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130 W dimmable constant current LED driver

using ICL5102 in PFC and LLC topology

About this document

Scope and purpose

This document presents details of the ICL5102 reference design and product feature set. It describes all the necessary steps to get the board and related environment up and running. It also provides all the necessary information needed for familiarity with this comprehensive solution.

The ICL5102 is a mixed-signal Power Factor Correction (PFC) and resonant controller for dimmable and non-dimmable LED light applications using LLC/LCC topology, for highest efficiency levels exceeding 92 percent at 230 V AC_{IN} and at full load. An outstanding integrated digital PFC stage with an adjustable Total Harmonic Distortion (THD) compensation enables THD less than 10 at 25 percent load/230 V AC_{IN}. In an ultra-wide line input voltage range from V AC_{IN} = 90 V up to 305 V a Power Factor (PF) above 90 percent at greater than 50 percent load is achieved. The ICL5102 LLC constant current board is designed to evaluate the performance and flexibility of the ICL5102 and demonstrates its performance, especially in a wide ambient temperature range from T_A = -40°C to T_A = 55°C at P_{OUTnom} = 130 W and 230 V AC_{IN}.

Intended audience

This document is intended for anyone using the ICL5102 reference design, either for their own application tests or to use it as a reference for a new ICL5102-based development.

Table of contents

1 Order code/ board connection/ operation set-up

1.1 Order code

REF-ICL5102-U130W-CC/ SA number: SA001715492/ SP number: SP001667160

1.2 Connection diagram

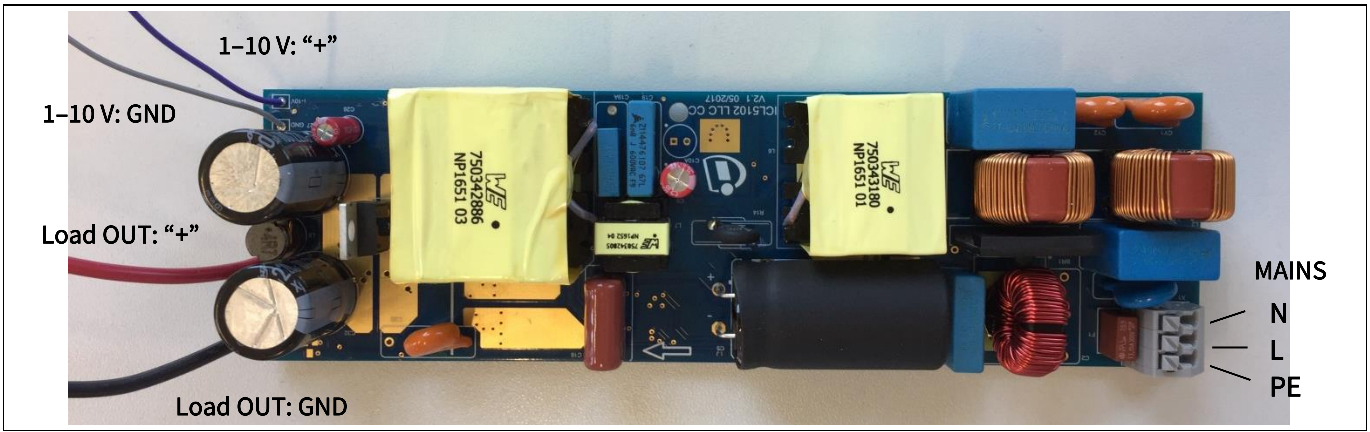


Figure 1 Top view of LED driver connection

1.3 Line input voltage

Connect an AC source at the MAINS INPUT as shown, from 90 V AC up to 305 V AC.

1.4 Constant current output

- Option 1 → Dimming. When using an LED module, ensure the LED voltage at minimum dimming level (V_{Dim} = 1.0 V) is not less than V_{Dim1V} = 38 V.
- Option 2 → Connect an LED in a voltage range of 38 V DC up to 76 V DC with a nominal current of minimum 1.75 A to the output stage from Load OUT: GND and Load OUT: “+”.
- Option 3 → Connect an electronic load to Load OUT: GND and Load OUT: “+”; in LED or CV mode.

Note: The output current varies from board to board by ± 3 percent (measured over 20 boards).

1.5 1–10 V dimming interface

Connect a DC source at 1–10 V: GND and 1–10 V: “+”. 10 V is equal to the maximum load current I_{OUTmax}. Minimum output current I_{OUTmin} is reached when the dimming voltage is equal to V_{DIM} = 1.0 V – for details see Chapter 3 Technical specification.

2 Introduction

This Application Note (AN) describes the characteristics and features of a 130 W SMPS LED demonstration board with dimmable constant current output in a voltage range from 76 V down to 38 V. High efficiency, high PF, low THD and a stable output current over the whole output voltage range makes it very suitable for high-quality LED lighting such as street lights, high-bay lighting or office lighting. With the highly integrated ICL5102 (combo controller with Critical Conduction Mode (CrCM)/Discontinuous Conduction Mode (DCM) PFC and half-bridge LLC integrated), the circuit design is considerably simplified, which results in space and Bill of Materials (BOM) cost savings. Furthermore, numerous monitoring and protection features ensure the highest reliability.

Key specification measurements and waveforms are shown in this AN.

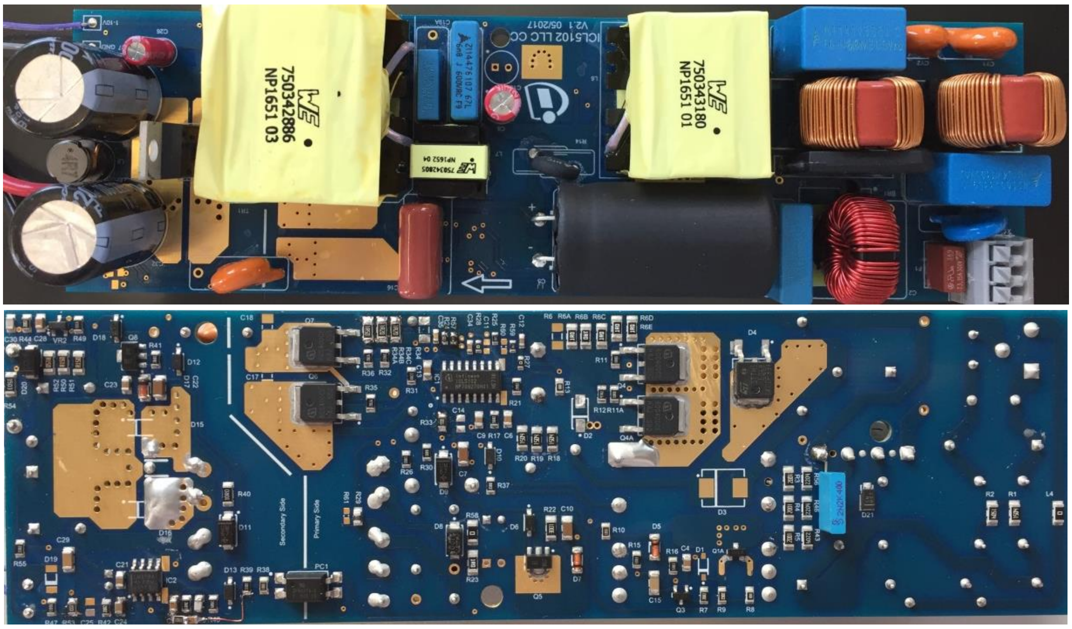


Figure 2 PFC and LLC dimmable constant current reference board

3 Technical specifications

This reference design consists of a CrCM/DCM PFC and a half-bridge LLC, with dimmable constant current output from 38 V (minimum dimming voltage at V_{DIM} = 1 V) up to 76 V LED forward voltage. The demo board is designed for 1–10 V dimming and a non-dimming constant current operation over the whole output voltage range.

The PFC stage of this reference design is controlled by the PFC block of the ICL5102. The PFC stage has an integrated digital PFC control loop. The improved adjustable (via resistor) THD compensation is designed especially for light-load condition at 25 percent load for THD less than 10 percent at 230 V. It operates in CrCM to achieve a good PF and very low THD over a wide load range. When the load decreases to the minimum level, the IC controls the PFC to operate in DCM. The PFC BUS voltage will be sensed highly accurately (± 1.6 percent) so there is no need for a compensation network. For PFC protection, an open-loop, BUS Over Voltage (OV) and Under Voltage (UV) and surge will be also detected.

The half-bridge LLC stage has a fixed duty cycle of D = 0.5 with a self-adapting dead-time from 250 ns to 750 ns. ICL5102 provides an extended operation frequency range up to a typical 330 kHz in order to provide a wide dimming range and support LCC topologies. The three-state self-adapting soft-start starts with HF and has a capacitive mode regulation implemented. The following protection functions are implemented: output short-circuit protection, LLC Over Current Protection (OCP), capacitive mode regulation, Over Temperature Protection (OTP), output Over Voltage Protection (OVP) and Brown Out (BO) detection. Active Burst Mode (ABM) provides standby power below 300 mW (board level) and can be disabled.

Features

- Input voltage range: 90–305 V AC
- Input voltage frequency: 47–63 Hz
- Regulated nominal output current: I_{OUTnom_min} = 1.75 A_{MIN} in an output voltage range from 38 V DC up to 76 V DC
- I_{OUTMIN} = 74–76 mA (5 percent of I_{OUTnom_min} at V_{DIM} = 1.0 V)
- Output current ripple at V_{OUT} = 76 V/1.75 A: $I_{OUTRipplemax}$ = 110 mA_{P_P} (± 3 percent)
- Dimming using an analog 1–10 V interface
- STB less than 300 mW
- Time to light: tT2L ~ 350 ms at 90 V AC/V_{Dim} = 1.0 V
- Efficiency at nominal load: ~ 92.0 percent at 230 V AC
- PF: greater than 90 percent at 50 percent load (230 V AC_{in})
- Input current THD: less than 10 percent at 25 percent load (230 V AC_{in})
- Low-temperature start-up at -40°C T_A
- OTP at 95 °C/auto-restart at 85°C
- Output OVP at V_{OUT} = 90 V DC
- BO/Brown In (BI) detection: at 71 V AC_{IN}/BI at 79 V AC_{IN}
- Harmonics: according to EN 61000-3-2 Class C
- EMI: according to EN 55015
- Safety : according to EN 61347-2-13
- Board dimensions: 178 mm (L) × 52 mm (B) × 32 mm

4 Schematic

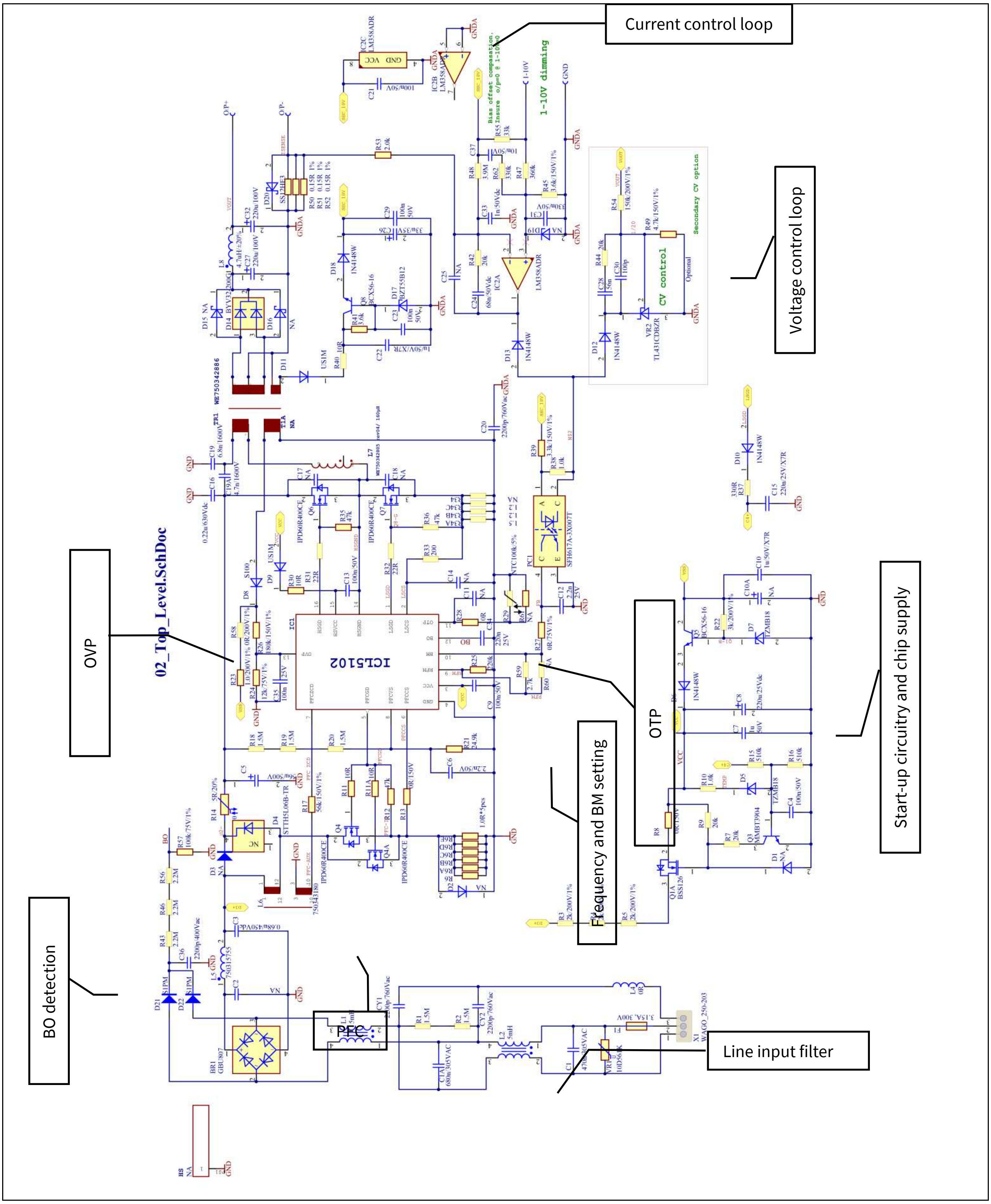


Figure 3 Schematic

5 Key measurements using LED load

5.1 Operating area

The output current of the reference design is tested under I_{OUTnom} = 1.75 A at 230 V AC in a voltage range between 76 V_{OUT} and 38 V_{OUT}. Within this area the driver is working in constant current operation as shown in Figure 4.

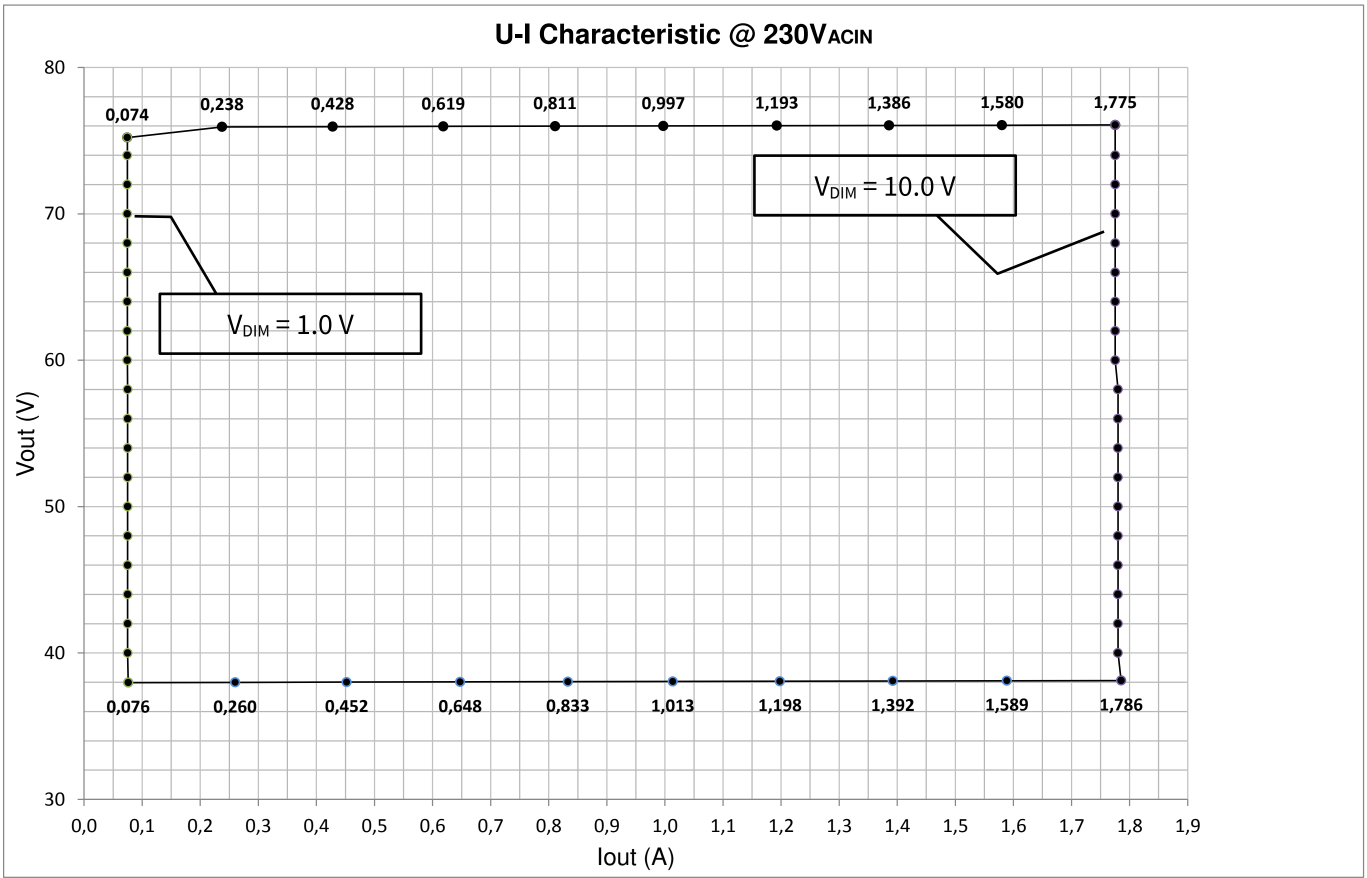


Figure 4 Constant current operating area

5.2 Dimming performance

The chart below shows the output current versus the 1–10 V dimming voltage tested at 230 V AC input voltage.

Note: *Do not exceed the maximum dimming level of V_{Dim} to make it greater than 10 V (OC) or (shut ON) below V_{Dim} – less than 1.0 V – which is not specified.*

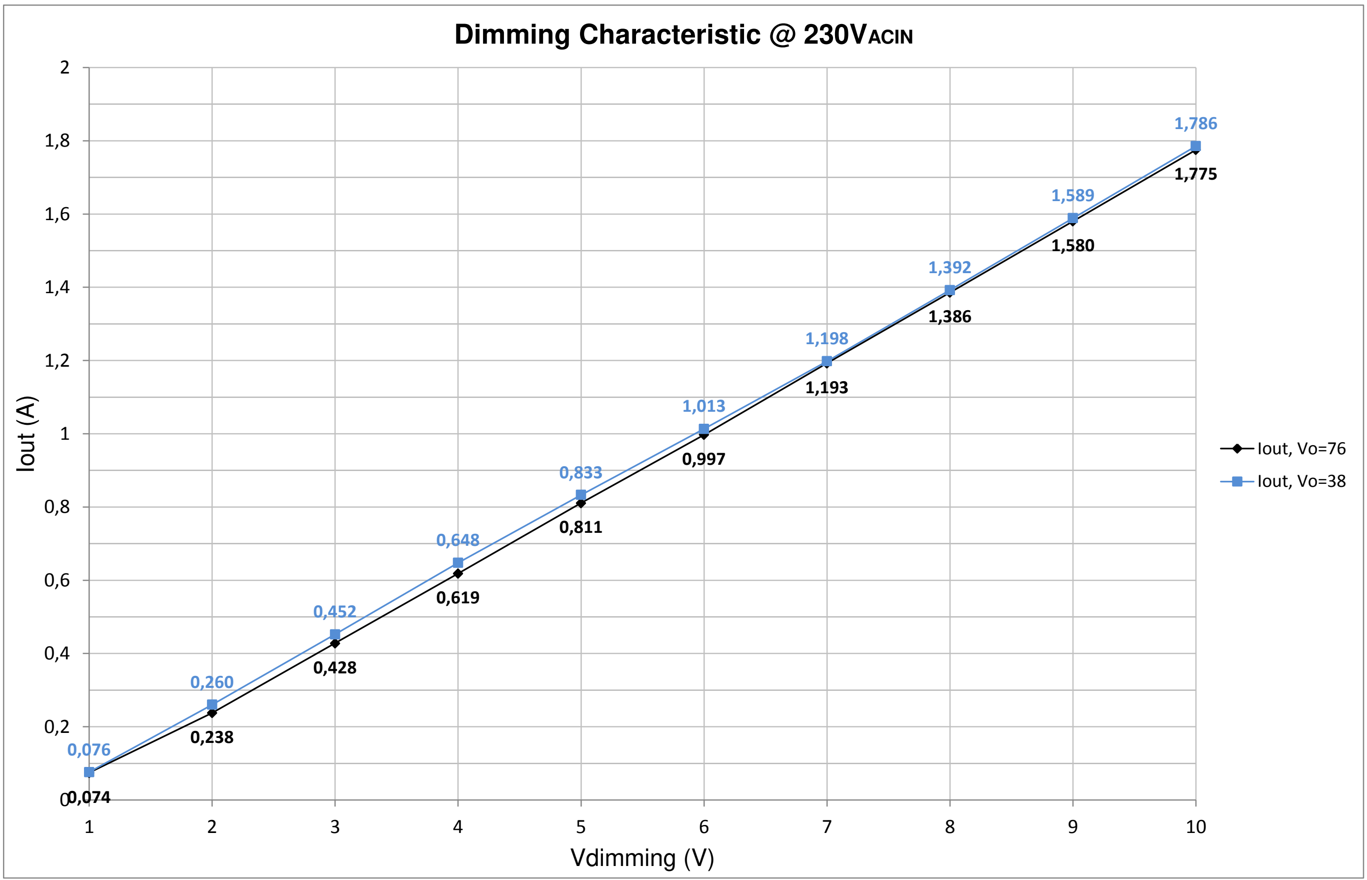


Figure 5 **Dimming characteristics**

Note: *When using an LED module:*

- While dimming, the forward voltage of the LED drops from its nominal value e.g. V_{fLED} = 76 V down to its lowest dimming level V_{Dim} = 59 V at V_{DIM} = 1.0 V
- The lowest specified dimming voltage at V_{Dim} = 1.0 V is V_{Dim1V} = 38 V

Note: *The LED driver is designed to start up without flashing at the lowest dimming level of V_{Dim} = 1.0 V.*

5.3 Efficiency

The charts below show the overall system efficiency (PFC + LLC) of the reference design measured at line input to the output stage at 76 V_{OUT} and 38 V_{OUT} respectively.

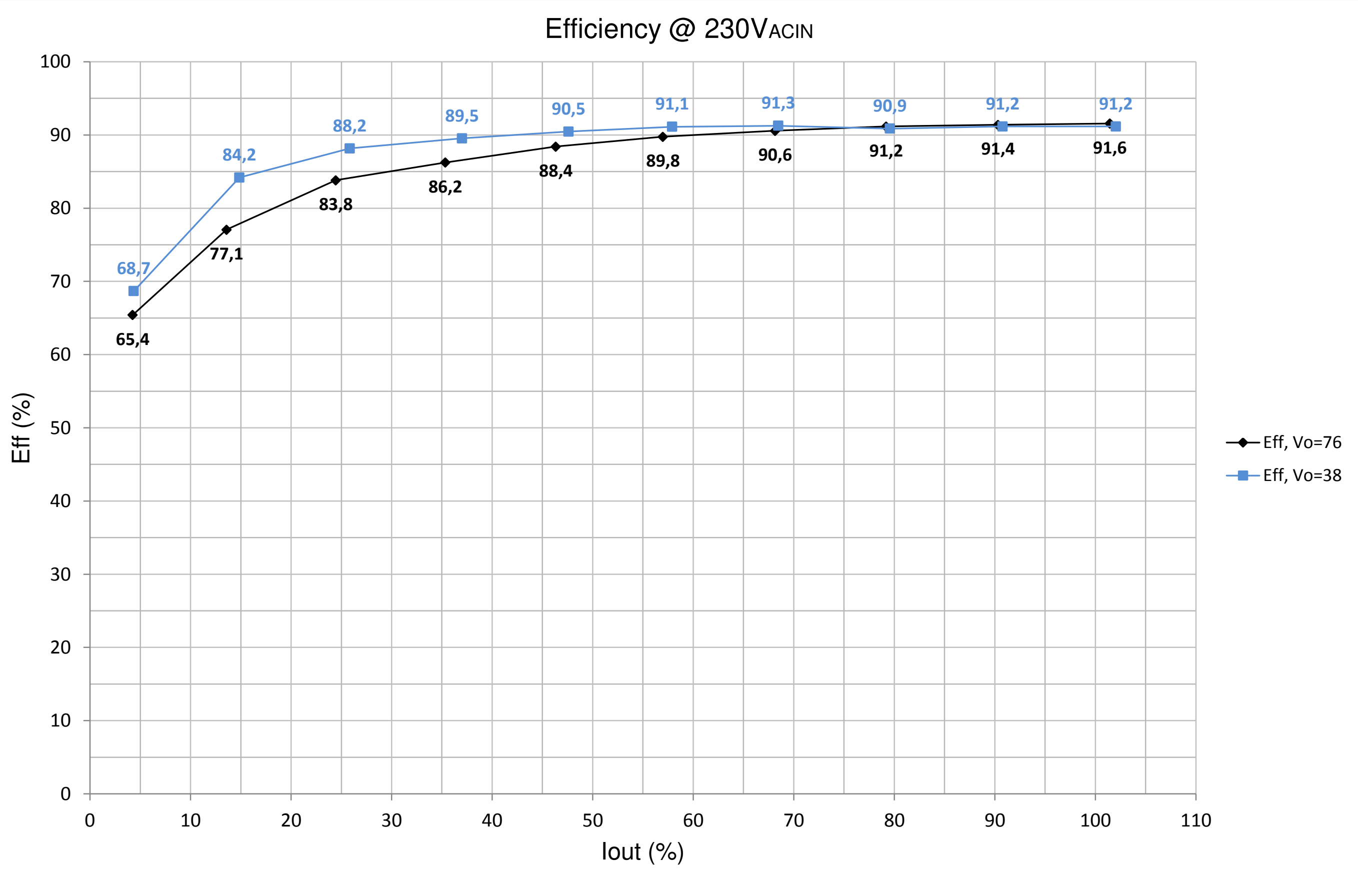


Figure 6 Efficiency at V AC_{IN} = 230 V AC_{IN}

5.4 Power factor vs P_{OUT}

The smart internal digital PFC stage results in a PF higher than 90 percent at 50 percent load, which is achieved at V_{IN} = 230 V AC.

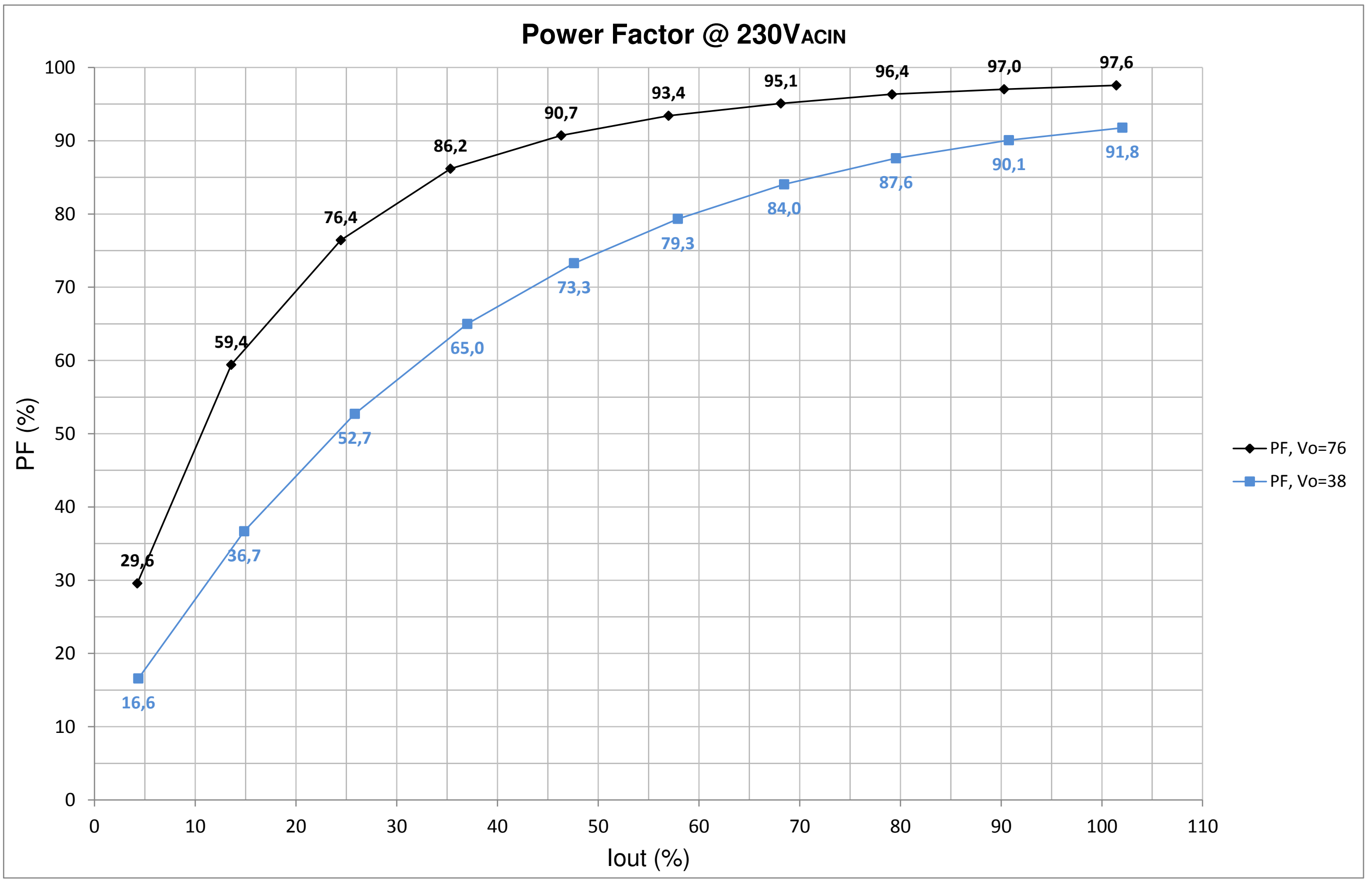


Figure 7 PF at 230 V AC_{IN}

5.5 THD vs P_{OUT}

Due to the smart THD adjustment via a resistor at the Zero Crossing Detection (ZCD) pin of the ICL5102, a THD below 10 percent at 25 percent load is achieved at V_{IN} = 230 V AC.

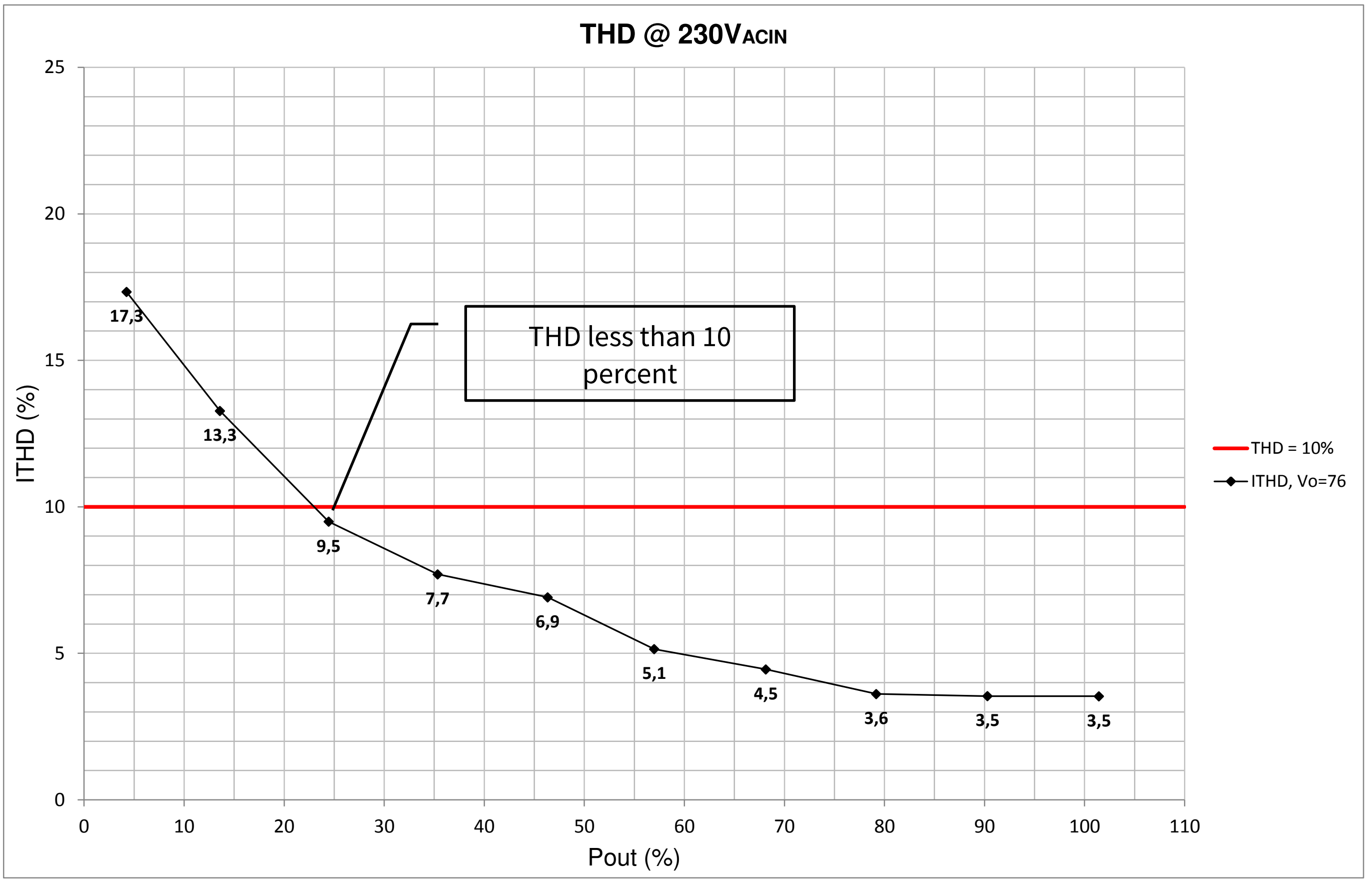


Figure 8 THD at 230 V AC_{IN}

5.6 Standby power/ABM

In order to decrease the standby power to a minimum, the ICL5102 has an integrated ABM. The outstanding performance of the integrated burst mode differentiates between four exit cases by using only one pin:

- Exit 1: Load jump during burst sleep (pause)
- Exit 2: Load jump during burst pulse (train)
- Exit 3: Burst pulse train time-out due to high static load
- Exit 4: Burst duty cycle in case of dimming to a certain level, which can be set

During ABM, capacitive load detection and a power limitation are active in order to prevent any malfunction. ABM can be disabled to achieve flicker-free light output.

Figure 9 ABM

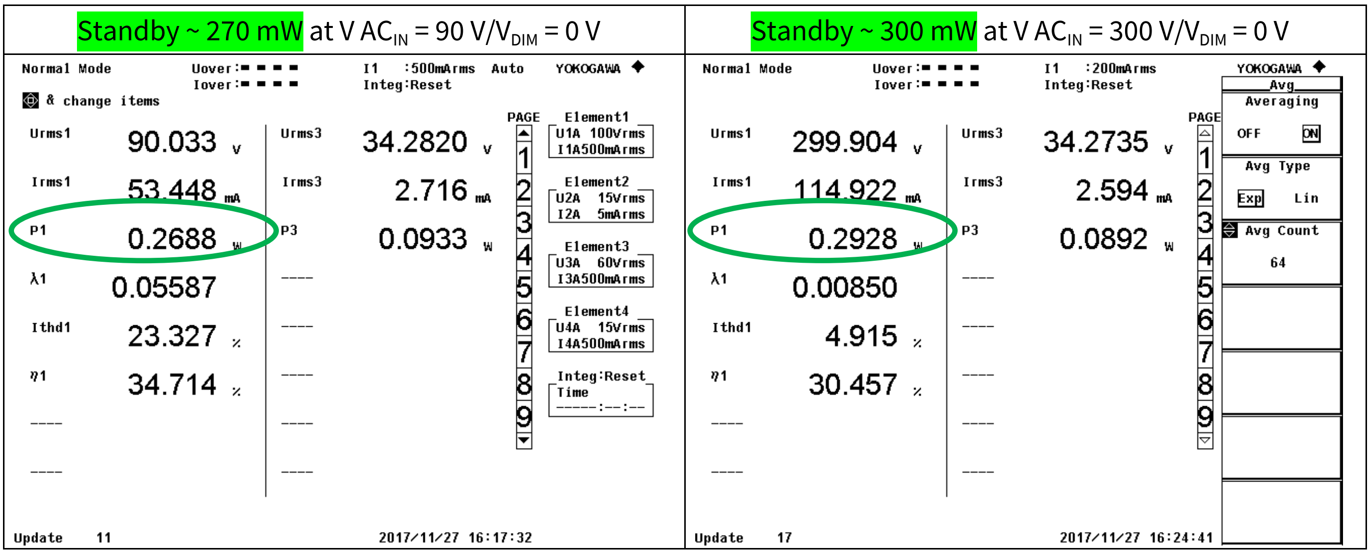


Figure 10 Standby mode

5.7 BO detection

The voltage at BO pin 12 must be above V_{BO} = 1.4 V during monitoring (initial start-up) to enable a BI. If the voltage at this pin drops below V_{BO} = 1.2 V for longer than 50 ms during operation, a BO is detected and the controller powers down and auto-restarts the internal system. Use a double rectifier and high ohmic resistors for the voltage divider.

5.7.1 BO distortion explanation

The BO detection function of the ICL5102 is based on a DC voltage on pin 12 (BO) that represents the average value of the rectified mains voltage, see Figure 11.

The level at the BO pin becomes incorrect when the half-bridge is not running, at start-up or in RUN mode when a protection shuts off e.g. BO. In both cases, the input diode bridge is not conducting. This causes a Common Mode (CM) voltage from mains to power GND, see the red arrow in Figure 11. It results in a shifting up of the average value of the RMS rectified voltage, see "Common mode distortion" in Figure 11. Note: The peak value stays the same. In order to compensate for this effect place a film capacitor C_{BO_1} from R_{BO_1} (as shown in Figure 11) to power GND.

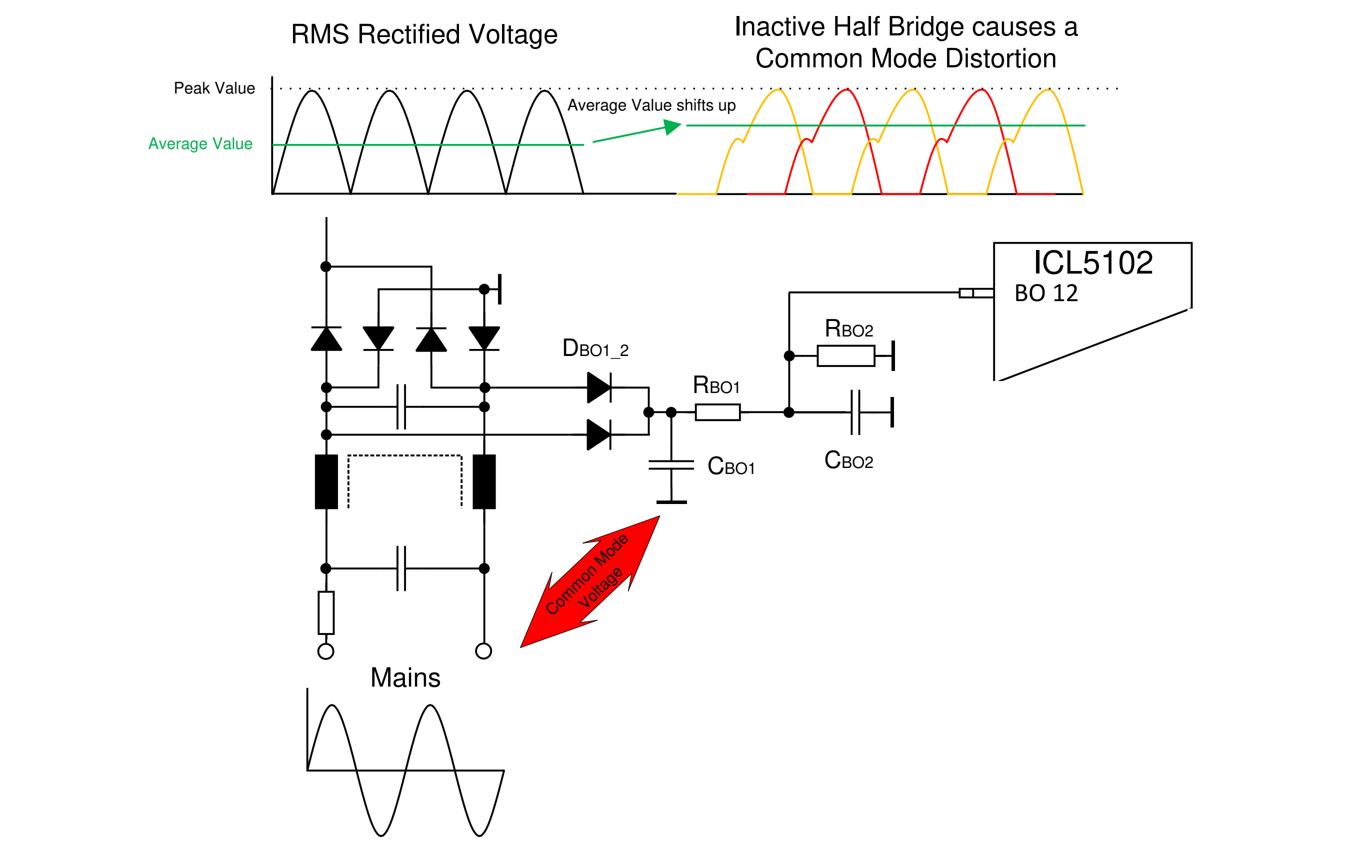


Figure 11 Impact of conducting vs non-conducting (distortion)

5.7.2 BO distortion measurements

The figures below show the rectified mains during start-up on the left-hand side, and RUN mode on the right-hand side.

Start-up: Change from CM voltage (BR not conducting) supply OFF, into DM voltage (BR conducting) supply ON	**RUN Mode:** Change from DM voltage (BR conducting) into CM voltage (BR not conducting)
	

Figure 12 BO distortion measurements

5.8 OTP

The OTP detects the temperature via an external NTC sensor. Figure 13 shows the operation of the OTP. If the voltage V_{OTP1} is less than 703 mV during start-up, the controller prevents a power-up. If the voltage at pin 11 drops below V_{OTP2} = 625 mV during RUN or burst mode, the IC powers down and auto-restarts when it rises above V_{OTP1} = 703 mV. Delay in both cases is 620 µs, and the typical current sourced by this pin is I_{OTP} = 100 µA. In order to disable OTP connect a 20 k resistor from pin 11 to GND.

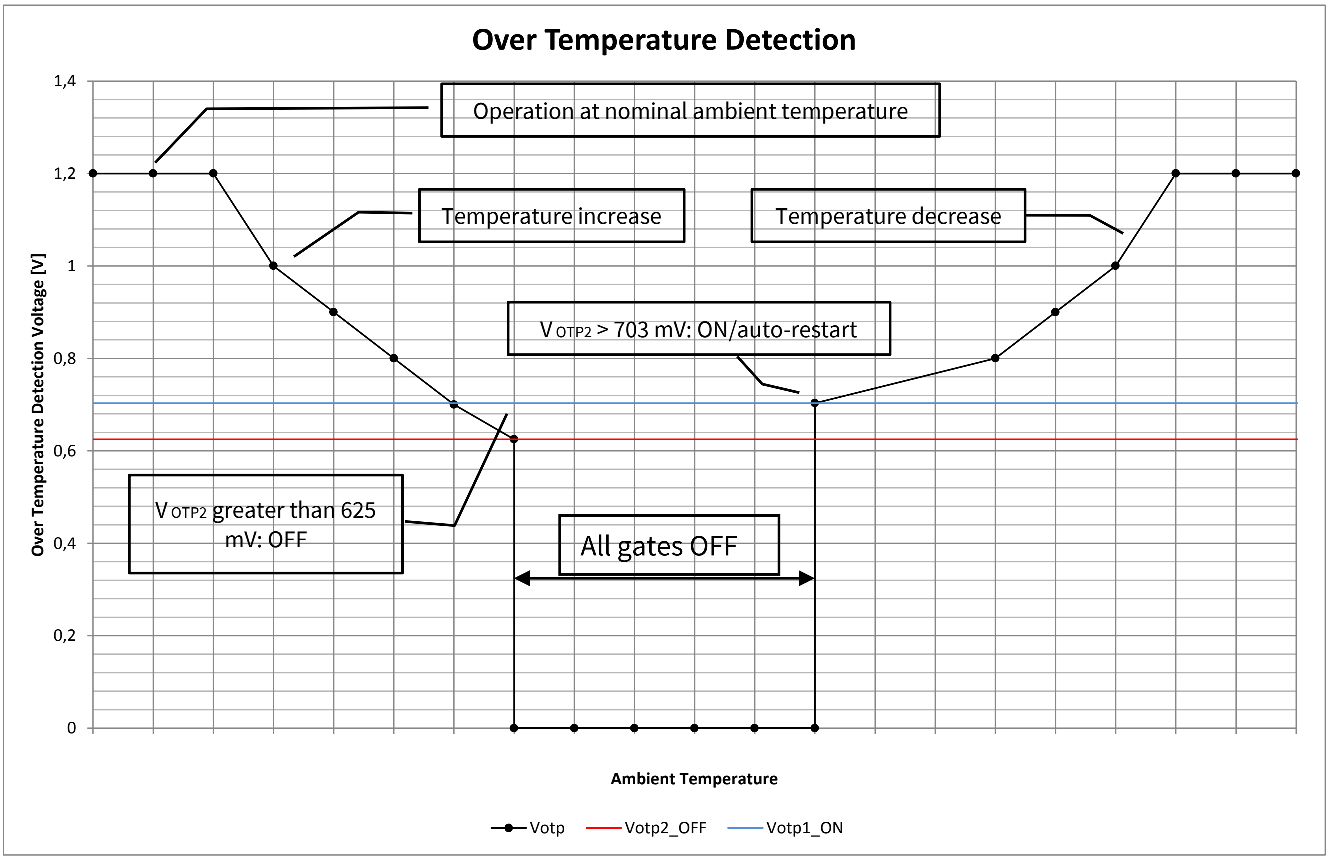


Figure 13 OTP

Note: *If OTP is disabled, do not set a capacitor parallel to the 20 k resistor to GND. This would lead to a malfunction during ABM. For OTP use an NTC and a capacitor less than 47 nF from pin 11 to GND, as shown in Figure 14.*

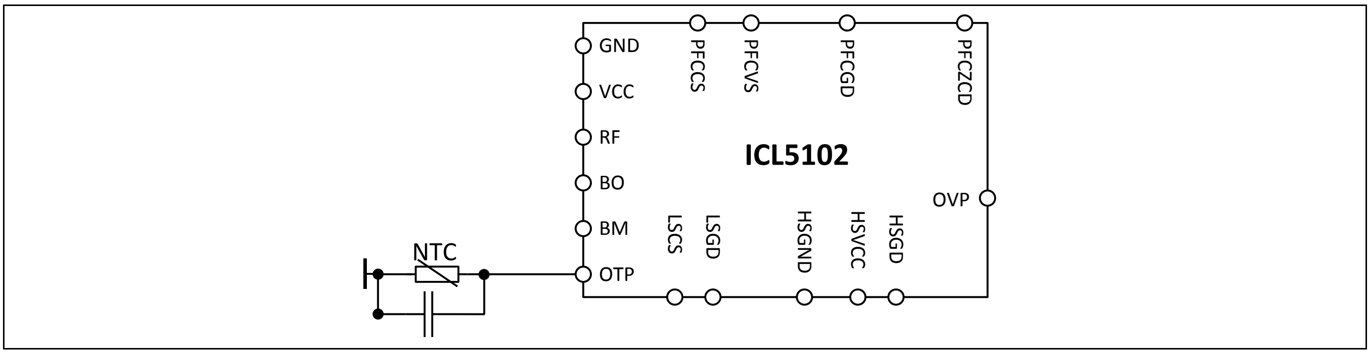


Figure 14 OTP set-up

5.8.1 Board hot spot

The board was tested around the temperature hub at the corner cases. The ambient temperature was T_A = 25°C, I_{OUT} = 1.75 and a mains voltage at 230 V. Figure 15 shows the thermal behavior of the evaluation board with a hot spot.

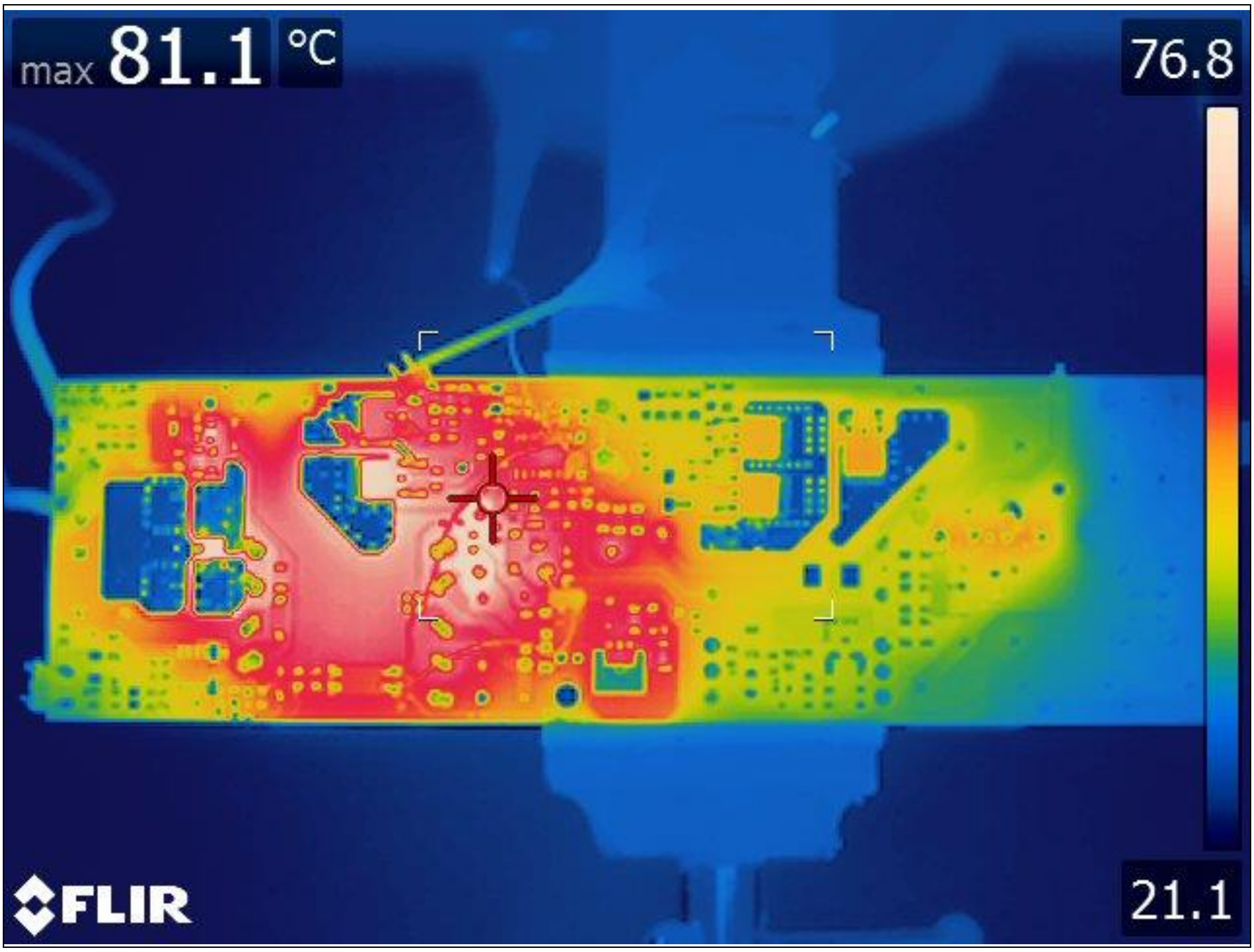


Figure 15 Hot spot on board

5.9 Surge protection

Description of SURGE protection

In case of a surge event, the voltage at the BUS capacitors C5 and C8 increases, and the driver stages of the ICL5102 are shut off when V_{BUS} is greater than 115 percent for longer than 50 ms. After the surge, the controller restarts automatically when V_{BUS} drops below 109 percent of the rated voltage. This feature allows for driving 500 V MOSFETs at the half-bridge stage when adequate EMI and DC-link networking is present.

5.10 Harmonics according to IEC EN 61000-3-2

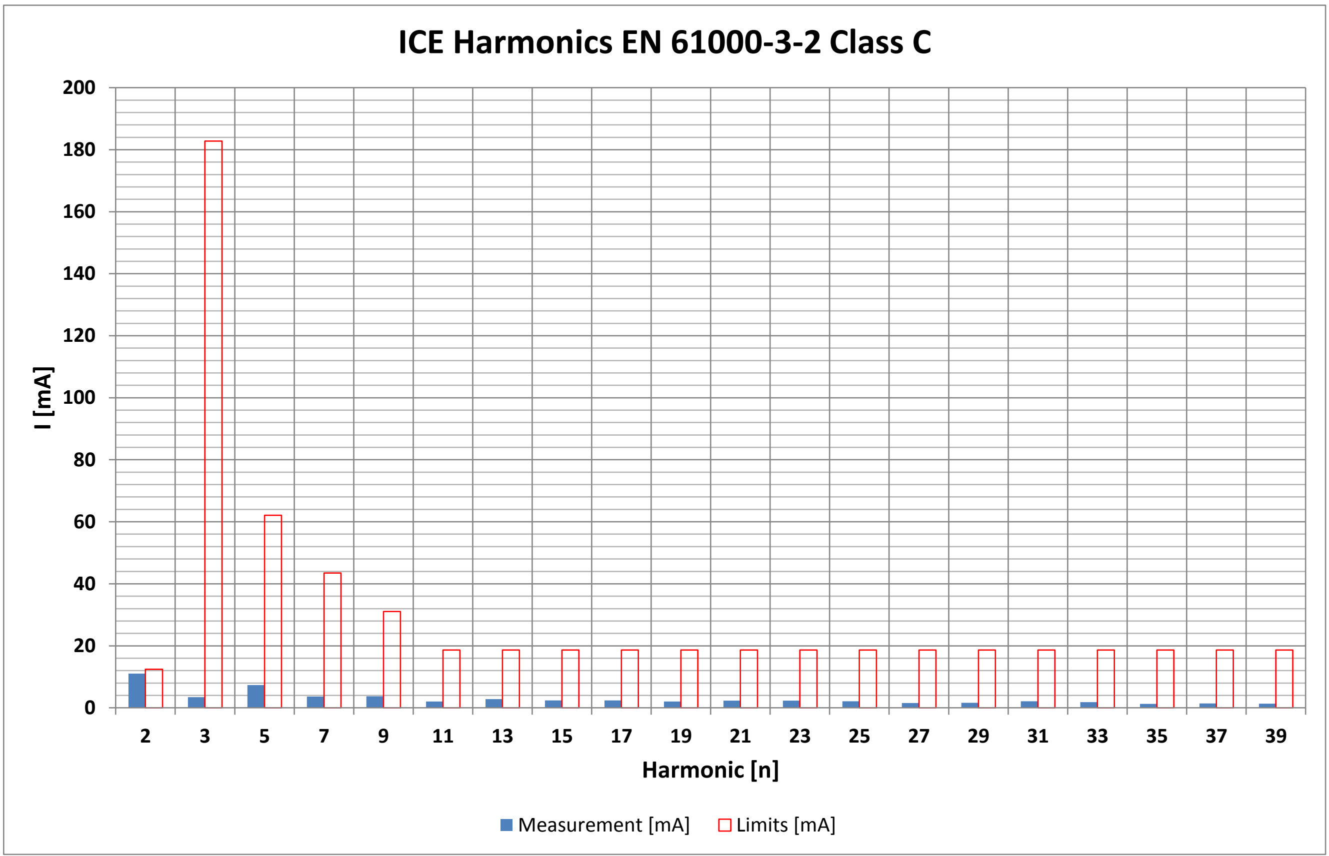


Figure 16 Harmonics according to EN 61000-3-2 Class C

5.11 EMI measurement

5.11.1 Filter design

In Figure 17 you can see the line input filter, which is optimized for EMI according to EN 55015 and meets the harmonics according to EN 61000-3-2 Class C.

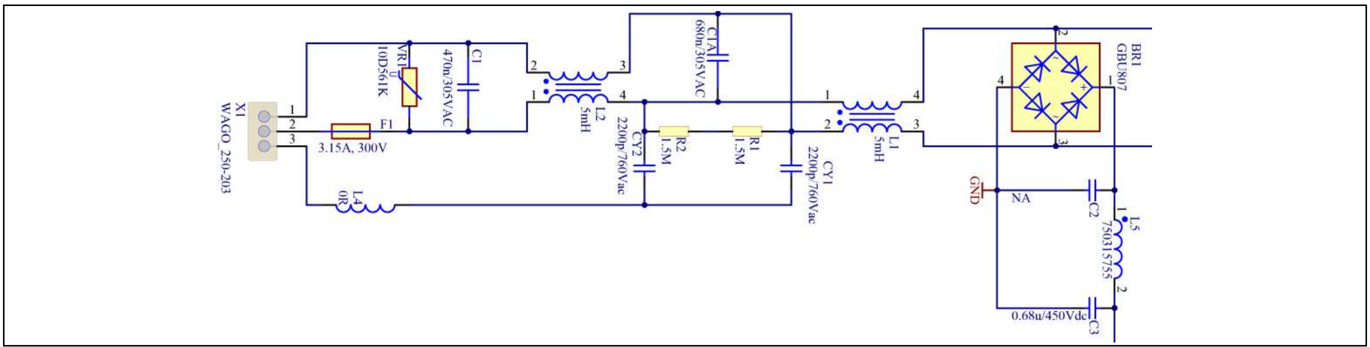


Figure 17 Line input filter

5.11.2 Conducted EMI measurement according to EN 55015

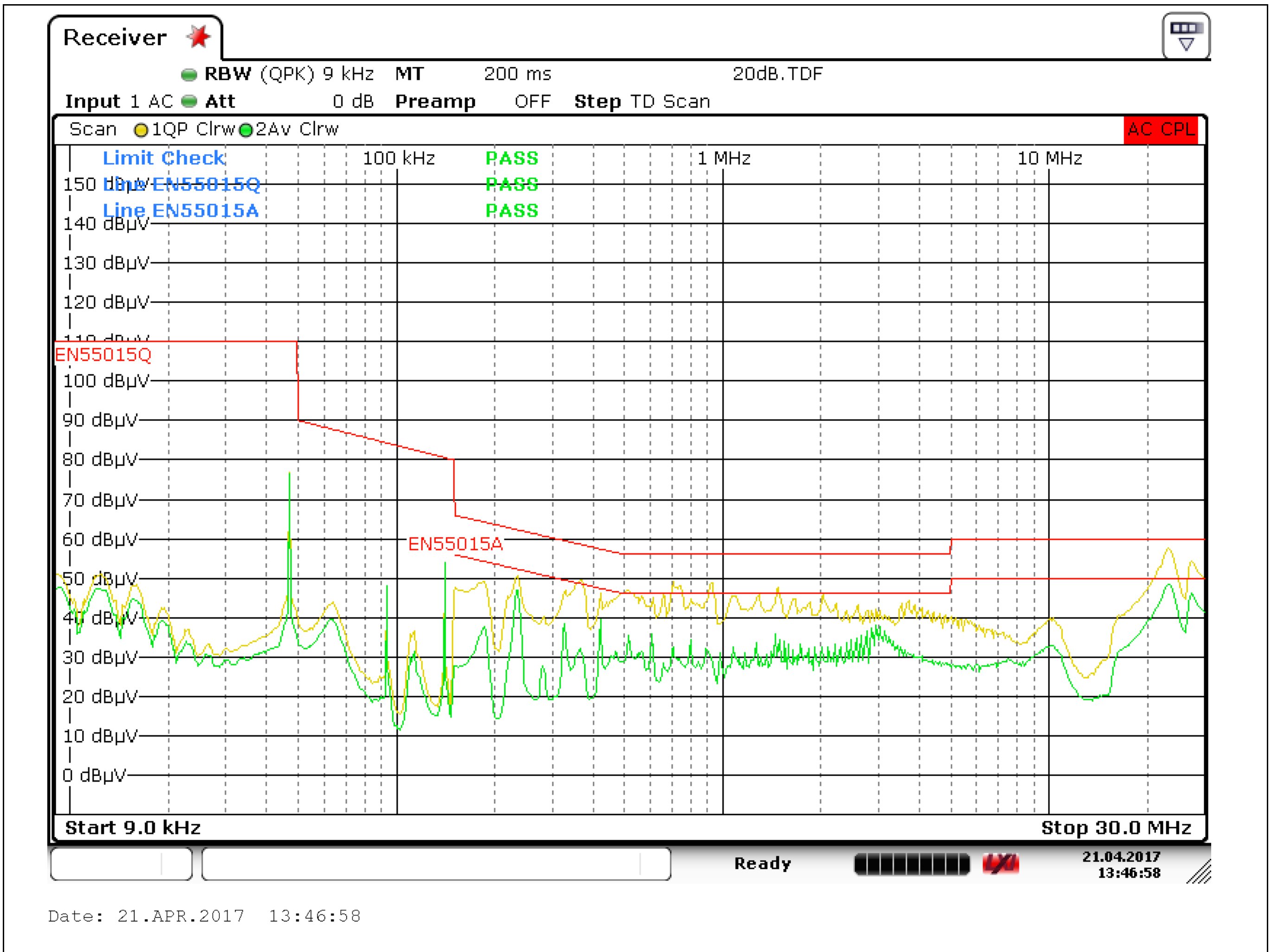


Figure 18 Conducted EMI measurement according to EN 55015

6 Magnetic power specification

6.1 CM choke specification L1 and L2

For the line input filter, standard CM choke 2 × 5.0 mH/2.5 A from Würth Elektronic, part number 744 8233 05, is used.

Electrical Properties:

Properties	Test conditions		Value	Unit	Tol.
Inductance	10 kHz/ 0.1 mA	L	2x 5.0	mH	±30%
Rated current	@ 70°C	I_R	2.5	A	max.
DC Resistance	@ 20°C	R_{DC}	2x 95	mΩ	max.
Rated voltage	50 Hz	U_R	250	V (AC)	max.
Insulation test voltage	50 Hz/ 5 mA/ 2 sec.	U_T	1500	V (AC)	

General information:

It is recommended that the temperature of the part does not exceed +125°C under worst case conditions.

- Storage Temperature: -20°C to 60°C
- Operating Temperature: -40°C to 125°C
- Temperature Rise: < 55K
- Test conditions of Electrical Properties: 20°C, 33% RH if not specified differently

WÜRTH ELEKTRONIK

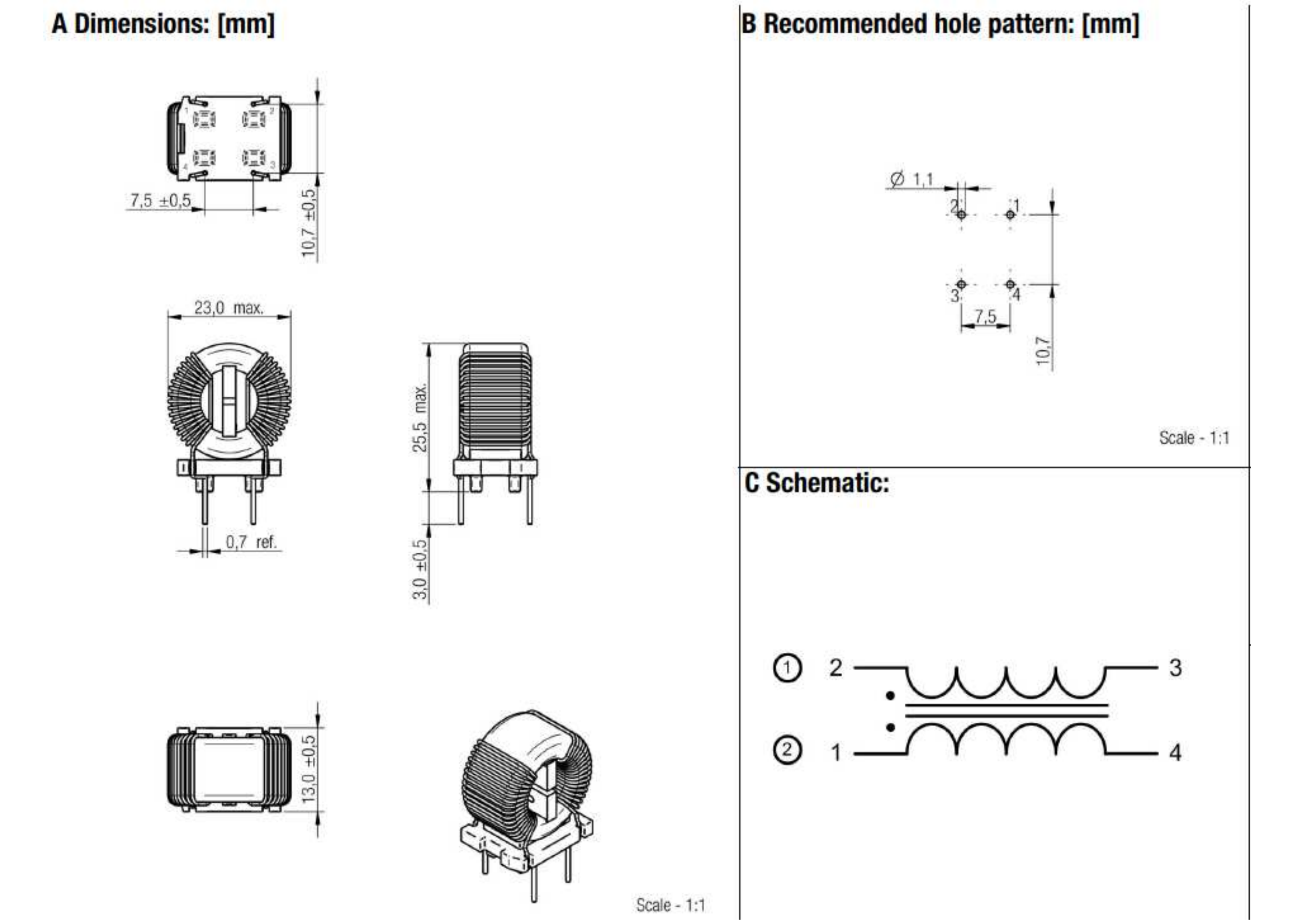


Figure 19 CM choke L1 and L2

6.2 DM choke specification L5

For the line input filter, standard DM choke 360 µH/130 Ω/180 µH typ./1000 V from Würth Elektronic, part number 750 3157 55, is used.

ELECTRICAL SPECIFICATIONS @ 25°C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	1–2	@20°C	.130 ohms max.
INDUCTANCE	1–2	40kHz, 1.0VAC, Ls	360uH±15%
INDUCTANCE	1–2	40kHz, 1.0VAC, 2.5A, Ls	180uH typ.
DIELECTRIC	1–CORE	1200VAC, 1 second	1000VAC, 1 minute

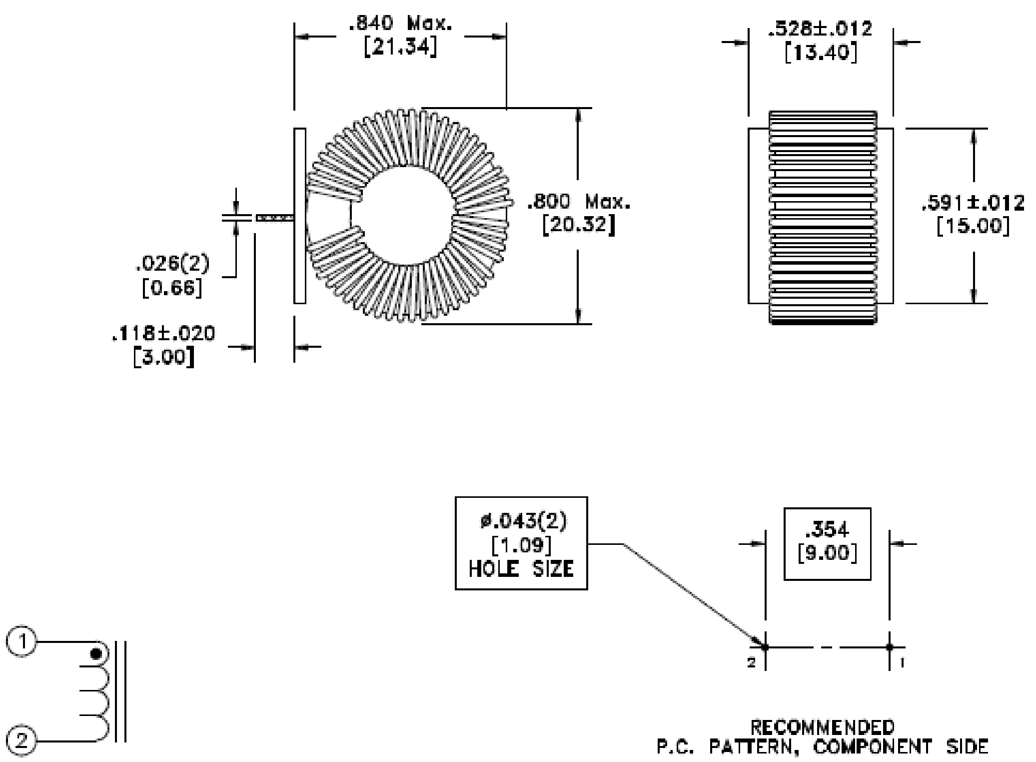


Figure 20 DM choke L5

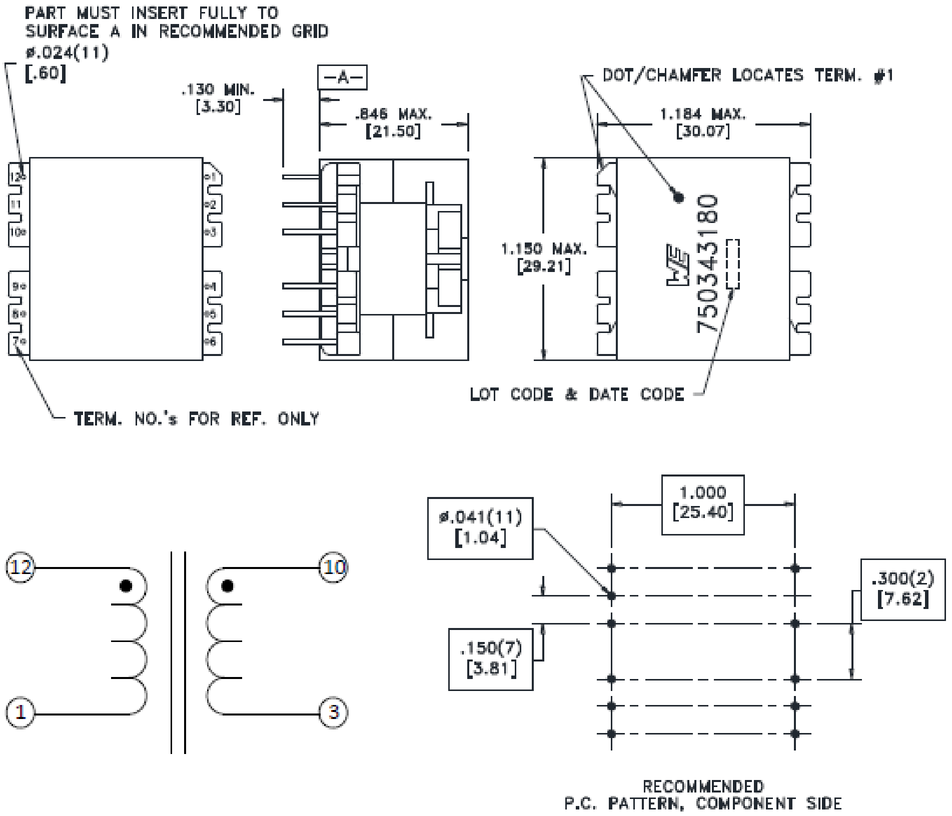
6.3 PFC choke specification L6

For the PFC stage, a standard PFC choke with 360 µH inductance from Würth Elektronic, part number 750 3431 80 Ref. 1, is used.

WÜRTH ELEKTRONIK

ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	12-1	@20°C	0.180 ohms max.
D.C. RESISTANCE	10-3	@20°C	0.250 ohms max.
INDUCTANCE	12-1	40kHz, 1V, Ls	425.00uH ±10%
INDUCTANCE	12-1	40kHz, 1V, 4.3A, Ls	360.00uH min.
DIELECTRIC	10-12	1250VAC, 1 second	1000VAC, 1 minute
DIELECTRIC	10-core	1250VAC, 1 second	1000VAC, 1 minute
DIELECTRIC	12-core	1250VAC, 1 second	1000VAC, 1 minute
TURNS RATIO		(12-1):(10-3)	9.18:1, ±2%



Apply tubing to terminal #1&12.

Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability.

DFM		Packaging Specifications Method: Tray PKG-0598	CONVENTION PLACEMENT	Tolerances unless otherwise specified: Angles: ±1° Decimals: ±.005 [.13] Fractions: ±1/64 Footprint: ± .001 [.03]	DRAWING TITLE TRANSFORMER	PART NO. 750343180
DATE						
ENG	NWA					
REV.	01			This drawing is dual dimensioned. Dimensions in brackets are in millimeters.		
DATE	2016-04-19	www.we-online.com/midcom				SPECIFICATION SHEET 1 OF 1

Figure 21 PFC choke L6

6.4 LLC resonant choke specification L7

As resonant choke for the LLC resonant tank, a choke with 160 µH inductance from Würth Elektronic, part number 750 3428 05 Rev. 4, is used.

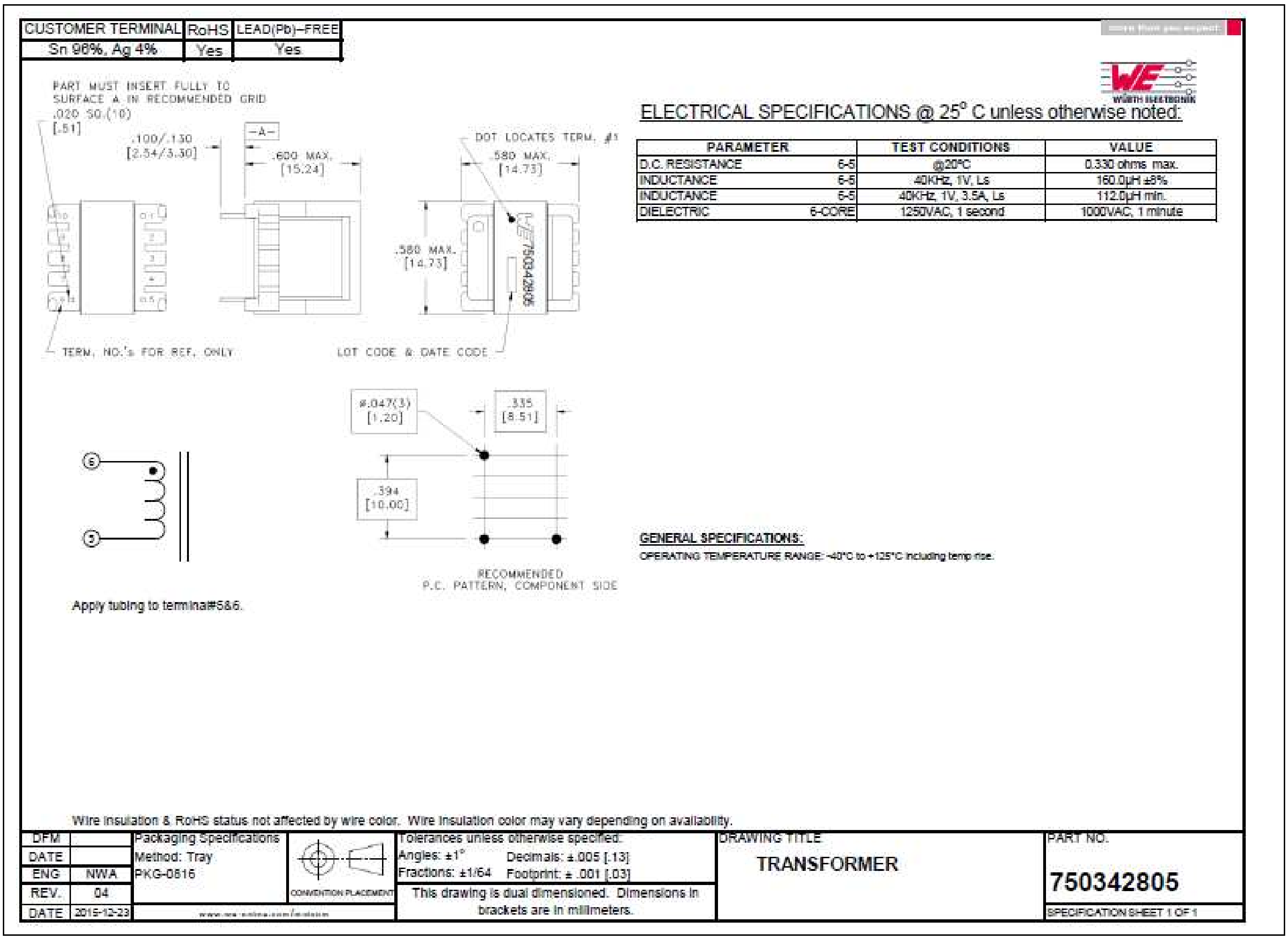
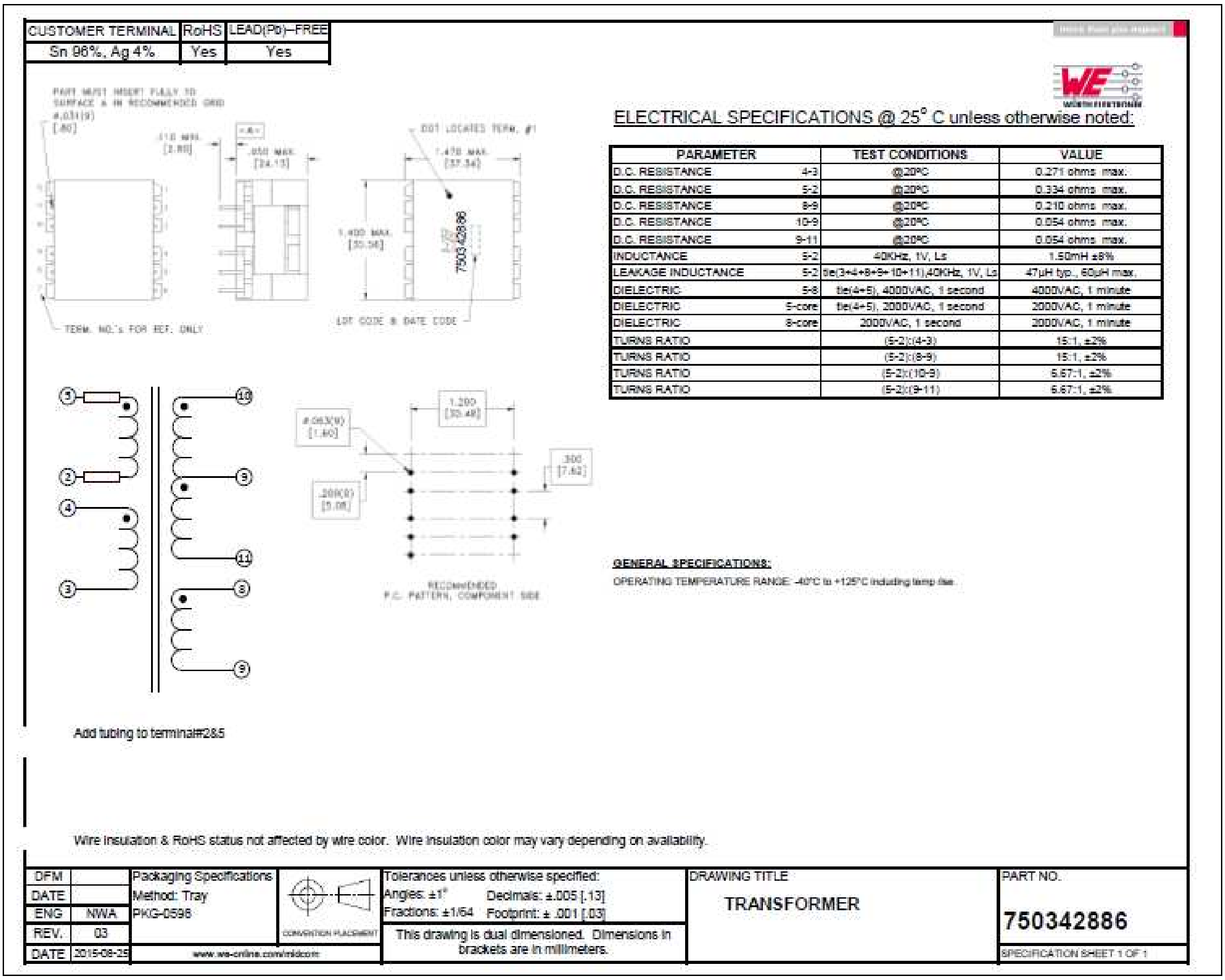


Figure 22 LLC resonant choke

6.5 LLC transformer specification TR1

As the main magnet for the LLC topology, a transformer with 1.5 mH inductance from Würth Elektronic, part number 750 3428 86, is used.



PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	4-3	@20°C	0.271 ohms max.
D.C. RESISTANCE	5-2	@20°C	0.334 ohms max.
D.C. RESISTANCE	8-9	@20°C	0.210 ohms max.
D.C. RESISTANCE	10-9	@20°C	0.054 ohms max.
D.C. RESISTANCE	9-11	@20°C	0.054 ohms max.
INDUCTANCE	5-2	40KHz, 1V, Ls	1.50mH ±8%
LEAKAGE INDUCTANCE	5-2	tie(3+4+8+9+10+11),40KHz, 1V, Ls	47µH typ., 60µH max.
DIELECTRIC	5-8	tie(4+5), 4000VAC, 1 second	4000VAC, 1 minute
DIELECTRIC	5-core	tie(4+5), 2000VAC, 1 second	2000VAC, 1 minute
DIELECTRIC	8-core	2000VAC, 1 second	2000VAC, 1 minute
TURNS RATIO		(5-2):(4-3)	15:1, ±2%
TURNS RATIO		(5-2):(8-9)	15:1, ±2%
TURNS RATIO		(5-2):(10-9)	5.67:1, ±2%
TURNS RATIO		(5-2):(9-11)	5.67:1, ±2%

Figure 23 LLC transformer

7 Board layout

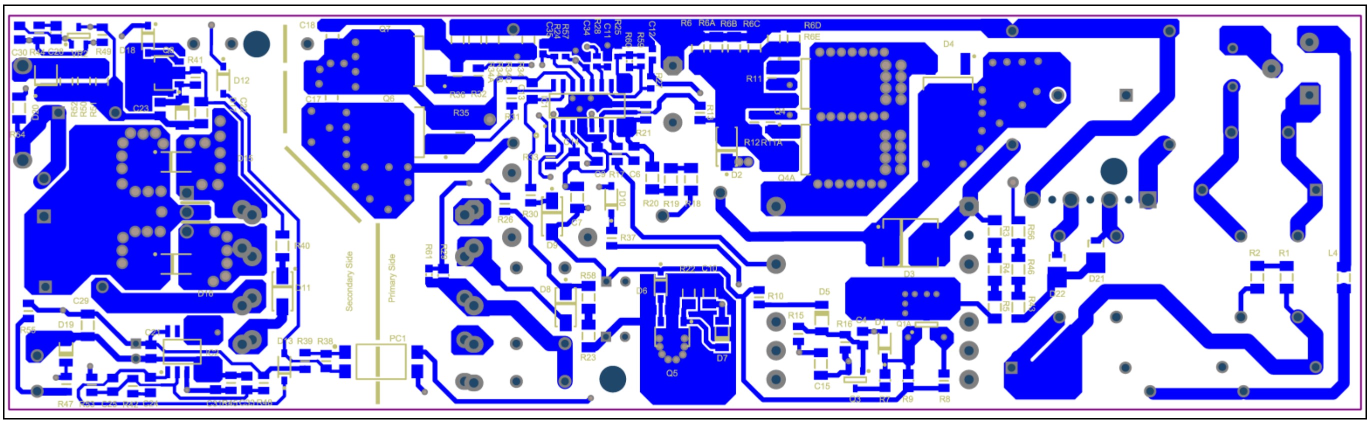


Figure 24 Layout (bottom view)

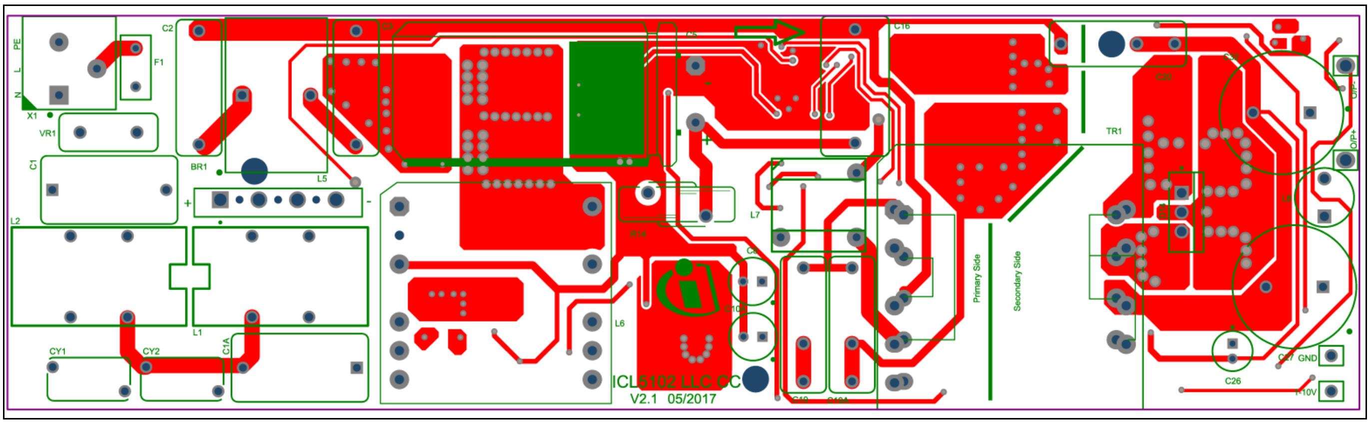


Figure 25 Assembly print (top view)

8 BOM

Part	Value	Package	Supplier	Order/Part Number
1-10V	Kabel, Spezifikation AWG24, 200mm, abisoliert 10mm, verzinnt, rot		Manufacturer	
BR1	GBU807, 8A/1kV	SIP-4Pin	Mouser	821-GBU807
C1	MKP 470n, 305Vac/pitch15	FCAP-18-9-15	Farnell	2291758
C1A	MKP 680n, 305Vac/pitch15	FCAP-18-11-15	Farnell	1781892
C3	MKP 0.68uF/450Vdc	FCAP-18-6-15	Farnell	2469037
C4	100nF/50V/10%/X7R	C0805	Farnell	2354124
C5	56uF/500V/20% Pitch 7.5	ECAP-35.5-18-7.5	Mouser	647-UCY2H560MHD
C6	2.2n/50V/10%/X7R	C0805	Farnell	1414681
C7	1uF/50V/10%/X7R	C1206	Mouser	810-C3216X7R1H105K
C8	220uF/25V/20%	ECAP-11-6.3-2.5	Farnell	2465679
C9	100nF/50V/10%/X7R	C0805	Farnell	2354124
C10	1uF/50V/10%/X7R	C1206	Mouser	810-C3216X7R1H105K
C12	2.2nF/25V/5%/C0G	C0603	Farnell	1457726
C13	100nF/50V/10%/X7R	C0805	Farnell	2354124
C15	220nF/25V/10%/X7R	C1206	Farnell	1856628
C16	0.22uF/630Vdc/5%	FCAP-18.5-9-15	Farnell	1744819
C19	6.8nF/600Vac/1600Vdc/5%	FCAP-18-5-15	RS	882-9225
C19A	4.7nF/600Vac/1600Vdc/5%	FCAP-13-4-10	Farnell	2468983
C20	2200pF, Class X1, 760 VAC / Class Y1, 500 VAC	FCAP-18-6-15/10	Farnell	1612164
C21	100nF/50V/10%/X7R	C0805	Farnell	2354124
C22	1uF/50V/10%/X7R	C1206	Mouser	810-C3216X7R1H105K
C23	100nF/50V/10%/X7R	C0805	Farnell	2354124
C24	68nF/50V/10%/X7R	C0805	Farnell	2070495
C26	33uF/35V/20% 5x11	ECAP-11-5-2	Farnell	2465672
C27	220uF/100V/20%	ECAP-25-16-7.5	Farnell	1144643
C28	56nF/50V/10%/X7R	C0805	Farnell	2522484
C29	100nF/50V/5%/X7R	C1206	Farnell	1650885
C30	100pF/50V/5%	C0805	Digikey	490-8031-1-ND
C31	330nF/50V/10%/X7R	C0805	Farnell	2320844
C32	220uF/100V/20%	ECAP-25-16-7.5	Farnell	1144643
C33	1nF/50Vdc/5%/C0G/NP0	C0805	Farnell	2280963
C34	220nF/25V/10%/X7R	C1206	Farnell	1856628
C35	100nF/25V/10%/X7R	C0603	Farnell	2478242
C36	2200pF/400Vac/20%	FCAP-8.4-4.3-6.4	Farnell	2309031
C37	10nF/50V/10%/X7R	C0805	Farnell	2407341
CY1	2200pF Class X1, 760 VAC / Class Y1, 500 VAC	FCAP-18-6-15/10	Farnell	1612164
CY2	2200pF Class X1, 760 VAC / Class Y1, 500 VAC	FCAP-18-6-15/10	Farnell	1612164
D2	US1M, 1.0A/1000V	DO-214AC	Farnell	1562250
D4	STTH5L06, 600V/ 5A/ TO252	TO-252	Farnell	2344054
D5	TZMB18, 18V	SOD-80	Mouser	78-TZMB18
D6	1N4148W	SOD-123	Farnell	1776392
D7	TZMB18, 18V	SOD-80	Mouser	78-TZMB18
D8	S100, 1.0A/100V	DO-214AC	Farnell	1611177
D9	US1M, 1.0A/1000V	DO-214AC	Farnell	1562250
D10	1N4148W	SOD-123	Farnell	1776392
D11	US1M, 1.0A/1000V	DO-214AC	Farnell	1562250
D12	1N4148W	SOD-123	Farnell	1776392
D13	1N4148W	SOD-123	Farnell	1776392
D14	BYV32-200G	TO-220AB	Farnell	2317407
D17	BZT55B12, 12V	SOD-80	Mouser	78-BZT55B12
D18	1N4148W	SOD-123	Farnell	1776392
D20	SS12HE3, 20V	DO-214AC	Mouser	78-SS12HE3_A/H
D21	S1PM, 1kV,1A	DO-220AA	Farnell	1812469
D22	S1PM, 1kV,1A	DO-220AA	Farnell	1812469
F1	Fuse 3.15A, 300V	Radial Lead Fuse	Farnell	1826515
Glue Pad	Glue Pad for C5 cut W:9.5mm L: 30mm, Thickness: 1.6mm		Mouser	517-4016-1/2
GND	Kabel, Spezifikation AWG24, 200mm, abisoliert 10mm, verzinnt, schwarz		Manufacturer	
Heat shrink	Heat shrink tube for C5 L:40mm		Farnell	
IC1	ICL5102	SO16	Infineon	ICL5102
IC2	LM358ADR	SO08	Farnell	7527007
L1	5mH	WE-CMB, Type M	Wuerth	744823305
L2	5mH	WE-CMB, Type M	Wuerth	744823305
L4	0Ω	R1206	Mouser	603-RC1206FR-070RL
L5	180uH, 2pin 9mm	R12	Wuerth	750315755
L6	750343180	PQ26	Wuerth	750343180 rev01
L7	750342805	EE13-20151221	Wuerth	750342805 rev4
L8	4.7uH	WE-TI 8095	Farnell	1635795
O/P+	Kabel, Spezifikation AWG18, 200mm, abisoliert 10mm, verzinnt, violet		Manufacturer	
O/P-	Kabel, Spezifikation AWG18, 200mm, abisoliert 10mm, verzinnt, grau		Manufacturer	
PC1	SFH617A-3X007T, 5300 VRMS, 110 °C Rated	SMD-4	Mouser	782-SFH617A-3X007T
Q1A	BSS126, VDS 600V, IDSS min 0.007A	SOT23	Farnell	2212899
Q3	MMBT3904	TO-236AB	Farnell	1757936
Q4	IPD60R400CE, P6 650V, DPAK	TO-252	Infineon	IPD60R400CE
Q4A	IPD60R400CE, P6 650V, DPAK	TO-252	Infineon	IPD60R400CE
Q5	BCX56-16	SOT89	Farnell	1081281
Q6	IPD60R400CE, P6 650V, DPAK	TO-252	Infineon	IPD60R400CE
Q7	IPD60R400CE, P6 650V, DPAK	TO-252	Infineon	IPD60R400CE
Q8	BCX56-16, 80V, 500mW, 1A	SOT89	Farnell	1081281
R1	1.5MΩ/200V/1%	R1206	Farnell	9237011
R2	1.5MΩ/200V/1%	R1206	Farnell	9237011
R3	2kΩ/200V/1%	R1206	Mouser	603-RC1206FR-072KL
R4	2kΩ/200V/1%	R1206	Mouser	603-RC1206FR-072KL