UM10722

SSL4120DB1123 - 90 W 1.9 A CC dimmable isolated LED driver demo board

Rev. 1.1 — 19 August 2014 **User manual**

Document information

Info	Content
Keywords	SSL4120T, LED driver, dimmable, isolated, demo board, power factor corrector, PFC, resonant, LLC, burst mode
Abstract	The SSL4120DB1123 is a dimmable global mains 90 W LED driver demo board featuring the NXP Semiconductors SSL4120T IC. The board has a two-stage (PFC + resonant) topology to achieve good THD performance (mains current class C compliance) over a wide mains input voltage range and output power range. The SSL4120DB1123 can drive a large LED voltage/current range.

Revision history

Rev	Date	Description
v 1.1	20140819	updated issue
v.1	20130823	first issue

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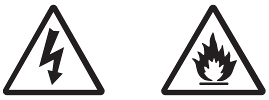
1. Introduction

Warning

Lethal voltage and fire hazard



The non-insulated high voltages that are present when operating this product constitute a risk of electric shock, personal injury, death and/or ignition of fire.

This product is intended for evaluation purposes only. It shall be operated in a designated test area by personnel qualified according to local requirements and labor laws to work with non-insulated mains voltages and high-voltage circuits. This product shall never be operated unattended.

The SSL4120DB1123 demo board is a dimmable LED driver example using a PFC and an LLC stage. This manual describes the specification and use of the SSL4120DB1123 board.

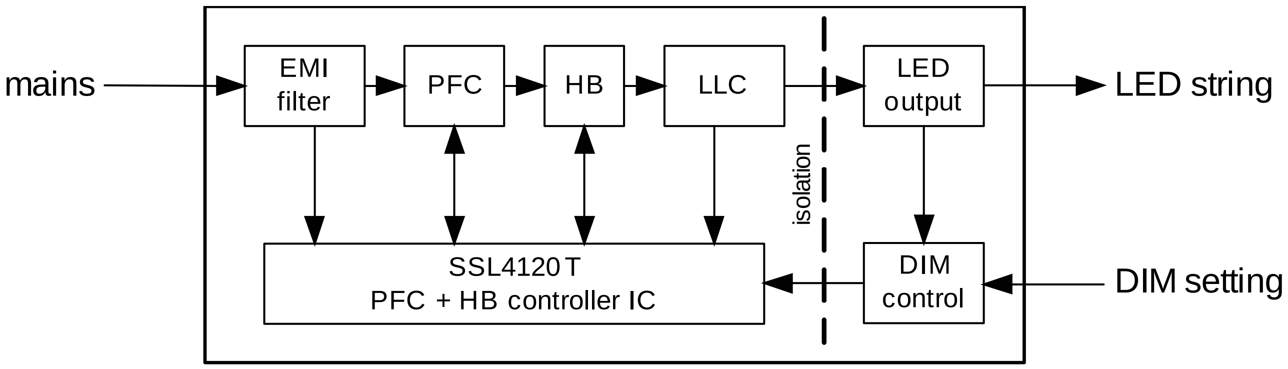


Fig 1. Demo board block diagram

1.1 Features and benefits

- Efficient PFC and LLC topology
- Large input voltage range
- Short turn-on delay time
- Low mains current harmonics
- LLC stage with large output voltage range
- Dimmable
- Single layer PCB 146 x 60 mm, wave soldering

2. Safety warning

The board must be connected to mains voltage. Avoid touching the demo board while it is connected to the mains voltage. An isolated housing is obligatory when used in uncontrolled, non-laboratory environments. Galvanic isolation of the mains phase using a variable transformer is always recommended.

a. Isolated b. Non isolated

Fig 2. Variable transformer isolation symbols

3. Board specifications

Table 1. Electrical specifications

Symbol	Description	Value	Condition
V_{mains}	mains voltage (AC)	90 V to 300 V (AC)	
$t_{d(on)}$	turn-on delay time	< 300 ms	
$P_{o(max)}$	maximum output power	90 W	V_o = 48 V
V_o	output voltage	15 V to 48 V	CC mode
$V_{o(max)}$	maximum output voltage	49 V	fault mode, no LED
I_o	output current[1]	0.190 to 1.9 A	DIM 10 % to 100 %
$\Delta I_o/\Delta V_{mains}$	line regulation	< 3 %	
$\Delta I_o/\Delta V_o$	load regulation	< 3 %	
$V_{I(DIM)}$	DIM input voltage	1 V to 10 V	
η	efficiency	> 90 %	full load
PF	power factor	> 0.95	full load
THD	total harmonic distortion	< 10 % < 20 %	full load quarter load
$P_{i(fault)}$	fault mode input power	< 3.0 W	no-load
$P_{i(standby)}$[2]	standby input power	< 0.2 W	

[1] Average

[2] $P_{i(standby)}$ is measured with pin SSHBC/EN shorted to ground

4. Demo board connections

4.1 Line voltage and LED module

The mains voltage must connect to the IEC C6 type input connector J1.

The LED module must connect to the LED output connector J6.

Fig 3. Mains connection and LED wiring

4.2 Dimming control secondary side

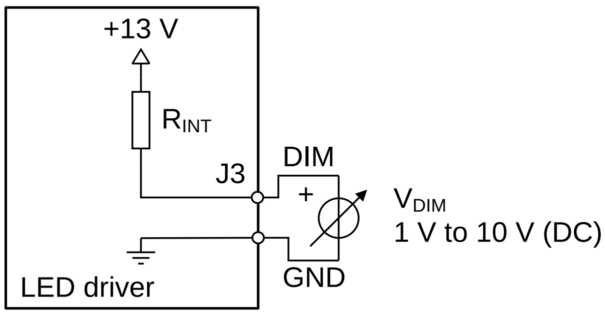
The dimming controller must connect to the DIM input connector J3.

The DIM input supports dimming control in two ways:

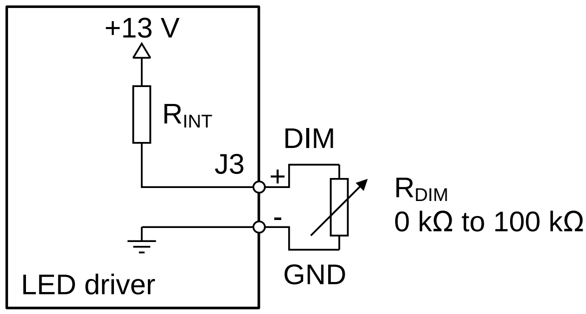
- 1 V to 10 V interface: an external voltage applied to the DIM input;
- External pull-down resistor.

The output is at maximum output current when the DIM input is not connected.

When the DIM input voltage is lower than 1.0 V the output current is 10 % of $I_{o(max)}$.



c. 1 V to 10 V DIM interface



d. External pull-down resistor DIM interface

Fig 4. DIM input connections

R_{INT} = 4.7 kΩ;

R_{DIM}: 100 kΩ Logarithmic

5. Functional description

The SSL4120DB1123 LED driver demo board is a dimmable constant current LED driver. This chapter describes some specific design choices for the LED driver. This driver board was especially designed to drive a wide LED voltage/current range.

More information about the SSL4120T IC application is described in the SSSL4120T data sheet and the AN11227 application note.

5.1 SSL4120T controller IC

The SSL4120T is a very robust and reliable PFC + resonant controller containing many features. The various internal protections ensure fail safe operation of the LED driver under all conditions.

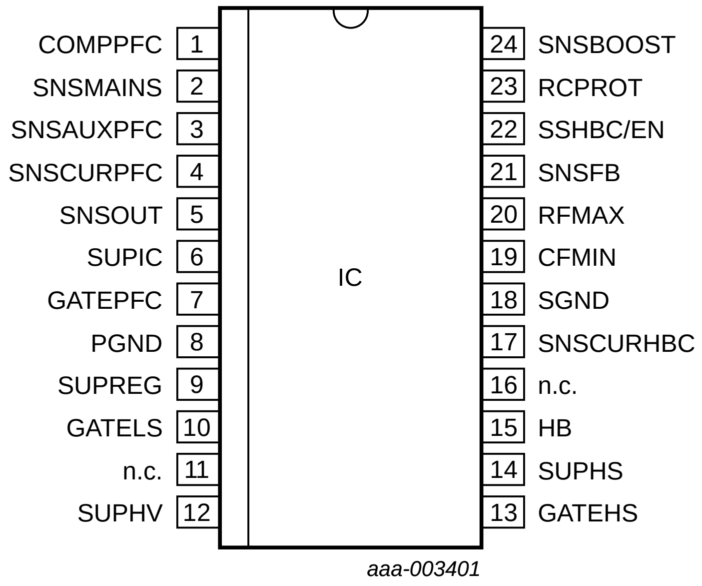


Fig 5. SSL4120T IC pin out

5.2 Board topology

The board topology is a PFC boost stage to meet the class C lighting requirements and an LLC resonant stage.

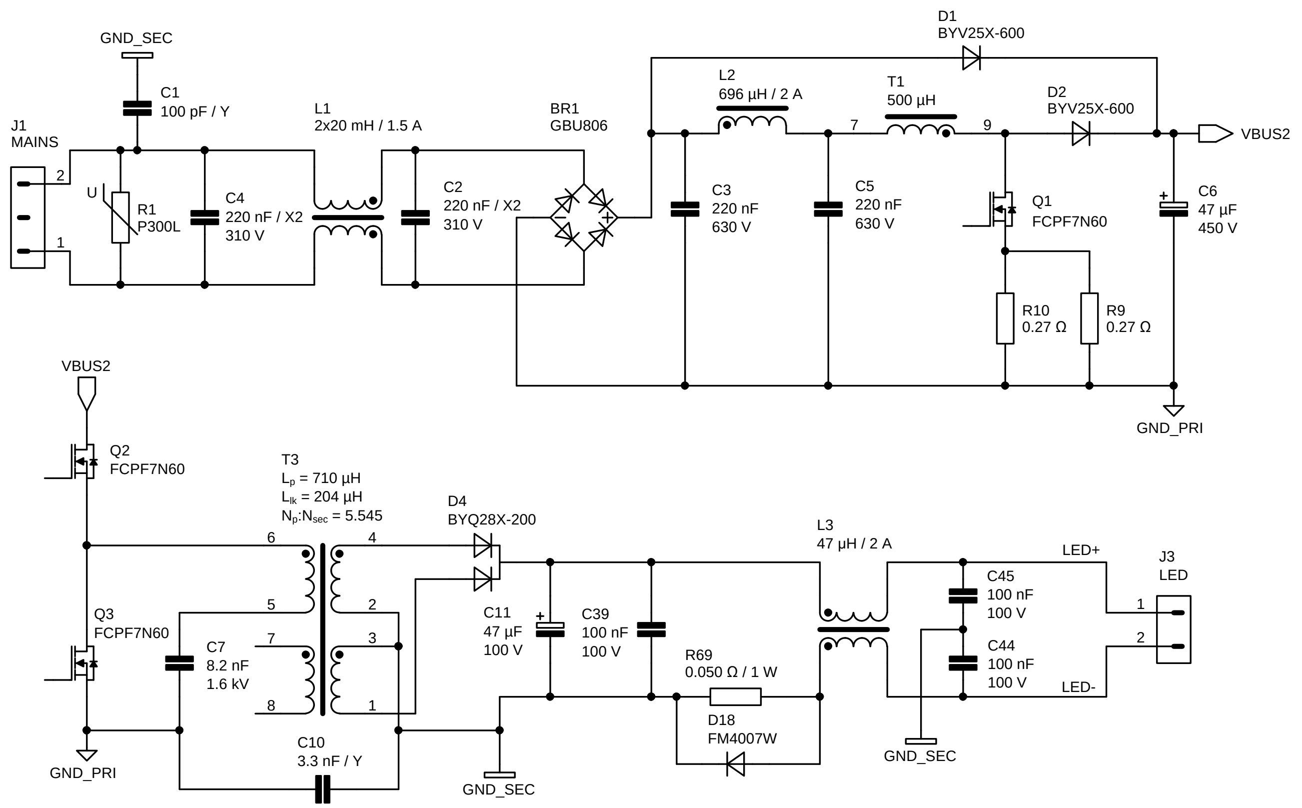


Fig 6. Large signal path of the board

5.3 EMI filter

The EMI filter consists of a differential mode inductor L2 and a common-mode inductor L1. The differential filter also includes C2, C3, C4 and C5. The common filter capacitors are C1 and C10.

5.4 Power Factor Correction (PFC)

The PFC is a boost stage consisting of components T1, Q1, D2 and C6. In normal operation the PFC stage operates in boundary condition mode BCM with valley switching. The section “PFC controller” in the SSL4120T data sheet[1] describes the valley switching.

The design choices for the PFC stage are based on the following targets:

- A wide mains input voltage range from 90 V (AC) to 305 V (AC)
- A large output power range must comply with the mains current harmonics class C requirements for lighting equipment of IEC 61000-3-2

The PFC choke inductance is maximized (lowest PFC switching frequency) for a large frequency range. The maximum PFC frequency of the SSL4120T is limited to 380 kHz. The controller keeps the PFC frequency under 380 kHz with valley skipping. The operating mode of the PFC is DCM in case of valley skipping.

A large PFC frequency range prevents discrete steps in the mains current which can be caused by the valley skipping.

The relation between the PFC inductance and the PFC minimum switching frequency is shown in the following equation:

$$L_{PFC} = \frac{V_{mains}{}^2 \times (V_{bus(nom)} - V_{mains})}{2 \times f_{sw(pfc)min} \times P_i \times V_{bus(nom)}}$$

Where:

- L_{PFC} = PFC inductance
- V_{mains} = AC mains voltage (RMS)
- P_i = input power
- $V_{bus(nom)}$ = nominal bus voltage
- $f_{sw(pfc)min}$ = PFC minimum switching frequency

Table 2 shows the calculated minimum PFC switching frequency for many different conditions and three PFC inductances. Frequencies higher than 380 kHz are limited by the PFC controller by means of valley skipping.

Table 2. Calculated PFC minimum switching frequency $f_{sw(pfc)min}$

V_{mains}	P_i	L_{PFC} = 250 µH	L_{PFC} = 500 µH	L_{PFC} = 750 µH
90 V (AC)	99 W	116 kHz	58 kHz	39 kHz
90 V (AC)	33 W	347 kHz	173 kHz	116 kHz
120 V (AC)	99 W	177 kHz	89 kHz	59 kHz
120 V (AC)	33 W	532 kHz	266 kHz	177 kHz
230 V (AC)	99 W	269 kHz	134 kHz	90 kHz
230 V (AC)	33 W	809 kHz	404 kHz	270 kHz
277 V (AC)	99 W	154 kHz	77 kHz	51 kHz
277 V (AC)	33 W	462 kHz	231 kHz	154 kHz

The PFC inductance is 500 µH. Selecting a larger value can cause audible noise at a 300 V high mains voltage and full load because the PFC frequency drops significantly when the peak of the mains voltage is close to the bus voltage.

The PFC output voltage V_{bus} is dimensioned for the use of a 450 V rated bus capacitor. $V_{bus(nom)}$ = 435 V, the ripple is ±10 V. For 90 W a capacitor of 47 µF is sufficient when there are no holdup time (mains voltage cycle skipping) requirements.

The PFC on-time $t_{on(VGATEPFC)}$ is modulated to increase near the zero crossings of V_{mains}. The increase improves the THD and class C performance significantly.

The modulation signal is injected using capacitor C22 into the compensation network on pin COMPPFC. The on-time is represented by the voltage $V_{COMPPFC}$ on pin COMPPFC.

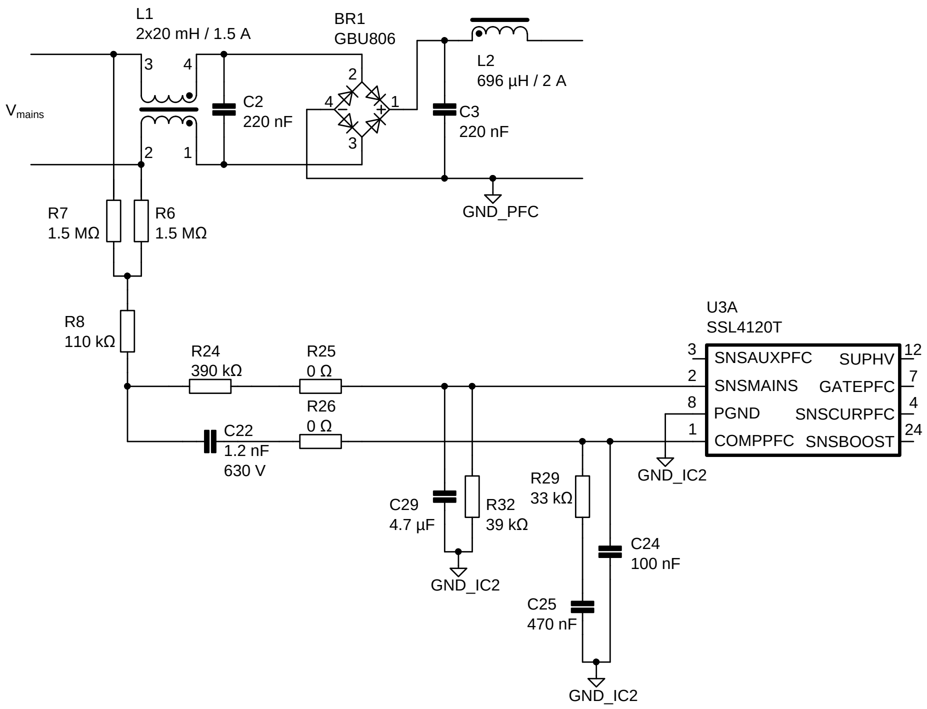
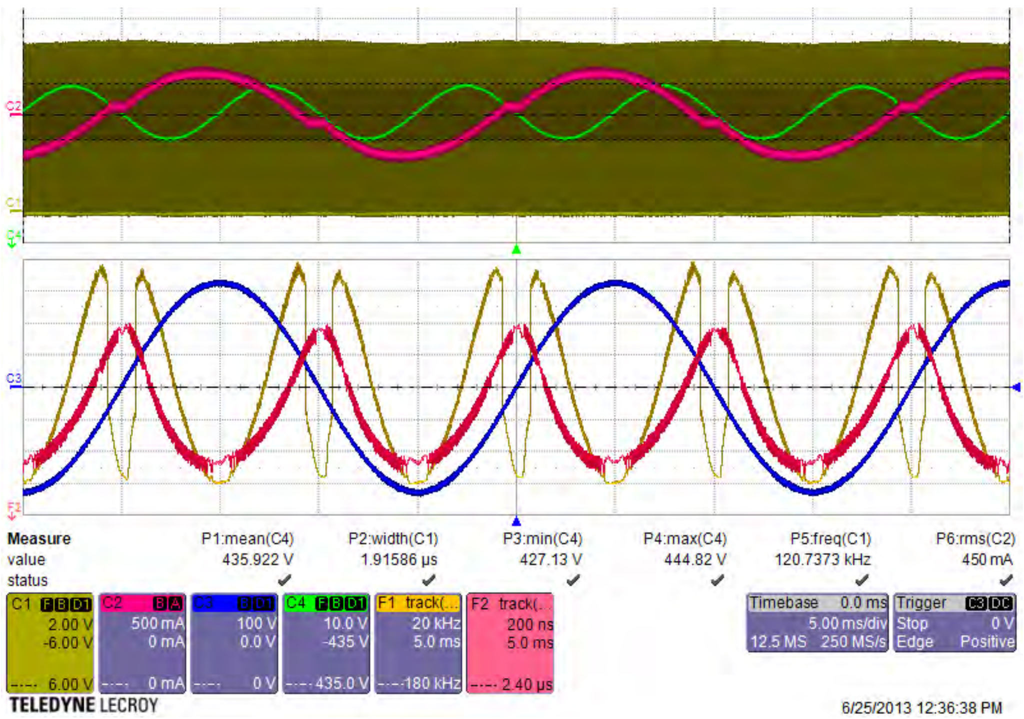


Fig 7. PFC on-time modulation with capacitor C22



Upper grid: C1 = $V_{GATEPFC}$; C2= I_{mains}; C4 = V_{bus}

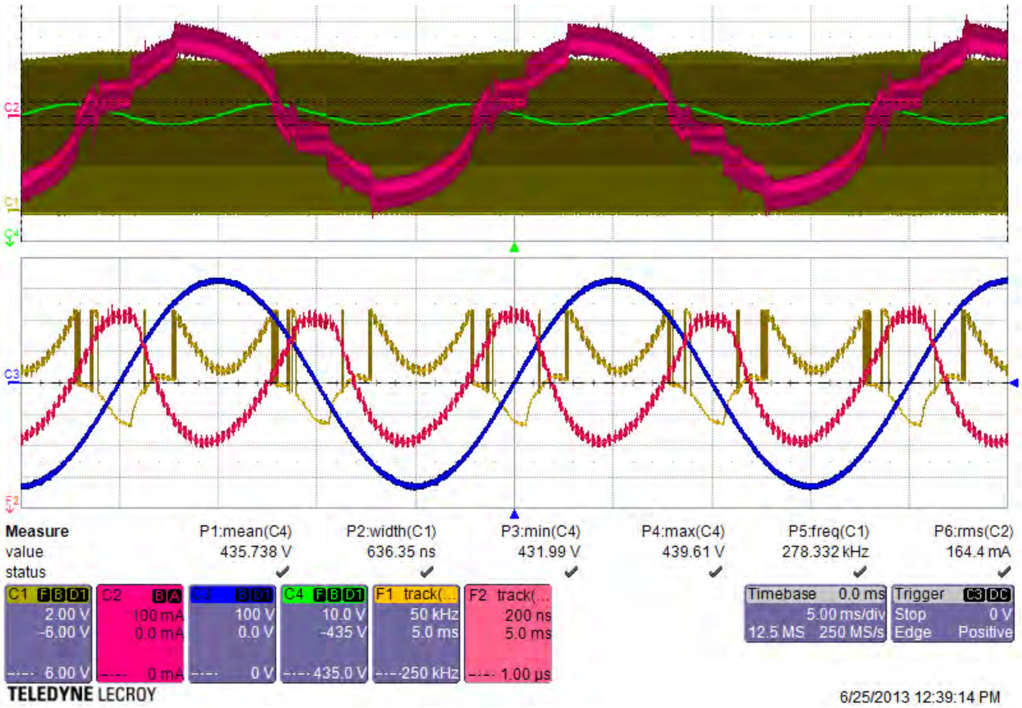
Lower grid: C3 = V_{mains}; F1 = $f_{(VGATEPFC)}$; F2 = $t_{on(VGATEPFC)}$

Fig 8. PFC signals at V_{mains} = 230 V (AC); V_o = 48 V; I_o = 1.9 A

Channel F1 shows the frequency of the PFC gate drive signal $V_{GATEPFC}$. During the zero crossing of V_{mains} the valley skipping of the PFC controller is visible.

Channel F2 shows the on time $t_{on(VGATEPFC)}$ of the PFC gate drive signal $V_{GATEPFC}$.

The THD in Fig 8 is about 5.6 %.



Upper grid: C1 = V_{GPFC}; C2= I_{mains}; C4 = V_{bus}

Lower grid: C3 = V_{mains}; F1 = f $_{(VGPFC)}$; F2 = $t_{on(VGPFC)}$

Fig 9. PFC signals oscillogram at V_{mains} = 230 V (AC); V_o = 15 V; I_o = 1.9 A

At low load, the PFC frequency increases and the frequency limit of the PFC controller is reached. At the mains angle when the maximum PFC frequency is reached, the valley skipping is active. A discrete step in the mains current is present. The discrete steps and the flat line during the V_{mains} zero crossing mostly determine the THD and class C performance.

The THD in Fig 9 is about 13 %.

5.5 Half-bridge and LLC output stage

The resonant circuit is a LLC topology driven with a half-bridge. The output section consisting of two diodes D4 is the standard half bridge rectification configuration. The LLC output is constant current regulated, intended to drive LED modules as a current source.

The LLC design choices are based on the following targets:

- High efficiency at full load / normal operating conditions
- Large output voltage range support

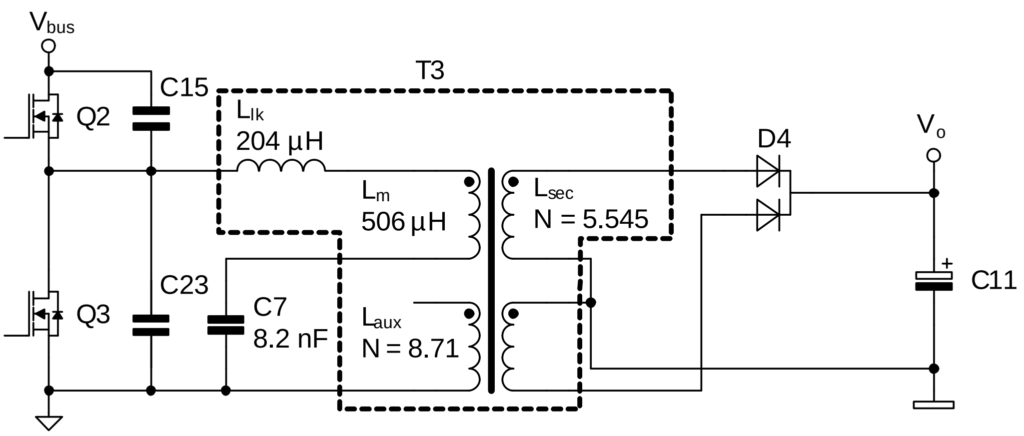


Fig 10. Simplified LLC circuit with integrated transformer

An integrated LLC transformer with m = 3.5 ($m = L_p / L_{lk}$ and $Lp = L_m + L_{lk}$) is used because a smaller frequency range is required to reach a lower V_o compared to m = 5 or m = 7.

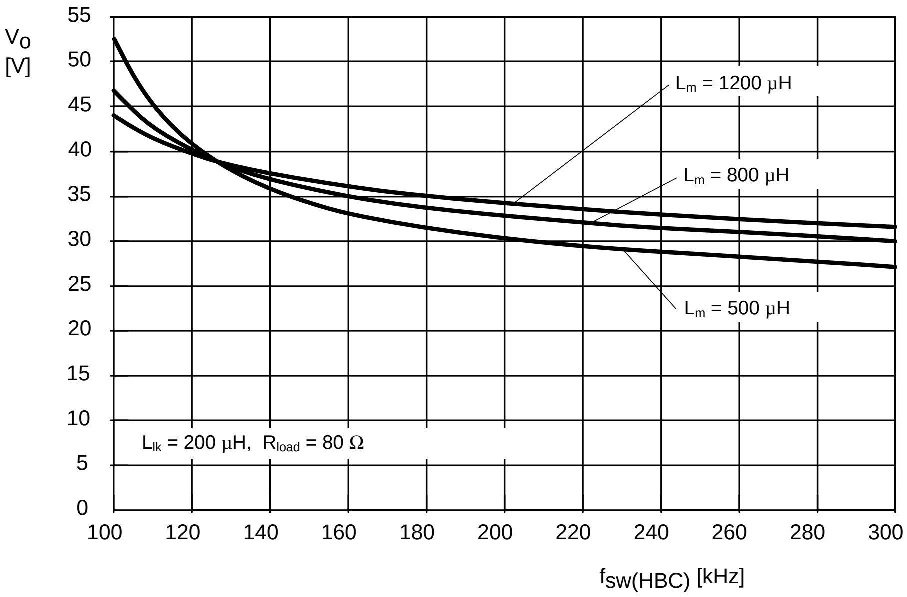


Fig 11. LLC voltage transfer for different $m = L_p / L_{lk}$ values with 80 Ω load

Increasing the capacitance values of C15 and C23 (currently 47 pF) helps to reach a slightly lower output voltage level.

5.6 Burst mode LLC operation

The large V_o and I_o range is achieved by the implemented burst mode of the LLC stage.

Burst mode operation is implemented to increase the output power range.

At I_o = 100 %; burst is active under 28 V

At I_o = 10 %; burst is active under 38 V

The drawback of the burst mode is possible audible noise and ripple of the LED current causing visible flicker. The resonant capacitor C7 is a film capacitor because ceramic capacitors can cause audible noise. To prevent visible flicker, the burst frequency is kept well above 1 kHz.

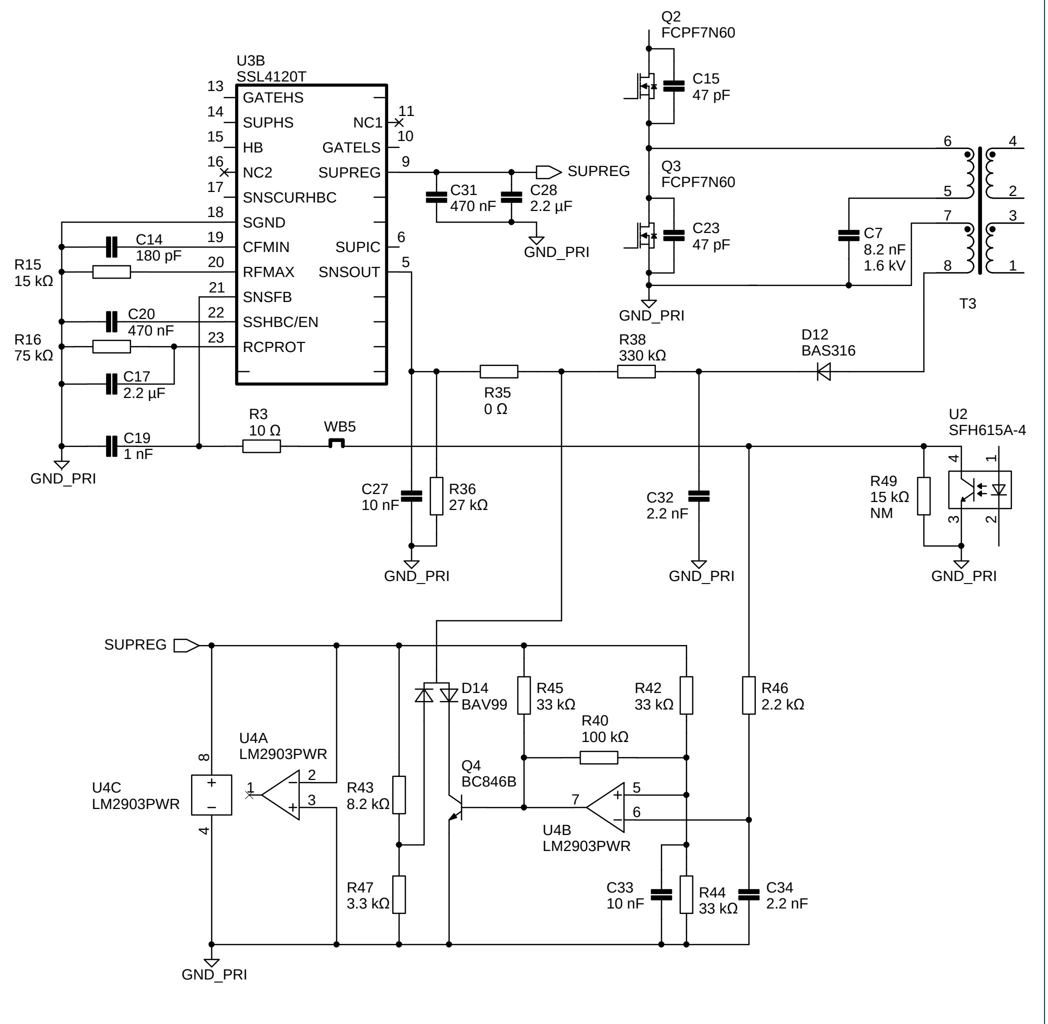


Fig 12. LLC burst mode control diagram

V_{SNSFB} is an input of the half-bridge frequency control. V_{SNSFB} is also used as input for the burst mode comparator U4B.

The PFC is always active (including bust mode) because bursting the PFC reduces the THD performance. Therefore, V_{SNSOUT} is kept above 0.5 V with a diode D14 in series with the collector on Q4.

In burst mode, the HB stage is stopped and started via pin SNSOUT, the external comparator circuit sets the burst mode level and hysteresis parameters.

- Burst level: set the half-bridge frequency during burst $f_{hbc(burst)}$ with resistors R42 and R44 (set to 230 kHz);
- Burst hysteresis: adjust the burst repetition frequency $f_{hbc(burst)}$ with resistor R40.

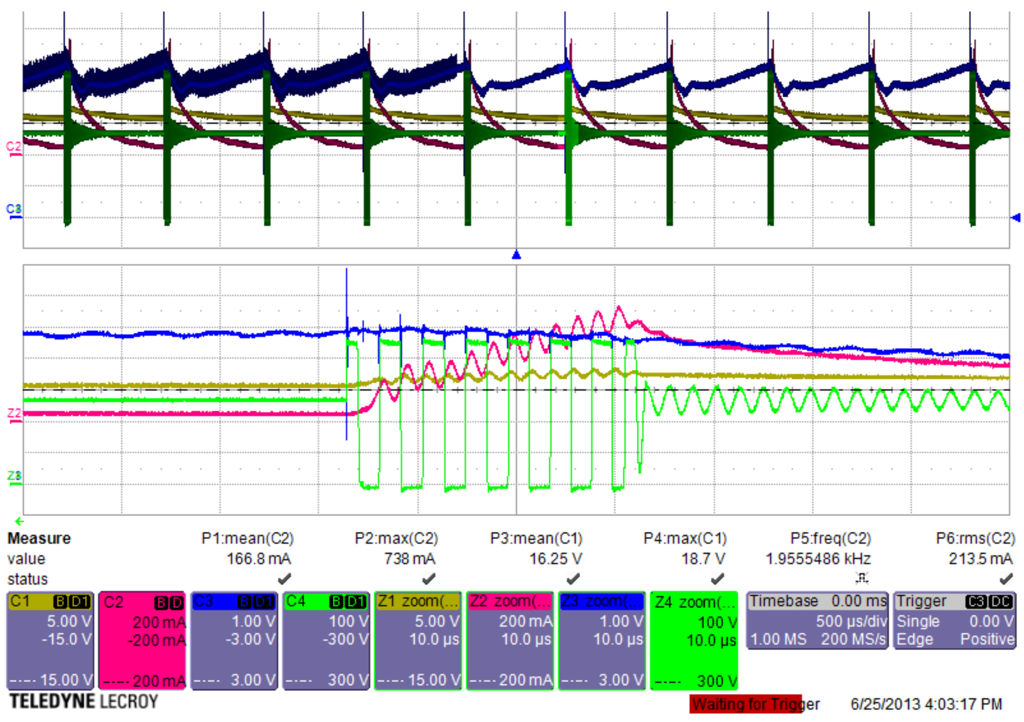
In addition to the hysteresis setting of the burst mode comparator, other items influence the minimum burst frequency. In general, using a smaller hysteresis and a faster control loop results in fewer burst pulses, higher burst frequency and low output current ripple.

Table 3. Minimum burst mode frequency tuning

Item	Effect
hysteresis burst mode comparator	less hysteresis → fewer pulses → higher $f_{burst(min)}$
LLC output capacitor	less capacitance → fewer pulses → higher $f_{burst(min)}$
LLC CC control loop speed	more gain → fewer pulses → higher $f_{burst(min)}$

The control loop gain is influenced by the following board components:

The optocoupler current transfer ratio (CTR), R70, C41, C40, R65, R61, U6B, LLC circuit, C19, R15 = R_{RFMAX}, C14 = C_{CFMIN}.



Upper grid: C1 = V_o; C2= I_o; C3 = V_{SNSFB}; C4 = V_{HB}

Lower grid: Z1 = zoom (C1); Z2 = zoom (C2); Z3 = zoom (C3); Z4 = zoom (C4);

Fig 13. Output signals oscillogram at V_o = 16 V; I_o = 0.19 A (real LED load)

The minimum burst frequency $f_{burst(min)}$ occurs at condition $V_{o(min)}$ and $I_{o(min)}$. Because $f_{burst(min)}$ is well above 1 kHz, therefore visible flicker is not an issue[3].

5.7 IC low-voltage supply circuit

An additional auxiliary winding on the PFC transformer provides the SSL4120T low-voltage supply at pin SUPIC.

Because the bus voltage is regulated, the PFC auxiliary winding with a full bridge rectifier generates a fixed supply. Because the fixed supply is independent of V_o, it is also independent of the number of LEDs attached in series.

Once the PFC starts switching, the PFC auxiliary winding almost immediately charges the SUPIC buffer capacitor C8. The capacitance C26 on pin SUPIC can be small and a short turn-on delay is achieved.

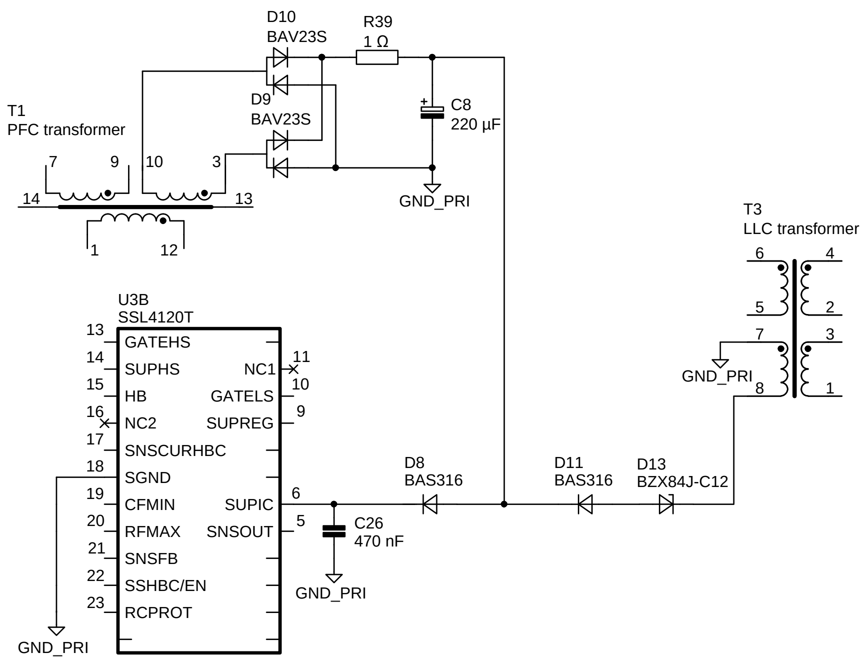
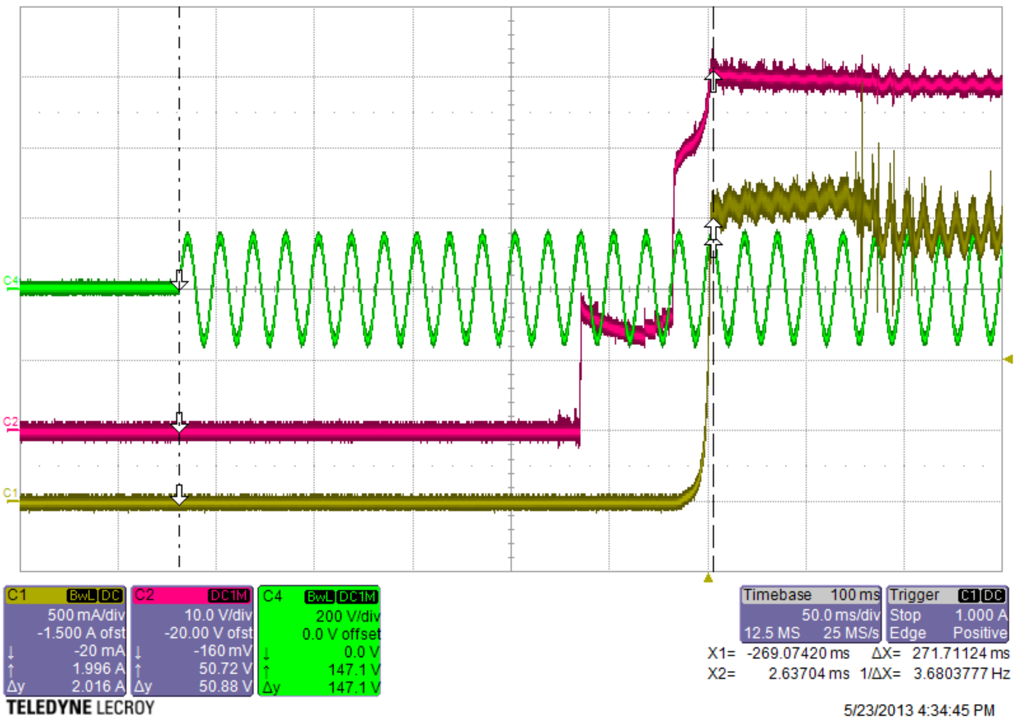


Fig 14. Low-voltage supply diagram

In case of fault/no-load conditions the PFC NMOST gate pulses are too short for the transformer to transfer energy to the IC supply. V_o increases to $V_{o(max)}$ and the auxiliary winding voltage of the LLC transformer also increases. The auxiliary winding of the LLC transformer takes over the supply from the PFC auxiliary winding. D13 is in series with D11 because the voltage of the LLC auxiliary winding is normally too high and can cause unnecessary power dissipation.

Table 4. Turn-on delay times

V_{mains}	$t_{d(on)}$
100 V (AC); 60 Hz	272 ms
120 V (AC); 50 Hz	213 ms
230 V (AC); 60 Hz	125 ms
277 V (AC); 60 Hz	129 ms



(1) C1 = I_o; C2 = V_o; C4 = V_{mains}

Fig 15. Turn-on delay time oscillogram at 100 V (AC); 60 Hz

5.8 LLC feedback control loop

The LED driver incorporates two regulation features:

- A Constant Voltage (CV) regulation
- A Constant Current (CC) regulation

In normal operation the CC loop is closed and the CV loop is open. The set point of the LED output current is controlled with the DIM input signal.

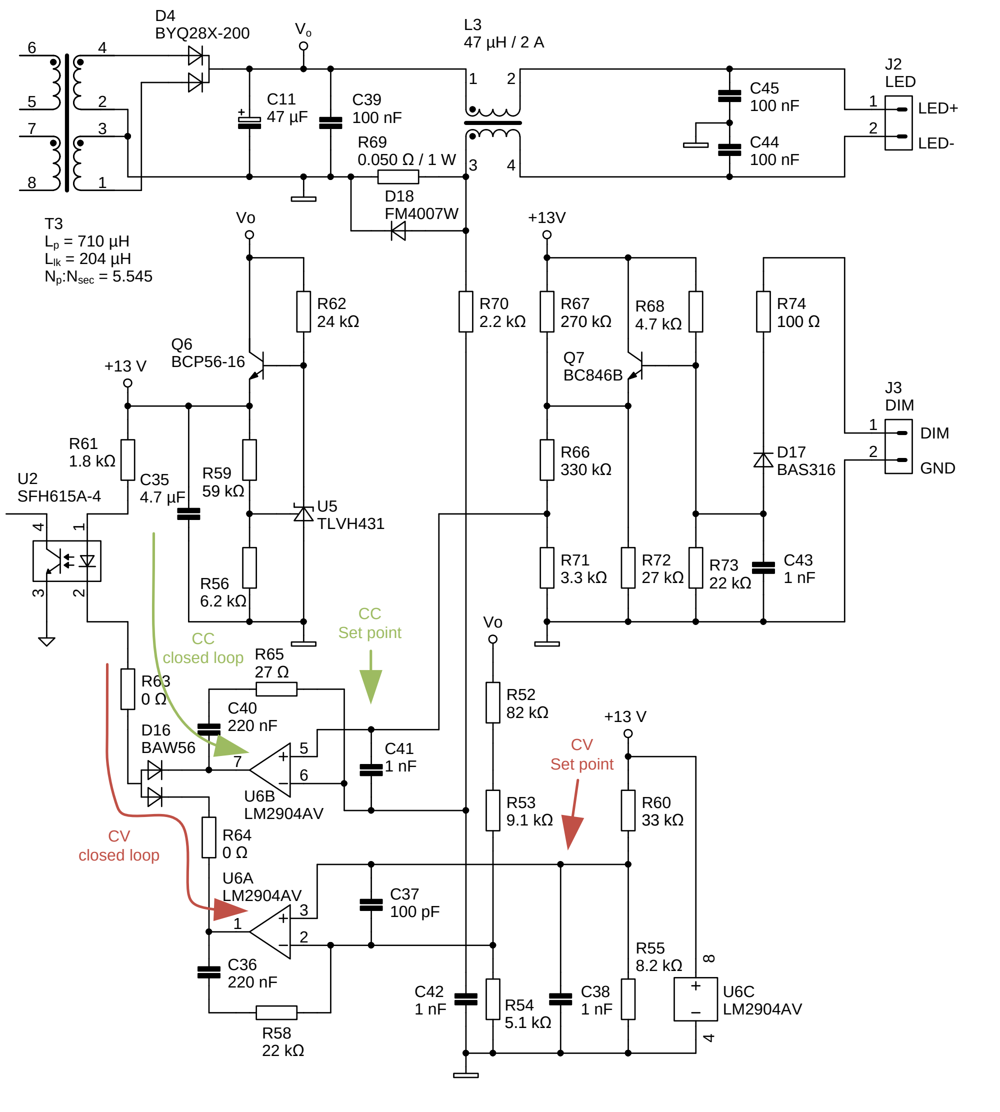
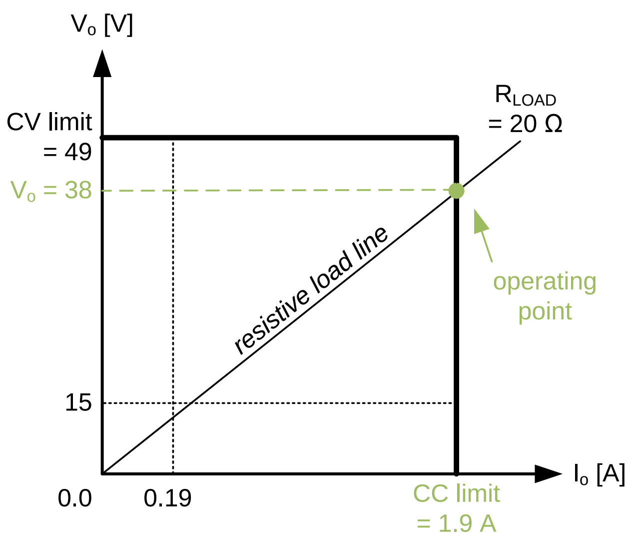
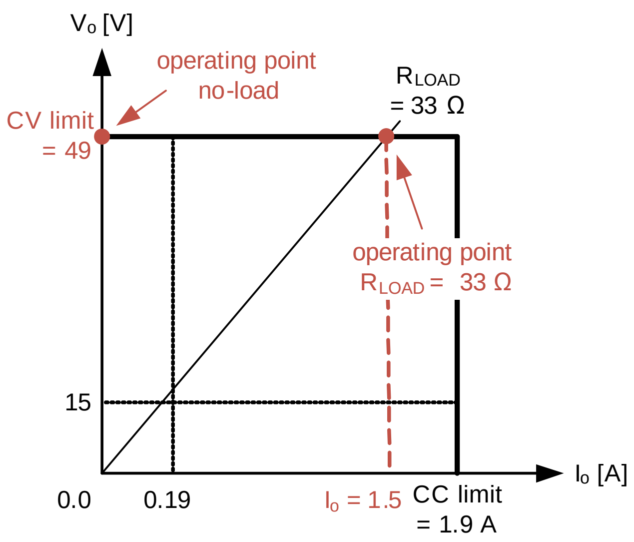


Fig 16. LLC control loop error amplifiers and output section of the LLC stage

The DIM input signal can reduce the CC set point. C37, C38, C43, C47 are placed to prevent HF noise from entering the control loop.



a. Resistive load line, no dimming, CC operation



b. Resistive load line, no dimming, CV operation

Fig 17. I-V diagrams of LED driver with constant voltage and constant current regulation

5.9 LED current control

The DIM input controls the constant current regulation set point which is derived from the accurate 13 V supply regulated with U5. The set point varies from 10 mV to 100 mV.

- Resistors R66, R71 and R67 set the 10 mV lower limit.
- Resistors R66, R71, R68 and R73 set the 100 mV upper limit.

The 13 V local supply draws current from V_o. The current is minimized by using a low current shunt regulator TLVH431 and a high gain optocoupler. The dissipation in Q6 is minimal for the specified V_o range.

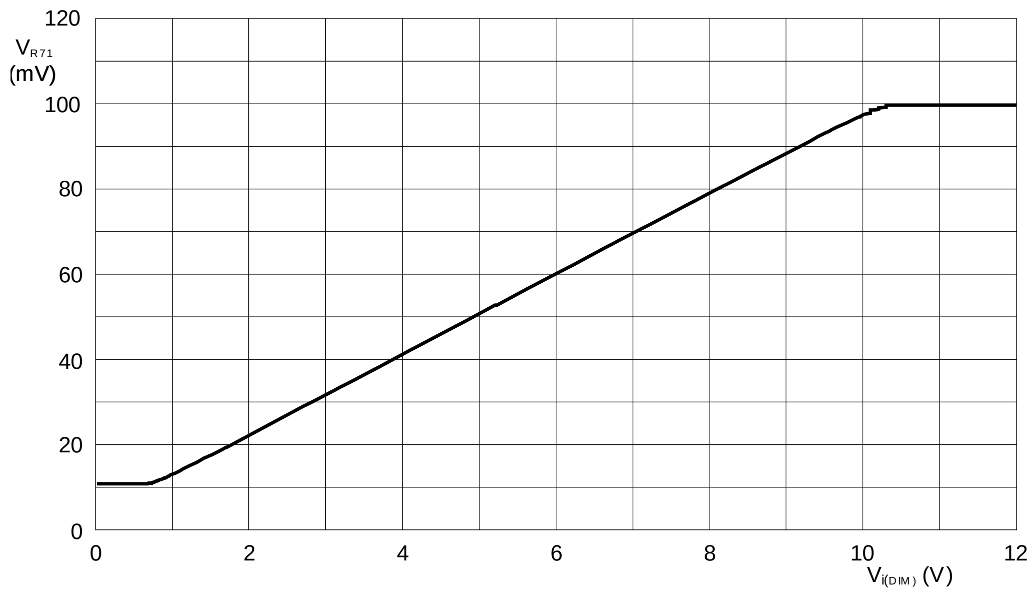


Fig 18. Current control set point as function of DIM input voltage

Fig 19b shows a typical load line of an LED module. The voltage slightly decreases while the LED module is dimmed.

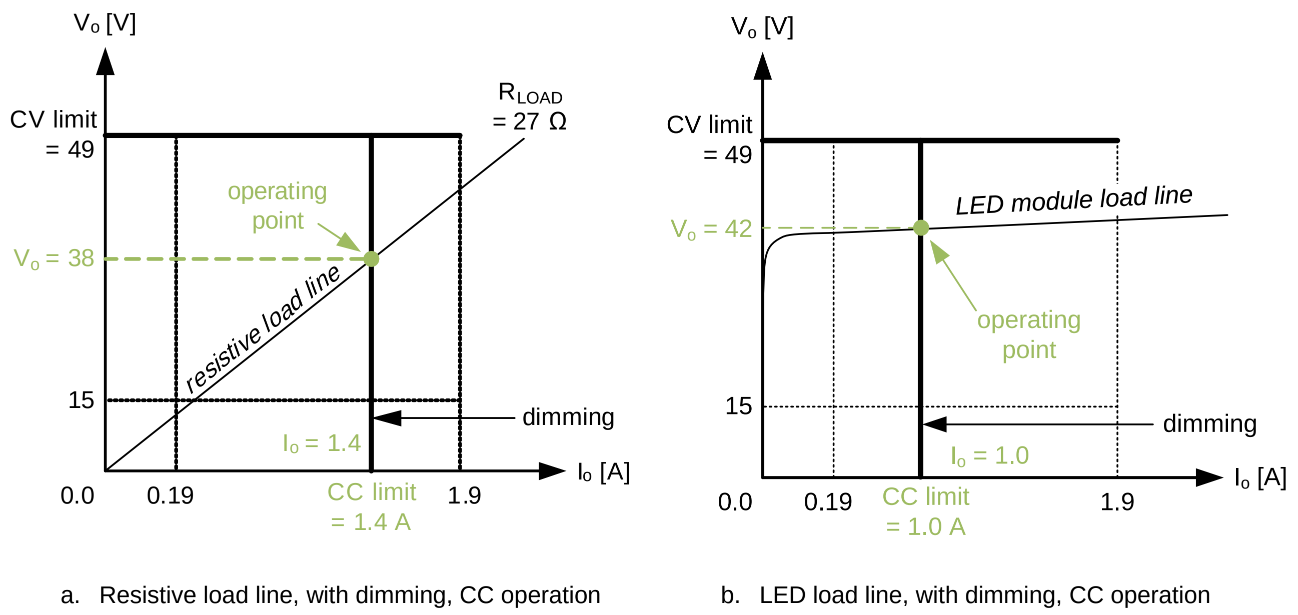


Fig 19. I-V diagrams of LED driver with constant voltage and constant current regulation

5.10 Output voltage control

Operation without a LED module connected is considered a ‘fault mode’ because the LED driver is intended to be connected with a LED module.

The voltage control limits the output voltage when no load is connected or when an LED string is broken. When the voltage control loop is closed the CC loop is open. In CV mode the output is V_o is regulated at $V_{o(max)}$ = 49 V.

5.11 Output short conditions

Several features provide protection against component damage when the LED output is shorted.

Two conditions must be considered:

- Short at start-up
- Short during operation

The SSL4120T protection features involved during output short are:

- LLC current sense input SNSCURHBC via sense resistor R41
- Half-bridge switching node voltage sense input HB
- Protection timer RCPROT pin with components R16 and C17

The output undervoltage protection via pin SNSOUT is disabled by the application to support the large V_o range.

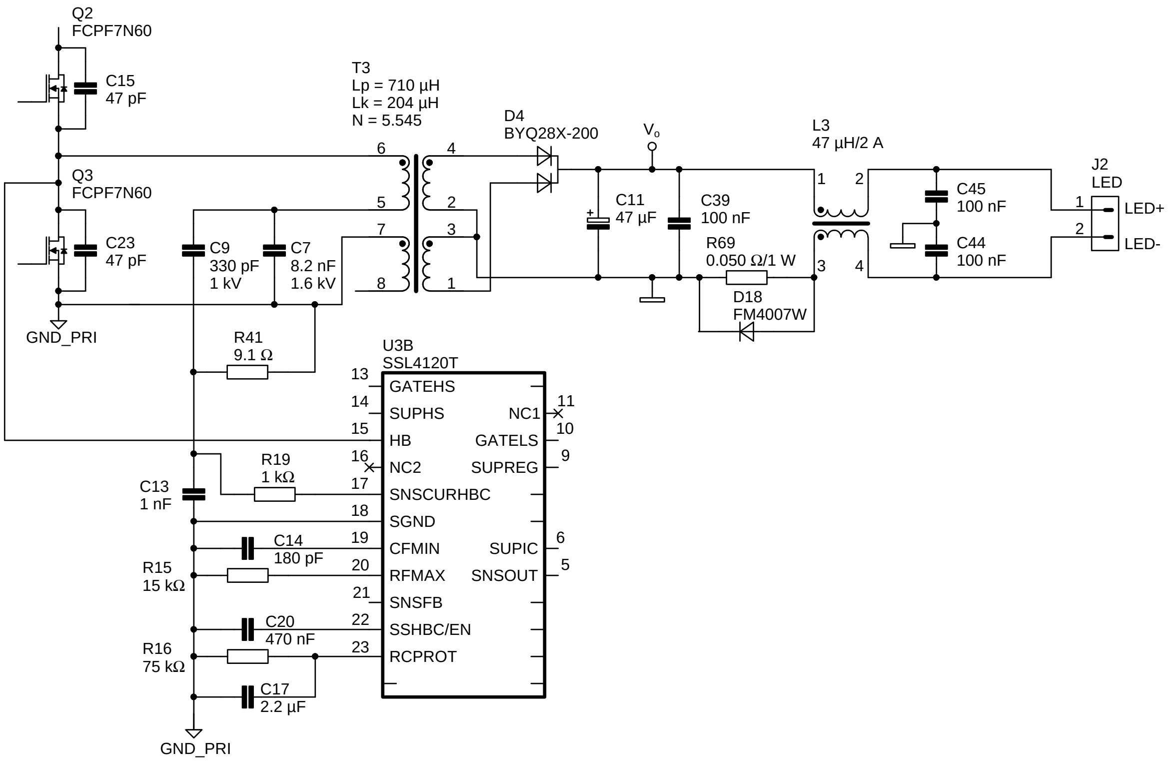
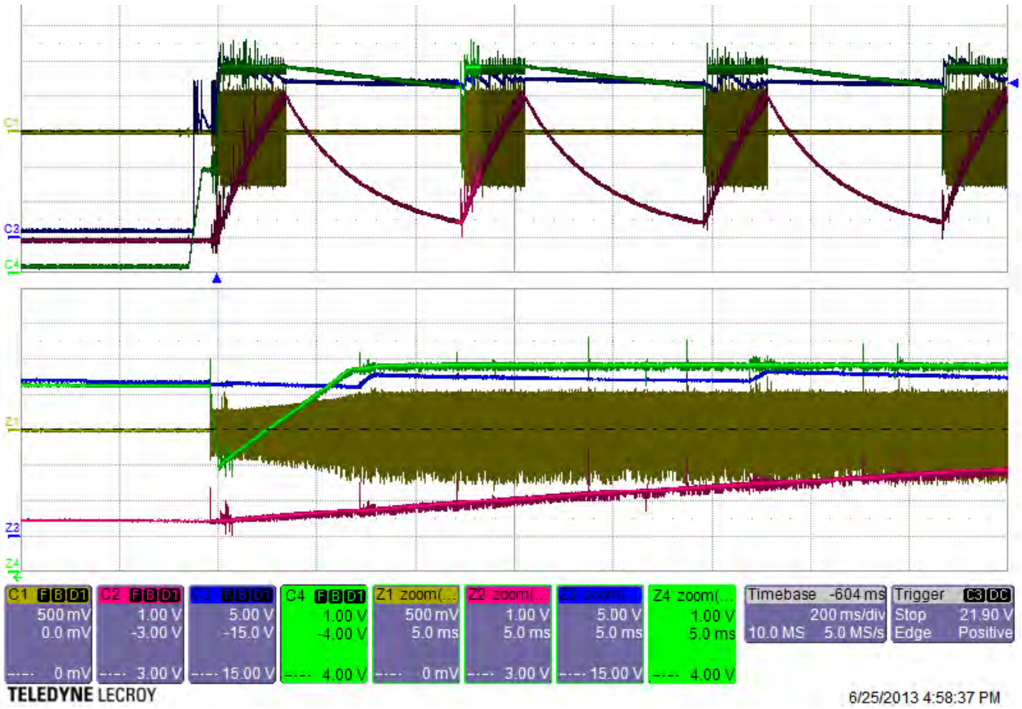


Fig 20. Part of the circuit diagram relevant for output short conditions

5.11.1 Output short at start-up

The SSL4120T performs a soft start. It starts at the highest half-bridge frequency and then ramps down. The half-bridge current is sensed via pin SNSCURHBC and the controller starts to regulate the half-bridge frequency using pin SSHBC/EN when $V_{SNSCURHBC} > 0.5$ V. During the current regulation the RCPROT fault timer is activated and C17 is charged. The RCPROT fault timer ends when $V_{RCPROT} > 4.0$ V. The controller stops switching. C17 is discharged by resistor R16 when the fault timer is inactive. The RCPROT timer duty cycle can be programmed by the application, which enables adjustment of the average input power during a short circuit.

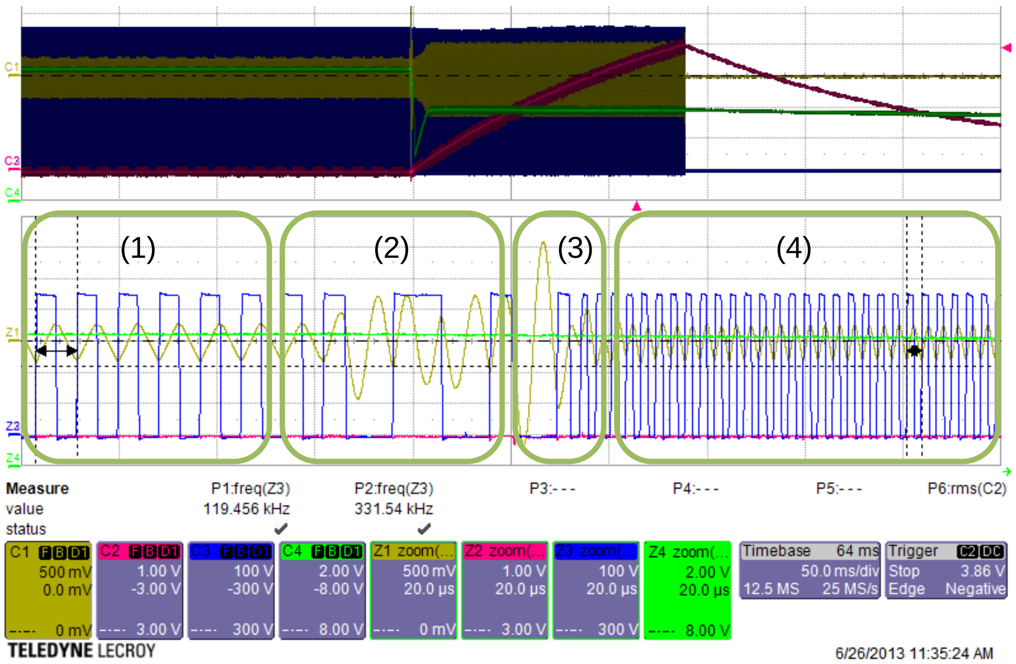


C1 = $V_{SNSCURHBC}$; C2 = V_{RCPROT}; C3 = V_{SUPIC}; C4 = $V_{SSHBC/EN}$

Fig 21. Output short during start-up oscillogram

5.11.2 Output short during operation

During operation the output capacitor is charged. Diode D18 (parallel to the LED current sense resistor) limits the sense voltage and protects the sense resistor and error amplifier.



C1 = $V_{SNSCURHBC}$; C2 = V_{RCPROT}; C3 = V_{HB}; C4 = $V_{SSHBC/EN}$

Fig 22. Output short with switch during operation at no load oscillogram

(1) Before output short, $V_o = V_{o(max)}$

(2) Adaptive non-overlap function delays the HBC oscillator to prevent hazardous switching of the half-bridge MOSFETs. The soft start capacitor C20 on pin SSHBC/EN is discharged. The SSL4120T tries to regulate the frequency to the border between capacitive and inductive mode of the LLC.

(3) $V_{(ocp)HBC}$ = 1.0 V is triggered via pin SNSCURHBC. The oscillator frequency is immediately set to the maximum frequency.

(4) Half-bridge running at the maximum frequency of 330 kHz until the RCPROT timer ends.

6. Mains input measurements

6.1 Efficiency

Table 5. Efficiency

V_{mains}	P_o = 100 %	P_o = 50 %	P_o = 33 %	P_o = 25 %
100 V (AC); 60 Hz	90.3 %	87.8 %	89.4 %	88.1 %
120 V (AC); 60 Hz	91.3 %	88.3 %	89.9 %	88.2 %
230 V (AC); 50 Hz	93.1 %	89.0 %	90.1 %	88.0 %
277 V (AC); 60 Hz	93.0 %	88.8 %	89.3 %	87.1 %

6.2 Power factor

Table 6. Power factor

V_{mains}	P_o = 100 %	P_o = 50 %	P_o = 33 %	P_o = 25 %
100 V (AC); 60 Hz	0.9982	0.9966	0.9932	0.9872
120 V (AC); 60 Hz	0.9977	0.9937	0.9880	0.9799
230 V (AC); 50 Hz	0.9894	0.9698	0.9425	0.9078
277 V (AC); 60 Hz	0.9738	0.9198	0.8629	0.7927

6.3 Mains current total harmonic distortion

Table 7. Mains current total harmonic distortion

V_{mains}	P_o = 100 %	P_o = 50 %	P_o = 33 %	P_o = 25 %
100 V (AC); 60 Hz	3.74 %	2.93 %	4.55 %	6.45 %
120 V (AC); 60 Hz	3.30 %	3.81 %	6.43 %	8.68 %
230 V (AC); 50 Hz	5.59 %	9.83 %	12.7 %	15.0 %
277 V (AC); 60 Hz	9.12 %	16.2 %	18.1 %	19.1 %

6.4 Mains current harmonics

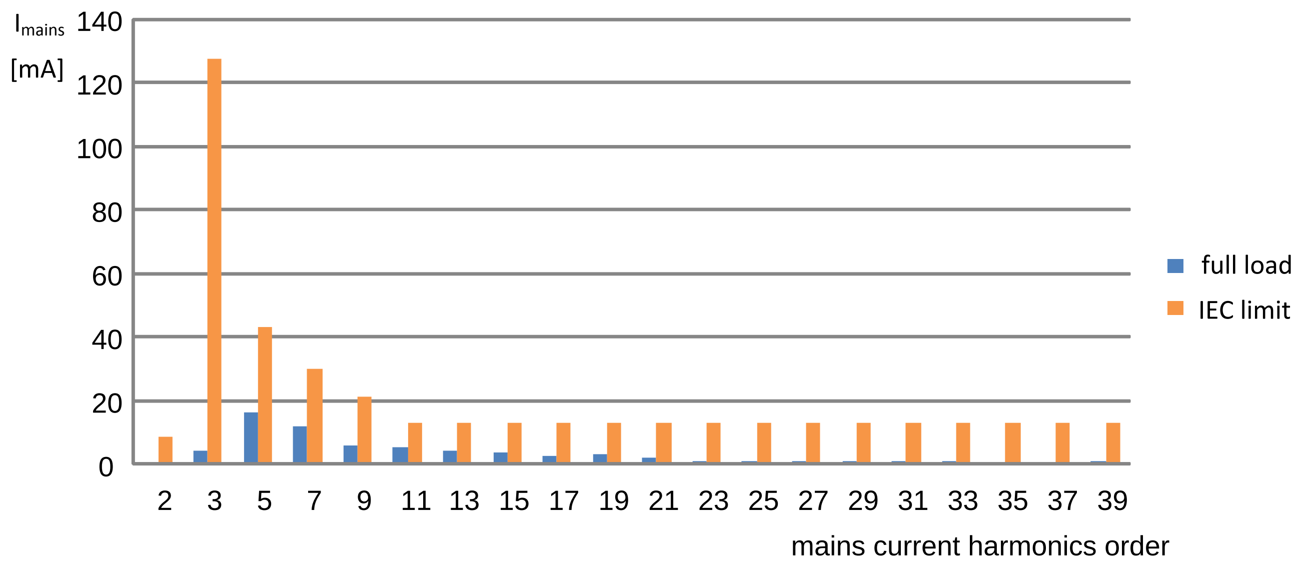


Fig 23. IEC 61000-3-2 mains current harmonics class C compliance at 230 V (AC); 50 Hz; full load

6.5 No-load input power

The no-load input power is measured with nothing connected to connectors J2 (LED) and J3 (DIM).

Table 8. No load power measurement

V_{mains}	$P_{i(standby)}$	I_{mains}
100 V (AC); 60 Hz	2.41 W	42.8 mA
120 V (AC); 60 Hz	2.43 W	43.3 mA
230 V (AC); 50 Hz	2.15 W	47.1 mA
277 V (AC); 60 Hz	2.09 W	45.8 mA

6.6 Standby input power

Some LED drivers have a standby power supply and a microcontroller to control a main power supply. When using the SSL4120T in the main power supply, a microcontroller can pull-down pin SSHBC/EN using a transistor.

The standby input power is measured while the pin SSHBC/EN is shorted to ground.

Table 9. Standby input power measurement

V_{mains}	$P_{i(standby)}$	I_{mains}
120 V (AC); 60 Hz	43 mW	30.0 mA
230 V (AC); 50 Hz	117 mW	35.4 mA
277 V (AC); 60 Hz	130 mW	44.9 mA

7. Schematic

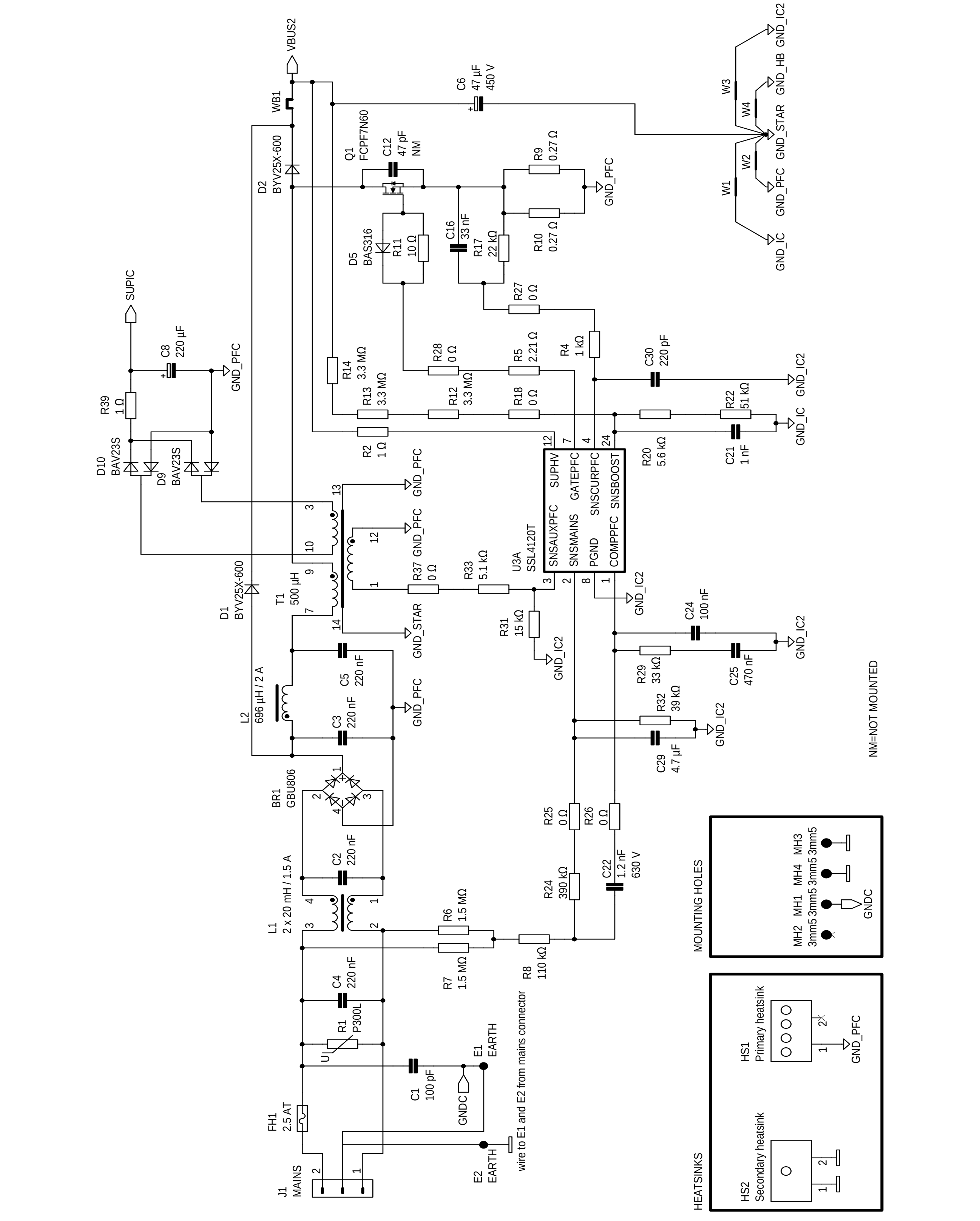


Fig 24. Mains input and PFC stage

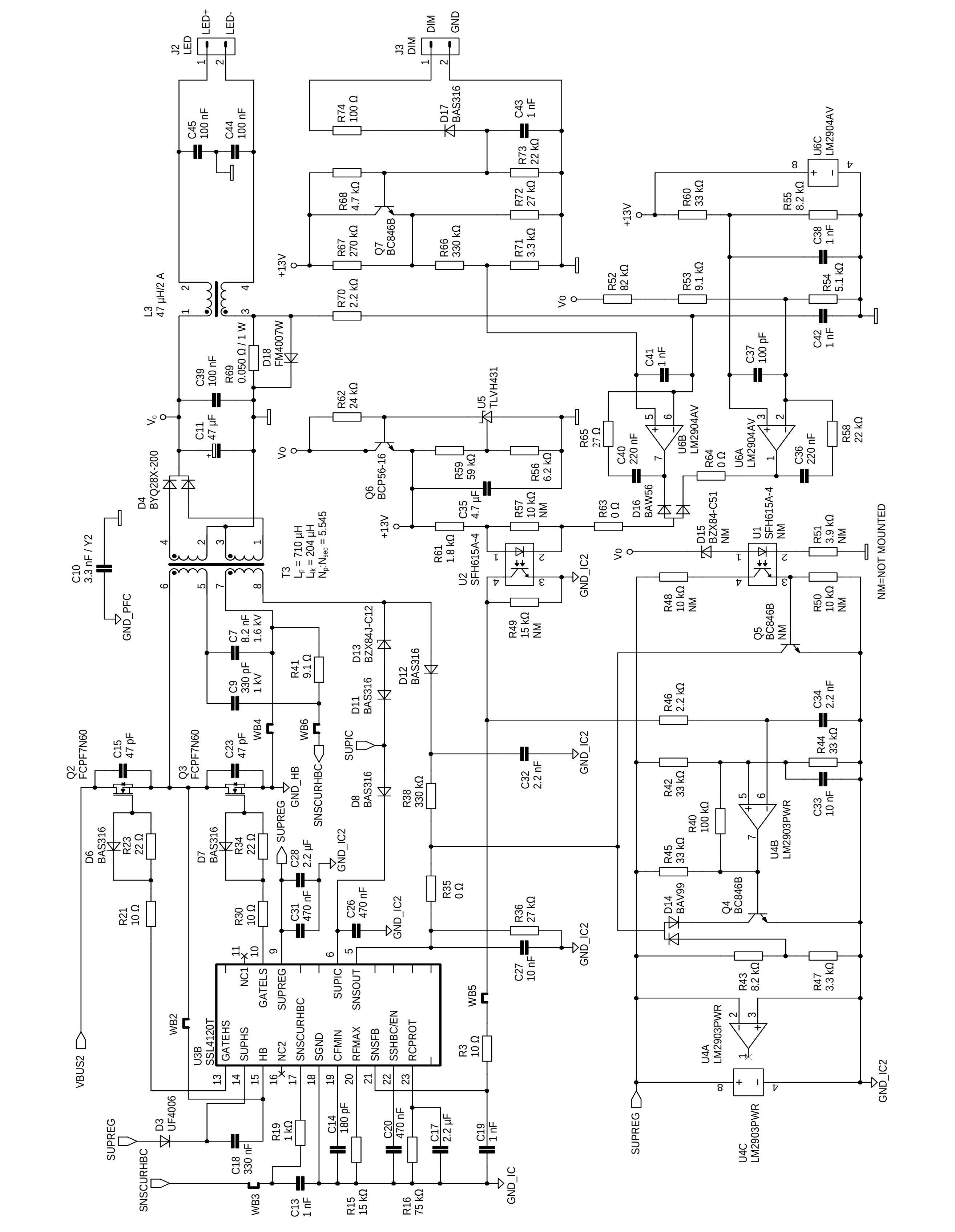


Fig 25. LLC stage and LED output

8. PCB layout

The PCB board information:

- Wave soldering
- Single layer
- Component numbering is starting at the mains connector
- Some holes are added where possible for experimentation

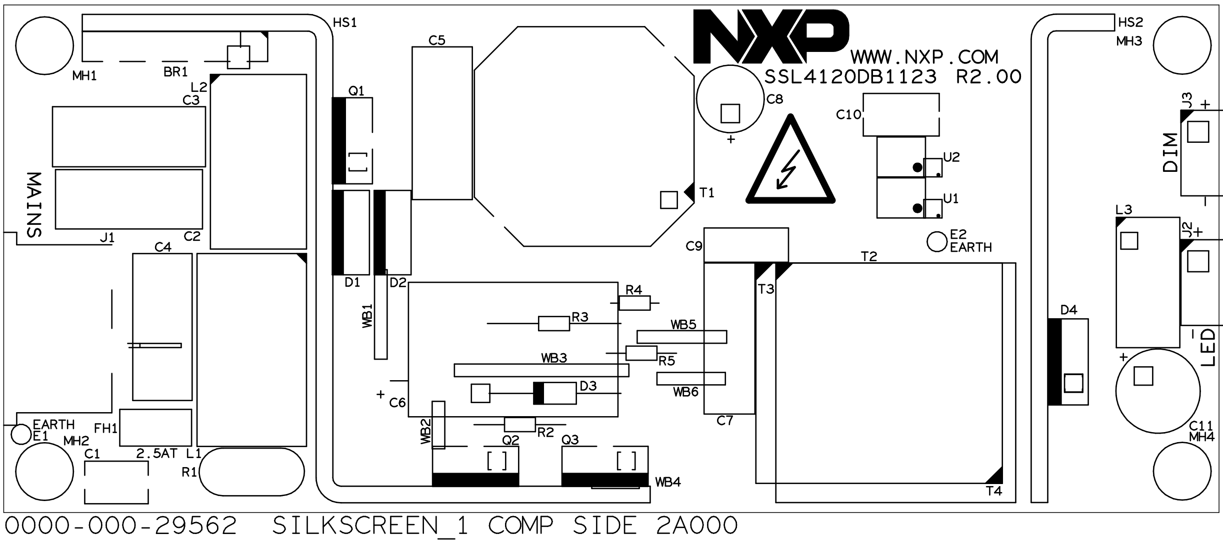


Fig 26. PCB top side component placing

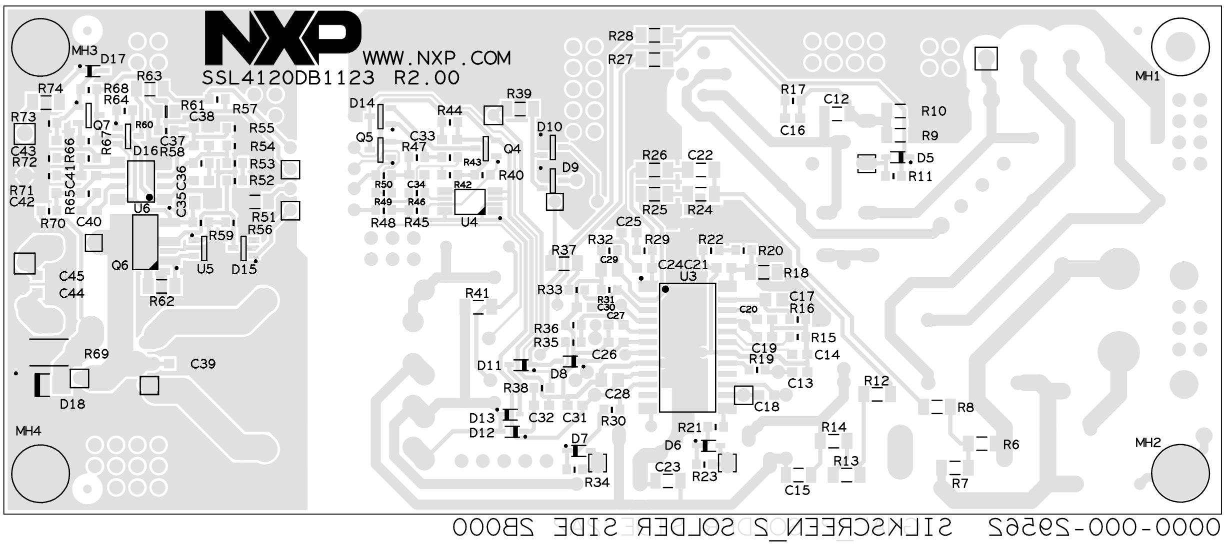
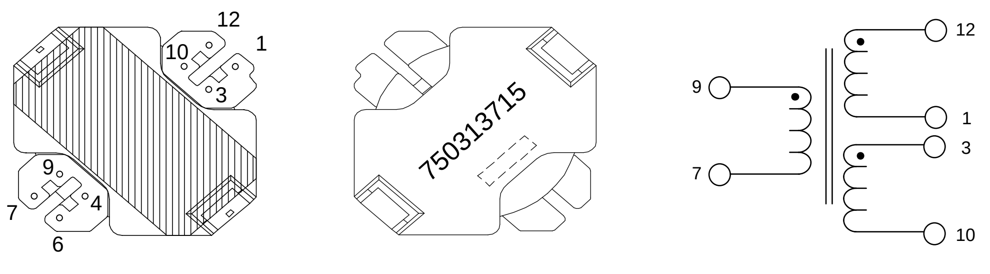


Fig 27. PCB bottom side copper and component placing

9. Transformer information

9.1 PFC transformer

Wurth Electronics Midcom Inc.; part number 750313715



a. Bottom view

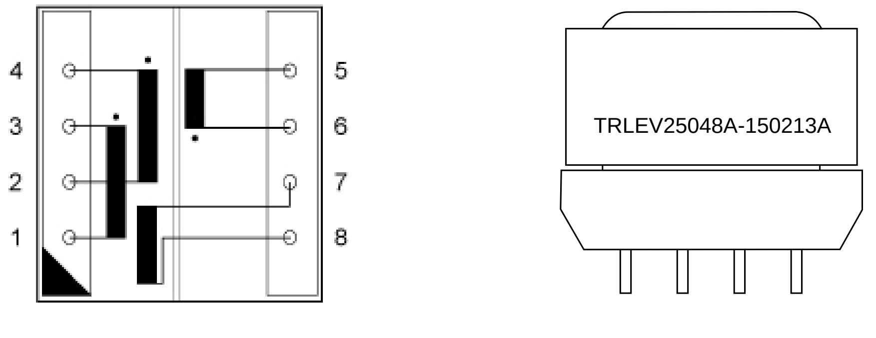
b. Top view

c. Winding pin out

Fig 28. PFC transformer drawings

9.2 Integrated LLC transformer

ITACOIL PCB inductive components; part number TRLEV25048A-150213A



a. Bottom view

b. Side view

Fig 29. LLC transformer drawings

10. EMI measurement

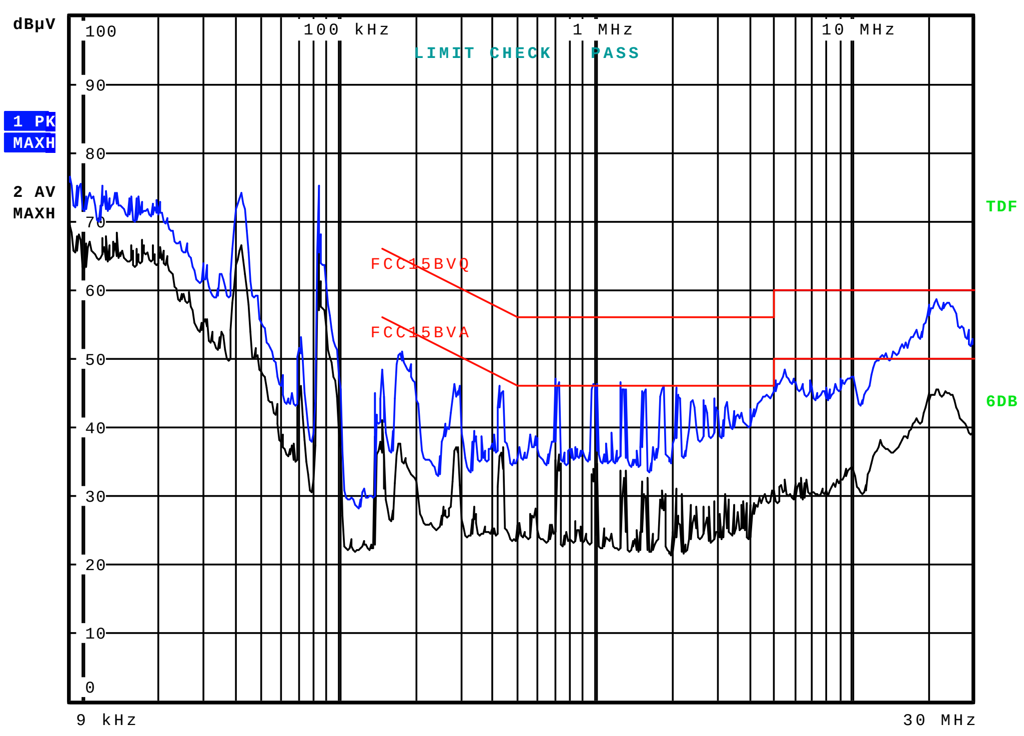


Fig 30. Conducted emission pre-scan L and N; V_{mains} = 115 V (AC)

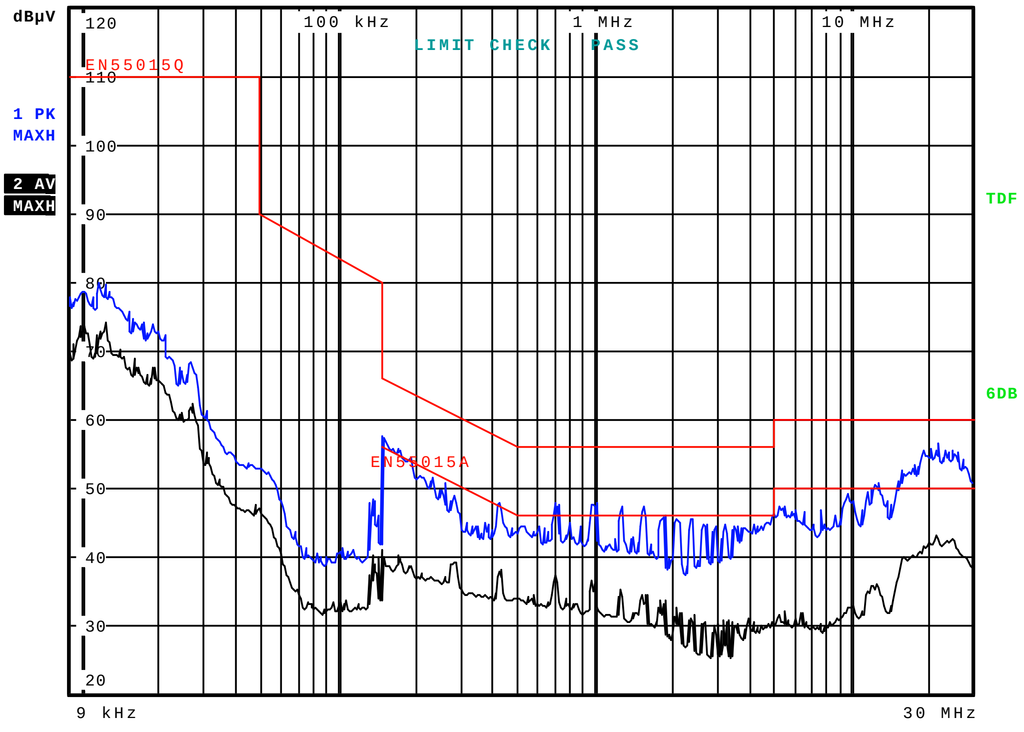


Fig 31. Conducted emission pre-scan L and N; V_{mains} = 230 V (AC)

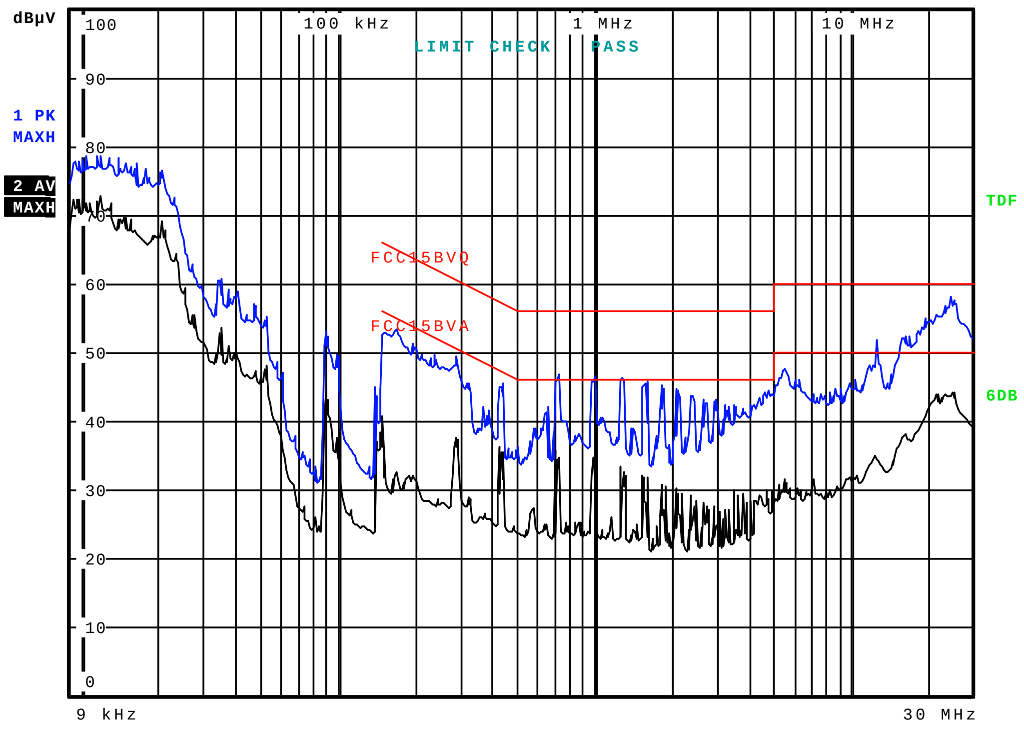


Fig 32. Conducted emission pre-scan results L and N; V_{mains} = 277 V (AC)

11. Thermal measurement

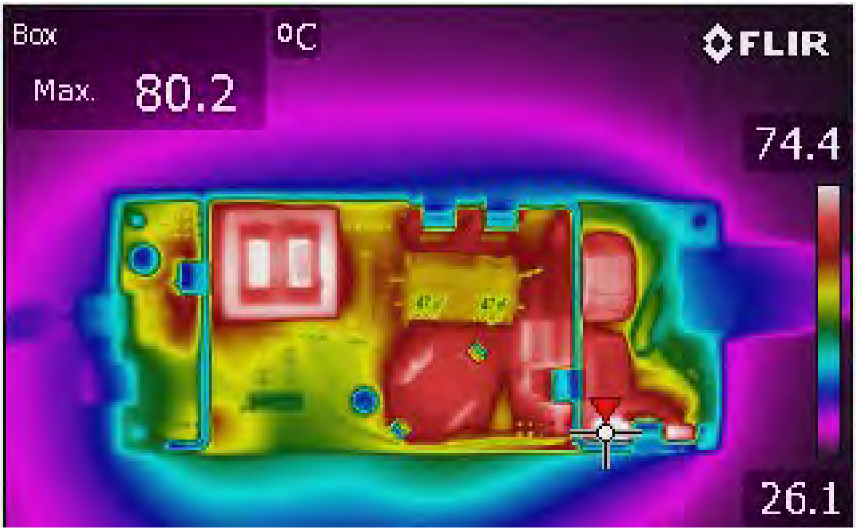


Fig 33. Thermal camera photograph top side PCB; V_{mains} = 90 V (AC); full load

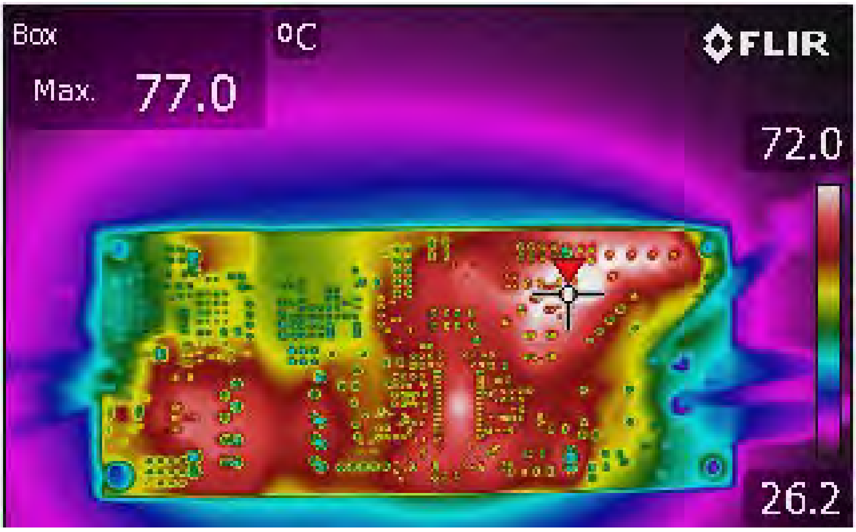


Fig 34. Thermal camera photograph bottom side PCB; V_{mains} = 90 V (AC); full load

12. Bill Of Materials (BOM)

Table 12. Bill of materials

Part Reference	Description and values	Manufacturer Part Number	Manufacturer
BR1	bridge rectifier; 8 A; 600 V	GBU806	Diode Inc
C1	capacitor; 100 pF; 10 %; 440 V; Y2	VY2101K29Y5SG63V7	Vishay
C2; C4	capacitor; 220 nF; 20 %; 310 V; X2	BFC233922224	Vishay
C3; C5	capacitor; 220 nF; 5 %; 630 V	ECW-FA2J224J	Panasonic
C6	capacitor; 47 µF; 20 %; 450 V	EEUEE2W470S	Panasonic
C7	capacitor; 8.2 nF; 5 %; 1.6 kV	B32672L1822J000	Epcos
C8	capacitor; 220 µF; 20 %; 35 V	UPJ1V221MPD1TD	Nichicon
C9	capacitor; 330 pF; 5 %; 1 kV	DEA1X3A331JA2B	Murata
C10	capacitor; 3.3 nF; 20 %; 300 V; Y2	B32021A3332M	Epcos
C11	capacitor; 47 µF; 20 %; 100 V	UBT2A470MPD	Nichicon
C12	capacitor; not mounted; 47 pF; 5 %; 630 V; C0G; 1206	GRM31A5C2J470JW01D	Murata
C15; C23	capacitor; 47 pF; 5 %; 630 V; C0G; 1206	GRM31A5C2J470JW01D	Murata
C13; C19; C21; C38; C41; C42; C43	capacitor; 1 nF; 10 %; 50 V; C0G; 0603	C0603C102K5GAC	Kemet
C14	capacitor; 180 pF; 1 %; 50 V; C0G; 0603	GRM1885C1H181FA01D	Murata
C16	capacitor; 33 nF; 10 %; 50 V; X7R; 0603	C0603C333K5RACTU	Kemet
C17; C28	capacitor; 2.2 µF; 10 %; 16 V; X7R; 0805	CC0805KKX7R7BB225	Yageo
C18	capacitor; 330 nF; 10 %; 50 V; X7R; 0603	C1608X7R1H334K	TDK
C20; C25; C26; C31	capacitor; 470 nF; 10 %; 50 V; X7R; 0603	C1608X7R1H474K	TDK
C22	capacitor; 1.2 nF; 5 %; 630 V; C0G; 1206	C3216C0G2J122J	TDK
C24	capacitor; 100 nF; 10 %; 50 V; X7R; 0603	C0603C104K5RACTU	Kemet
C27; C33	capacitor; 10 nF; 10 %; 50 V; X7R; 0603	C0603C103K5RACTU	Kemet
C29; C35	capacitor; 4.7 µF; 10 %; 25 V; X7R; 0805	TMK212AB7475KG-T	Taiyo Yuden
C30	capacitor; 220 pF; 5 %; 50 V; C0G; 0603	C0603C221J5GACTU	Kemet
C32; C34	capacitor; 2.2 nF; 10 %; 50 V; X7R; 0603	C0603C222K5RAC7411	Kemet
C36; C40	capacitor; 220 nF; 10 %; 25 V; X7R; 0603	GRM188R71E224KA88D	Murata
C37	capacitor; 100 pF; 5 %; 100 V; C0G ; 0603	GRM1885C2A101JA01J	Murata
C39; C44; C45	capacitor; 100 nF; 10 %; 100 V; X7R; 0603	GRM188R72A104KA35D	Murata
D1; D2	diode; 600 V; 5 A; TO220F-2P	BYV25X-600,127	NXP Semiconductors
D3	diode; 800 V; 1 A	UF4006-E3/73	Vishay
D4	diode; dual; 200 V; 10 A	BYQ28X-200,127	NXP Semiconductors
D5; D6; D7; D8; D11; D12; D17	diode; 100 V; 215 mA	BAS316,135	NXP Semiconductors
D9; D10	diode; dual; 200 V; 225 mA	BAV23S,215	NXP Semiconductors
D13	diode; zener; 12 V; 550 mW; SOD323F	BZX84J-C12,115	NXP Semiconductors

D14	diode; dual; 100 V; 215 mA	BAV99,215	NXP Semiconductors
D15	diode; zener; not mounted; 51 V; 250 mW, SOT-23	BZX84-C51,215	NXP Semiconductors
D16	diode; dual; 90 V; 215 mA	BAW56,235	NXP Semiconductors
D18	diode; 1 kV; 1 A; SMX	FM4007W-W	Rectron
FH1	fuse; 2 A; slow	SS-5H-2A-APH	Cooper Bussmann
J1	mains inlet with solder tab	771W-BX2/01	Qualtek
J2; J3	header; side entry; 5.08 mm; 2 way	1508060000	Weidmuller
L1	choke; common-mode; 20 mH; 1.5 A	744823220	Wurth
L2	inductor; 696 μH; 2 A	750312186	Wurth
L3	choke; comm. mode; 47 μH; 2 A	744841247	Wurth
Q1; Q2; Q3	transistor; MOSFET-N; 600 V; 6.8 A	FCPF7N60NT	Fairchild
Q4; Q7	transistor; BJT; NPN; 65 V; 200 mA	BC846B,215	NXP Semiconductors
Q5	transistor; not mounted; BJT; NPN; 65 V; 200 mA	BC846B,215	
Q6	transistor; BJT; NPN; 100 V; 1 A	BCP56-16,115	NXP Semiconductors
R1	varistor; 300 V; 180 pF	V300LA10P	Littelfuse
R2	resistor; 1 Ω; 1 %; 400 mW; THT	MBA02040C1008FC100	Vishay
R3	resistor; 10 Ω; 1 %; 400 mW; THT	MBA02040C1009FC100	Vishay
R4	resistor; 1 k Ω; 1 %; 400 mW; THT	MBA02040C1001FC100	Vishay
R5	resistor; 2.21 Ω; 1 %; 400 mW; THT	MBA02040C2218FC100	Vishay
R6, R7	resistor; 1.5 MΩ; 1 %; 250 mW; 1206	HV732BTTD1504F	KOA Speer
R8	resistor; 110 kΩ; 1 %; 250 mW; 1206	HV732BTTD1103F	KOA Speer
R9	resistor; 270 mΩ; 1 %; 500 mW; 1206	RCWE1206R270FKEA	Vishay/Dale
R10	resistor; 270 mΩ; 1 %; 500 mW; 1206	RCWE1206R270FKEA	Vishay
R11; R21; R30	resistor; 10 Ω; 1 %; 100 mW; 0603	RC0603FR-0710RL	Yageo
R12; R13; R14	resistor; 3.3 MΩ; 1 %; 250 mW; 1206	RC1206FR-073M3L	Yageo
R15; R31	resistor; 15 kΩ; 1 %; 100 mW; 0603	RC0603FR-0715KL	Yageo
R16	resistor; 75 kΩ; 1 %; 100 mW; 0603	RC0603FR-0775KL	Yageo
R17; R58; R73	resistor; 22 kΩ; 1 %; 100 mW; 0603	RC0603FR-0722KL	Yageo
R18; R25; R26; R27; R28; R37; R63	resistor; 0 Ω; 250 mW; 1206	RC1206JR-070RL	Yageo
R19	resistor; 1 kΩ; 1 %; 100 mW; 0603	RC0603FR-071KL	Yageo
R20	resistor; 5.6 kΩ; 1 %; 100 mW; 0603	AF0603FR-075K6L	Yageo
R22	resistor; 51 kΩ; 1 %; 100 mW; 0603	RC0603FR-0751KL	Yageo
R23; R34	resistor; 22 Ω; 1 %; 100 mW; 0603	RC0603FR-0722RL	Yageo
R24	resistor; 390 kΩ; 1 %; 250 mW; 1206	RC1206FR-07390KL	Yageo
R29; R42; R44; R45; R60	resistor; 33 kΩ; 1 %; 100 mW; 0603	RC0603FR-0733KL	Yageo
R32	resistor; 39 kΩ; 1 %; 100 mW; 0603	RC0603FR-0739KL	Yageo
R33; R54	resistor; 5.1 kΩ; 1 %; 100 mW; 0603	RC0603FR-075K1L	Yageo

R35; R64	resistor; 0 Ω; 1 %; 100 mW; 0603	AC0603FR-070RL	Yageo
R36; R72	resistor; 27 kΩ; 1 %; 100 mW; 0603	RC0603FR-0727KL	Yageo
R38; R66	resistor; 330 kΩ; 1%; 100 mW; 0603	RC0603FR-07330KL	Yageo
R39	resistor; 1 Ω; 1 %; 250 mW; 1206	RK73H2BTTD1R00F	KOA Speer
R40	resistor; 100 kΩ; 1 %; 100 mW; 0603	RC0603FR-07100KL	Yageo
R41	resistor; 9.1 Ω; 1 %; 330 mW; 1206	ERJ8BQF9R1V	Panasonic
R43; R55	resistor; 8.2 kΩ; 1 %; 100 mW; 0603	RC0603FR-078K2L	Yageo
R46; R70	resistor; 2.2 kΩ; 1 %; 100 mW; 0603	RC0603FR-072K2L	Yageo
R47; R71	resistor; 3.3 kΩ; 1 %; 100 mW; 0603	RC0603FR-073K3L	Yageo
R49	resistor; not mounted; 15 kΩ; 1 %; 100 mW; 0603	RC0603FR-0715KL	Yageo
R48; R50	resistor; 10 kΩ; 1 %; 100 mW; 0603	RC0603FR-1310KL	Yageo
R51	resistor; not mounted; 3.9 kΩ; 1 %; 250 mW; 1206	RC1206FR-073K9L	Yageo
R52	resistor; 82 kΩ; 1 %; 100 mW; 0603	RC0603FR-0782KL	Yageo
R53	resistor; 9.1 kΩ; 1 %; 100 mW; 0603	RC0603FR-079K1L	Yageo
R56	resistor; 6.2 kΩ; 1 %; 100 mW; 0603	RC0603FR-076K2L	Yageo
R57	resistor; not mounted; 10 kΩ; 1 %; 100 mW; 0603	RC0603FR-1310KL	Yageo
R59	resistor; 59 kΩ; 1 %; 100 mW; 0603	RC0603FR-0759KL	Yageo
R61	resistor; 1.8 kΩ; 1 %; 125 mW; 0805	RC0805FR-071K8L	Yageo
R62	resistor; 24 kΩ; 1 %; 250 mW; 1206	RC1206FR-0724KL	Yageo
R65	resistor; 27 Ω; 1 %; 100 mW; 0603	RC0603FR-0727RL	Yageo
R67	resistor; 270 kΩ; 1 %; 100 mW; 0603	RC0603FR-07270KL	Yageo
R68	resistor; 4.7 kΩ; 1 %; 100 mW; 0603	RC0603FR-074K7L	Yageo
R69	resistor; 50 mΩ; 1 %; 1 W; 2512	RL2512FK-070R05L	Yageo
R74	resistor; 100 Ω; 1 %; 250 mW; 1206	RC1206FR-07100RL	Yageo
T1	transformer; PFC; 500 µH; 3.5 A; RM10	750313715R01	Wurth
T3	transformer; LLC	TRLEV25048A-150213A	www.Itacoilweb.it
U1	optocoupler; not mounted; CTR 160-320 %	SFH615A-4	Vishay
U2	optocoupler; CTR 160-320 %	SFH615A-4	Vishay
U3	IC LED driver controller SSL4120T	SSL4120T	NXP
U4	comparator; dual	LM2903PWR	Texas Instruments
U5	voltage regulator; 1 %; 70 mA	TLVH431AQDBZR,215	NXP
U6	opamp; dual	LM2904AVQDRQ1	Texas Instruments
WB1; WB5	wire bridge; green; 5E; AWG22	923345-05-C	3M
WB2; WB4	wire bridge; orange; 3E; AWG22	923345-03-C	3M
WB3	wire bridge; white; 9E; AWG22	923345-09-C	3M
WB6	wire bridge; yellow; 4E; AWG22	923345-04-C	3M

13. Appendix

13.1.1 Optional no-load efficiency improvement

By default the no-load power consumption $P_{i(no\text{-}load)}$ = 2.7 W. In case $P_{i(no\text{-}load)}$ reduction is required in this mode, the modification in this appendix can be applied.

When a switch is placed between the PCB output and the LED load then the no-load input power $P_{i(no\text{-}load)}$ must be specified.

According EU Ecodesign regulation No 1194/2012 the following requirements hold for $P_{i(no\text{-}load)}$ and $P_{i(standby)}$ must be:

< 1.0 W from September 2014 onwards;

< 0.5 W from September 2016 onwards.

EU Ecodesign regulation No 1194/2012 definitions:

'no-load mode' means the condition of a lamp control gear where it is connected to the supply voltage and where its output is disconnected in normal operation from all the primary loads by the switch intended for this purpose (a faulty or missing lamp, or a disconnection of the load by a safety switch is not normal operation);

'standby mode' means a mode of lamp control gear where the lamps are switched off with the help of a control signal under normal operating conditions. It applies to lamp control gear with a built-in switching function and permanently connected to the supply voltage when in normal use;

In no-load conditions this board can reach P_i < 0.5 W when the following list with modifications is applied to the default circuit.

Table 13. Modifications to support $P_{i(no\text{-}load)}$

Component	Value	Modification
D15	BZX84-C51	mount
Q5	BC546B	mount
R48	10 kΩ	mount
R50	10 kΩ	mount
R51	3.9 kΩ	mount
R52	-	do not mount
R64	-	not mount
U1	SFH615A-4	mount

In normal operation the PFC is not in burst mode. To reach the low $P_{i(no\text{-}load)}$, the HBC and PFC stage must be operated in burst mode.

When V_o is higher than the $V_{D15} + V_{U1}$ the optocoupler triggers the SSL4120T controller to disable the PFC and the HBC stage via pin SNSOUT.

The PFC and HBC are disabled when V_{SNSOUT} < 0.3 V.

After V_o drops below $V_{D15} + V_{U1}$, the V_{SNSOUT} rises to the normal operating level.

14. References

Table 14. Table of references

Reference ID	Description
1	SSL4120 data sheet, Rev. 2, 1 November 2012
2	SSL8516T data sheet, GreenChip PFC and flyback controller, Rev.1, 5 May 2014
3	UM10776 user manual, SSL8516DB1195 75 W 1.6 A dimmable LED driver, Rev.1, 6 May 2014
4	AN11227 SSL4120 resonant power supply control IC with PFC, Rev. 1, 27 November 2012
5	Flicker parameters for reducing stroboscopic effects from solid-state lighting systems, ASSIST, volume 11, issue 1, may 2012

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16. Contents

Date of release: 19 August 2014
Document identifier: UM10722