AN2102

22W LED driver – No Flicker & high PF @ low cost

Overview

RediSem's 22W LED driver is designed around the RED2501 LED driver IC. It uses a unique single stage resonant converter with a passive charge-pump PFC circuit to give flicker-free DC output with good power factor and harmonic input. The design uses a single control IC, Bipolar transistors and passive PFC components to generate low output ripple with an excellent power factor, therefore achieving high performance for a low cost. The Resonant converter topology has inherently low EMI, making EMI compliance without a Y-capacitor possible resulting in low CM surge transmission to the LED. The 22W design uses a single charge-pump PPFC design. Some benefits of the 22W LED driver are:

- Low output current ripple < 10% - No LED flicker
- High efficiency >89%
- Low EMI (without a Y-capacitor) due to resonant converter
- Low cost TO92 700V Bipolar transistor half-bridge
- Low cost single boost Passive PFC circuit
- 320VAC for 1 hour operation due to half-bridge topology
- Single IC solution, equivalent to a 2 stage converter
- Low cost Primary-Side Regulation (PSR)
- Protection including SELV, short-circuit, open circuit, over-temperature

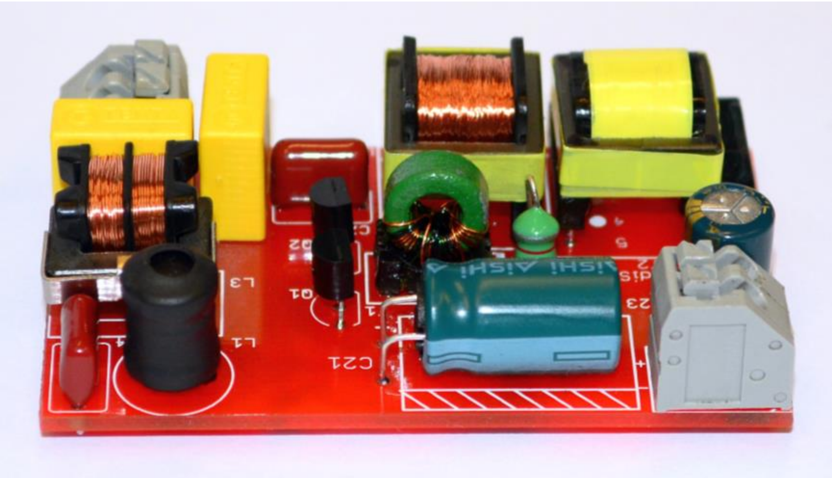


Figure 1: RediSem's 22W LED driver

Product Specifications

The 22W design uses a single charge pump boost stage in order to save cost. This results in good-enough THD and PF whilst providing a low ripple to the LED load. Later in this application note it is shown how it is possible to improve THD and Harmonics with simple changes and a small cost increase. Please review RediSem's other application designs if a better TDH or PF is required. This driver's output power of 22.5W has been chosen such that the input power is just below the 25W threshold for Class C harmonic requirement. For even better THD and PF, consider using a 2 charge pump technique. For more details about RediSem's patented PPFC topologies and the charge pump, please review the design guide AN2101.

Input	198 - 264VAC, 50Hz
Input voltage survival	0 - 320VAC 1 hour
Input Power	<25W
Output Current	Constant Current 500mA +/- 5%
Output Voltage	21-45V
Output Power	22.5W
Efficiency	> 89% at full load
Output Current Ripple (pk-pk)	< 10% pk-pk
THD	Complies with IEC61000-3-2 Class D
Power Factor	>0.9 @ full load, 230VAC
Size	66x39mm, 15mm component height
SELV	Peak output voltage < 50V
Protection	Short circuit, Open Circuit, OTP
Surge	1kV Differential, 2kV Common mode
Converter Topology	Single-Stage CC LLC converter with single PPFC boost stage
Controller IC	RED2501AD SO8 LLC PSR IC
Component Count	46 electronic components

Schematic

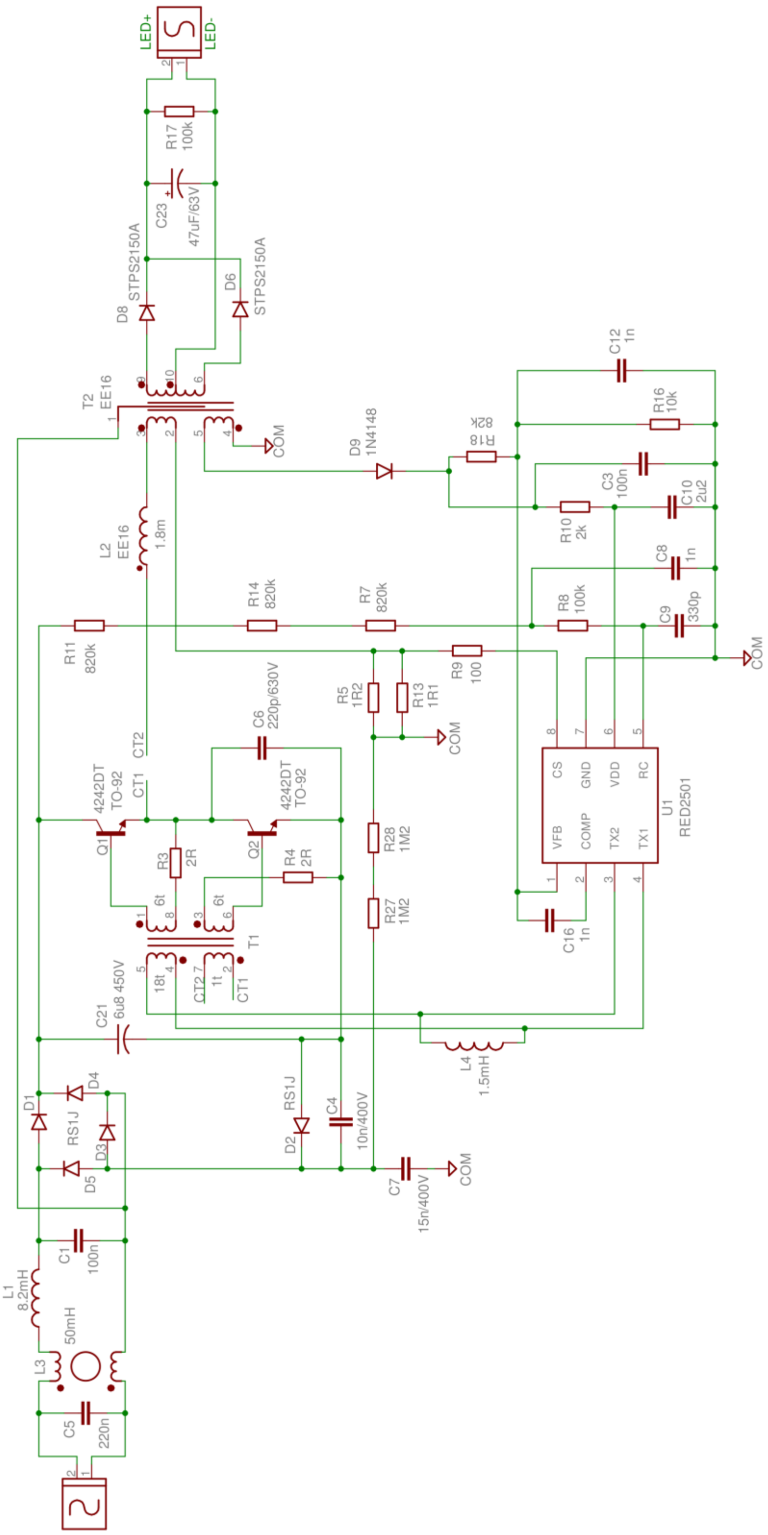


Figure 2: 22W LED Driver Schematic

Test Results

Tests have been carried out with an open unit on the bench at 25C ambient temperature. Efficiencies usually improve slightly if the unit is allowed to heat up. Pk-pk output ripple is measured with switching frequency ripple and 100Hz ripple. LF ripple is measured without the switching frequency ripple.

Input voltage	**198V**	**230V**		**264V**
Load Condition	**45V**	**23V**	**45V**	**23V**
Input Power	24.13W	14.02W	24.98W	14.18W
Output Power	21.60W	11.64W	22.36W	11.66W
Output Voltage	45V	23V	45V	23V
Output current	480mA	506mA	497mA	507mA
Output Ripple pk-pk LF		4.3%	7.2%	
Output Ripple pk-pk		8.1%	9.5%	
Efficiency	89.5%	83.0%	89.53%	82.2%

Output regulation							
Output voltage	**Io**	**Input power**	**Efficiency**	**Power Factor**	**THD**	**LF Ripple**	
45V	497mA	24.98W	89.53%	0.9008	34.0%	37mA	7.4%
43V	497mA	23.95W	89.25%	0.9039	33.0%	36mA	7.2%
41V	498mA	22.94W	89.01%	0.9088	31.1%	34mA	6.8%
39V	499mA	21.95W	88.65%	0.9135	29.1%	32mA	6.4%
37V	500mA	20.95W	88.32%	0.9178	26.9%	31mA	6.2%
35V	501mA	19.94W	87.93%	0.9206	25.1%	30mA	6.0%
33V	502mA	18.95W	87.42%	0.9209	24.0%	29mA	5.8%
31V	503mA	17.95W	86.87%	0.9154	25.1%	27mA	5.4%
29V	504mA	16.97W	86.12%	0.9054	27.6%	25mA	5.0%
27V	505mA	15.99W	85.27%	0.8944	30.2%	24mA	4.8%
25V	505mA	15.01W	84.12%	0.8823	32.7%	23mA	4.6%
23V	506mA	14.02W	83.03%	0.8689	35.1%	22mA	4.3%
21V	507mA	13.03W	81.69%	0.8542	37.6%	20mA	3.9%

Line Regulation			
Input voltage	**Io**	**Input power**	**Efficiency**
185Vac	463mA	22.46W	88.63%
190Vac	474mA	22.90W	89.00%
198Vac	484mA	23.35W	89.13%
210Vac	494mA	23.80W	89.25%
220Vac	495mA	23.85W	89.25%
230Vac	497mA	23.95W	89.23%
240Vac	498mA	24.00W	89.21%
250Vac	499mA	24.06W	89.20%
260Vac	499mA	24.08W	89.11%
264Vac	499mA	24.09W	89.07%
270Vac	499mA	24.11W	89.00%
280Vac	500mA	24.20W	88.84%
290Vac	500mA	24.23W	88.73%
300Vac	501mA	24.30W	88.65%
310Vac	501mA	24.33W	88.55%
320Vac	501mA	24.35W	88.47%

Harmonics			
	25V	**45V**	**Class D Limit**
Power Factor	0.8687	0.9039	
THD	35.20%	33.03%	
3rd Harmonic	34.17%	27.08%	78.20%
5th	6.89%	10.37%	43.70%
7th	3.88%	12.13%	23.00%
9th	2.94%	8.13%	11.50%
11th	0.20%	5.10%	8.05%
13th	0.79%	2.33%	6.81%

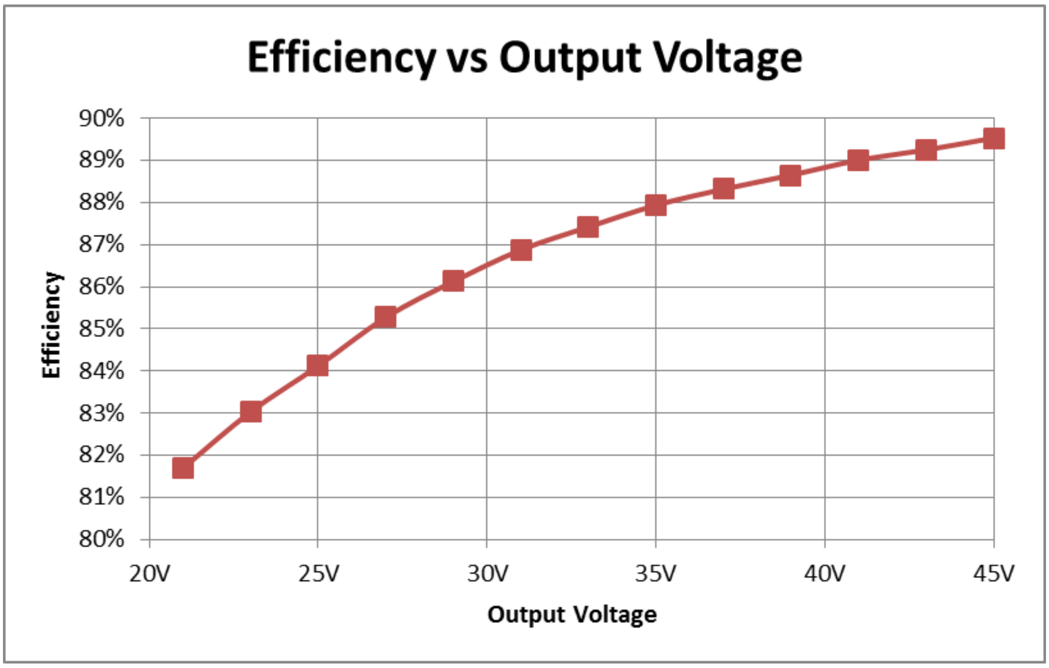


Figure 3: Efficiency @ 230VAC over output voltage range

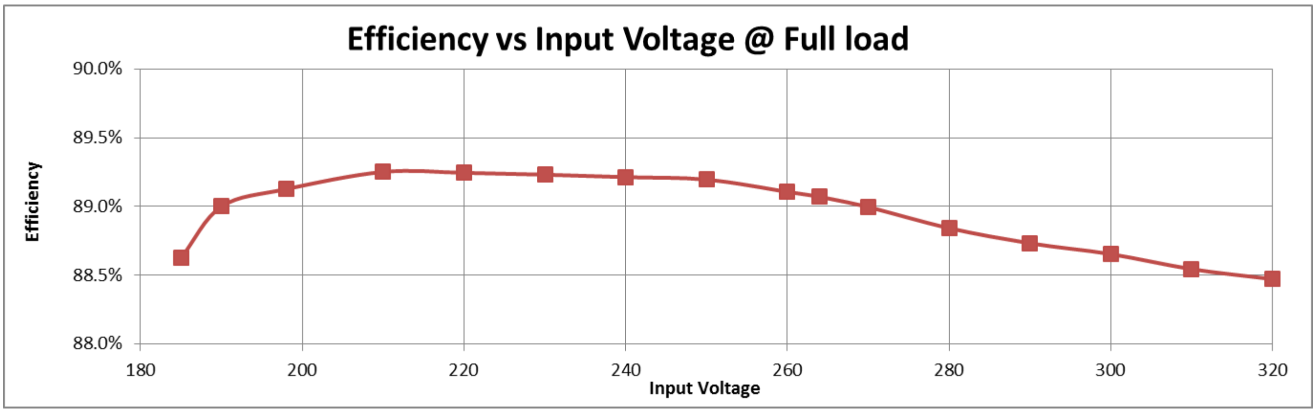


Figure 4: Efficiency over a wide mains input range (full load 45V out)

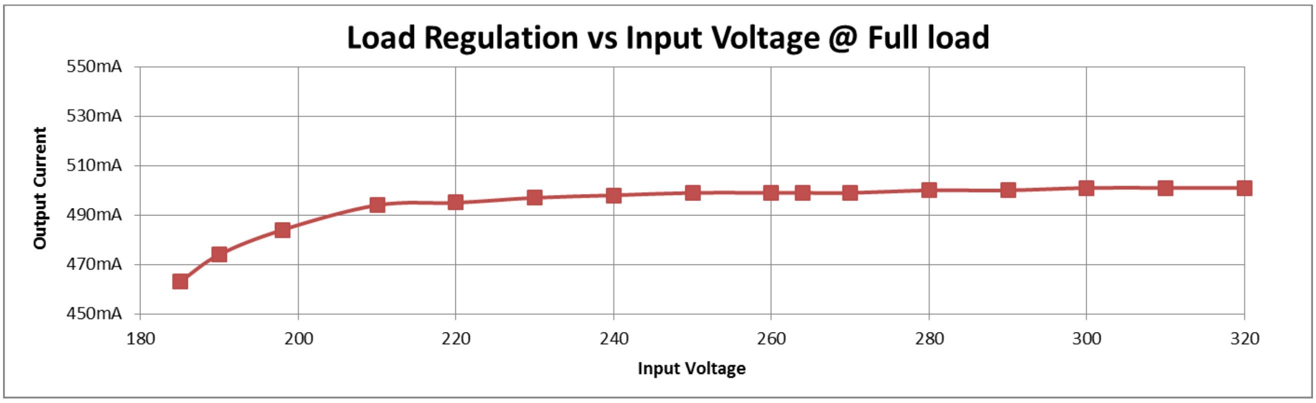


Figure 5: Output regulation over a wide mains input range (full load 45V out)

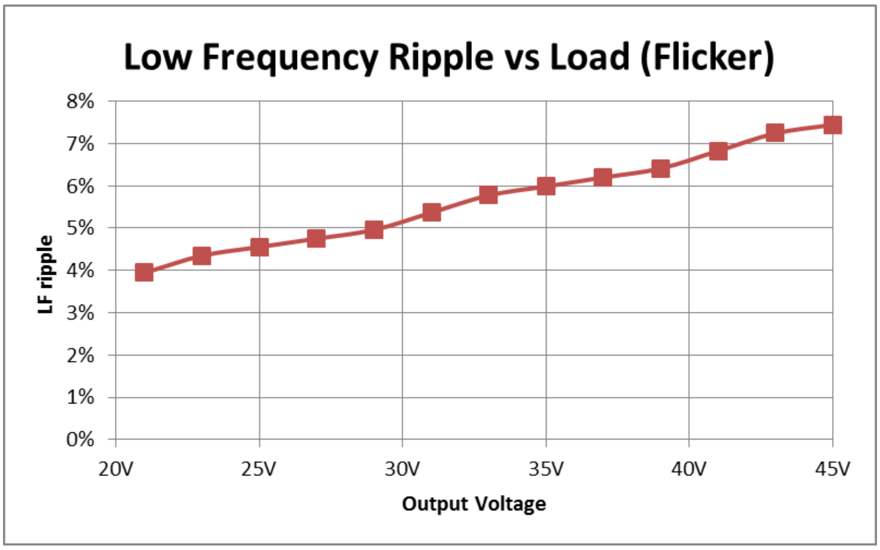


Figure 6: Low Frequency ripple (Flicker) @ 230V over output voltage

Thermal characteristics

Component temperatures have been measured with the PCB housed in a plastic box in a fan circulated oven.

Temperature	198V		264V	
	43V	23V	43V	23V
Ambient	55.5C	55.3C	55.3C	55.5C
Top transistor Q1	95.0C	99.5C	102.1C	111.0C
Bottom transistor Q2	84.7C	88.0C	89.9C	95.8C
Transformer T2	104.7C	95.5C	105.6C	97.6C
Main inductor L2	105.8C	105.8C	111.1C	112.6C
Bulk Cap C21	82.4C	81.5C	84.1C	84.3C
Common mode L3	77.9C	74.8C	77.6C	75.5C
Diff mode L1	79.2C	72.9C	77.6C	71.7C
Schottky diode D8	95.9C	93.7C	97.8C	94.5C
Schottky diode D12	86.7C	85.5C	88.2C	86.1C

Waveforms

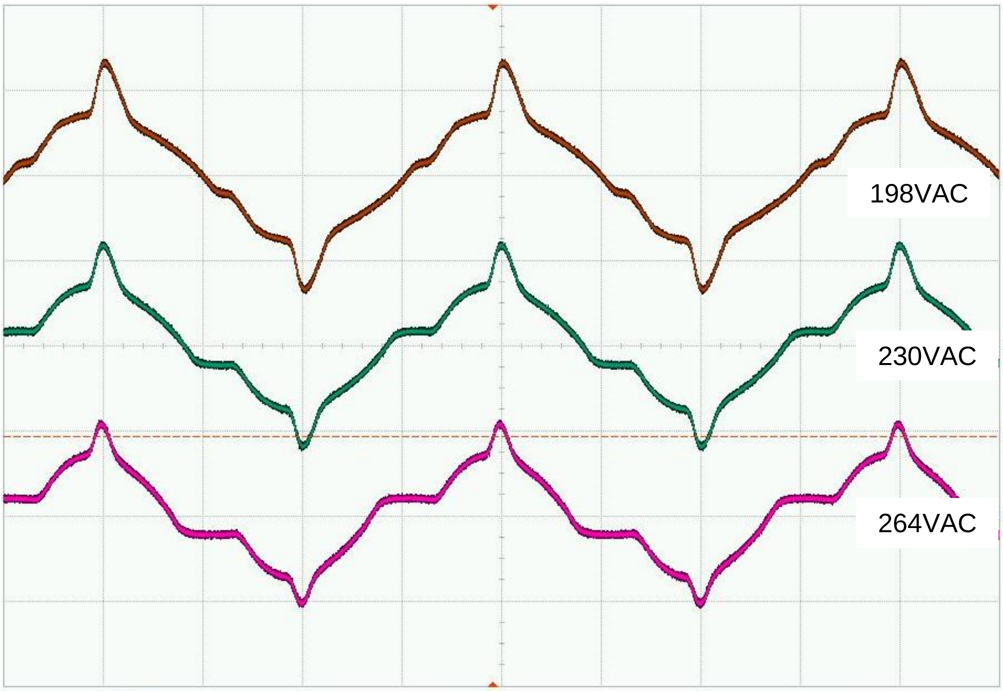


Figure 7: 50Hz Input current 22W @ 198, 230, 264VAC

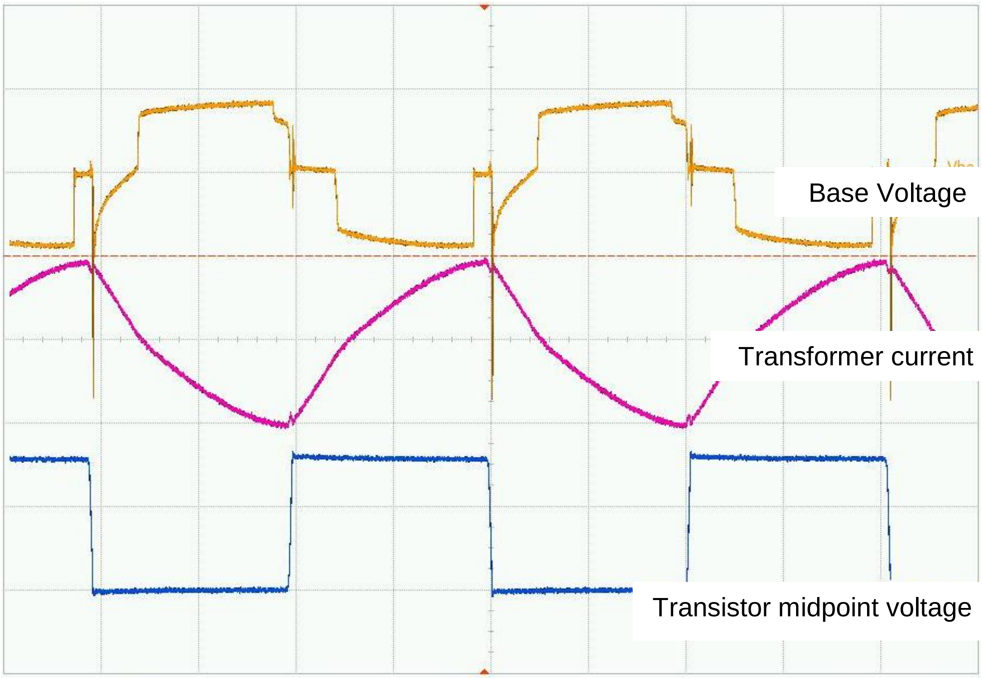


Figure 8: LLC switching current, midpoint, Vbe

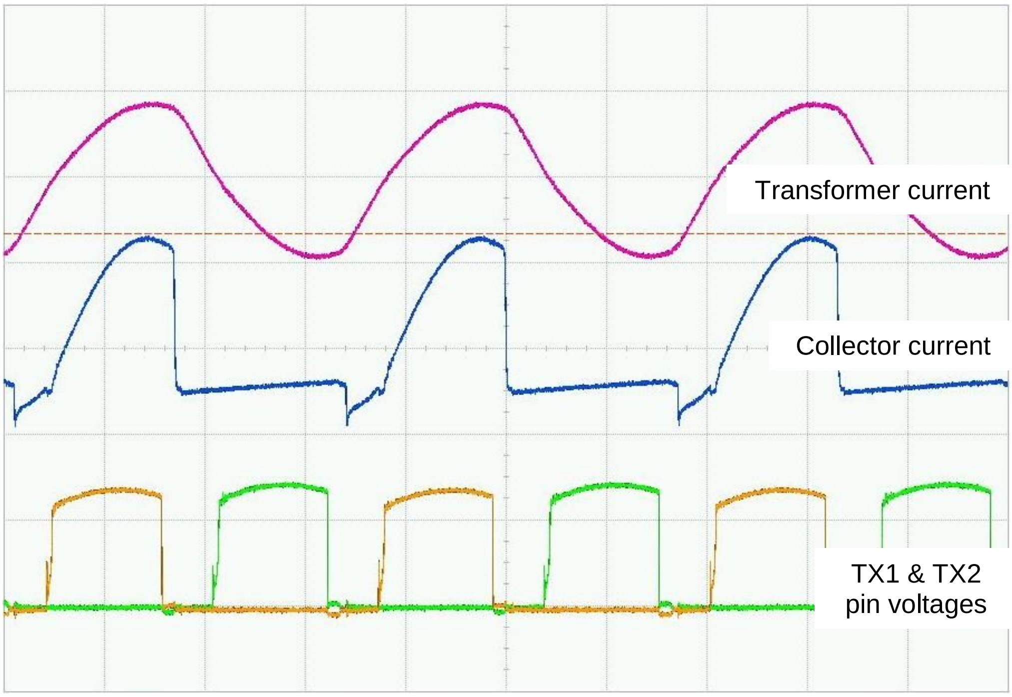


Figure 9: Base drive waveforms, TX1, TX2, transistor current, total current

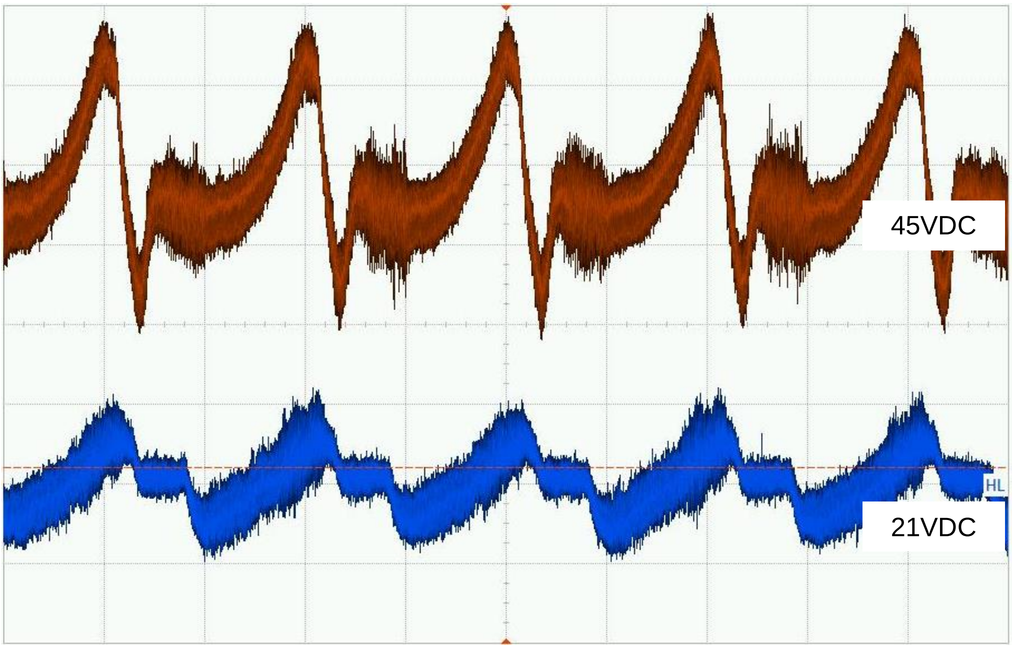


Figure 10: 100Hz Output current ripple, full load & half load 230VAC (10mA/div)

Conducted EMI results

The 22W driver was tested with the LED load grounded (worst case) and as the schematic, without a Y-capacitor.

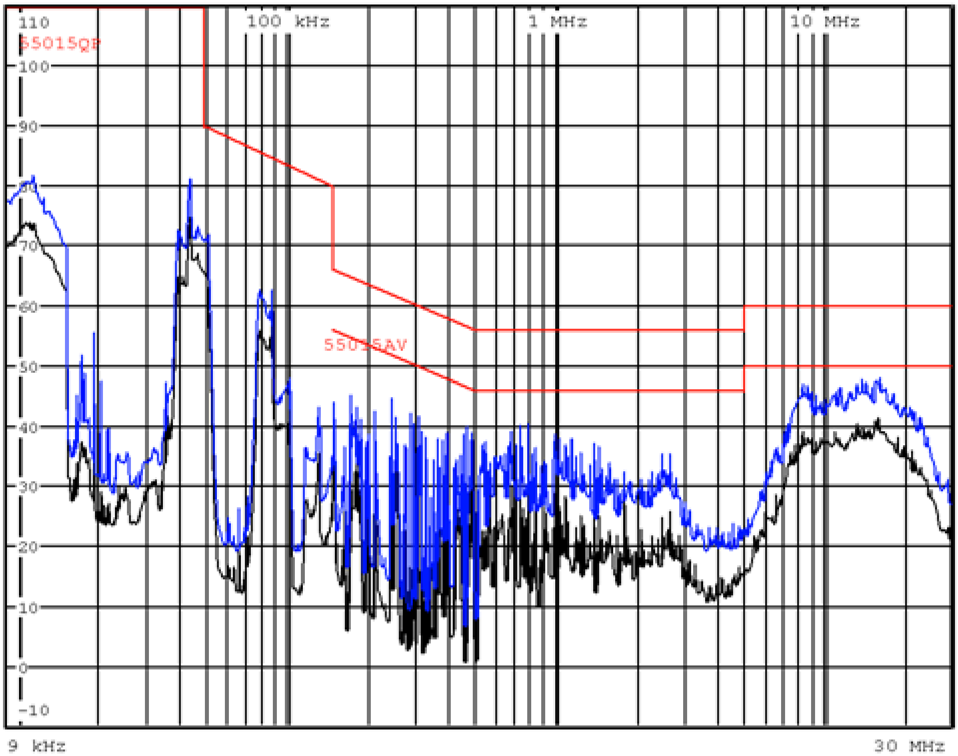


Figure 11: 22W driver conducted emissions

Improving the 22W Driver PF and THD

With a few minor modifications it is possible to upgrade the THD and PF of the 22W design. Change C4 to 5.6nF and C7 to 10nF and both THD and PF greatly improve. These improvements result in a higher bulk capacitor voltage at low LED voltages and 264VAC input, so it is necessary to change the bulk capacitor voltage to 500V or two 250V capacitors in series. The changes result in a worst case voltage on C21 of less than 475V peak.

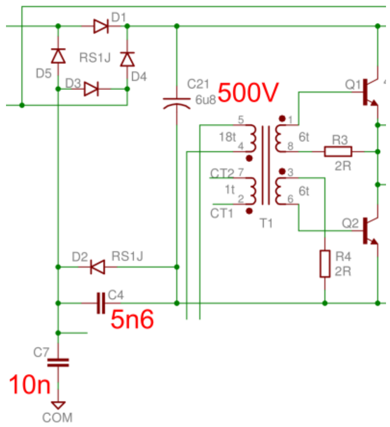


Figure 12: PF improvement changes

Output voltage	Power Factor	THD
45V	0.9624	11.5%
43V	0.9647	8.2%
41V	0.9650	5.9%
39V	0.9631	5.0%
37V	0.9598	5.5%
35V	0.9550	7.8%
33V	0.9492	10.5%
31V	0.9420	13.3%
29V	0.9337	16.1%
27V	0.9242	18.9%
25V	0.9134	21.6%
23V	0.9013	24.3%
21V	0.8877	27.0%

Improved Harmonics			
	25V	**45V**	**Class D Limit**
Power Factor	0.9134	0.9647	
THD	21.60%	8.15%	
3rd Harmonic	19.50%	5.02%	78.20%
5th	8.68%	4.02%	43.70%
7th	1.37%	3.80%	23.00%
9th	1.32%	2.11%	11.50%
11th	1.20%	1.80%	8.05%
13th	0.46%	1.31%	6.81%

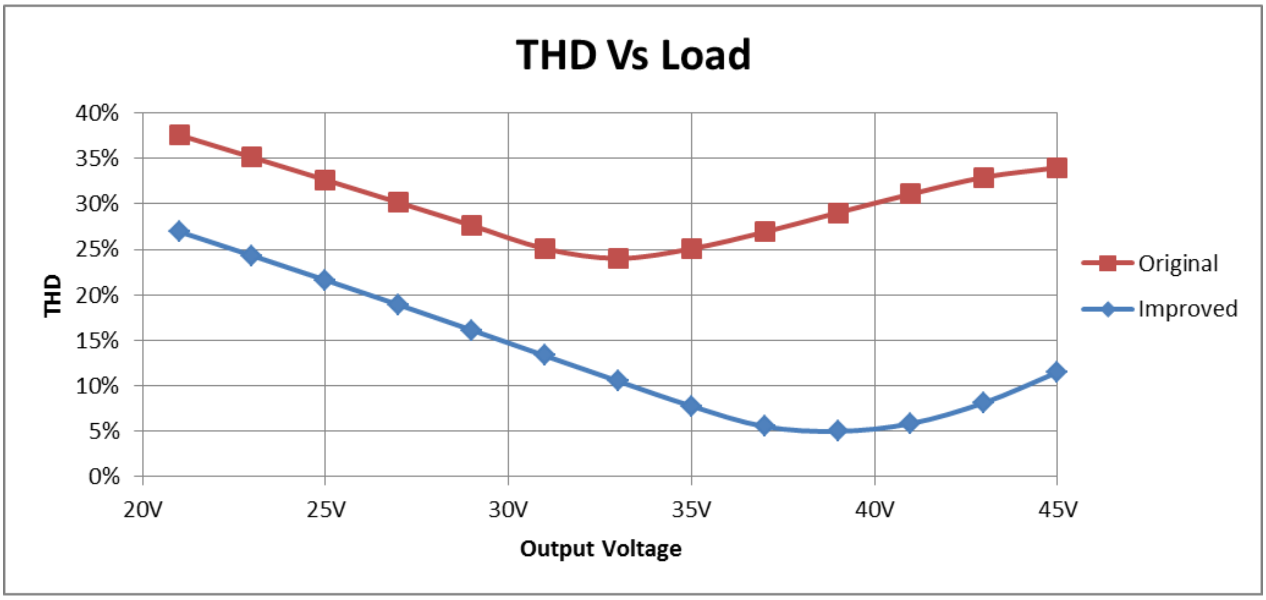


Figure 13: THD @ 230V over output voltage (original vs Improved)

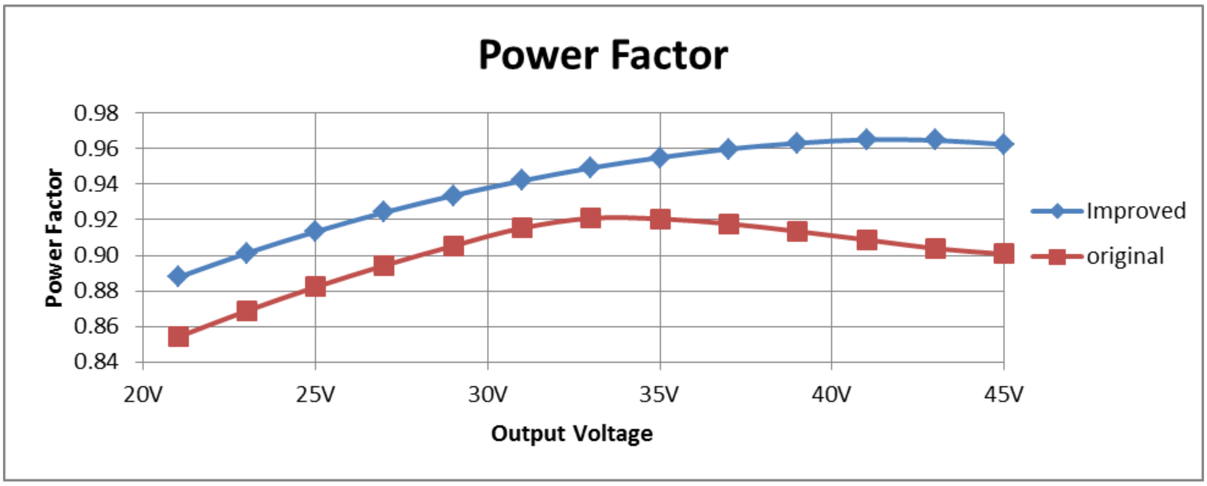


Figure 14: Power Factor @ 230V over output voltage (original vs Improved)

22W Driver BOM

Code	Description	Qty	Supplier	Part no.
C1	100nF X2 MKP 20% 275VAC	1	Tenta	MEX104K275A203
C3	100nF 0603 X7R 10% 25VDC	1		
C4	10nF MKP 5% 400VDC	1	Faratronic	C312G103J3SC000
C5	220nF X2 MKP 20% 275VAC	1	Tenta	MEX224K275A203
C6	220pF 1206 X7R 10% 500VDC	1		
C7	15nF MKP 5% 400VDC	1	Faratronic	C312G153J40C000
C8,16,12	1nF 0603 X7R 10% 50VDC	3		
C9	330pF 0603 COG 5% 50VDC	1		
C10	2.2uF 0603 X7R 10% 16VDC	1		
C 21	6.8uF ELEC 20% 450VDC	1	Aishi	EGX2WM6R8W20OT
C23	47uF ELEC 20% 63VDC	1	Aishi	ERM1JM470F12OT
D1,2,3,4,5	RS1J SMA Fast Diode 600VDC 1A	5	TSC	RS1J R3
D6, D8	STPS2150 SMA Schottky 150VDC 2A	2	ST	STPS2150A
D9	1N4148	1		
L1	8.2mH Drum Core 8x10	1	Boody	0
L2	1.8mH EE16 Resonant Inductor	1	Boody	0
L3	50mH UU9.8 CM	1	Boody	0
L4	1.5mH 0410 0.25W Axial	1		
R3,4	2R 0603 0.06W 1%	2		
R5	1R2 1206 0.25W 1%	1		
R7,11,14	820k 0805 0.125W 1%	3		
R8	100k 0603 0.06W 1%	1		
R9	100R 0603 0.06W 1%	1		
R10	2k 0603 0.06W 1%	1		
R13	1R1 1206 0.25W 1%	1		
R16	10k 0603 0.06W 1%	1		
R18	82k 0603 0.06W 1%	1		
R27,28	1M2 0805 0.125W 1%	2		
P1, P2	Terminal 2 Pin	2		
Q1,Q2	BJT 700V 1.5A TO92 NPN	2	Jilin Sino	3DD4242DT Ts=1.5-2us
T1	Base Drive 18:6:6:1 turns	1	ACME	A062T9*5*4CRX
T2	EE16 power transformer	1	Boody	0
U1	RED2501 LLC LED controller IC	1		
	Total Component Count	46		

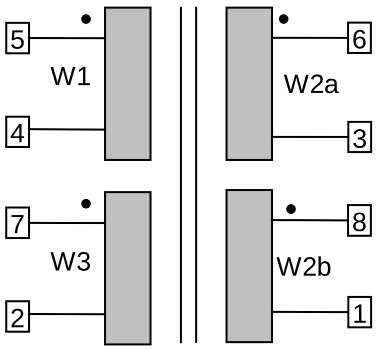
Supplier List

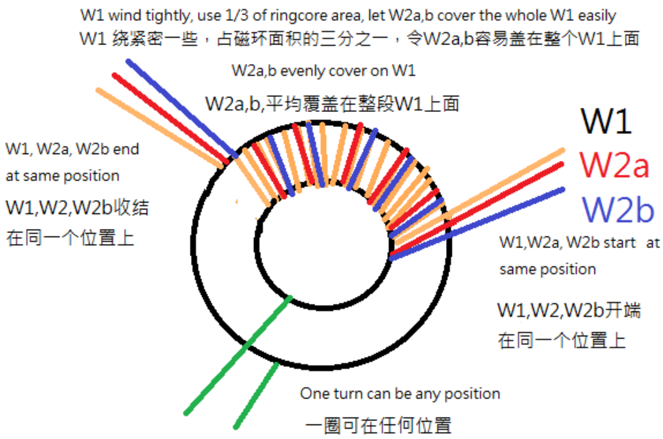
Jilin – Jilin Sino Microelectronics (Huawei) - 吉林华微 www.hwdz.com.cn
ACME Electronics -越峰电子 www.acme-ferrite.com.tw
Boody - 惠州宝电 http://www.boody.com.cn
Fara - Xiamen Faratronic - 厦门法拉 http://www.faratronic.com
Aishi - Aihua Global - 湖南艾华 www.aihuaglobal.com
TSC - Taiwan Semiconductor - 台半 www.taiwansemi.com

Wound Components

Base Drive transformer (T1)

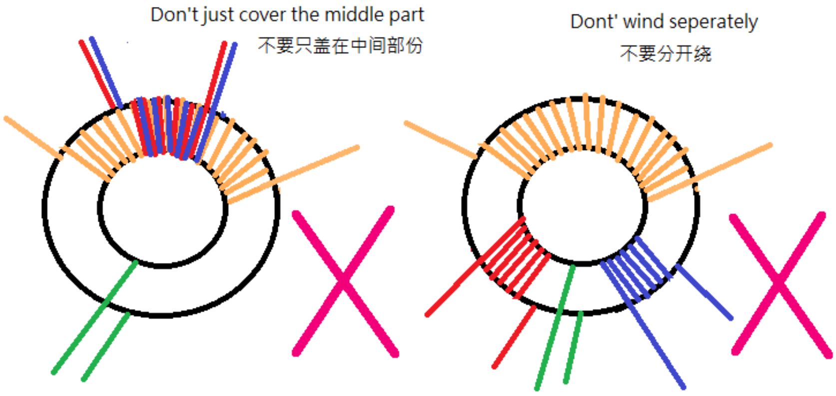
The base drive transformer is a key part of the converter. It is important to start with the suggested core material, size and turns ratio before changing parameters. Read the application note AN2101 for more details. L4 has been added in parallel with the base drive winding to “trim” the base drive inductance for optimal switching performance.





Ring Core

Manufacturer	ACME Electronics
Material	A062
Size	9 x 5 x 4

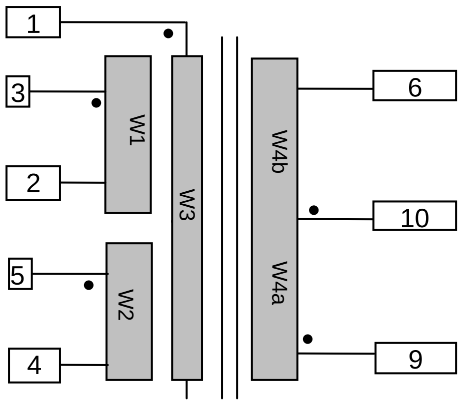


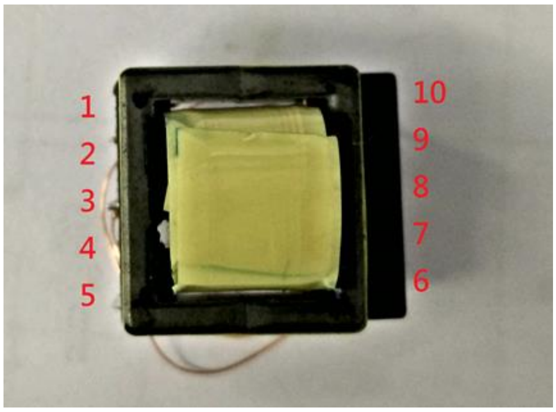
Winding	Turns	Wire
W1	18	0.2
W2a	6	0.2
W2b	6	0.2
W3	1	0.3

Transformer (T2)

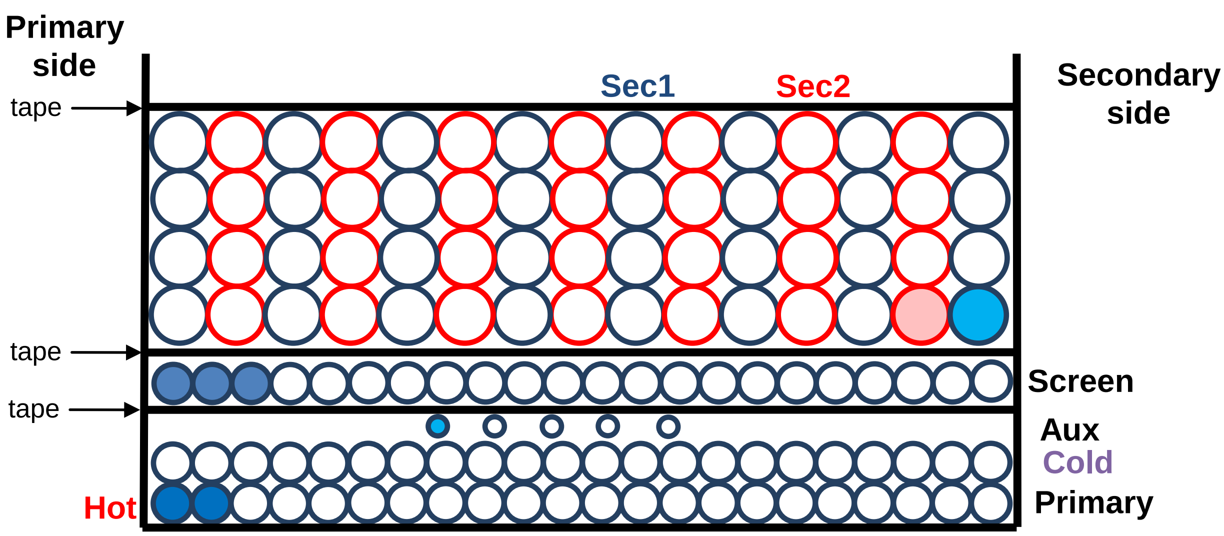
Core: EE16
Material: Acme P47, TDK PC44 or equivalent, gapped

The recommended transformer structure is shown below. It is important to follow the winding structure and direction as it particularly affects EMI. The two secondaries should be wound bifilar as this gives best EMI performance and lowest overshoot on the output diodes.



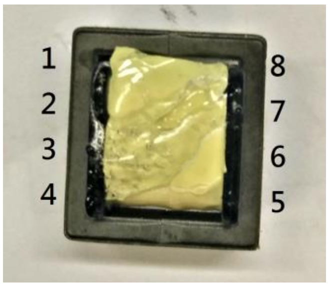


Winding	Turns	Start Pin	End Pin	Wire	Layers	Type	Purpose	Direction
W1	61	3	2	0.25mm	2	ECW	Primary	Clockwise 順時
W2	8	5	4	0.14mm	1	ECW	Aux	Clockwise 順時
Tape	1							
W3	9	1	-	0.23mmx3s	1	ECW	Prim Screen	Anti-clockwise 逆時
Tape	1							
W4a	33	9	10	0.25mm	4	TEXE	Secondary	Clockwise 順時
W4b	33	10	6	0.25mm		TEXE	Secondary	Clockwise 順時
Tape	2							



Drum Inductor winding (L1)

Core dimensions: 8mm diameter x 10mm high x 3mm centre core diameter
Wire: 0.13mm ECW
Winding: 500 turns
Inductance: 8.2mH +/- 10%



Resonant Inductor winding (L2)

Core: EE16
Material: Acme P47, TDK PC44 or equivalent, gapped
Wire: 10 x 0.07mm ECW
Winding: 200 turns, start at Pin4 & end Pin7
Inductance: 1.8mH +/- 3%

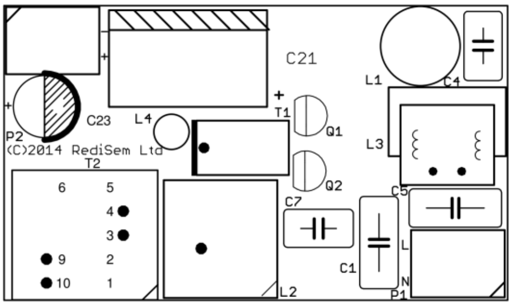
Note that Pin4 is connected to the “hot” noisy end of the winding. This keeps the noisy end of the winding on the inside of the bobbin and the quieter end on the outside to act as a screen. If the converter is being affected by noise, the core can be connected to a quiet point.

Common Mode inductor (L3)

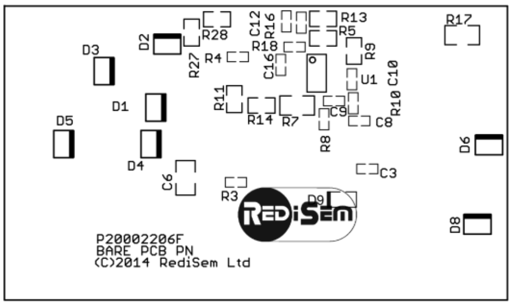
Core: UU9.8
Material: μ_i = 10k or greater with polished cores
Wire: 0.21 ECW
Winding: 140 turns
Inductance: > 50mH

It is possible to use thinner wire and more turns in this design, such as 0.15mm and 100mH for better EMI performance to give greater EMI margin in the region of 300kHz to 5MHz. As it is, this CM inductor is the same as what is used on the 40W design in AN2103.

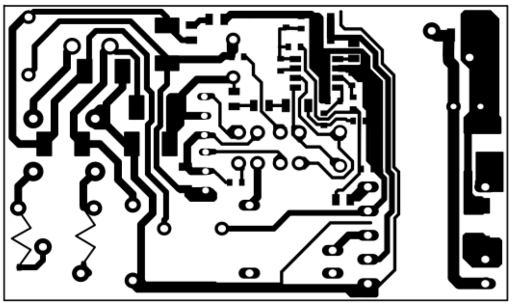
PCB Layout



Top Silkscreen



Bottom Silkscreen



Bottom Copper

About RediSem

RediSem designs and supplies semiconductor ICs for energy efficient power management applications. RediSem uniquely combines extensive experience in power electronics with in-depth knowledge of IC design and manufacturing and works with the world's top suppliers and customers. RediSem's unique patented IC and converter technologies deliver maximum efficiency and performance, while reducing overall bill of materials cost through the use of bipolar transistors.

RediSem's range of LED control ICs can be used with RediSem's patented single stage LED control solution to provide very high efficiencies with low EMI – all with a single IC. When combined, these features deliver a low cost, high performance LED driver solution.

RediSem's fluorescent driver controller ICs achieve the advanced performance of MOSFET drivers by using bipolar transistors at a fraction of the BOM cost. RediSem's range of SMPS (Switched Mode Power Supply) control ICs enables low-cost LLC converters with bipolar transistors that deliver very high efficiencies already meeting DoE Level VI regulations, have low standby power and have much lower EMI compared to flyback converters.

All RediSem ICs are supported by comprehensive turn-key application designs enabling rapid time to market. For further information please use our contact details below

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