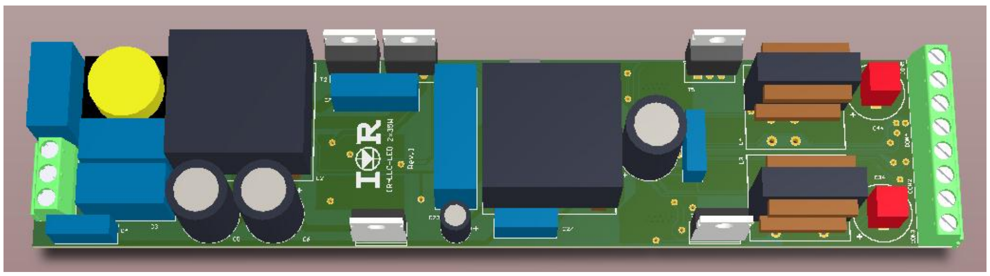
Application Note AN-1189

2x35W Isolated LLC LED Driver with Active PFC

By Akos Hodany



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1. Introduction

A 2-channel dimmable LED driver system is presented in this application note. Schematic, BOM, PCB layout example are presented here as well as a short design aid for circuit dimensioning. The circuit provides 2x35W maximum output power with isolated 700mA constant current outputs. The driver comprises a boost PFC stage (controlled by the IRS2505L PFC controller), an LLC resonant half-bridge stage (controlled by the IRS27952S half-bridge controller) and two separate buck stages for output current regulation (controlled by IRS2980AS hysteretic buck controllers). The circuit includes two analog (0-10V) dimming inputs for easy PWM LED dimming. The presented system provides high power efficiency, compact size, low cost and excellent power factor and THDI figures.

Safety Warning

An **electrical shock hazard** exists at any time when operating the circuit. The presented circuit should be handled by qualified electrical engineers only! General electrical safety precautions are important whenever doing measurements with the demo PCB!

Disclaimer

The presented LED driver circuit is intended for evaluation purposes only and has not been submitted or approved by any external test house for conformance with UL or international safety or performance standards. International Rectifier does not guarantee that this design will conform to any such standards.

2. System Specification

Parameter	***Description***	***Value***	***Units***
V_{in}	Nominal input voltage range	110-230	[VAC]
V_{in_low}	Lowest operating voltage	90	[VAC]
V_{in_high}	Highest operating voltage	260	[VAC]
I_{LED}	Output current (CH1, CH2)	700	[mA]
V_{out}	Output voltage range (CH1, CH2)	0-60	[V]
P_{out}	Output power	2 x 35	[W]
PF	Power Factor	>0.9	[-]
THDI	Current THD	<10	[%]
η	Nominal power efficiency	>87	[%]
PCB size	-	40.6 x 193	[mm]

Table 1: System Specification

3. Connection Diagram

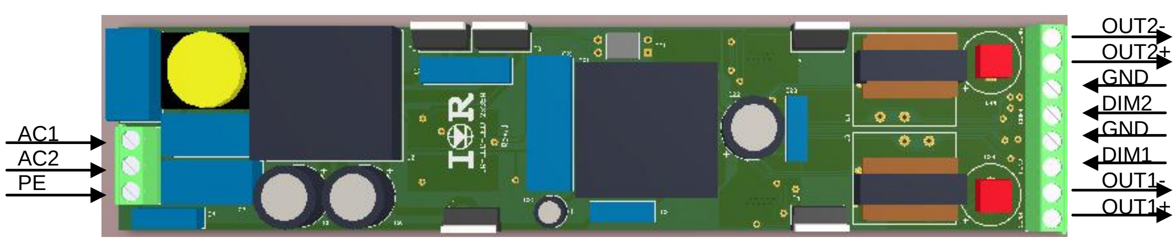


Figure 1: Connection Diagram

4. Circuit Schematic

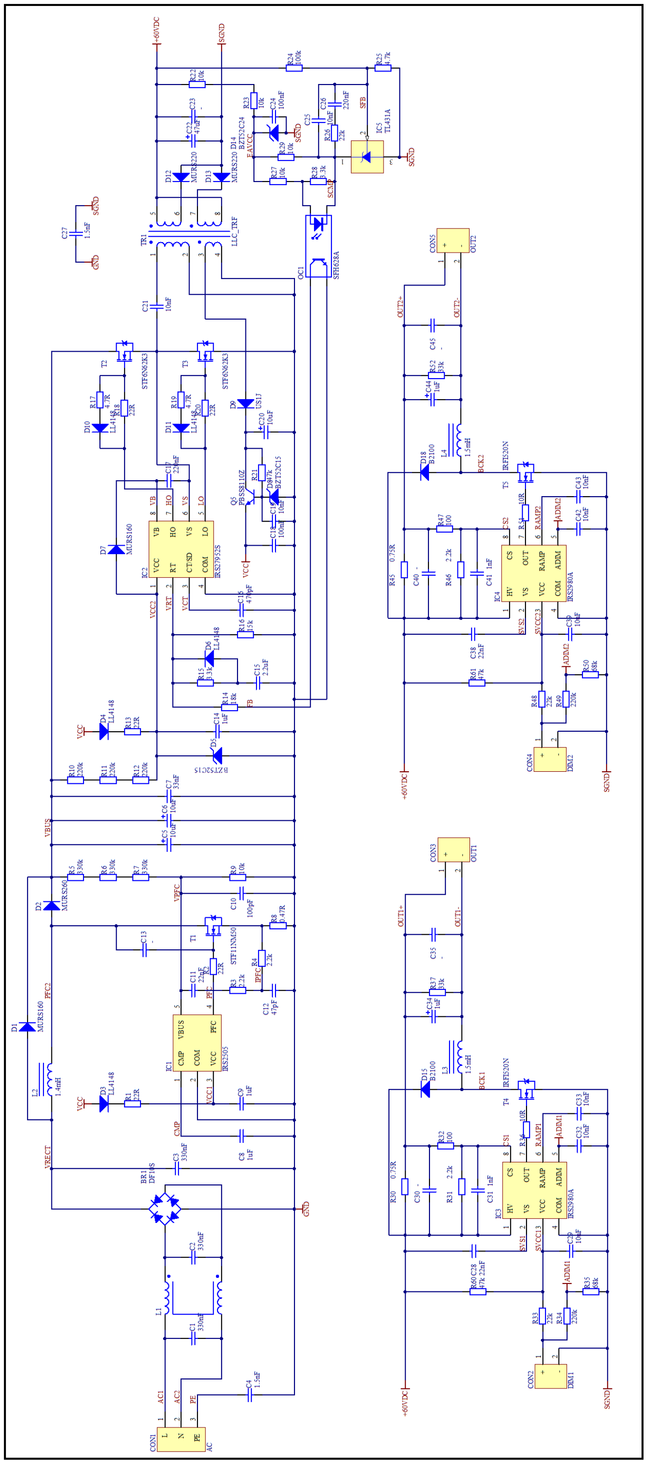


Figure 2: Circuit schematic

5. Boost PFC dimensioning

5.1 PFC specification

Parameter	*Description*	*Value*	*Units*
V_{in}	Nominal input voltage range	110-230	[VAC]
V_{in_low}	Lowest operating voltage	90	[VAC]
V_{in_high}	Highest operating voltage	260	[VAC]
V_{bus}	Nominal bus voltage	420	[V]
$P_{PFC,in}$	PFC Input power	80	[W]

Table 2: PFC Specification

5.2 PFC Inductor Dimensioning

Set the PFC inductor value for optimal on-time modulation as follows:

$$L_{PFC} = 15 \cdot 10^{-6} \cdot \frac{\left(V_{BUS} - \sqrt{2} V_{in,\max}\right) V_{in,\max}}{2 \cdot \sqrt{2} \cdot P_{PFC,in}} \cong 1.4mH \qquad (1)$$

Calculate the peak current at the bottom of the nominal input voltage range (considering slightly higher losses in this operating point, therefore ~5% higher input power):

$$I_{LPFC,PK} = \frac{\sqrt{2} \cdot 2 \cdot 1.05 \cdot P_{PFC,in}}{V_{in,\min}} = \frac{\sqrt{2} \cdot 2 \cdot 1.05 \cdot 80W}{110V} \cong 2.2A \qquad (2)$$

Calculate the number of turns (Selected core: ICT EVD25/13/13, $A_e \approx 75mm^2$):

$$N_{LPFC} \geq \frac{L_{PFC} I_{LPFC,PK}}{\Delta B A_e} = \frac{1400\mu H \cdot 2.2A}{0.3T \cdot 75mm^2} = 137 \tag{3}$$

We can use a round value here:

$$N_{LPFC} = 140 \tag{4}$$

5.3 PFC Overcurrent Protection Dimensioning

The sense resistor can be set as follows:

$$R_8 = R_{CS,PFC} \approx \frac{V_{BUSOC+}}{(1-0.5D_{MAX})\cdot 1.1 \cdot I_{LPFC,PK}} \cdot \frac{R_3 + R_4 + R_9}{R_9} \tag{5}$$

Where D_{MAX} is the duty cycle at the line peak of $V_{in,\min}$:

$$D_{MAX} \approx \frac{V_{BUS} - \sqrt{2}V_{in,\min}}{V_{BUS}} = \frac{420V - \sqrt{2}\cdot 110V}{420V} = 0.63 \tag{6}$$

So the current sense resistor:

$$R_8 \approx \frac{0.56V}{(1-0.5\cdot 0.63)\cdot 1.1 \cdot 2.2A} \cdot \frac{14.4k\Omega}{10k\Omega} \cong 0.49\Omega \tag{7}$$

Select the nearest standard value:

$$R_8 = 0.47\Omega \tag{8}$$

Note that the current limit value may be increased a bit in order to ensure fully functional PFC behavior even at $V_{IN\_LOW} = 90V$ (by decreasing R_8). Check against L_{PFC} saturation current!

5.4 PFC Inductor Specification

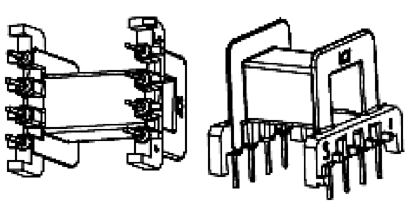
General information:

Core type	EVD25/13/13
Manufacturer	ICT
Bobbin	Horizontal
Pins	8
Part Nr. Core	ICT 60000161
Part Nr. Bobbin	ICT 60001571
Inductance (W1)	1400µH ±5%
DC resistance (W1)	800mΩ max.
Saturation current	2.4A min.
Peak applied voltage	500V max.
Maximum core temperature	100ºC

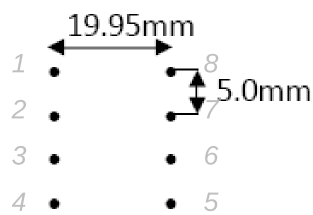
Winding information:

Winding	*Start pin*	*Finish pin*	*Turns*	*Wire*
W1	4	5	140	20x0.1mm CuLL

Physical layout:



Pinout (top view):



6. LLC Converter Dimensioning

6.1. LLC Converter Specification

Parameter	***Description***	***Value***	***Units***
V_{bus}	Bus voltage range (including bus voltage ripple)	400-440	[V]
V_{sec}	LLC nominal output voltage	60	[V]
I_{sec}	LLC nominal output current	1.25	[A]

Table 3: LLC Converter Specification

6.2 LLC Resonant Tank Dimensioning

The LLC resonant tank dimensioning usually requires a couple of iterations. The actual implementation of the resonant transformer affects several design constraints. Important factors are: L_r resonant inductance (stray inductance of the transformer measured on the primary), L_{pri} nominal (total) inductance of the primary winding and the $f_{SELF-RES}$ self-resonance frequency. The transformer self-resonance may limit the usable L_{pri} inductance in some cases, depending on the winding arrangement (due to the stray capacitance of the windings).

For a typical LLC tank design (with integrated magnetics) for the designated power level, use the following usual values to start the design iteration: $L_{pri} = 1 - 2mH$, $L_r = 0.2...0.3 \cdot L_{pri}$, $C_r = 3.3...10nF$, $f_{r1} = 50...200kHz$.

Set the desired resonance frequency first:

$$f_{r1} = 90kHz \tag{9}$$

Resonant inductor:

$$L_r = \frac{1}{(2\pi \cdot f_{r1})^2 \cdot C_r} \tag{10}$$

Where: $C_r = C_{21}$ (refer to schematic).

With $C_r = C_{21} = 10nF$ assumption we get:

$$L_r = \frac{1}{2\pi \cdot 90kHz \cdot 10nF} \cong 315\mu H \tag{11}$$

Final resonant inductor value (primary stray inductance measurement):

$$L_r = 330\mu H \pm 5\% \tag{12}$$

Re-calculated nominal resonant frequency:

$$f_{r1} = \frac{1}{2\pi\sqrt{L_r C_r}} = 87.61kHz \tag{13}$$

Total primary inductance can be pre-selected by defining a typical k-factor ($k = L_m / L_r$) as shown in the AN-1160 Application Note [2]. After fine tuning iteration (allocating the self-resonance frequency well above ~700kHz), in this particular case we can select:

$$L_{pri} = 1200\mu H \pm 5\% \tag{14}$$

So the actual k-factor will be:

$$k = \frac{L_m}{L_r} = \frac{L_{pri} - L_r}{L_r} = \frac{1200\mu H - 330\mu H}{330\mu H} = 2.64 \tag{15}$$

The nominal voltage gain of the resonant tank:

$$M_V = \sqrt{\frac{L_{pri}}{L_{pri} - L_r}} = \sqrt{\frac{1200\mu H}{1200\mu H - 330\mu H}} = 1.1744 \tag{16}$$

Transformer turns ratio:

$$n = \frac{N_{pri}}{N_{sec}} = \frac{V_{BUS,MAX}}{2(V_{sec} + V_{FW})} M_v = \frac{440V}{2 \cdot (60V + 1V)} \cdot 1.1744 = 4.236 \tag{17}$$

Equivalent AC load resistance:

$$R_{AC} = \frac{8n^2(V_{sec} + V_{FW})}{\pi^2 I_{sec}} = \frac{8 \cdot 4.236^2 \cdot 61V}{\pi^2 \cdot 1.25A} \cong 710\Omega \tag{18}$$

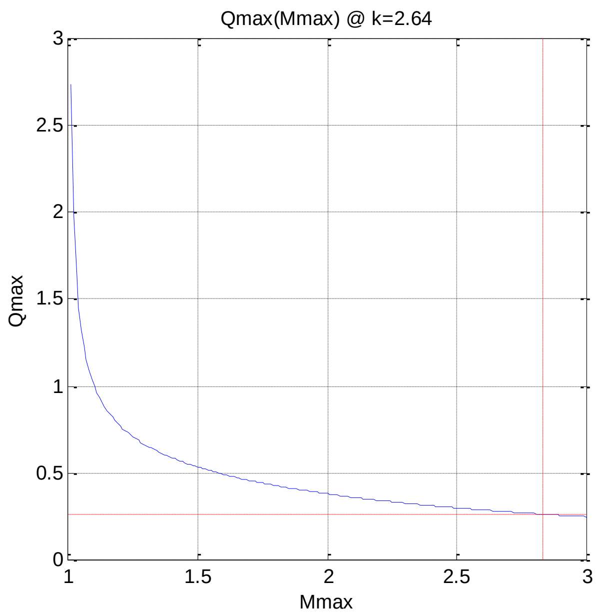
The corresponding quality factor at full load:

$$Q = \frac{1}{2\pi f_{r1} C_r R_{AC}} = \frac{1}{2\pi \cdot 87.61kHz \cdot 10nF \cdot 710\Omega} \cong 0.26 \qquad (19)$$

Plot the $Q_{MAX}(M_{MAX})$ function from the following equation:

$$Q_{MAX} = \frac{1}{k}\sqrt{\frac{1+k\left(1-\frac{1}{M_{MAX}^{\ 2}}\right)}{M_{MAX}^{\ 2}-1}} \qquad (20)$$

Find the M_{MAX} gain with $k = 2.64$ parameter graphically:



Read the maximum gain from the curve above:

$$M_{MAX} \cong 2.8 \qquad (21)$$

Note that this is the attainable maximum gain with $Q = Q_{MAX}$ assumption, while ensuring ZVS even at full load (refer to [2]). Considering the pre-regulated bus voltage, this gain is much higher than necessary in this particular case. This means, that the converter will operate safely in the ZVS region even at the minimum bus voltage. (In other words: the Q factor of designed LLC tank stays below the Q_{MAX} upper limit while maintaining the necessary voltage gain at low bus voltage, therefore it operates always in the ZVS range.)

Define the following minimum frequency factor:

$$x_{\min} = \frac{1}{\sqrt{1 + k\left(1 - \frac{1}{\left(\frac{V_{BUS,MAX}}{V_{BUS,MIN}}\right)^2}\right)}} = \frac{1}{\sqrt{1 + 2.64 \cdot \left(1 - \frac{1}{\left(\frac{440}{400}\right)^2}\right)}}$$

$$x_{\min} \cong 0.83 \quad (22)$$

The corresponding minimum frequency:

$$f_{\min} = f_{r1} \cdot x_{\min} \cong 73kHz \quad (23)$$

Define the maximum operation frequency as follows:

$$1.2 f_{r1} \le f_{\max} < \frac{f_{SELF-RES}}{5} \quad (24)$$

Where $f_{SELF-RES}$ is the self-resonant frequency of the LLC transformer measured on the primary winding (consider design iteration, here $f_{SELF-RES} \approx 800kHz$).

$$105kHz \le f_{\max} < 160kHz \tag{25}$$

The selected maximum frequency:

$$f_{\max} = 125kHz \tag{26}$$

Define the minimum number of turns for the primary winding (Selected core: ICT EVD25/13/13, $A_e \approx 75mm^2$):

$$N_{pri,\min} = \frac{n(V_{\sec} + V_{FW})}{2 f_{\min} M_V \Delta B A_e} = \frac{4.236 \cdot 61V}{2 \cdot 73kHz \cdot 1.1744 \cdot 0.3T \cdot 75mm^2} \cong 67 \tag{27}$$

We can select a bit higher number close to a multiple of n:

$$N_{pri} = 72 \tag{28}$$

Thus the number of turns for the secondary:

$$N_{\sec,1} = N_{\sec,2} = \frac{N_{pri}}{n} = \frac{72}{4.236} = 17 \tag{29}$$

Note that there are two secondary windings.

Number of turns for the auxiliary winding (consider a relatively high auxiliary voltage for an easy VCC start-up):

$$N_{AUX} \cong N_{\sec,1} \frac{V_{AUX}}{V_{\sec}} = 17 \cdot \frac{40V}{60V} \approx 12 \tag{30}$$

Estimate the peak current flowing through the primary winding:

$$I_{pri,PK} = \sqrt{\left(\frac{I_{\sec}\pi}{2n}\right)^2 + I_1^{\,2}} \tag{31}$$

Where I_1 is the current level where the magnetizing current equals the resonant current:

$$I_1 = \frac{n \cdot (V_{\sec} + V_{FW})}{4 \cdot (L_{pri} - L_r) f_{r1} M_V}$$

$$I_1 = \frac{4.236 \cdot 61V}{4 \cdot (1200\mu H - 330\mu H) \cdot 87.61kHz \cdot 1.1744} = 0.72A \tag{32}$$

So the peak current on the primary:

$$I_{pri,PK} = \sqrt{\left(\frac{1.25A \cdot \pi}{2 \cdot 4.236}\right)^2 + 0.72A^2} = 0.856A \tag{33}$$

For the RMS current we get:

$$I_{pri,RMS} = \frac{I_{pri,PK}}{\sqrt{2}} = 0.6A \qquad (34)$$

The peak current on the secondary side:

$$I_{\sec,PK} = \frac{\pi I_{\sec}}{2} = 1.96A \qquad (35)$$

For the secondary RMS current we get:

$$I_{\sec,RMS} = \frac{\pi I_{\sec}}{4} = 0.98A \qquad (36)$$

6.3 LLC Controller Settings

Calculate the LLC oscillator timing capacitor ($C_{16} = C_T$):

$$C_T = \frac{T_{DT} - 40ns}{0.85 \cdot 10^3} \qquad (37)$$

Where T_{DT} is the half-bridge dead-time required for ZVS operation. Set $T_{DT} \approx 400ns$ as a first approach (usually it has to be verified by measurement if it is long enough):

$$C_T = \frac{400ns - 40ns}{0.85 \cdot 10^3} = 424\,pF \qquad (38)$$

Select the nearest standard value:

$$C_{16} = C_T = 470\,pF \qquad (39)$$

Thus the resulting dead-time:

$$T_{DT} = C_T \cdot 0.85 \cdot 10^3 + 40ns = 440ns \qquad (40)$$

Set the minimum frequency by:

$$R_{16} = R_{\min} = \frac{1}{2 f_{\min} T_{DT} \cdot 10^{-3}} - 1k\Omega \cong 15k\Omega \qquad (41)$$

Calculate the required resistance for the maximum frequency setting:

$$R_{eq} = \frac{1}{2 f_{\max} T_{DT} \cdot 10^{-3}} - 1k\Omega = 8.1k\Omega \qquad (42)$$

Thus the maximum frequency setting resistor:

$$R_{14} = R_{\max} = \frac{R_{\min} R_{eq}}{R_{\min} - R_{eq}} = 17.6k\Omega \qquad (43)$$

Select the nearest standard value:

$$R_{14} = 18k\Omega \tag{44}$$

Similarly, the soft-start frequency setting can be defined as (set $f_{SS} = 300kHz$):

$$R_{SS,eq} = \frac{1}{2 f_{SS} T_{DT} \cdot 10^{-3}} - 1k\Omega = 2.788k\Omega \tag{45}$$

Thus the soft-start frequency setting resistor:

$$R_{15} = R_{SS} = \frac{R_{\min} R_{SS,eq}}{R_{\min} - R_{SS,eq}} \approx 3.3k\Omega \tag{46}$$

Please refer to the IRS2795(1,2)S datasheet [3] and to the AN-1160 Application Note [2] for more information.

6.4 LLC Transformer Specification

General information:

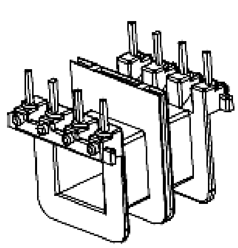
Core type	EVD25/13/13
Manufacturer	ICT
Bobbin	Horizontal
Pins	8
Part Nr. Core	ICT 60002043
Part Nr. Bobbin	ICT 60003572
Part Nr. Bobbin case	ICT 60003573
Primary inductance (PRI)	1200µH ±5%
Leakage inductance (PRI) *	330µH ±5%
Self-resonant frequency (PRI)	>750kHz
Peak applied voltage	500V max.
Maximum core temperature	100ºC

*W3 ***or*** W4 shorted during leakage inductance measurement.

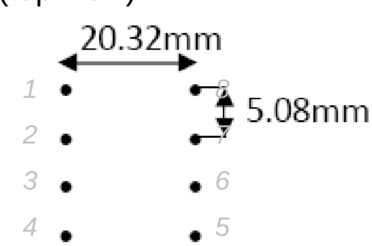
Winding information:

Winding	*Start pin*	*Finish pin*	*Turns*	*Wire*
PRI	1	2	72	10x0.1mm CuLL + isolation between layers
AUX	3	4	12	1x0.2mm CuLL
SEC1	7	8	17	30x0.1mm CuLL
SEC2	5	6	17	30x0.1mm CuLL

Physical layout:



Pinout (top view):



7. Buck Converter Dimensioning

7.1 LED Current Regulation

Set the buck current sense resistors (R_{30} and R_{45}) according to the required LED current:

$$R_{CS} = \frac{V_{CS}}{I_{LED}} \quad (47)$$

Where:

$$V_{CS} = 0.5V \quad (48)$$

With $I_{LED} = 0.7A$ we get:

$$R_{CS} = \frac{0.5V}{0.7A} = 0.714\Omega \quad (49)$$

Select the nearest *higher* standard value:

$$R_{30} = R_{45} = 0.75\Omega \quad (50)$$

Adjust the current by setting the current sense gain with R_{31} and R_{46}:

$$R_{31} = \frac{R_{32}R_{CS}}{R_{30} - R_{CS}} \approx 2.2k\Omega \quad (51)$$

And similarly:

$$R_{46} = \frac{R_{47}R_{CS}}{R_{45} - R_{CS}} \approx 2.2k\Omega \quad (52)$$

The nominal buck operation frequency can be calculated as shown in the IRS2980S datasheet [4].

7.2 Buck Inductor Specification

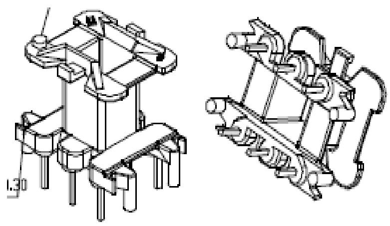
General information:

Core type	EF20/09/06
Manufacturer	ICT
Bobbin	Vertical
Pins	6
Part Nr. Core	ICT 60000153
Part Nr. Bobbin	ICT 60000004
Inductance (W1)	1500µH ±5%
DC resistance (W1)	750mΩ max.
Saturation current	0.8A min.
Peak applied voltage	100V max.
Maximum core temperature	100ºC

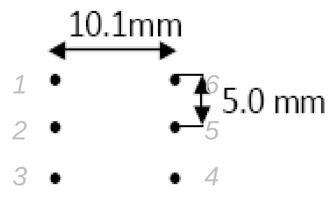
Winding information:

Winding	*Start pin*	*Finish pin*	*Turns*	*Wire*
W1	1	3	140	15x0.1mm CuLL

Physical layout:



Pinout (top view):



8. PCB Layout

8.1 PCB Layout Considerations

In order to ensure correct circuit functionality and to avoid issues caused by high-frequency signal disturbance, proper care should be taken when designing the PCB layout. Typical design problems due to poor layout can include high-frequency voltage and/or current spikes, poor EMC results, latch up, abnormal circuit behavior, component failures, low manufacturing yields and poor system reliability. The following layout tips should be followed as early in the design phase as possible in order to reduce potential problems of the implemented circuit, shorten design cycles, and to increase reliability and manufacturability:

1. Keep the traces of the switching signals as short as possible (like: drain switching node, output diode node, etc.). This will help to reduce high-frequency ringing and noise coupling due to parasitic inductance of PCB traces.

2. Keep high-frequency switching nodes away from sensitive circuit nodes (like: low voltage control signals). This will help to reduce noise coupling from switching nodes to critical circuit nodes.

3. Place the VCC filter capacitor as close to the control IC pins as possible. This will ensure the best possible filtering.

4. Route separate traces for power and signal grounds and connect the small-signal ground to the power ground at a single point only. Place this star ground connection close to the current sense resistors and minimize the distance from the IC ground pin. This will minimize the cross coupling between power ground and signal ground, providing noise-free current and voltage sense signals for the control IC.

5. Reduce the distance of the power switches to their gate drive pins as much as possible. This will help reduce the parasitic inductance in the traces, thus reduces possible voltage spikes at gate drive switching and help prevent latch up due to voltage over- or under-shoot.

6. Place critical sensing nodes (sensing filters, etc.) as close to the IC as possible. This will help to eliminate false triggering or circuit malfunction due to noise being coupled onto the sensitive control signals.

8.2 PCB 3D views

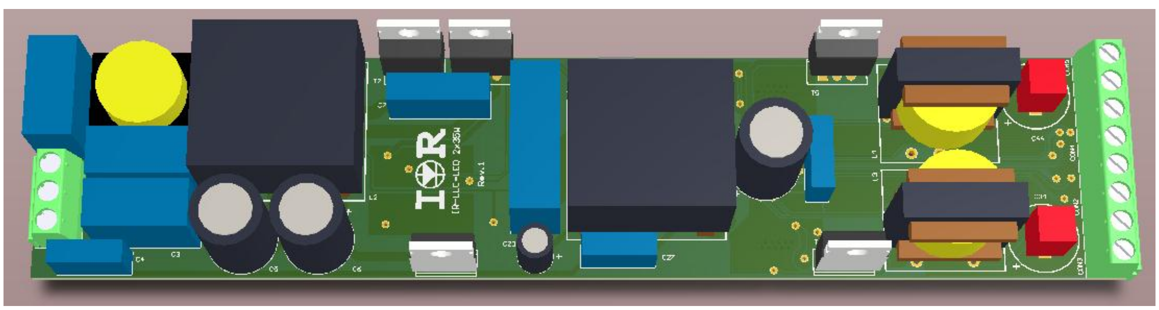


Figure 3: PCB 3D view – top side

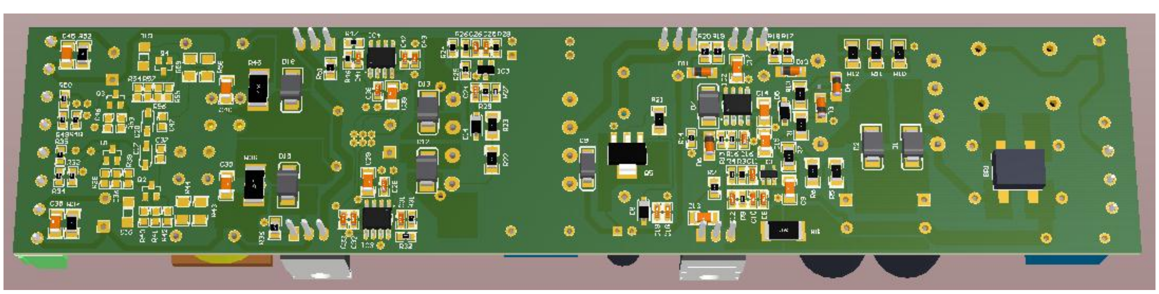


Figure 4: PCB 3D view – bottom side

8.3 PCB Top Assembly Drawing

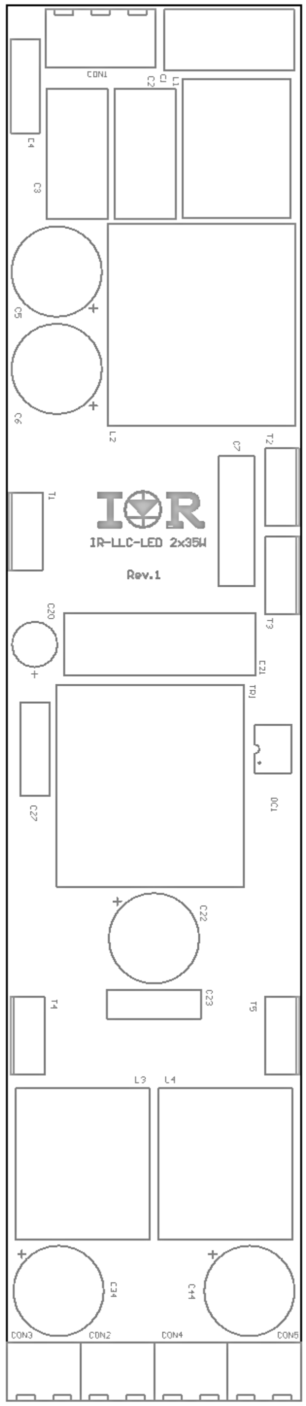


Figure 5: PCB Top assembly drawing

8.4 PCB Bottom Assembly Drawing

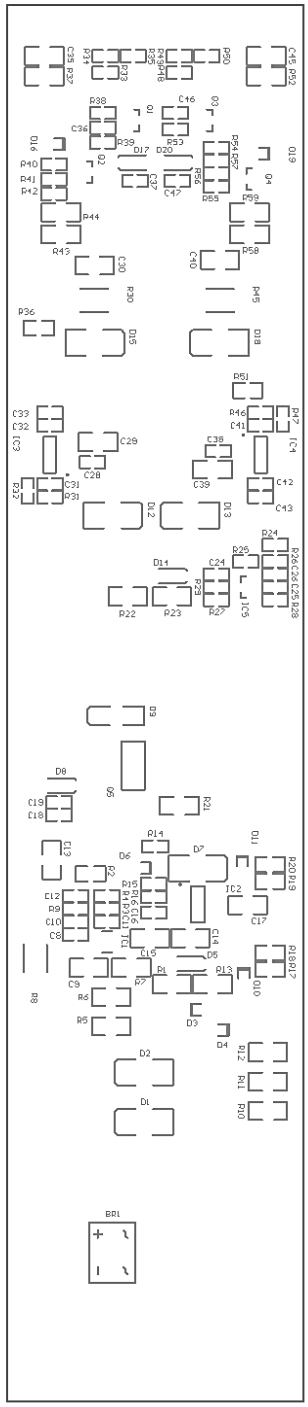


Figure 6: PCB Bottom assembly drawing

(Note: do not populate components that are not in the BOM)

8.5 PCB Top Layer

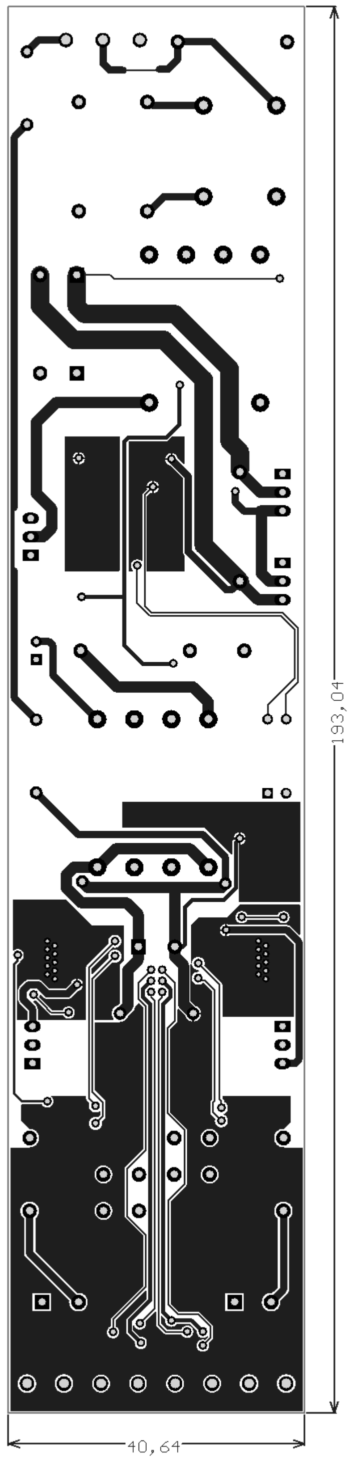


Figure 7: PCB Top layer

(not to scale)

8.6 PCB Bottom Layer

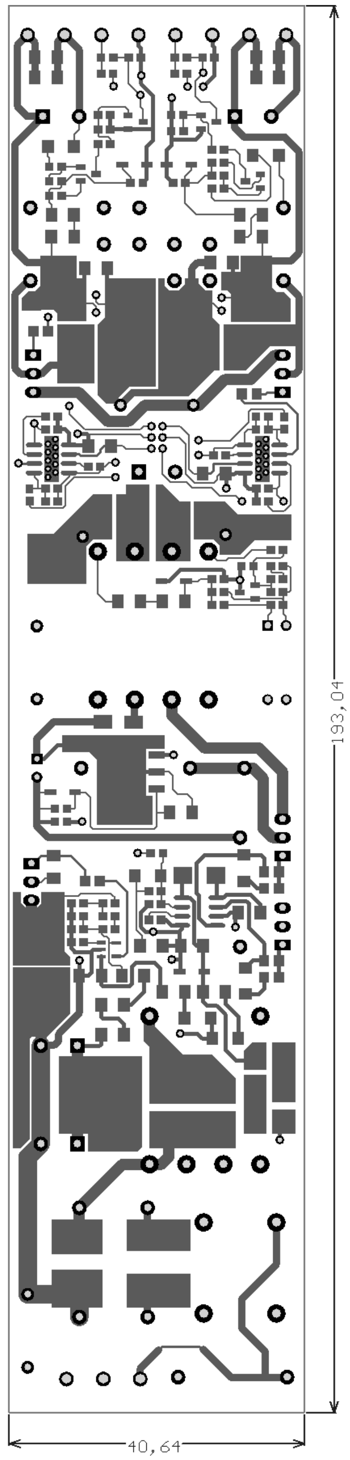


Figure 8: PCB Bottom layer

(bottom view, not to scale)

9. Bill of Materials

Index	Description	Part Number	Manufacturer	Qty	Designator
1	Bridge rectifier 1.5A/1000V	DF10S	Fairchild	1	BR1
2	Capacitor 47pF/X7R/25V/0603	-	Epcos	1	C12
3	Capacitor 100pF/X7R/25V/0603	-	Epcos	1	C10
4	Capacitor 470pF/C0G/25V/0603	-	Epcos	1	C16
5	Capacitor 1nF/X7R/25V/0603	-	Epcos	2	C31, C41
6	Capacitor 10nF/X7R/25V/0603	-	Epcos	6	C19, C25, C32, C33, C42, C43
7	Capacitor 22nF/X7R/25V/0603	-	Epcos	3	C11, C28, C38
8	Capacitor 100nF/X7R/25V/0603	-	Epcos	2	C18, C24
9	Capacitor 220nF/X7R/25V/0603	-	Epcos	1	C26
10	Capacitor 1uF/X7R/25V/0603	-	Epcos	1	C8
11	Capacitor 220nF/X7R/25V/1206	-	Epcos	1	C17
12	Capacitor 1uF/X7R/25V/1206	-	Epcos	2	C9, C14
13	Capacitor 2.2uF/X7R/25V/1206	-	Epcos	1	C15
14	Capacitor 10uF/X7R/25V/1206	-	Epcos	2	C29, C39
15	Capacitor 1.5nF/Y2/RAD	B32021A3152M	EPCOS	2	C4, C27
16	Capacitor 10nF/700VAC/RAD	B32653A1103K	Epcos	1	C21
17	Capacitor 33nF/630V	B32652A6333J	Epcos	1	C7
18	Capacitor 330nF/X2/RAD	B32922D3334M	Epcos	3	C1, C2, C3

19	Capacitor 1uF/100VDC/RAD	MKS2-D041001K00KSSD	WIMA	2	C34, C44
20	Polarized Capacitor (Radial) 10uF/100V	ECA2AAM100X	Panasonic	1	C20
21	Polarized Capacitor (Radial) 47uF/160V	EEUEE2C470	Panasonic	1	C22
22	Polarized Capacitor (Radial) 10uF/450V	B43888C5226M	Epcos	2	C5, C6
23	Diode Small Signal 200mA SOD-80	LL4148	Vishay	5	D3, D4, D6, D10, D11
24	Diode Ultra-Fast Rectifier 1A/600V/SMB	MURS160	Diodes Inc	2	D1, D7
25	Diode Ultra-Fast Rectifier 2A/200V/SMB	MURS220	Diodes Inc	2	D12, D13
26	Diode Schottky Rectifier 2A/100V/SMB	B2100	Diodes Inc	2	D15, D18
27	Diode Ultra-Fast Rectifier 2A/600V/SMB	MURS260	Diodes Inc	1	D2
28	Diode Ultra-Fast Rectifier 1A/600V/SMA	US1J	Diodes Inc	1	D9
29	Ferrite core common-mode choke 15mH	5730350015	Vogt	1	L1
30	Ferrite core single inductor 1.4mH EVD25	ICT EVD25/13/13	ICT	1	L2
31	Ferrite core single inductor 1.5mH EF20	ICT EF20/09/06	ICT	2	L3, L4
32	Ferrite Core Transformer with Multiple Windings	ICT EVD25/13/13	ICT	1	TR1
33	Power MOSFET STF11NM50 TO-220	STF11NM50	ST	1	T1
34	Power MOSFET STF6N62K3 TO-220	STF6N62K3	ST	2	T2, T3
35	Power MOSFET IRFI520N TO-220	IRFI520N	International Rectifier	2	T4, T5
36	IRS2505L PFC Control IC SOT23-5	IRS2505L	International Rectifier	1	IC1
37	IRS2980AS LED Driver IC SO-8	IRS2980AS	International Rectifier	2	IC3, IC4
38	IRS27952S Resonant Half-Bridge Converter Control IC SO-8	IRS27952S	International Rectifier	1	IC2

39	Shunt Regulator, normal pinout SOT23	TL431A	Diodes Inc	1	IC5
40	Optocoupler, 4-pin DIP4	SFH628A	Vishay	1	OC1
41	Resistor 100R/1%/0.1W/0603	-	-	2	R32, R47
42	Resistor 2.2k/1%/0.1W/0603	-	-	4	R3, R4, R31, R46
43	Resistor 3.3k/1%/0.1W/0603	-	-	2	R15, R28
44	Resistor 4.7k/1%/0.1W/0603	-	-	1	R25
45	Resistor 10k/1%/0.1W/0603	-	-	3	R9, R27, R29
46	Resistor 15k/1%/0.1W/0603	-	-	1	R16
47	Resistor 18k/1%/0.1W/0603	-	-	1	R14
48	Resistor 22k/1%/0.1W/0603	-	-	3	R26, R33, R48
49	Resistor 68k/1%/0.1W/0603	-	-	2	R35, R50
50	Resistor 100k/1%/0.1W/0603	-	-	1	R24
51	Resistor 220k/1%/0.1W/0603	-	-	2	R34, R49
52	Resistor 4.7R/1%/0.125W/0805	-	-	2	R17, R19
53	Resistor 10R/1%/0.125W/0805	-	-	2	R36, R51
54	Resistor 22R/1%/0.125W/0805	-	-	3	R2, R18, R20
55	Resistor 22R/1%/0.25W/1206	-	-	2	R1, R13
56	Resistor 10k/1%/0.25W/1206	-	-	2	R22, R23
57	Resistor 33k/1%/0.25W/1206	-	-	2	R37, R52
58	Resistor 47k/1%/0.25W/1206	-	-	3	R21, R60, R61

59	Resistor 220k/1%/0.25W/1206	-	-	3	R10, R11, R12
60	Resistor 330k/1%/0.25W/1206	-	-	3	R5, R6, R7
61	Resistor 0.47R/1W/2512	ERJ1TRQFR47U	Panasonic	1	R8
62	Resistor 0.75R/1W/2512	ERJ1TRQFR75U	Panasonic	2	R30, R45
63	Terminal Block 3-pin	MKDSN-1.5/3-5.08	Phoenix Contact	1	CON1
64	Terminal Block 2-pin	MKDSN-1.5/2-5.08	Phoenix Contact	1	CON2, CON3, CON4, CON5
65	Transistor NPN 100V/1A SOT223	PBSS8110Z	NXP	1	Q5
66	Zener Diode 24V SOD123	BZT52C24	Diodes Inc	1	D14
67	Zener Diode 15V SOD123	BZT52C15	Diodes Inc	2	D5, D8

Table 4: Bill of Materials

10. Measurement results

10.1 Typical input and output figures

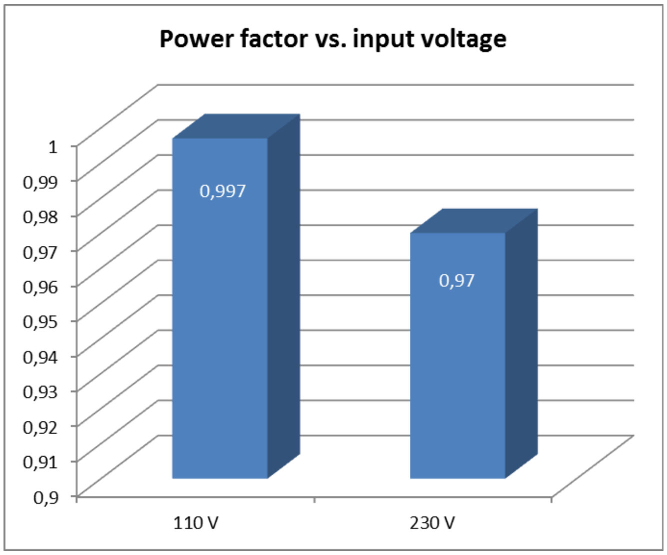


Figure 9: Typical power factor vs. input voltage

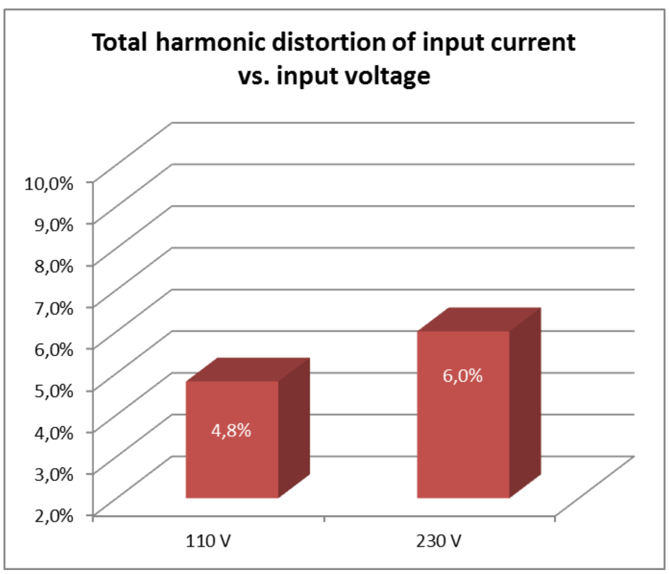


Figure 10: Typical THDI vs. input voltage

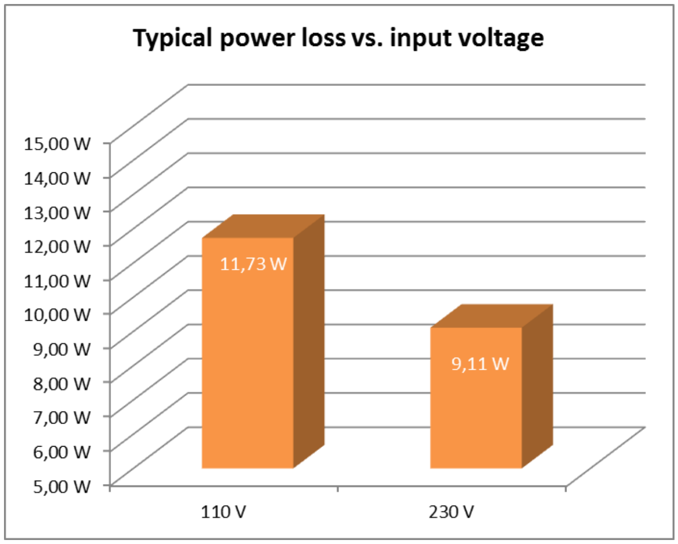


Figure 11: Typical power loss vs. input voltage

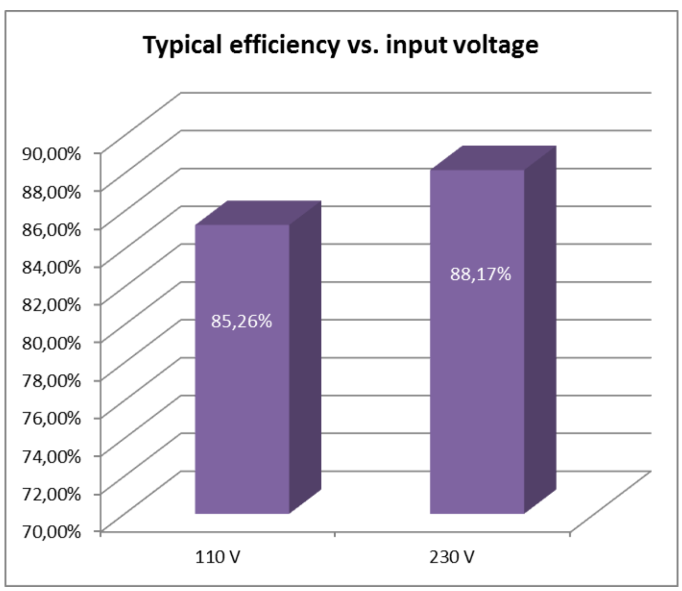


Figure 12: Typical power efficiency vs. input voltage

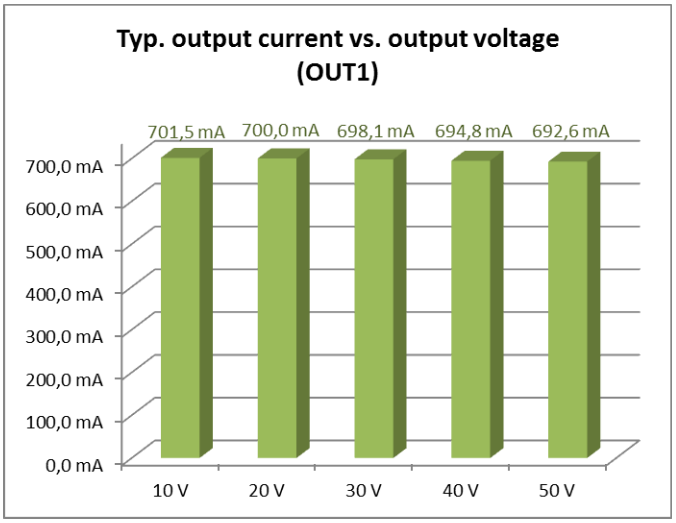


Figure 13: Typical output current regulation

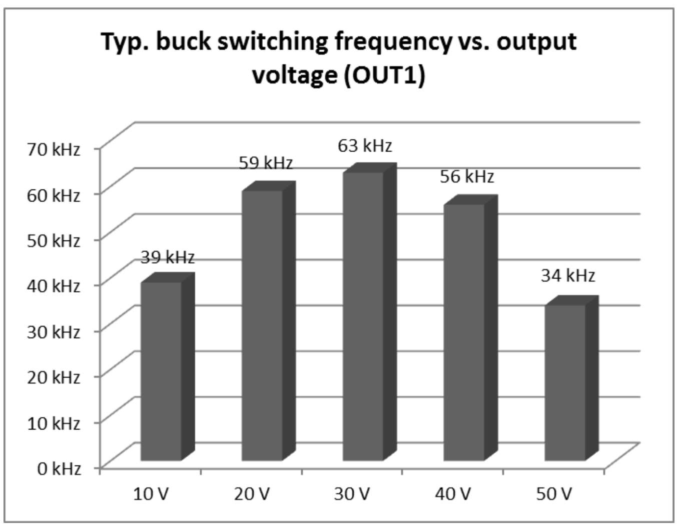


Figure 14: Typical buck switching frequency

10.2 Input waveforms

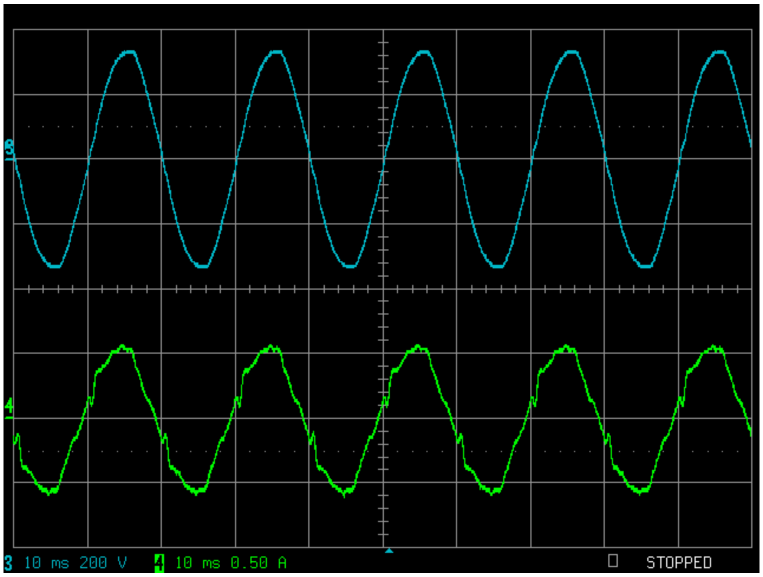


Figure 15: Input voltage (CH3) and input current (CH4) at 230VAC

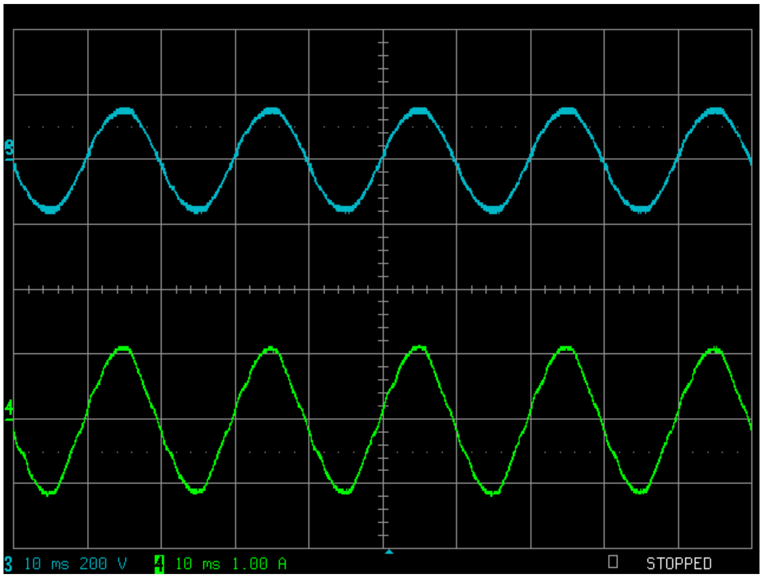


Figure 16: Input voltage (CH3) and input current (CH4) at 110VAC

10.3 Output waveforms

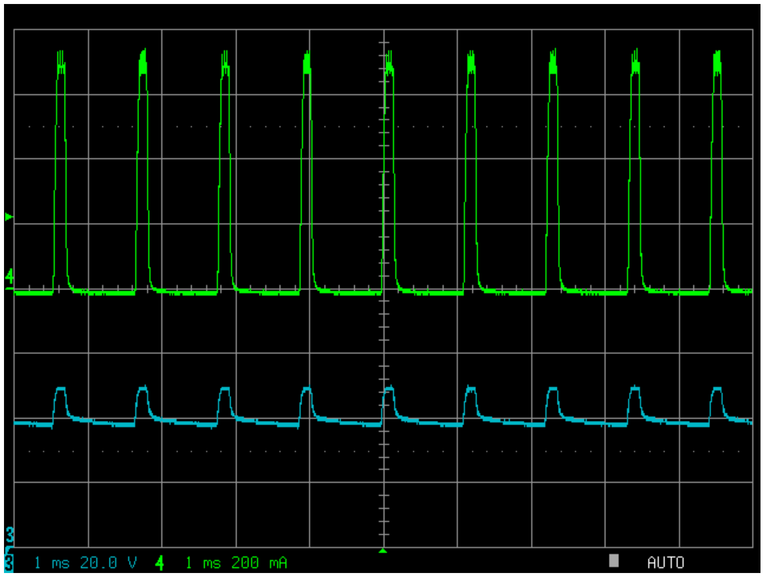


Figure 17: OUT1 Output voltage (CH3) and output current (CH4) at DIM1=2V

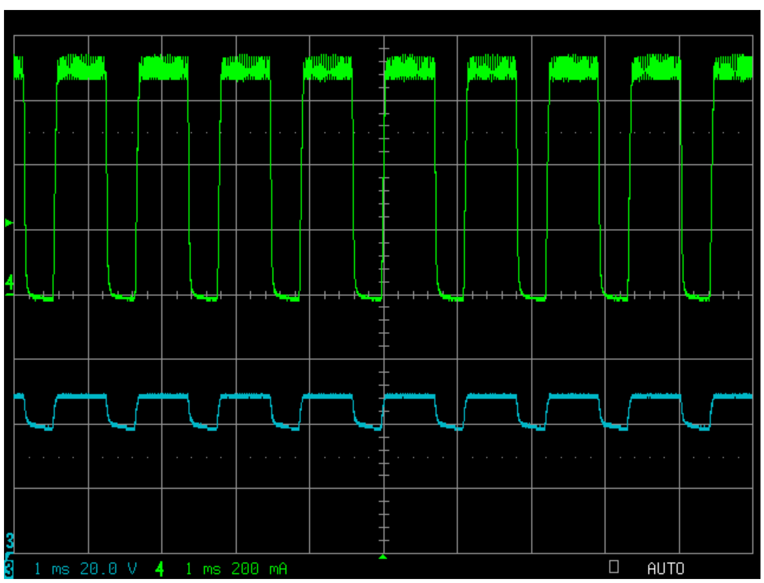


Figure 18: OUT1 Output voltage (CH3) and output current (CH4) at DIM1=6V

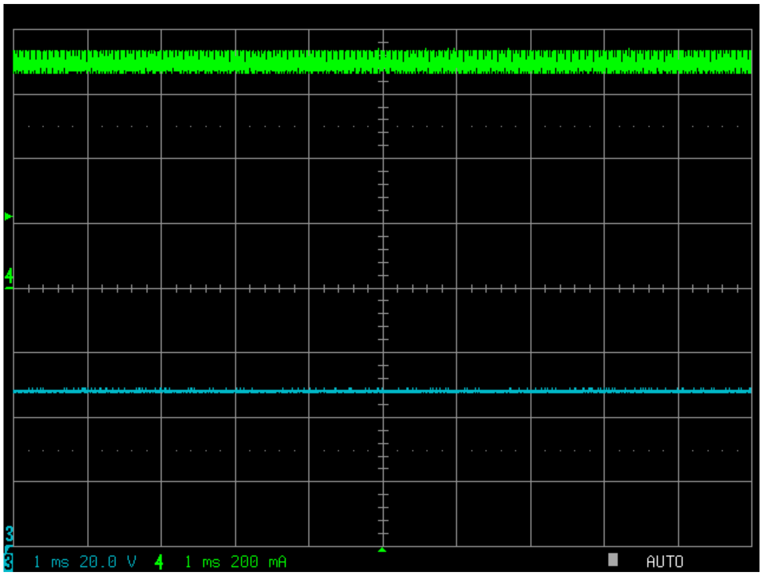


Figure 19: OUT1 Output voltage (CH3) and output current (CH4) at DIM1=10V

10.4 Data series

Vin_target	230 V	110 V
Vin rms	232,4 V	111,3 V
Iin rms	342,6 mA	717,5 mA
Sin rms	79,62 VA	79,60 VA
PF	0,97	0,997
Pin	77,00 W	79,60 W
Vout1	49,5 V	49,2 V
Iout1	695,8 mA	696,4 mA
Pout1	34,42 W	34,27 W
Vout2	47,9 V	48,1 V
Iout2	698,6 mA	699,2 mA
Pout2	33,47 W	33,60 W
THD I	6,0%	4,8%
THDV	0,20%	0,20%
IH1	341,9 mA	715,8 mA
IH3	3,2%	3,3%
IH5	1,3%	2,3%
IH7	0,8%	2,7%
IH9	2,2%	1,0%
IH11	2,0%	0,4%
IH13	1,1%	0,1%
IH15	0,9%	0,5%
IH17	0,8%	0,5%
IH19	0,5%	0,2%
IH21	0,5%	0,2%
Pd	9,11 W	11,73 W
η	88,17%	85,26%

Table 5: Data series

11. List of Abbreviations

BOM *Bill of Materials*
CRM *Critical Conduction Mode*
EMC *Electromagnetic Compatibility*
LED *Light Emitting Diode*
LLC *Inductor-inductor-capacitor resonant converter*
PCB *Printed Circuit Board*
PF *Power Factor*
PFC *Power Factor Correction*
PWM *Pulse Width Modulation*
THDI *Total Harmonic Distortion of Current*
ZVS *Zero Voltage Switching*

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Figure 19: OUT1 Output voltage (CH3) and output current (CH4) at DIM1=10V 38

13. References

[1] IRS2505L Boost PFC Control IC Datasheet
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[2] AN-1160 Design of Resonant Half-Bridge Converter using IRS2795(1,2) Control IC
http://www.irf.com/technical-info/appnotes/an-1160.pdf

[3] IRS2795(1,2)S Resonant Half-Bridge Converter Control IC Datasheet
http://www.irf.com/product-info/datasheets/data/irs27951s.pdf

[4] IRS2980S LED Driver Control IC Datasheet
http://www.irf.com/product-info/datasheets/data/irs2980spbf.pdf

14. Revision History

Date	*Revision*	*Changes*	*Author*
02-July-13	1	Initial version	Akos Hodany
28-Aug-13	2	Added PCB drawings, Added BOM, Minor corrections, Formatting for release	Akos Hodany