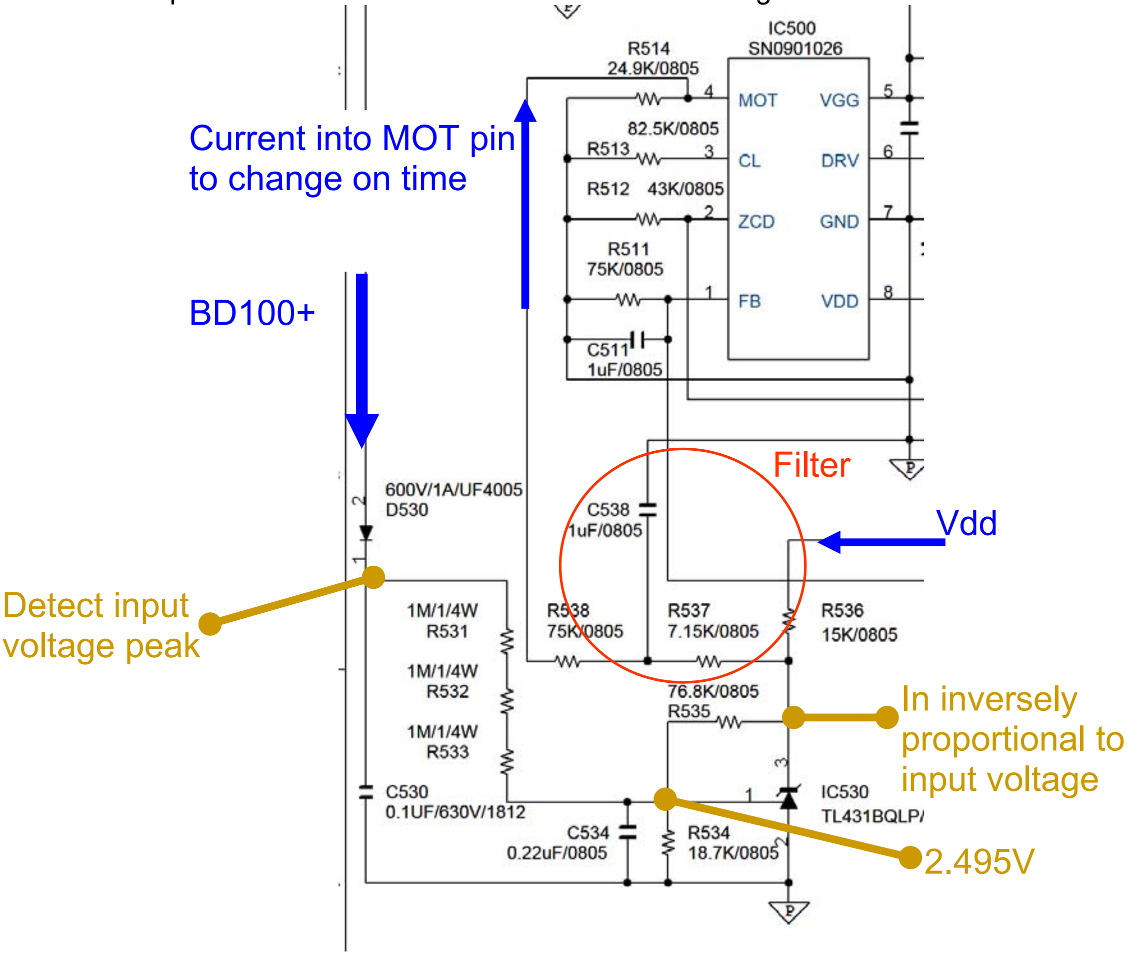

Table 6. **High/Low Line On Time Compensation**

5.4 Current Feedback and Voltage Limit

This block combines two functions in a single TL103WA; one is voltage limit and the other is current feedback. Voltage limit point is set by R564 and R567. When the output voltage divided by R564 and R567 is greater than 2.5V, TL103WA pin 1 is pulled low and the voltage limit function is triggered. Current feedback uses R568 to transfer output current into a voltage signal. R570, C570 and C568 work as a filter to convert the output 120Hz signal into a DC average voltage. This voltage is compared with the voltage which is set on TL103WA pin 5 to achieve current feedback. Detail is shown in Figure 6.

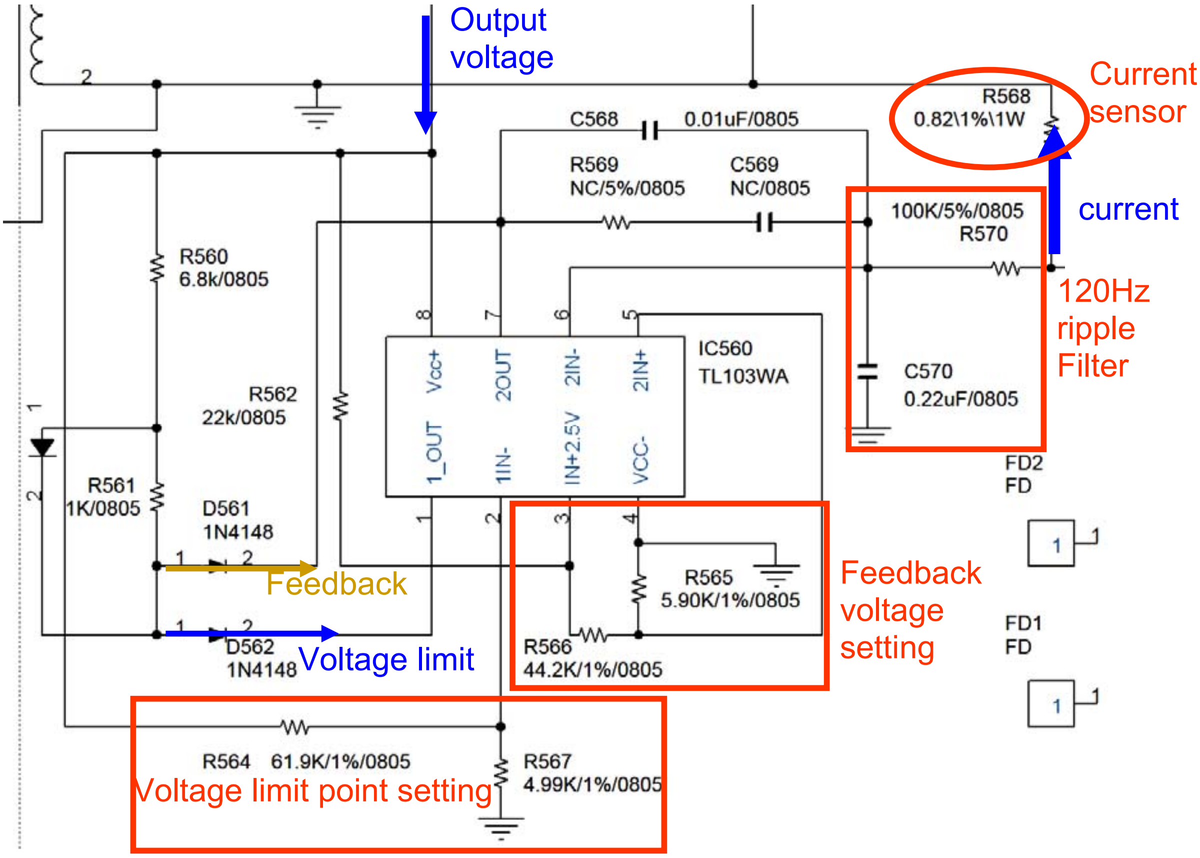

Table 7. **Current Feedback and Voltage Limit.**

6 Design Key Points

6.1 Transformer Design

Table 8. Transformer Design Tool

Vinmin=	90	AC		Vinmax=	285	AC			
	127.278	Peak			403.047	Peak			
Vo1=	30	V							
Io1=	0.35	A							
Po=	10.5								
Po_90degree=	21	W							
eff=	84	%							
Pin_90degreek=	25	W							
Vf1=	1	V							
Turn Ratio									
Np/Ns	2.7								
(VRO)=	83.7	Output voltage reflected to primary		set to 70~100					
OPP point	0	%more	Plim_90degree	25	W				
Freq=	79.7	KHz	Plim	12.5	W				
Freq=	79.7	KHz	frequency when power limit						
On time limit	4.977714	us	Must be less than 5us						
L=	639.8158	uH							
Total Power Limit Point									
Ipk	0.990212		Must be less than 4A						
Ae=	41	mm^2							
B=	0.3	T							
N>	51.50842	turns		Diode voltage rating			Winding current rating		
Winding turns				179.2767	V		RMS	0.42388	A
Tvo1=	20	turns							
Tpri=	54	turns	Must over	51.50842 turns					
Vdd=	19.15	V	Set to higher voltage to keep circuit work in wider output voltage						
Vdd diode Vf=	1	V							
Tvdd	13	turns							

Regarding the transformer design, there are two limits which should be obeyed because of TPS92210 limitation. One is that the on time should not be over 5us, and the other is that the transformer primary peak current should not be over 4A. Although the transformer on time can be set to 5us, it is recommended to use 4~4.5us to allow for transformer tolerances. One of the primary functions of the transformer is to maintain safety isolation between primary and secondary circuits. The transformer on this design does not fully meet these requirements.

6.2 Solutions to Common Flickering Issues

There are three different conditions which could cause flickering of the LED.

Firstly, the inrush current when the TRIAC is turned on. This occurs every cycle and is one of the most common causes of flickering. When the TRIAC is turned on, input voltage is much higher than the voltage on the driver C001, this voltage difference creates an inrush current. The inrush current charges all inductances in it's path, including L001, L100 and the choke inside the dimmer. This is then followed by inductance discharge. The voltage on C001 will become higher than the input voltage and the input current will become lower than the TRIAC holding current. The TRIAC will shut down when input current is lower than the required holding current. The following pictures show input and output current when R004 and R005 are shorted.

When R004 and R005 are removed inrush current sometimes shuts down the TRIAC and makes the output current unstable. Figure 7 shows input current changes, these are different for every cycle. Figure 8 shows the effect of the input current cycle by cycle variation makes on the output current. The output current is unstable and causes the LED light to flicker.

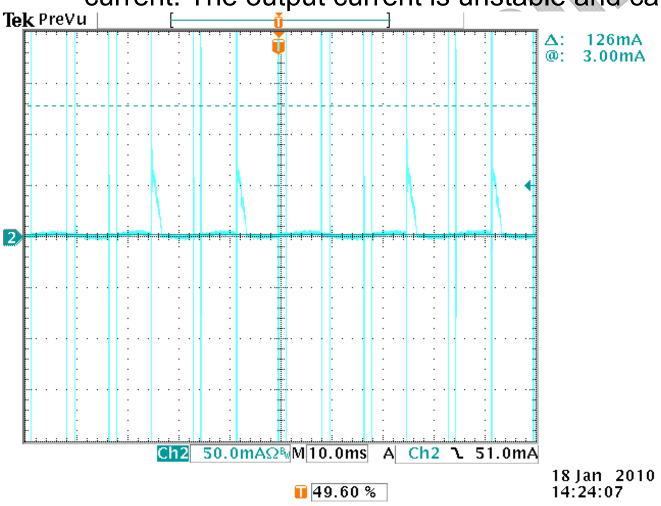

Table 9. Input Current Without R004, R005

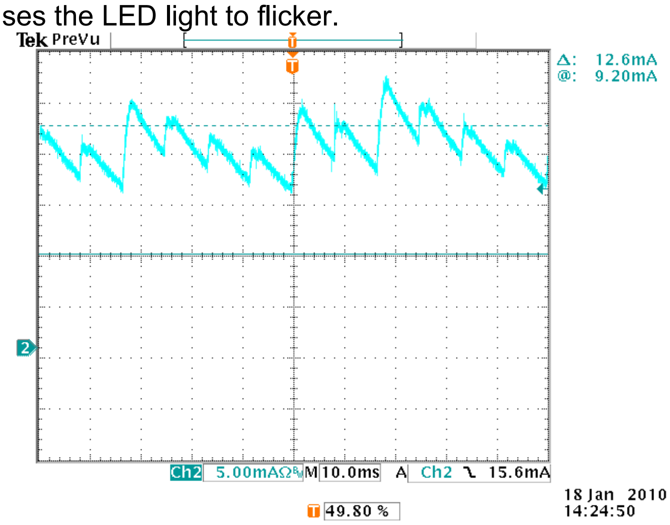

Table 10. Output Current Without R004, R005

When zooming in to see the input current we can find that without R004 and R005 the input current goes to zero and causes the TRIAC to shut down, see figure 9. After R004 and R005 are added the input current is the same every cycle, see figure 11.

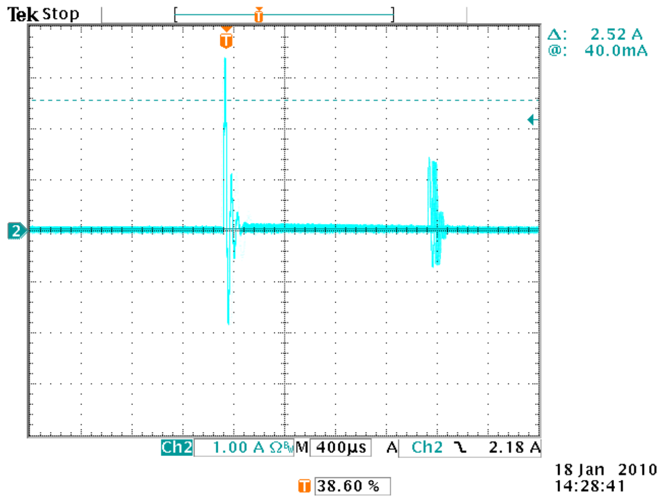

Table 11. Inrush Current Causes TRIAC to turn Off

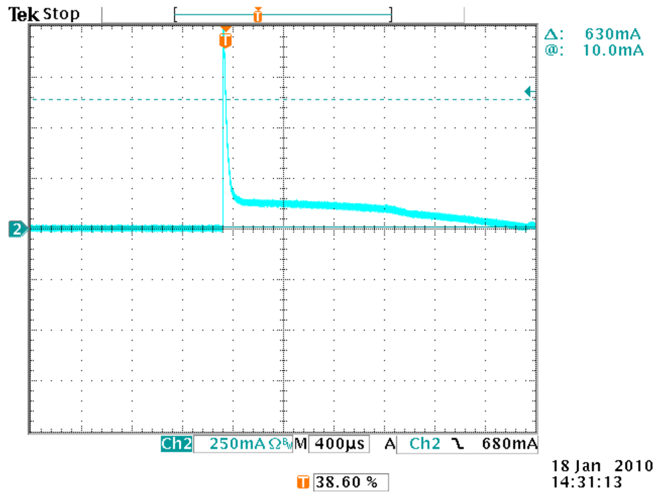

Table 12. Inrush Limited by Resistor

Figure 11 and Figure 12 show that by limiting inrush current with R004 and R005 flickering can be avoided.

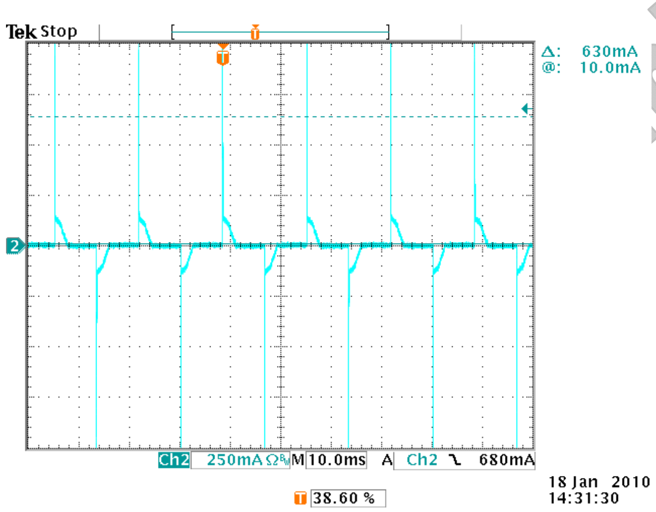

Table 13. Input Current With R004, R005

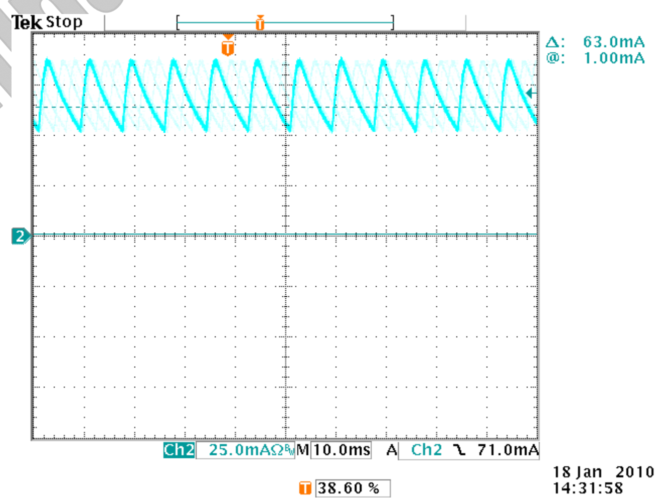

Table 14. Output Current With R004, R005

Secondly, low VDD when dimming would make the TPS92210 shut down and cause flickering. During dimming, the output voltage reduces, VDD will also reduce. Once VDD is lower than UVLO, the TPS92210 will shut down. Because the driver shuts down and restarts again, output current is not stable and flickering is observed. Detail is shown in figure 13.

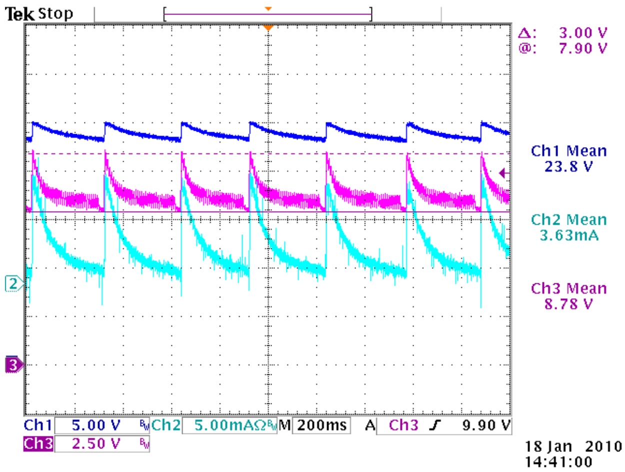

Table 15. Flickering Caused by Low VDD Voltage

While output current is decreased when dimming, LED VF also decreases. Low output voltage can cause VDD to drop below UVLO of the IC, so the IC shuts down and restarts. This restart cycle makes the output current oscillate. With the output current changing flickering of the LED will be observed. Details shown in Figure 13. Ch1 is output voltage, Ch2 is output current and Ch3 is VDD voltage.

Because the TRIAC on time is not always the same, there can be as much as 100us difference between each cycle, the LED brightness may always be different from cycle to cycle. This effect is not obvious when the TRIAC on time is high. But when the TRIAC on time is short, 100us shift corresponds to a high percentage of the total on time. The TRIAC on time difference cannot be avoided. However we can increase the output capacitor to average the output current and so decrease this effect.

6.3 Layout Guide

Although the reference design board size is 30mm*70mm, the whole circuit can easily be put into a smaller space. Based on the concept of easy modification of this reference design, all resistors and capacitors were chosen to be larger than the 0805 package, and are all located in readily accessible places so that they can be easily replaced. Also, the transformer is selected based on been easily modified, using an EI 22 core because it is one of the more popular core shapes. The size of the board can be reduced by decreasing the size of resistors and capacitors, putting SMD components on both top side and bottom side, as well as changing through hole components into smaller size. Such components may be L001, Q500, T500, C100 and C101 or SMD such as D500, D530, IC530, D100, and D550.

Please note the following two points about decreasing sizes. First, do not change C100, C101 into a ceramic material with multilayer structure because it easily produces coupling of audible noise. Second, changing transformer shape should also take thermals into consideration.

Further on TPS92210 layout, separate small signal ground and power train ground are required to avoid noise influencing the control. The width of the traces which carry small signals including R511, R512, R513, R514, C511, C538, TPS92210 DRV pin and GND pin with large current should be more than 1mm.

7 Performance Characteristics

Figures 14 to 17 show low input range data. This data was taken with R004 and R005 set to 22 Ohms

Figures 18 to 21 show high input range data. This data was taken with R004 and R005 set to 68 Ohms

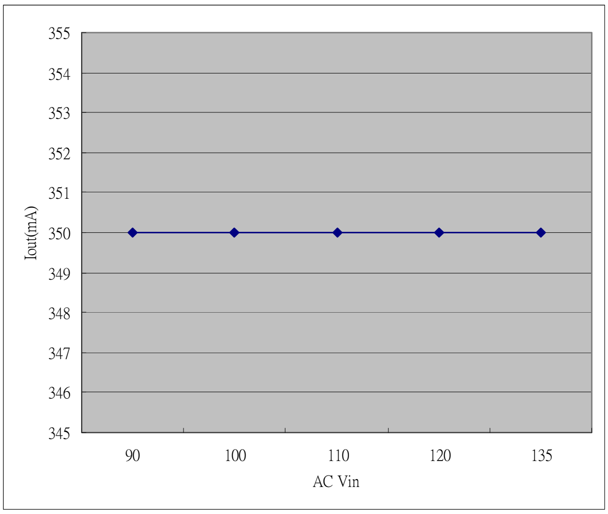

Table 16. Low Input Range Output Current

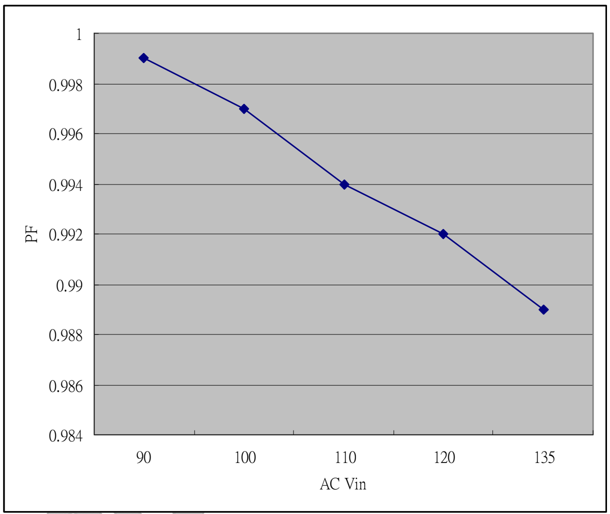

Table 17. Low Input Range Power Factor

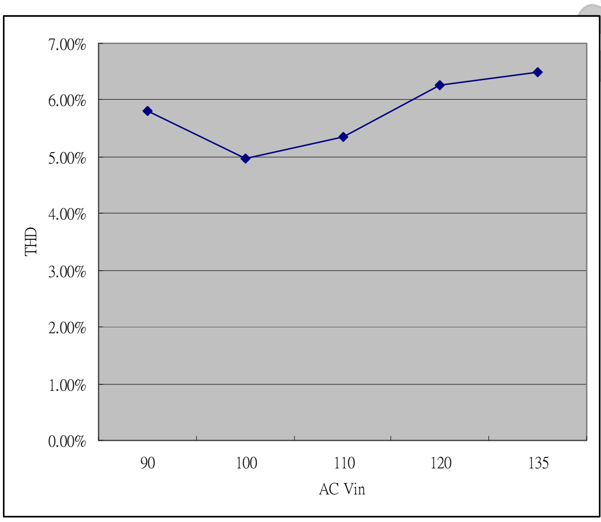

Table 18. Low Input Range Total Harmonic Distortion

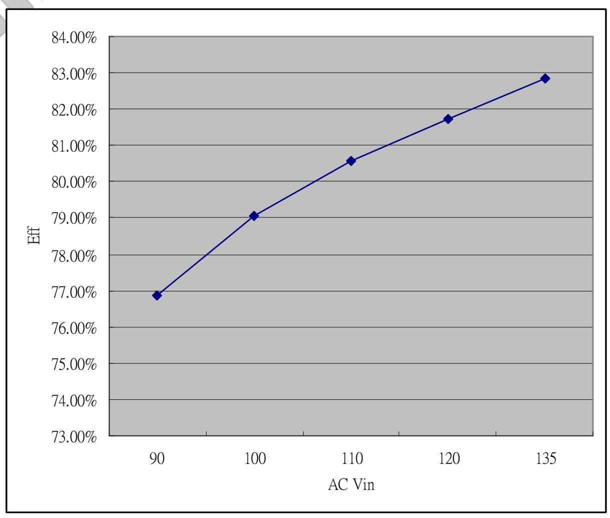

Table 19. Low Input Range Efficiency

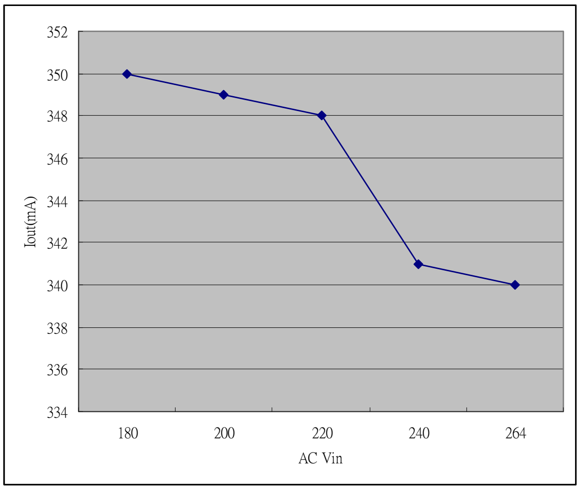

Table 20. High Input Range Output Current

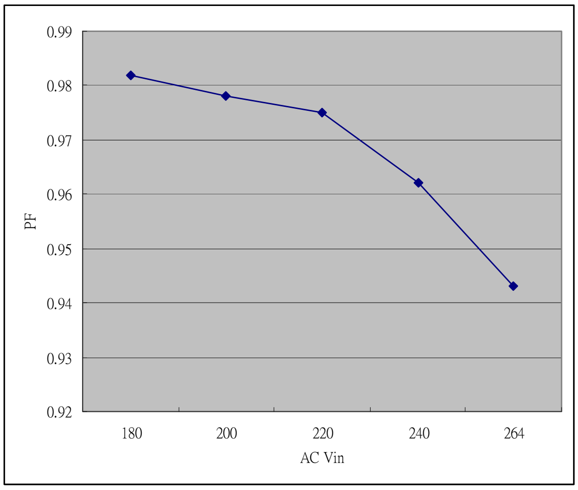

Table 21. High Input Range Power Factor

HIGH LINE

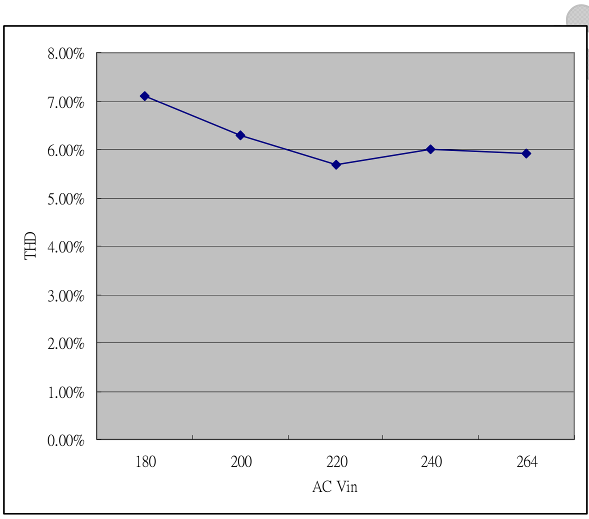

Table 22. High Input Range Total Harmonic Distortion

HIGH LINE

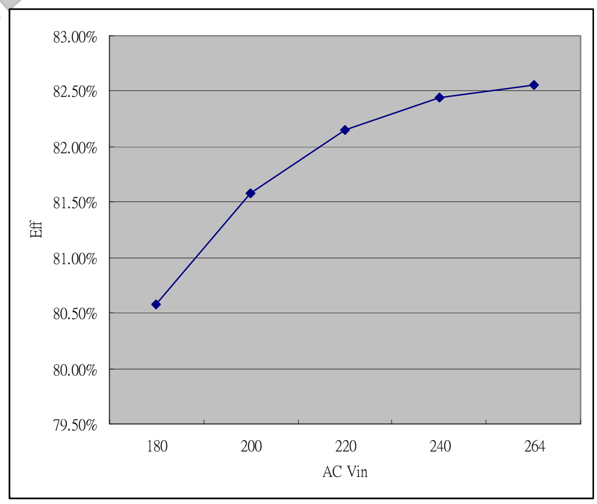

Table 23. High Input Range Efficiency

8 Dimming Waveform

Figure22 ~ Figure25 shows 120Vac dimming waveform.

CH1 Vout CH2 Iout CH3 Vin CH4 Iin

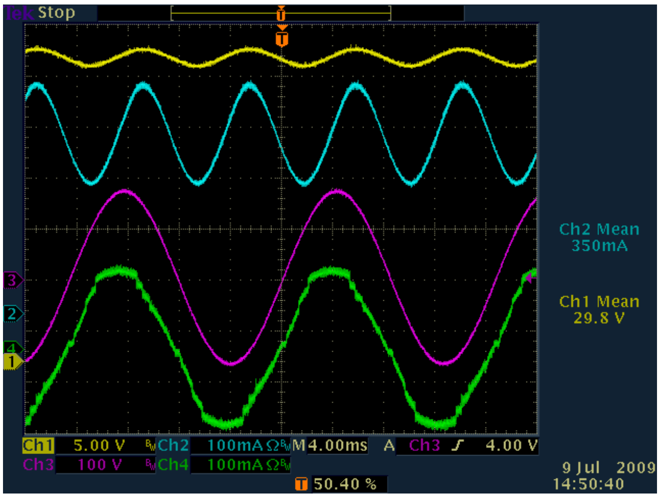

Table 24. Low Input Range 100% Brightness

CH1 Vout CH2 Iout CH3 Vin CH4 Iin

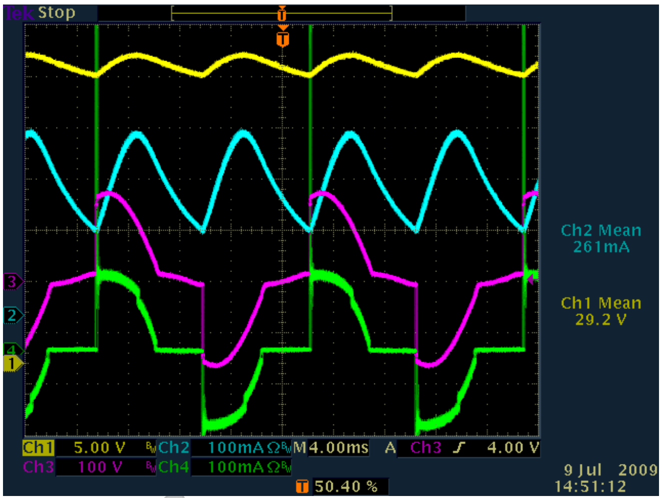

Table 25. Low Input Range 75% Brightness

CH1 Vout CH2 Iout CH3 Vin CH4 Iin

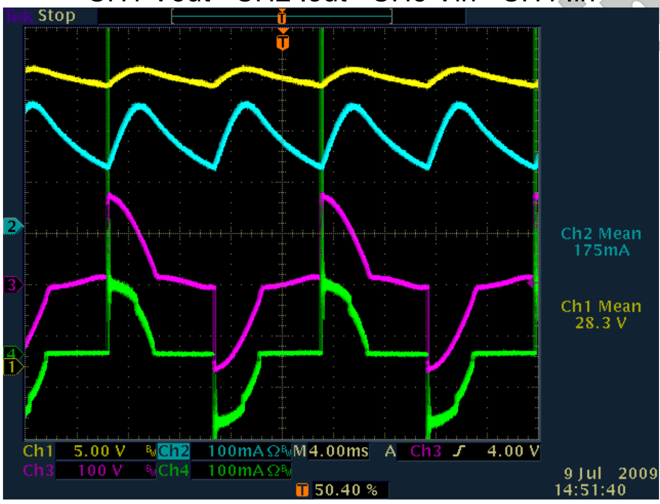

Table 26. Low Input Range 50% Brightness

CH1 Vout CH2 Iout CH3 Vin CH4 Iin

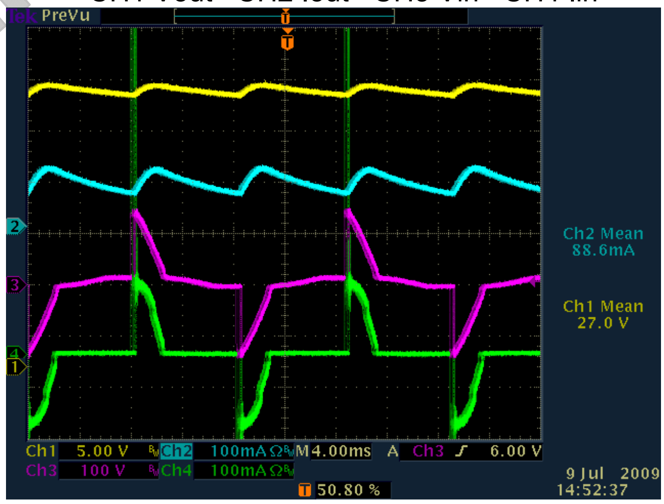

Table 27. Low Input Range 25% Brightness

Figure26 ~ Figure29 shows 240Vac dimming waveform.

CH1 Vout CH2 Iout CH3 Vin CH4 Iin

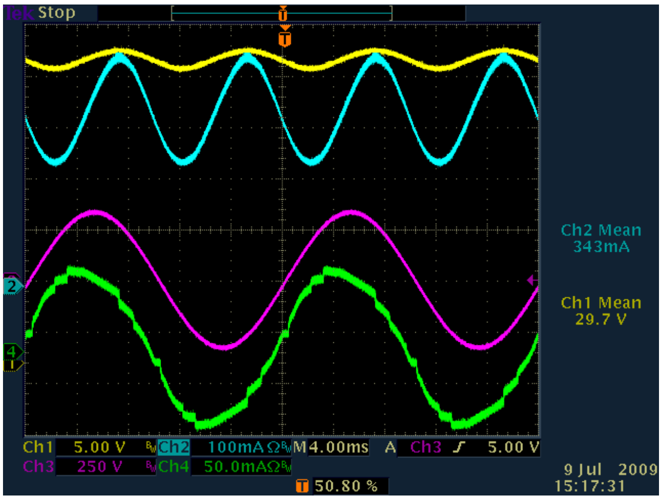

Table 28. High Input Range 100% Brightness

CH1 Vout CH2 Iout CH3 Vin CH4 Iin

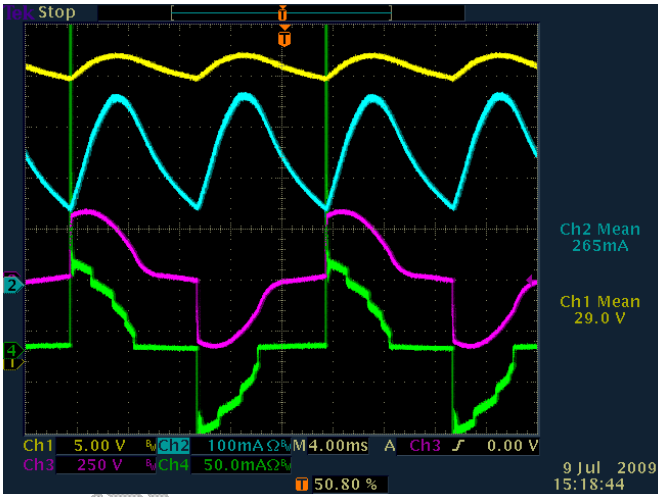

Table 29. High Input Range 75% Brightness

CH1 Vout CH2 Iout CH3 Vin CH4 Iin

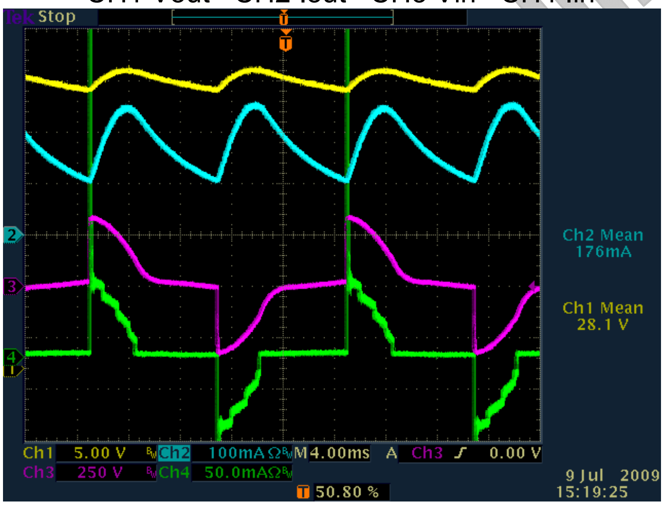

Table 30. High Input Range 50% Brightness

CH1 Vout CH2 Iout CH3 Vin CH4 Iin

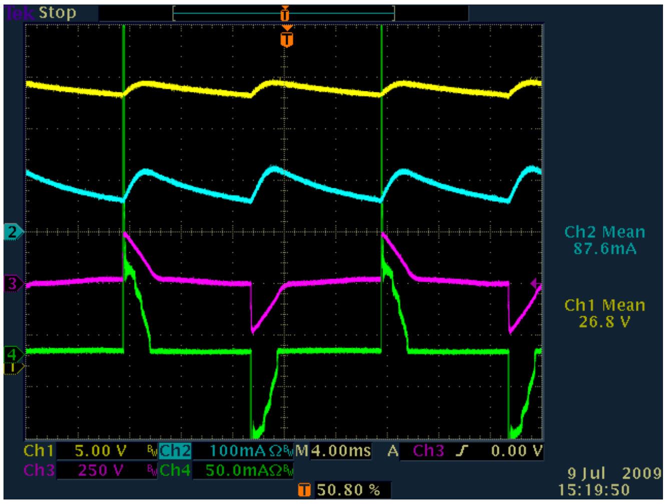

Table 31. High Input Range 25% Brightness

9 EVM Layout

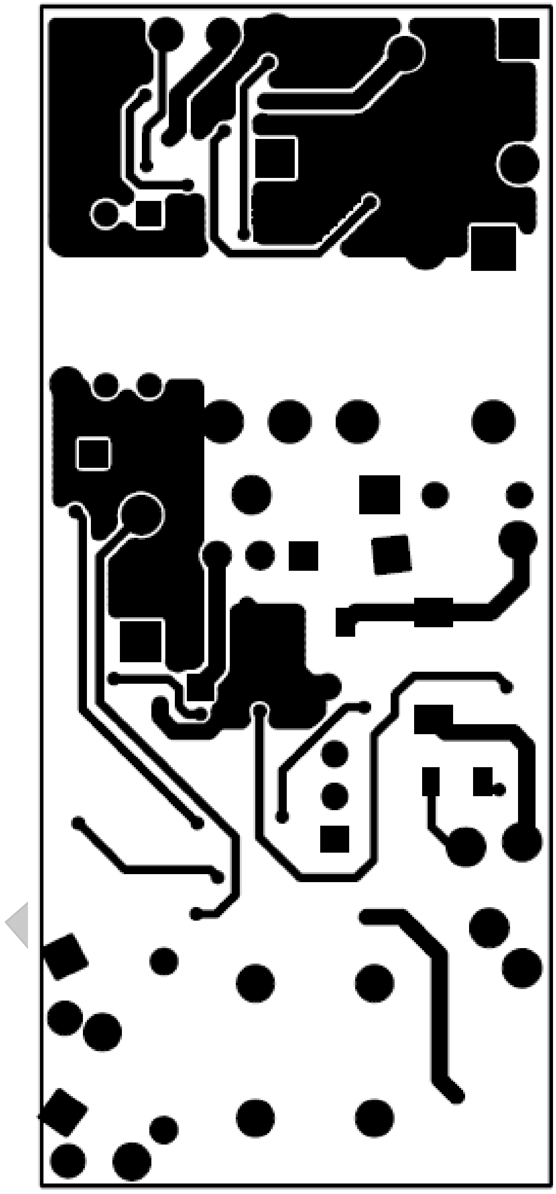

Table 32. Bottom Side Copper

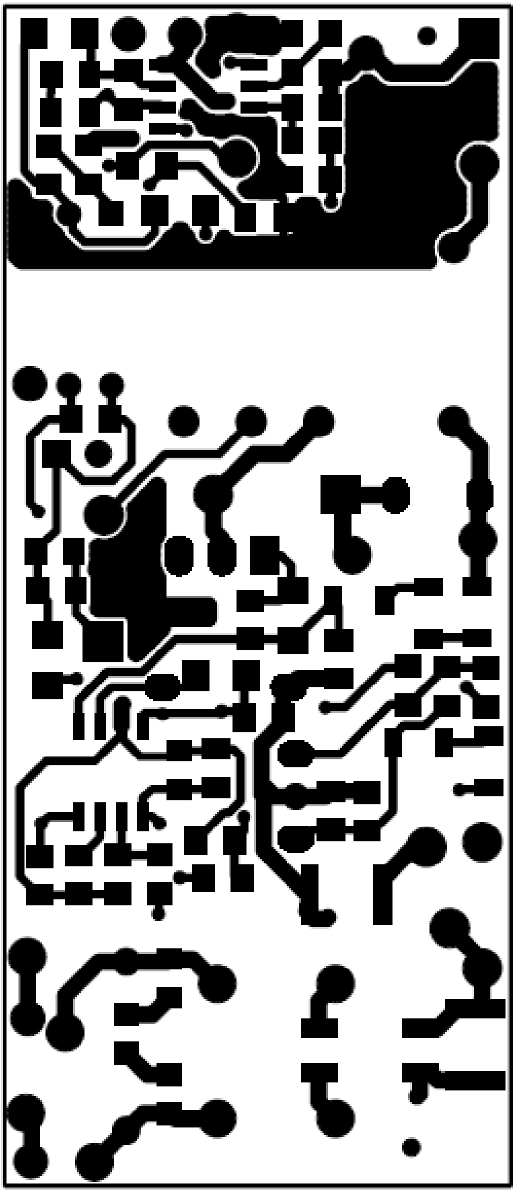

Table 33. TOP Side Copper

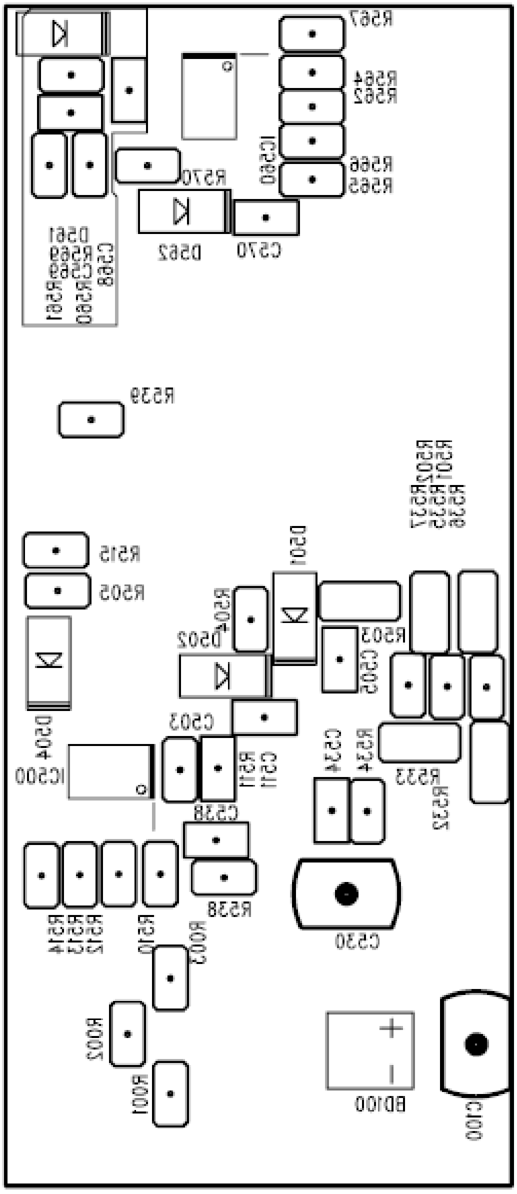

Table 34. Bottom Side Component Placement

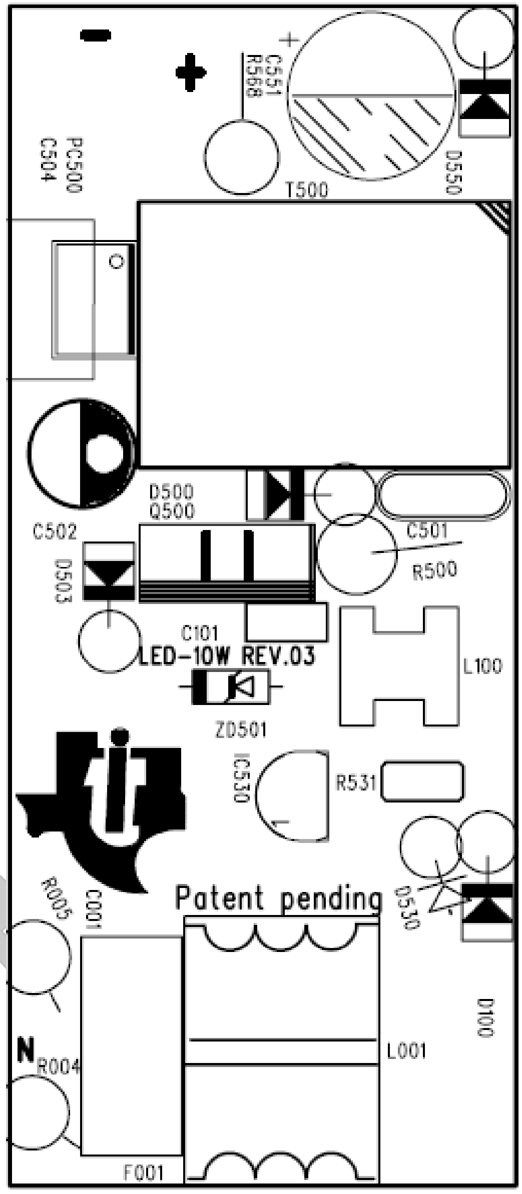

Table 35. TOP Side Component Placement

10 List of Materials

Table 3 below lists the EVM components as per the schematic shown in Figure 2. Part types and manufacturers can be modified according to specific application requirements.

Table 36. List of Materials

Location	Quantity	Vendor	Vendor P/N
BD100	1	PANJIT	MB6S
D500	1	PANJIT	UF4007
D501,D502,D504,D561,D562	5	PANJIT	1N4148
D503,D100	2	PANJIT	UF4005
D550,D530	2	PANJIT	UF4004
IC500	1	TI	TPS92210
IC530	1	TI	TL431/TO92
IC560	1	TI	TL103WA
Q500	1	Infineon	SPA04N80C3
PC500	1	NEC	PC817A
ZD501	1		15V/1W
R001,R002,R003	0		NC/1206
R004,R005	2		47 Ohm /1W DIP
R500	1		150K/2W DIP
R501,R502,R503	3		1.5M/1/4W/1206
R504	1		10/0805
R505	0		NC/0805
R510	1		124K/0805
R514	1		24.9K/0805
R511	1		75K/0805
R512	1		43K/0805
R513	1		82.5K/0805
R538	1		75K/0805
R515	1		2.2/0805
R531,R532,R533	3		1M/1206
R534	1		18.7K/0805
R535	1		80.6K/0805
R536	1		6.2K/0805
R537	1		7.15K/0805
R560	1		6.8k/0805
R561	1		1K/0805

Location	Quantity	Vendor	Vendor P/N
R564	1		61.9K/1%/0805
R565	1		5.23k/1%/0805
R567	1		4.99K/1%/0805
R566	1		44.2K/1%/0805
R568	1		0.75/1%/1/4W DIP
R569	0		NC/0805
R562	1		22K/5%/0805
R570	1		100K/5%/0805
R539	1		470K/5%/0805
C530	1	Taiyo	C.mon 0.1uF 630V 1812 X7R
C100	1	Taiyo	C.mon 0.047UF 630V X7R 1812
C101	1	Taiyo	C.mon 0.022UF 630V X7R 1812
C100	1	ARCO	C.MEF 0.047UF 630V
C101	1	ARCO	C.MEF 0.022UF 630V
C001	1	ARCO	C.MEF 0.047UF/275V R46 X1-Cap
C501	1		C.DIS 1KV 1000pF
C551	1	NCC	C.ELE 470UF 35V KY
C502	1	NCC	C.ELE 100UF 35V KY6.3*11
C569	0		NC/0805
C503,C534,C570	3		0.22uF/0805 X7R
C504	1		C.DIS 470PF 400V CD Y1-Cap
C511,C538	2		1uF 50V 0805 X7R
C568	1		0.01uF 50V 0805 X7R
C505	1		0.1uF 50V 0805 X7R
T500	1		SW2219
L001	1	YUJING	OTC15 0.18 VOTC1501806000A
L100	1	TDK	1000uF/ 7*7-SLF7045T-102MR14-PF
F001	1		Fuse 1AH/250V
PCB	1		PCB

11 References

1. TPS92210 Data sheet, Texas Instruments Ref. SLUS989