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

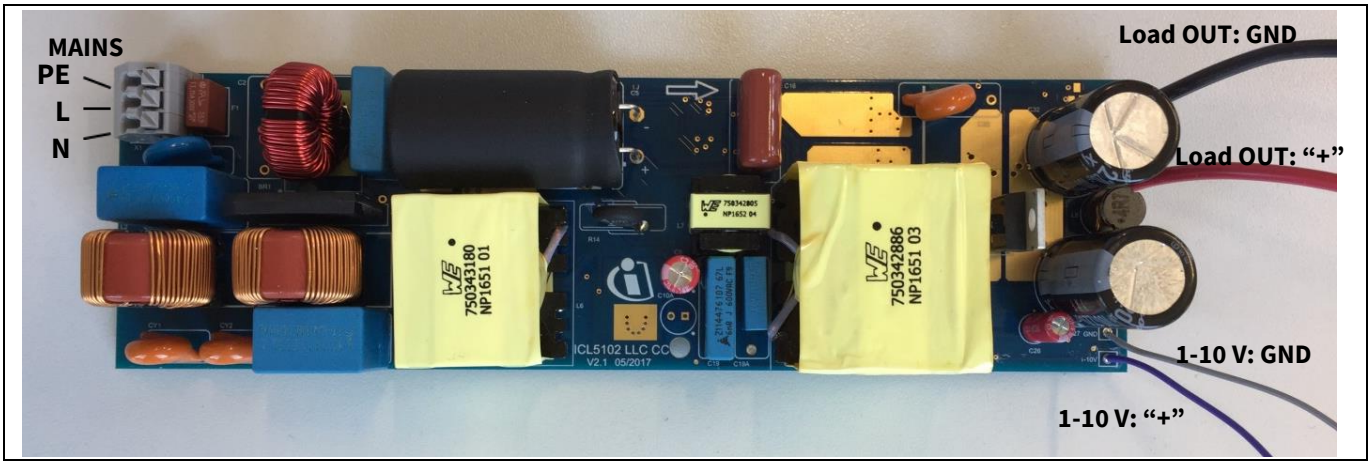


Figure 1 Top view of LED driver connection

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.

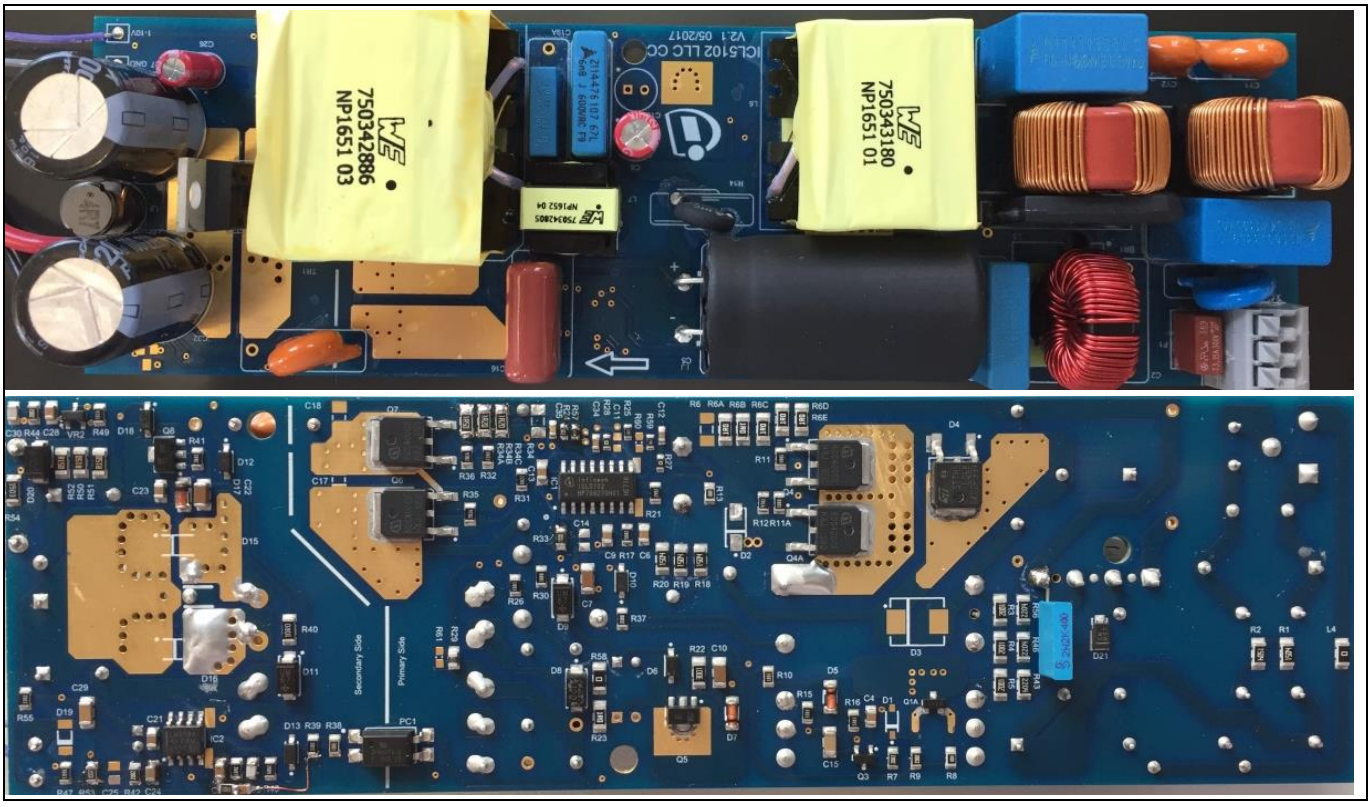


Figure 2 PFC and LLC dimmable constant current reference board

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

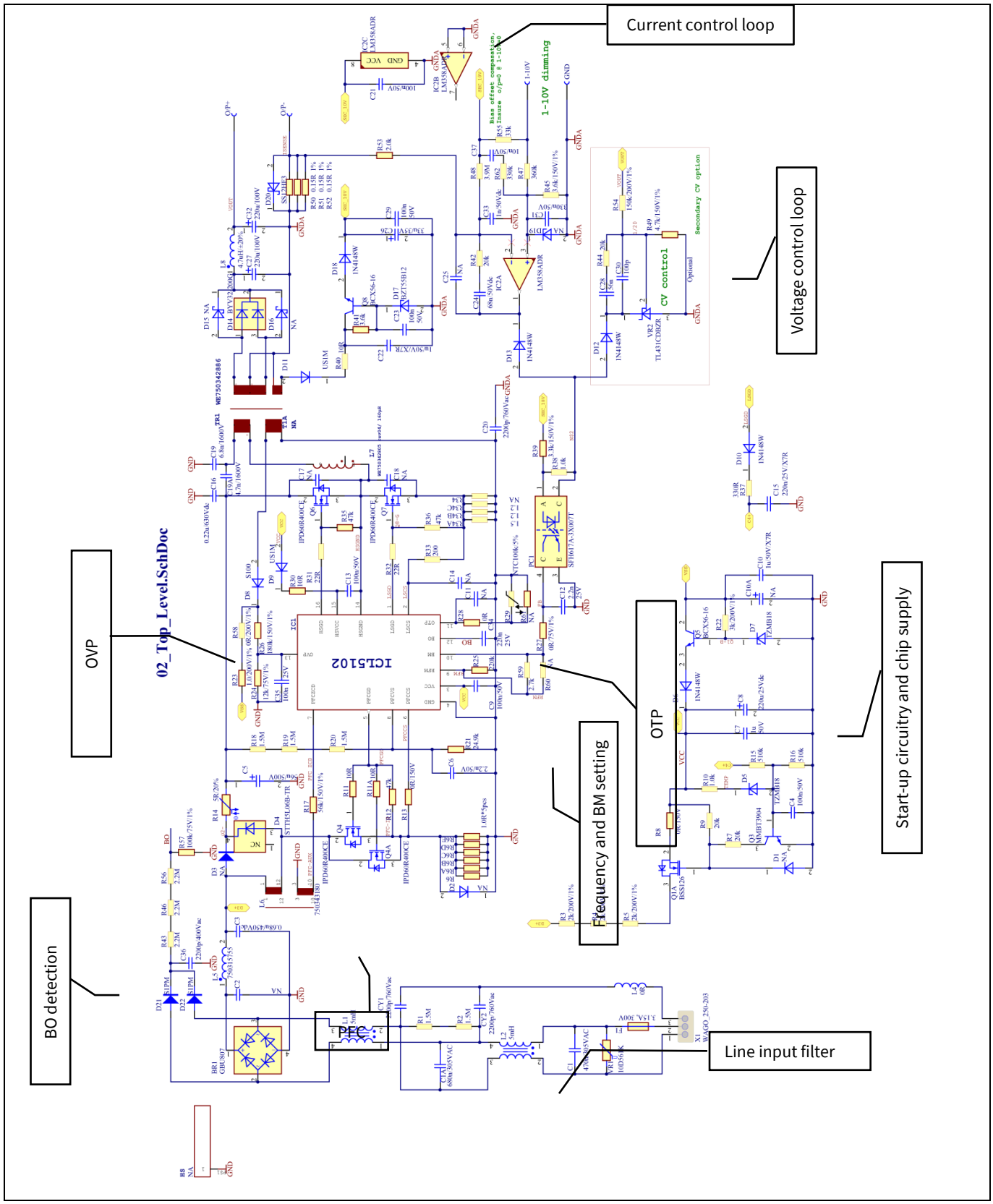


Figure 3 Schematic

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.

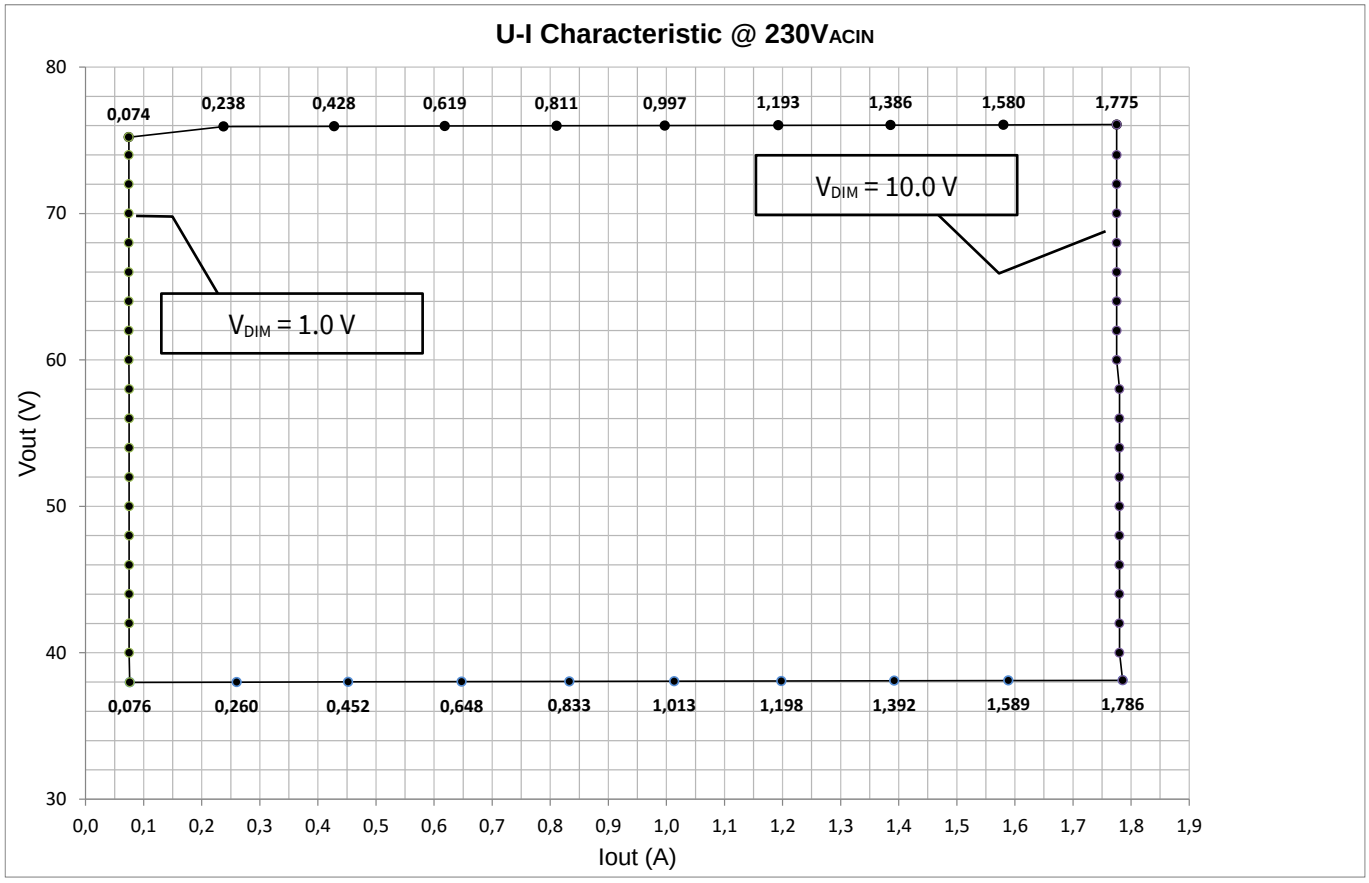


Figure 4 Constant current operating area

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.

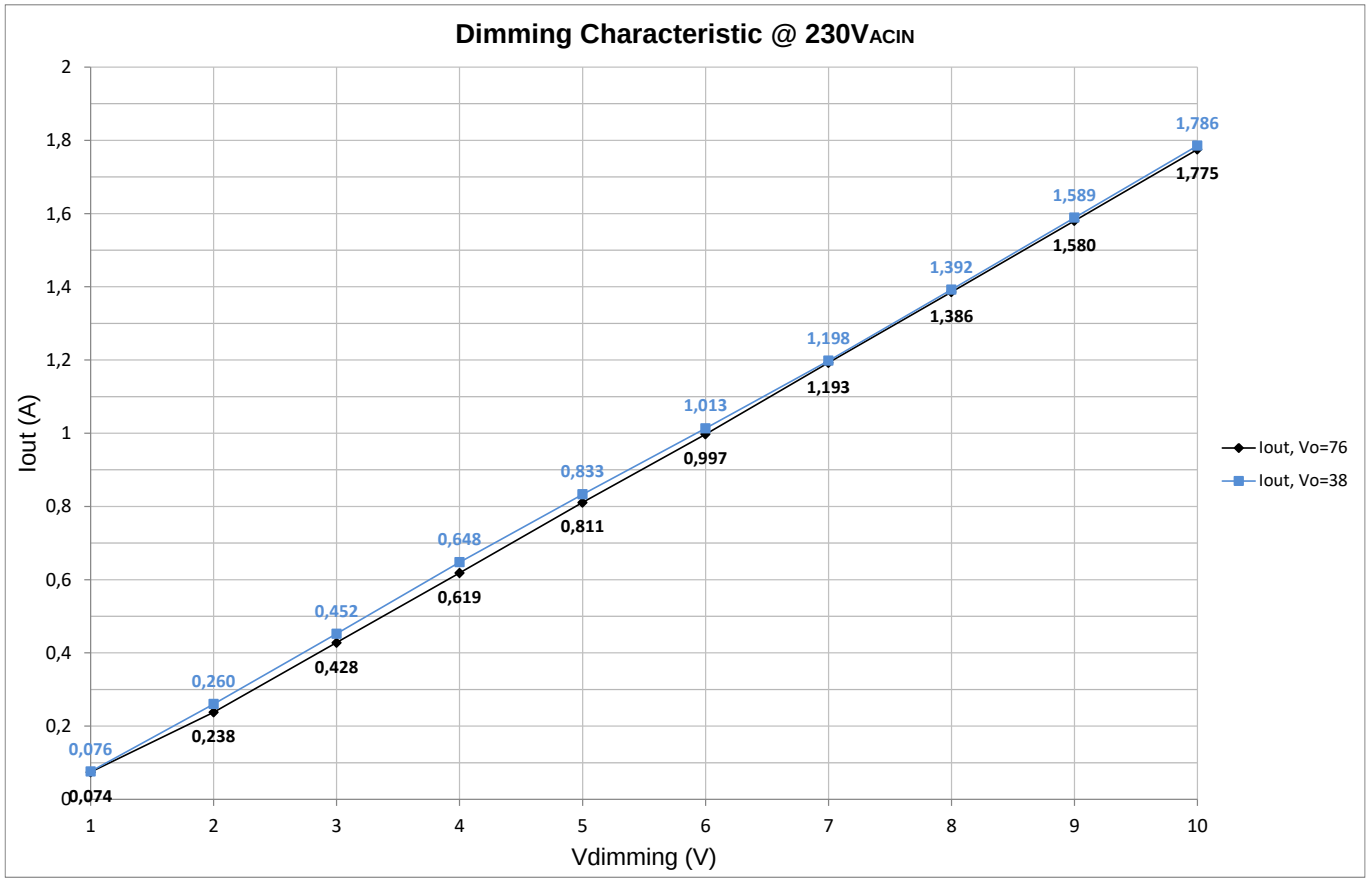


Figure 5 Dimming characteristics

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.

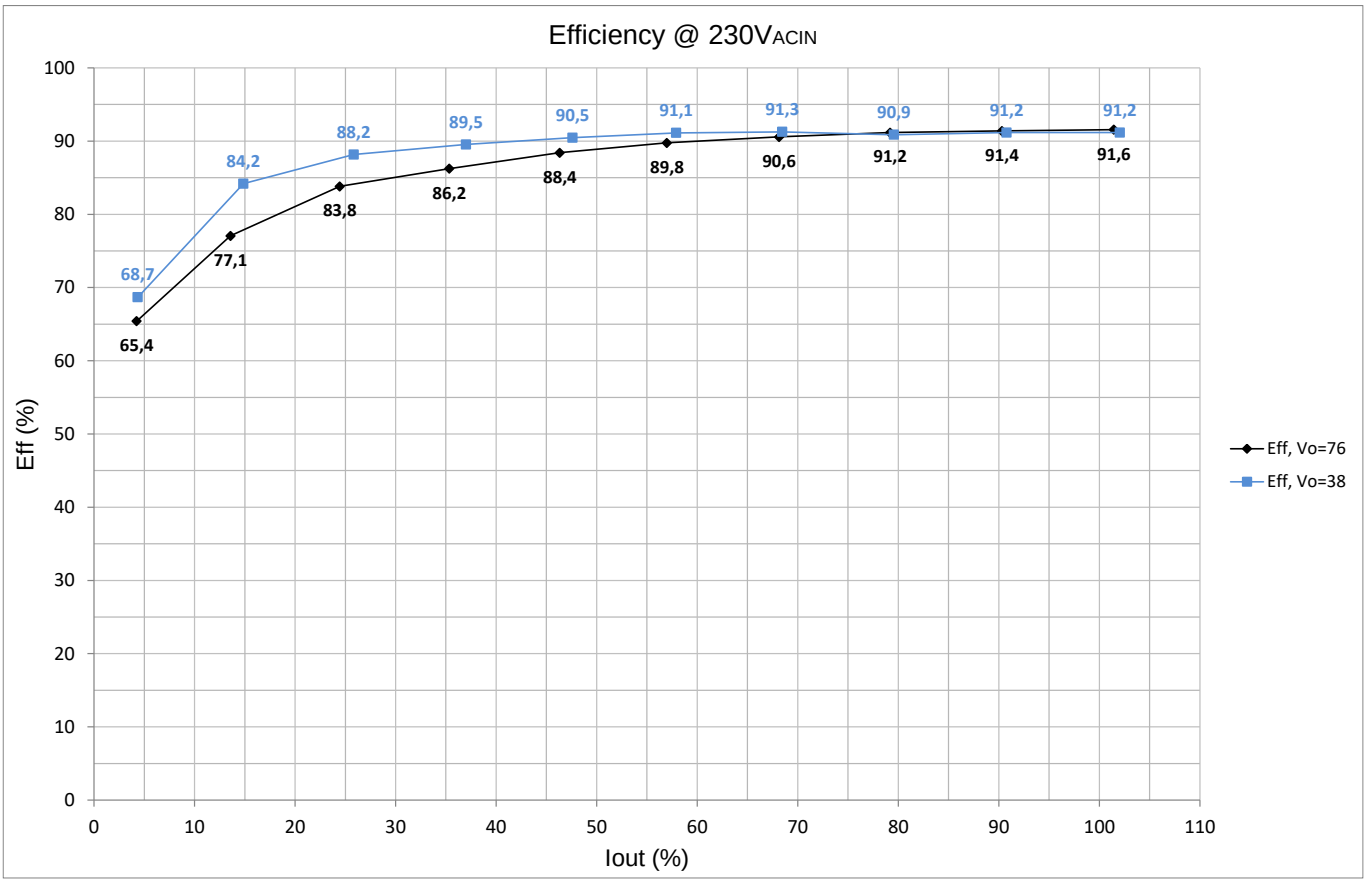


Figure 6 Efficiency at V AC_{IN} = 230 V AC_{IN}

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.

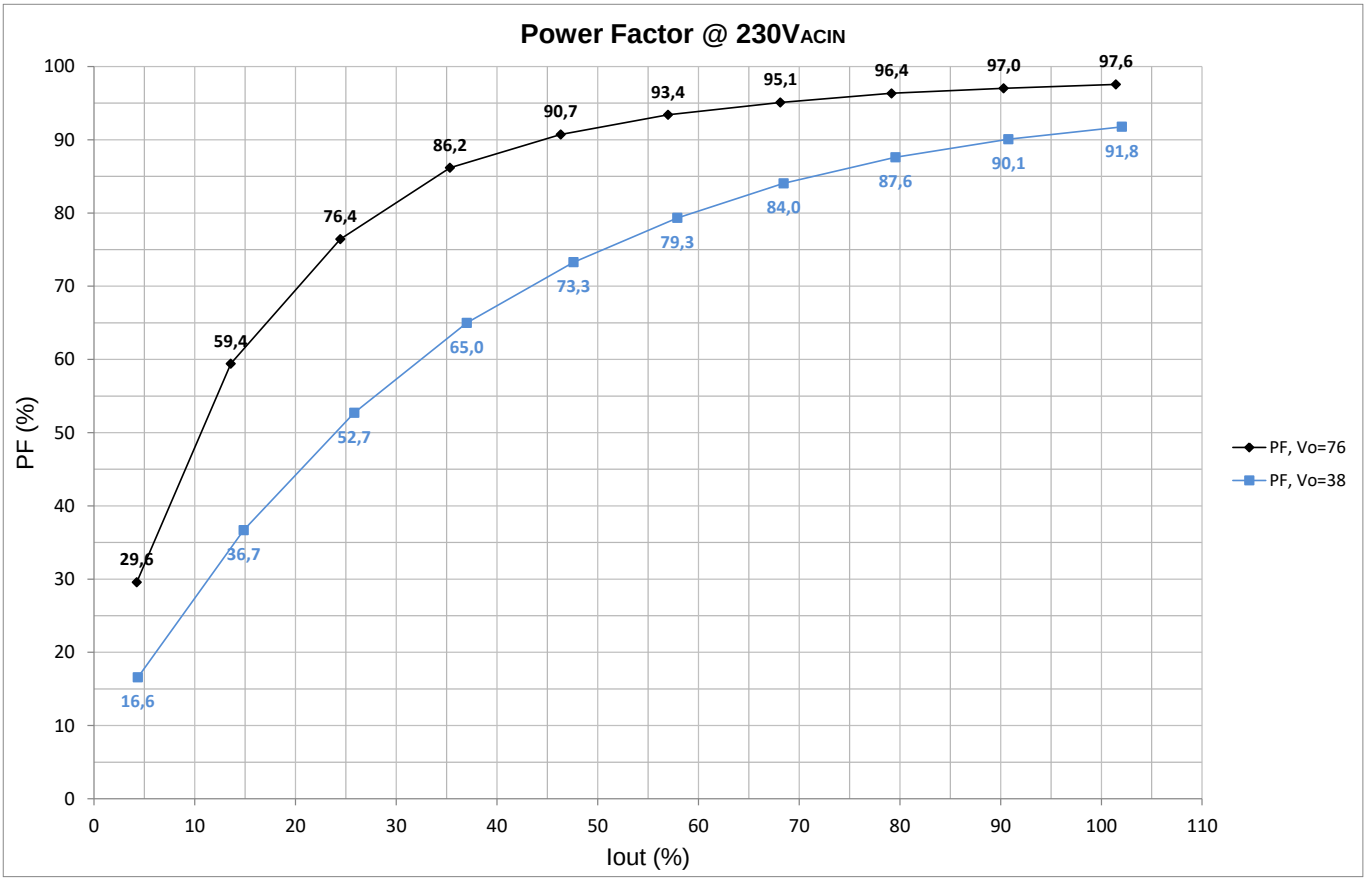


Figure 7 PF at 230 V AC_{IN}

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.

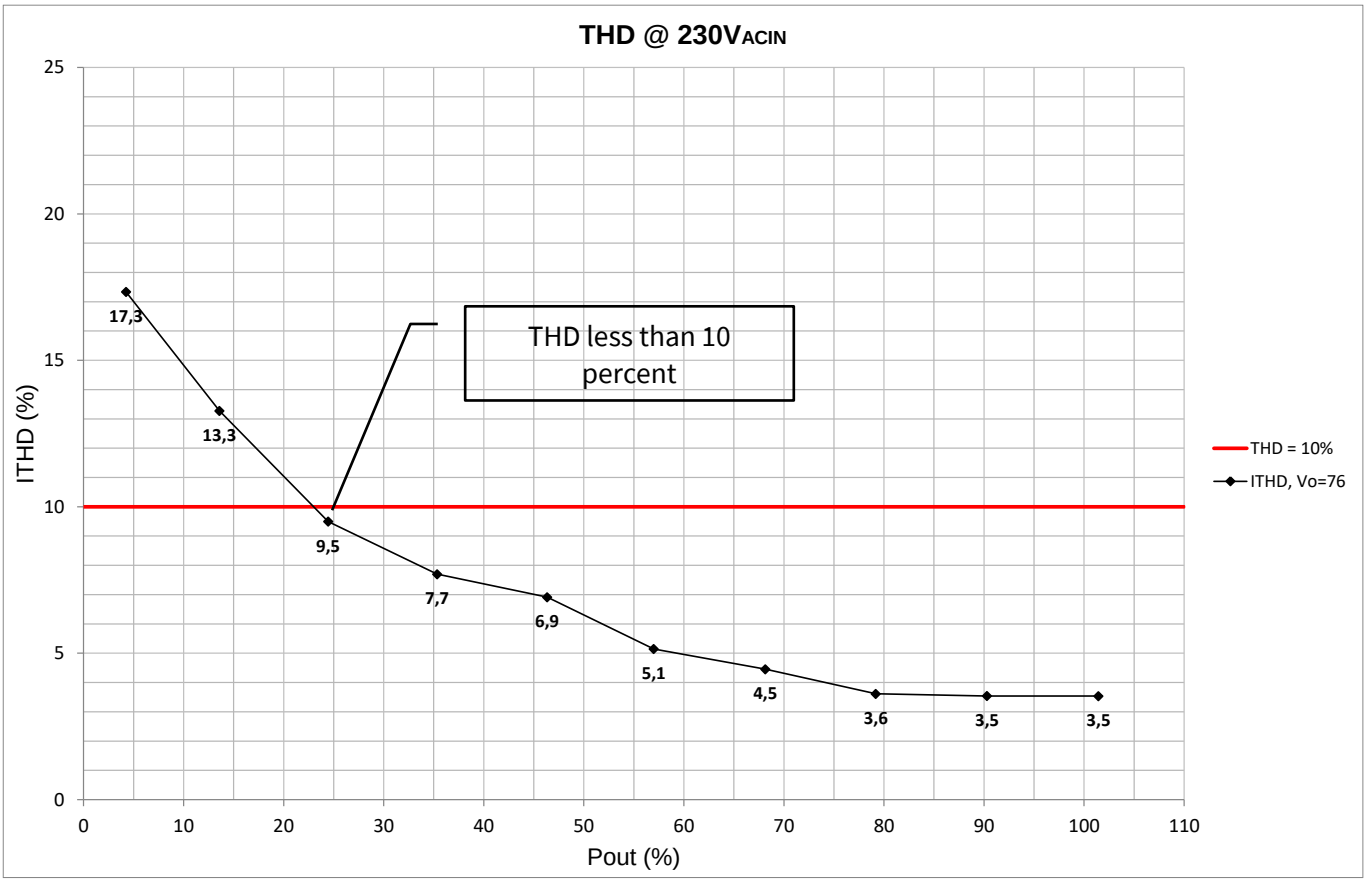


Figure 8 THD at 230 V AC_{IN}

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

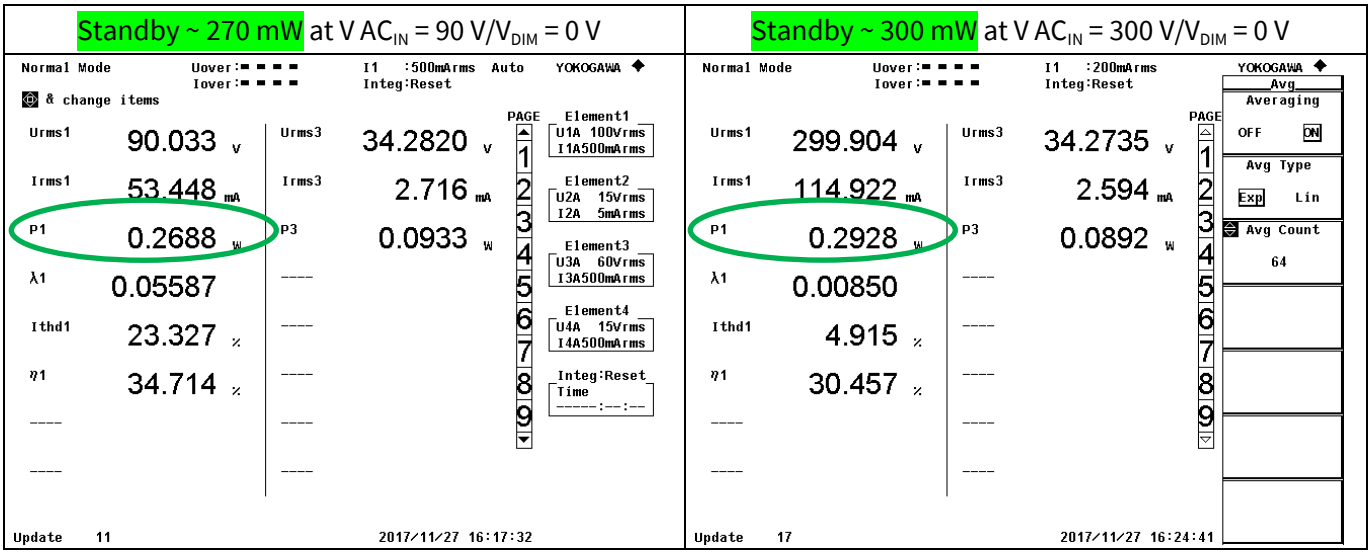


Figure 10 Standby mode

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.

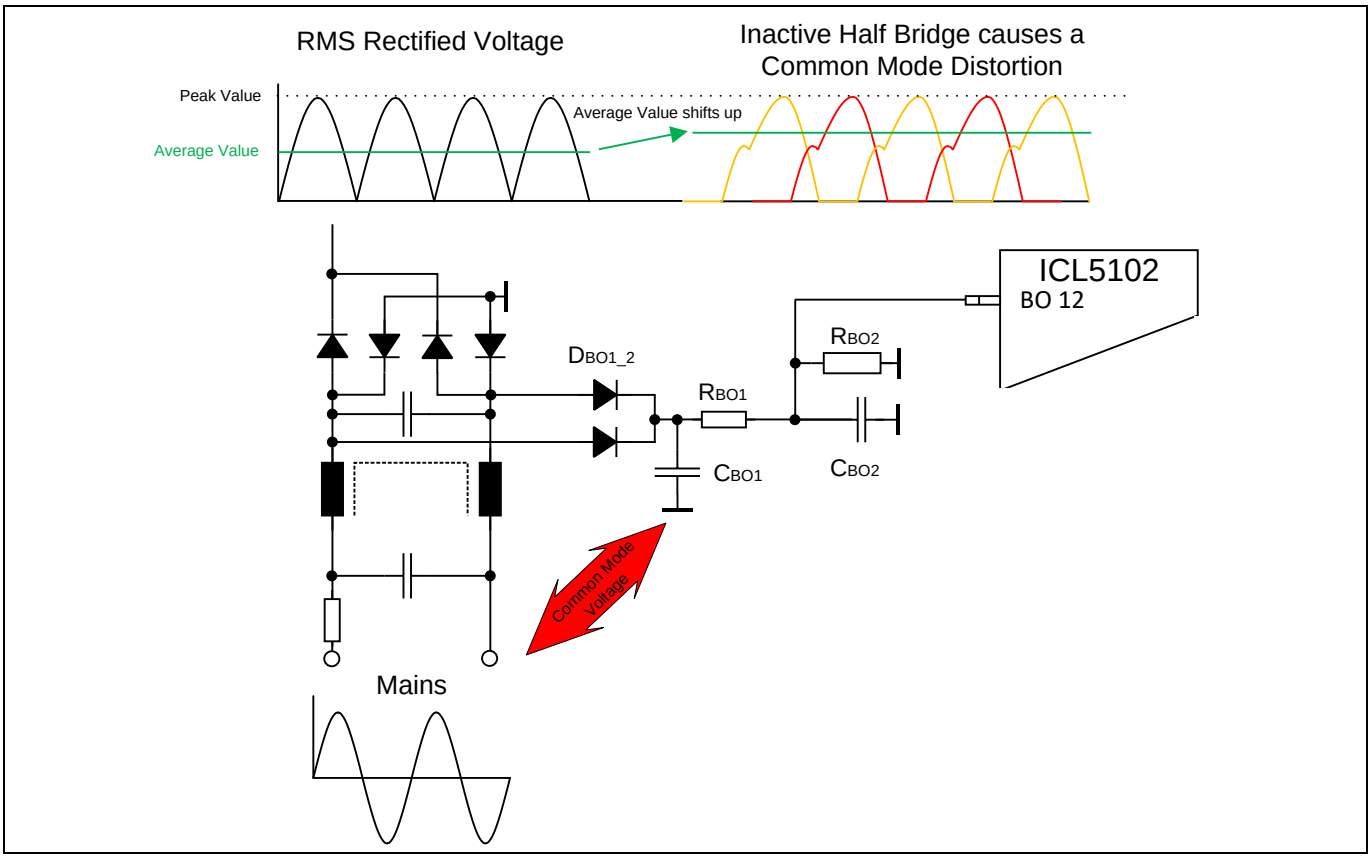


Figure 11 Impact of conducting vs non-conducting (distortion)

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.

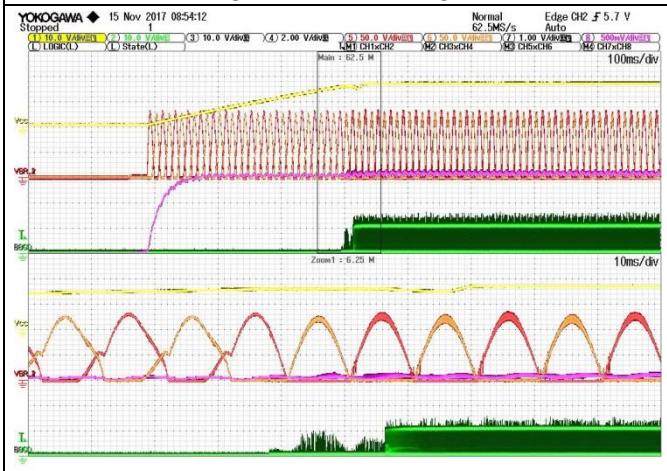
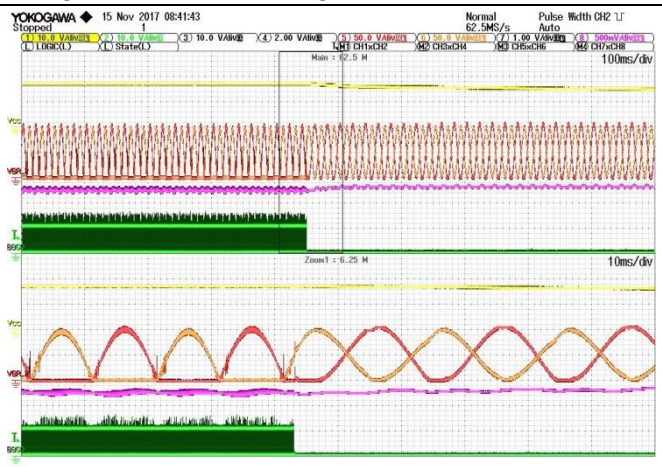
Start-up:	**RUN Mode:**
Change from CM voltage (BR not conducting) supply OFF, into DM voltage (BR conducting) supply ON	Change from DM voltage (BR conducting) into CM voltage (BR not conducting)
	

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.

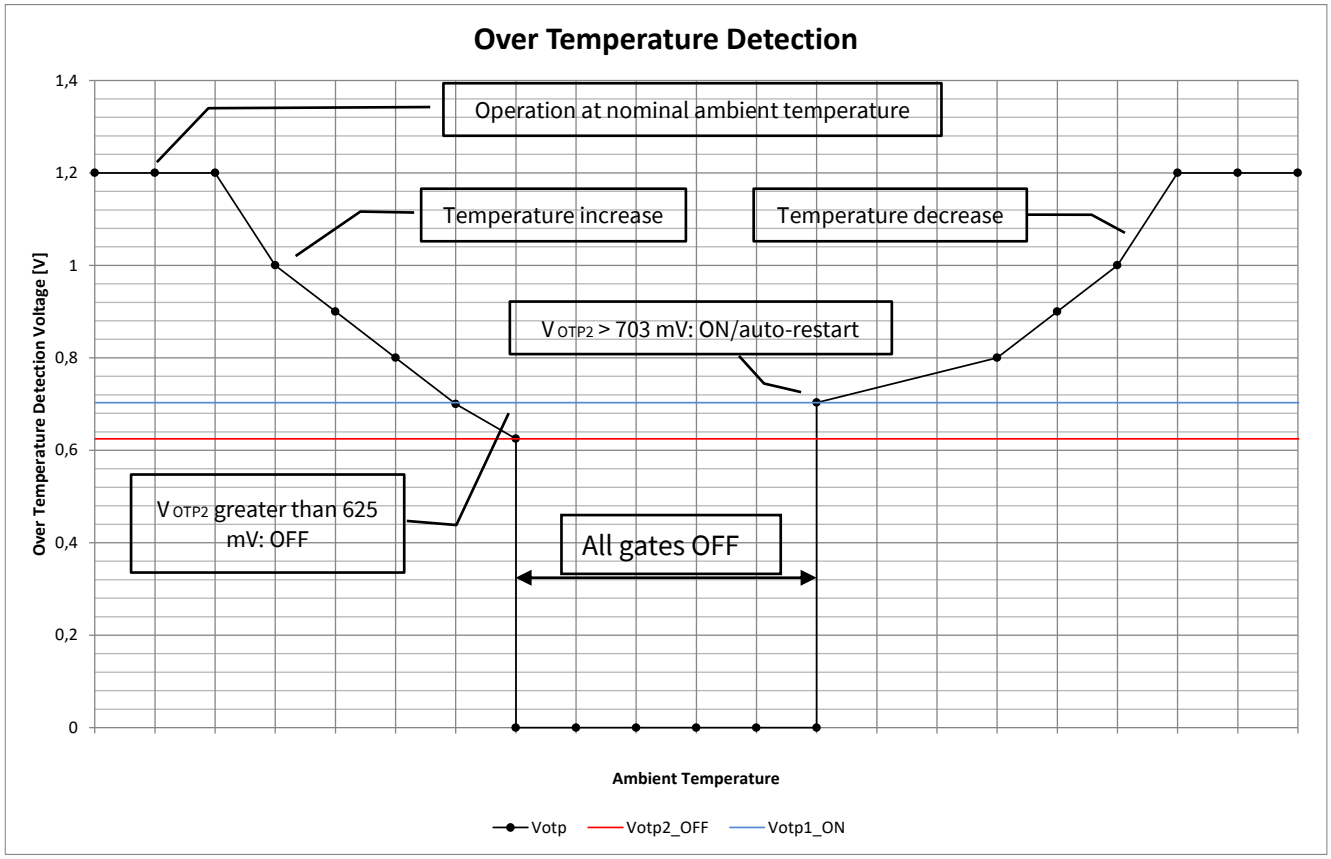


Figure 13 OTP

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.

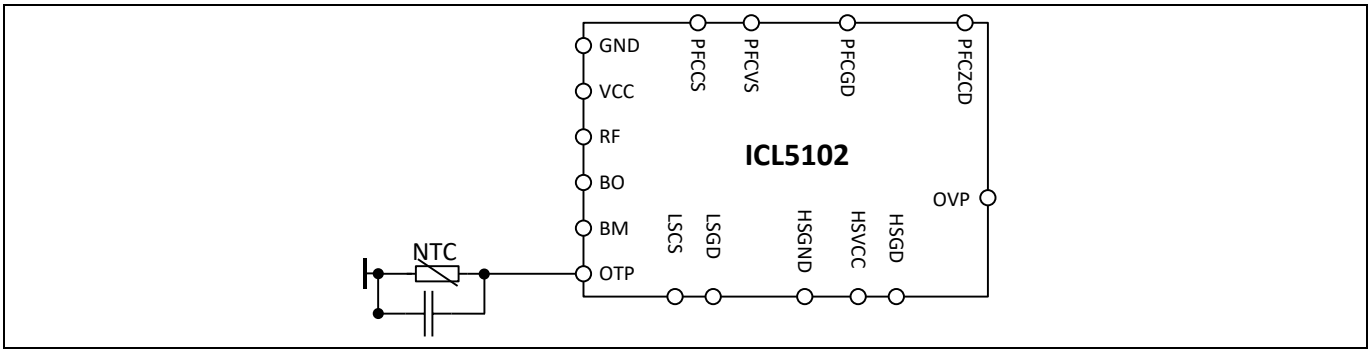


Figure 14 OTP set-up

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.

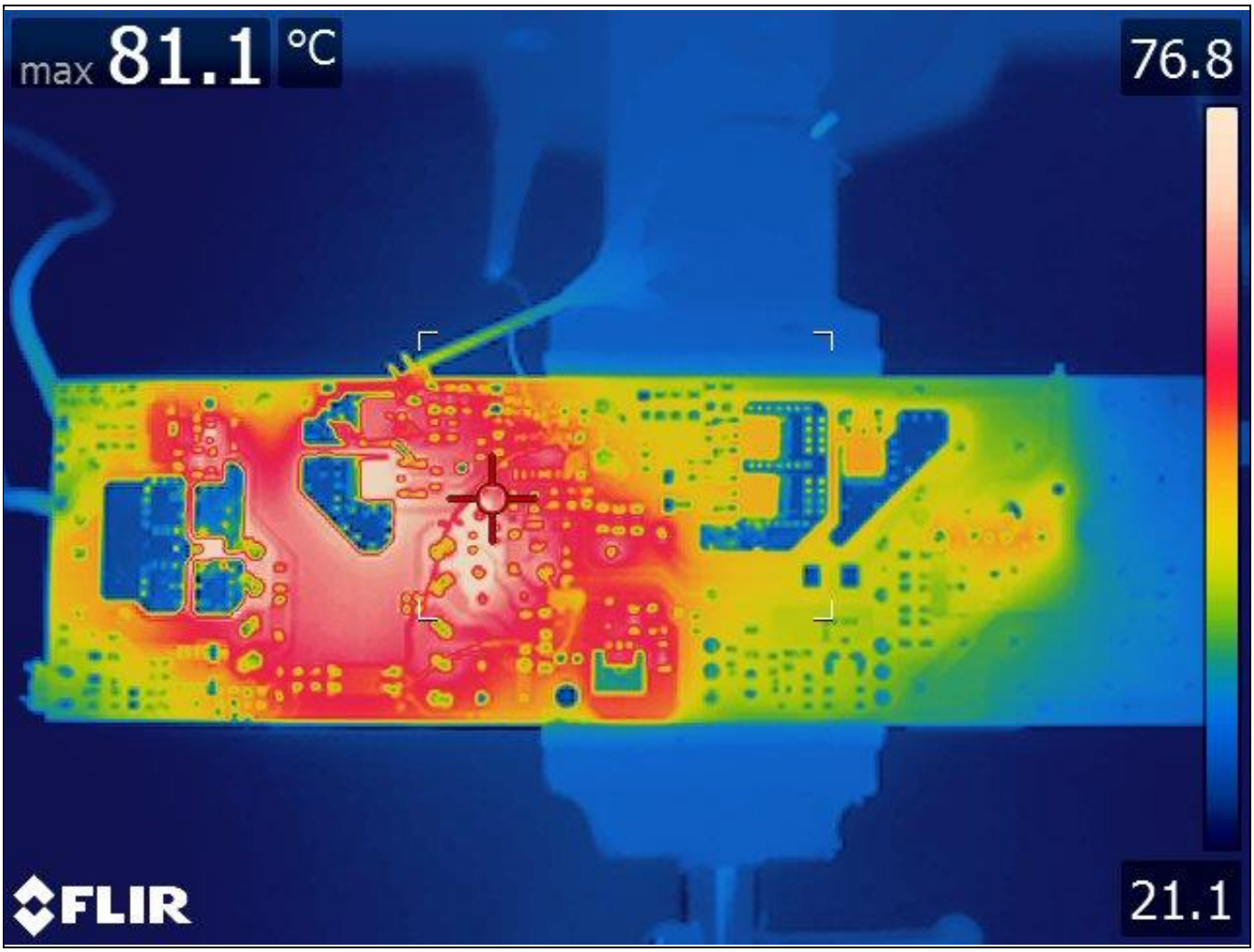


Figure 15 Hot spot on board

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

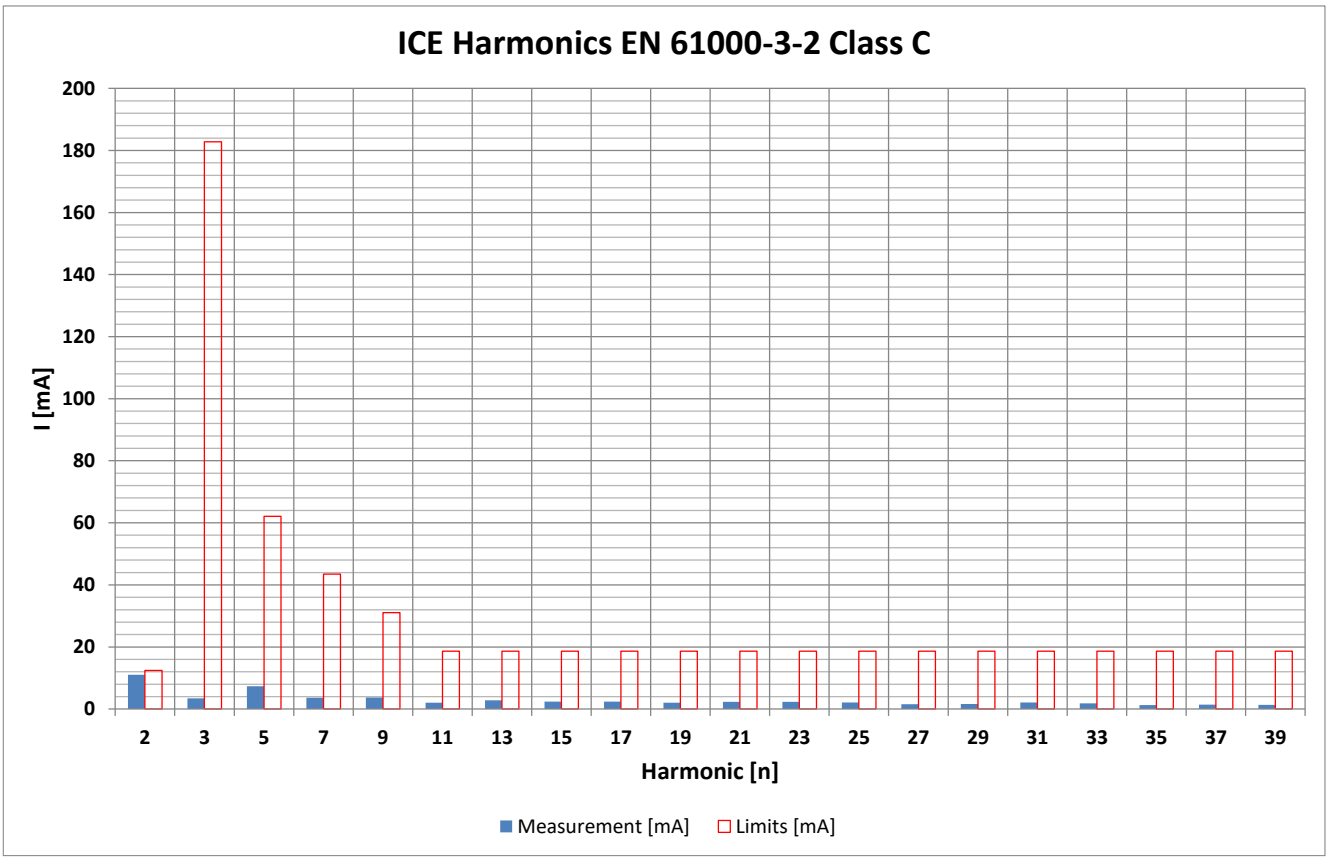


Figure 16 Harmonics according to EN 61000-3-2 Class C

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.

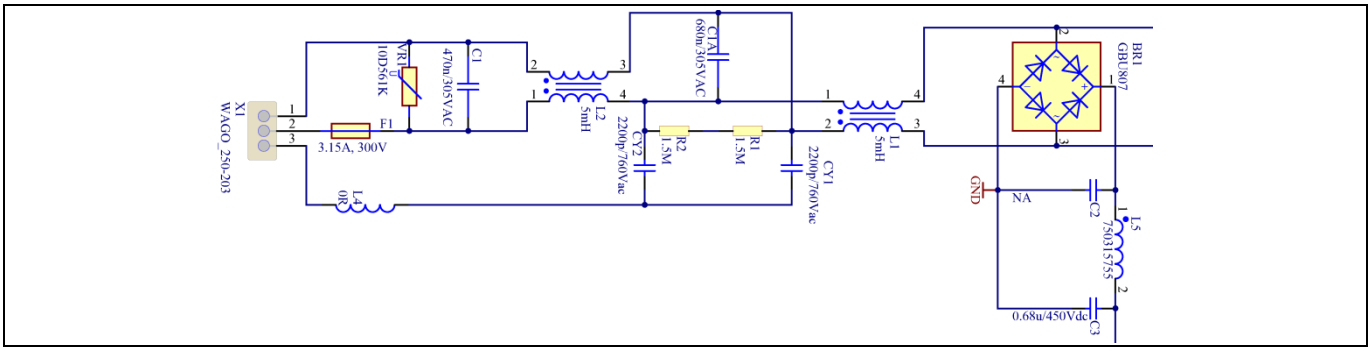


Figure 17 Line input filter

5.11.2 Conducted EMI measurement according to EN 55015

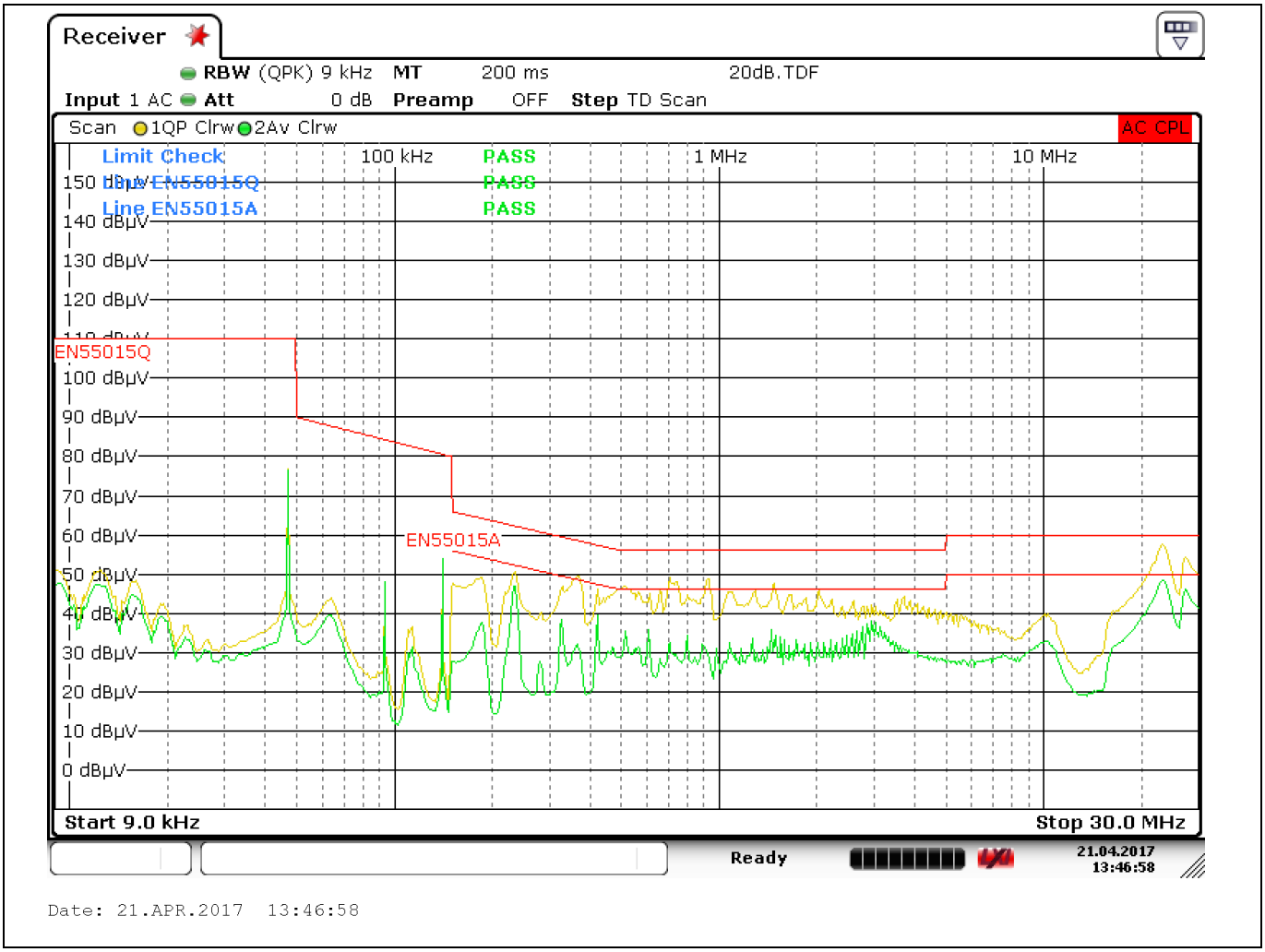
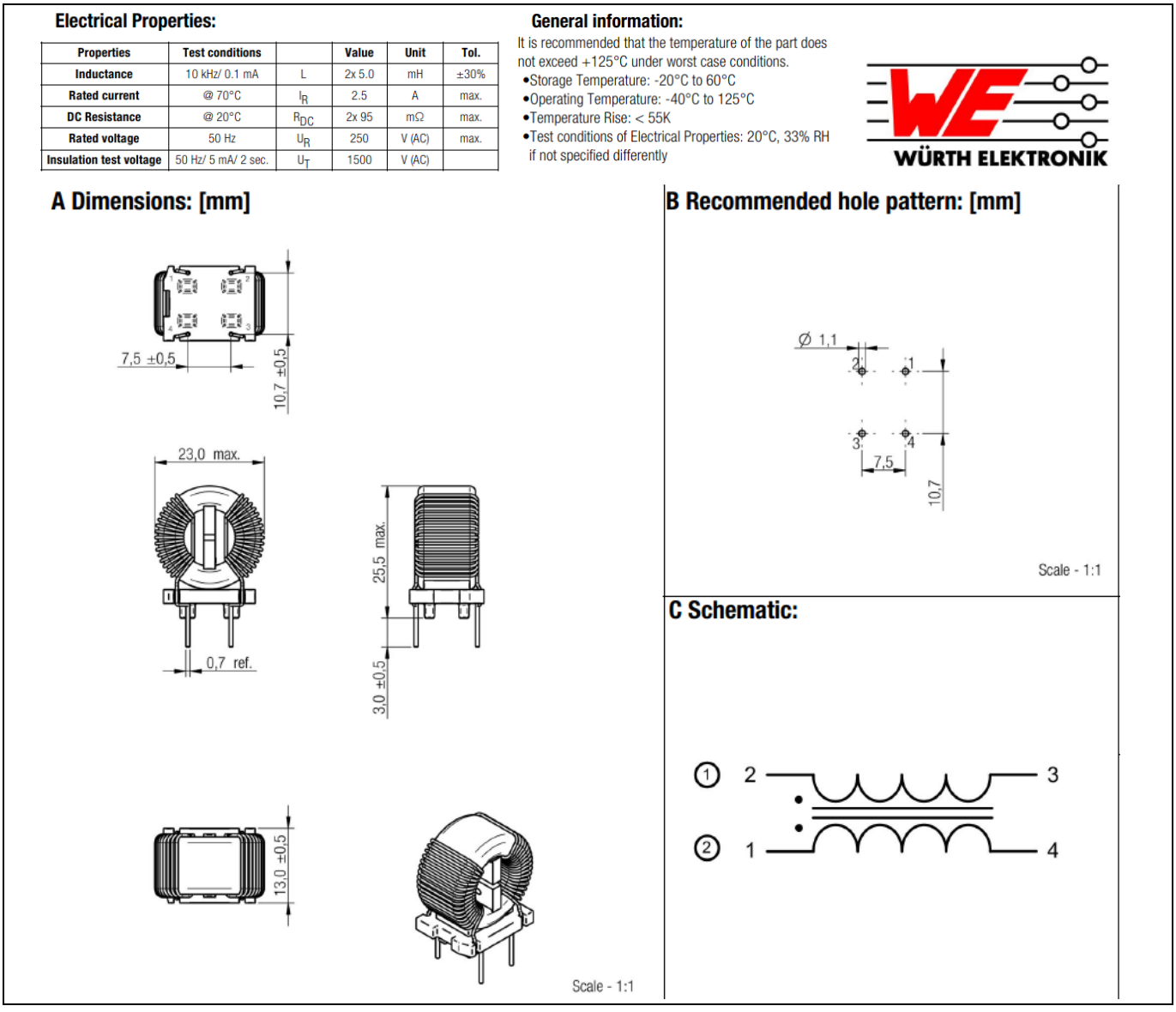


Figure 18 Conducted EMI measurement according to EN 55015

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.



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)	

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.

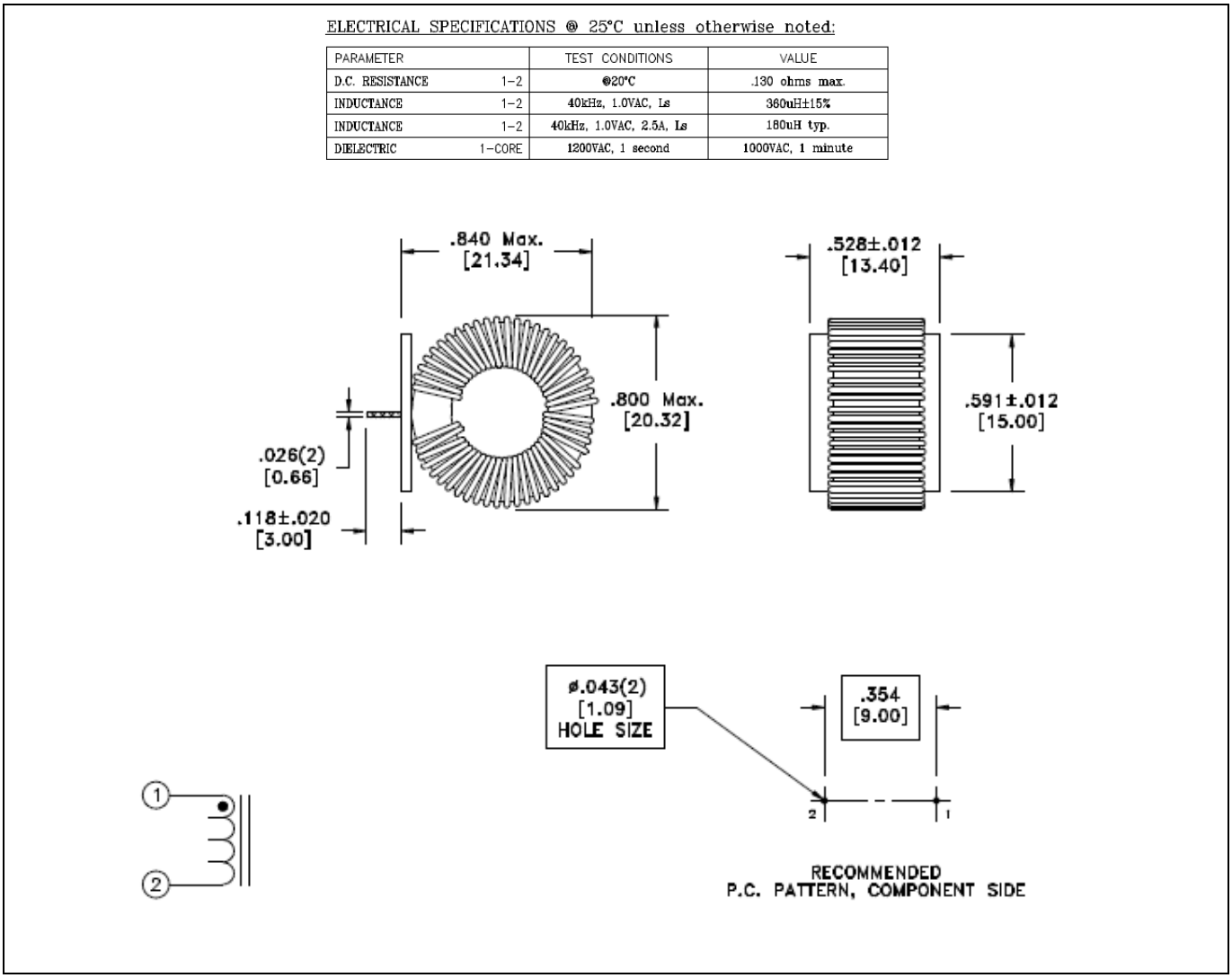
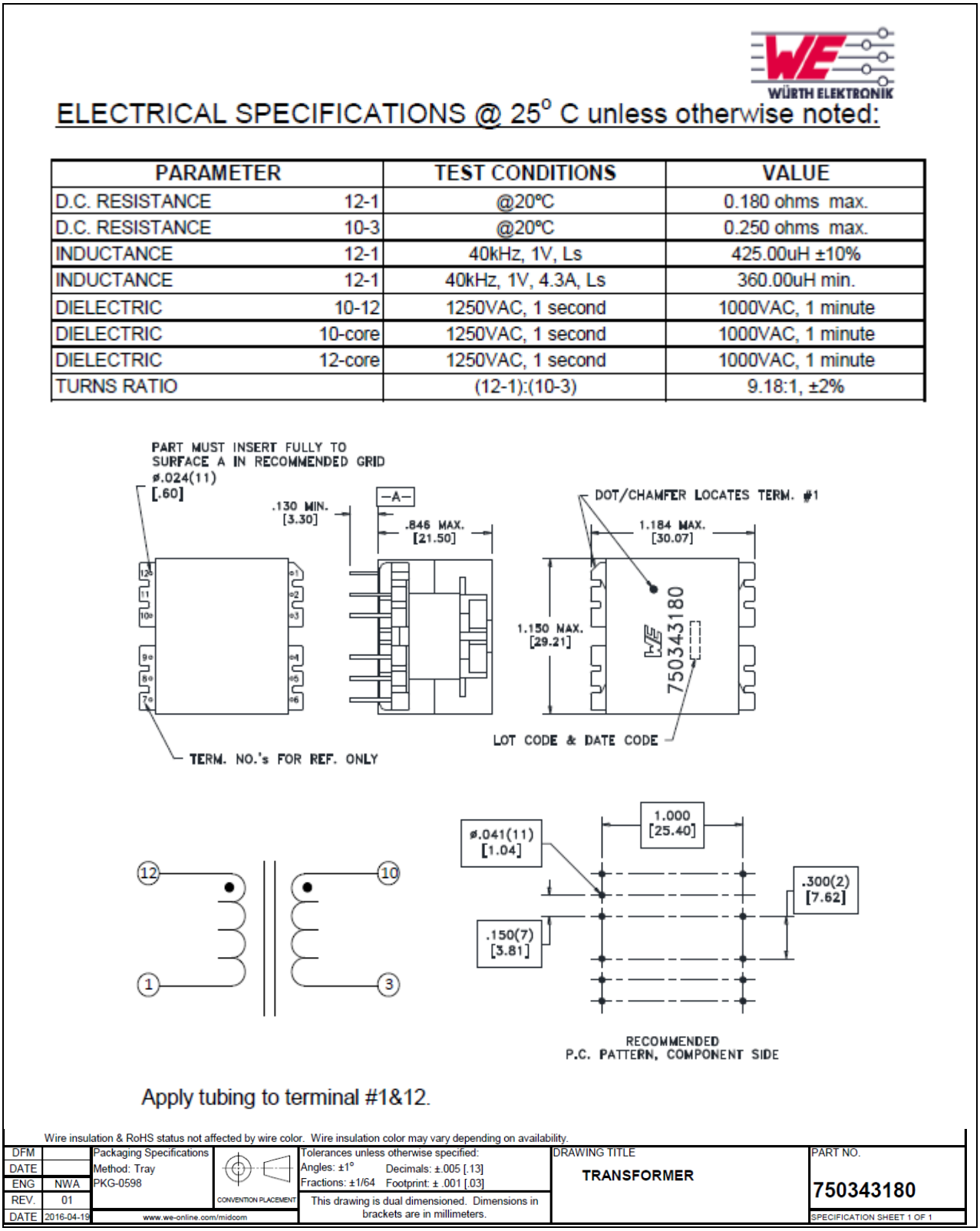


Figure 20 DM choke L5

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.



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%

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.

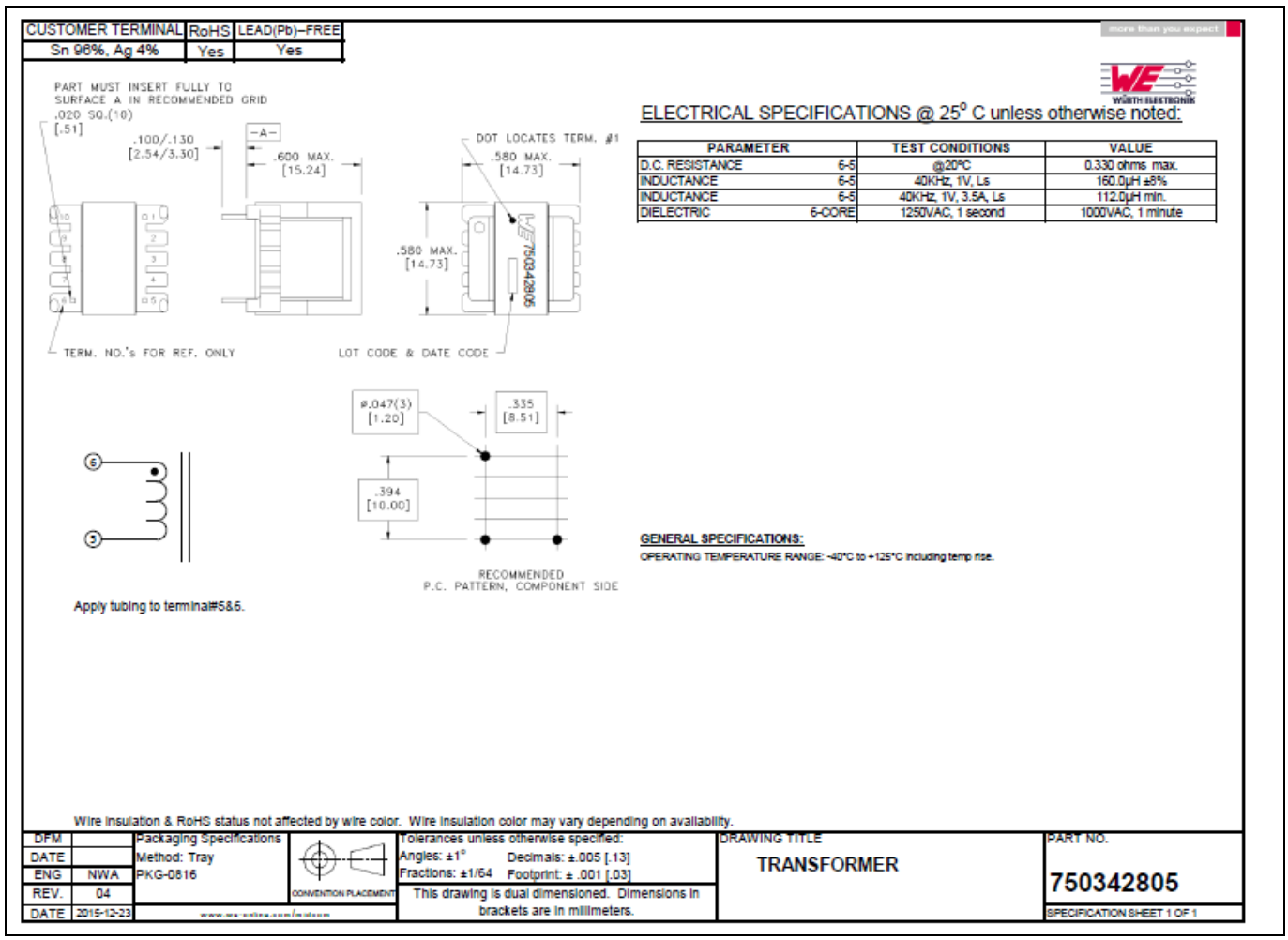


Figure 22 LLC resonant choke

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.

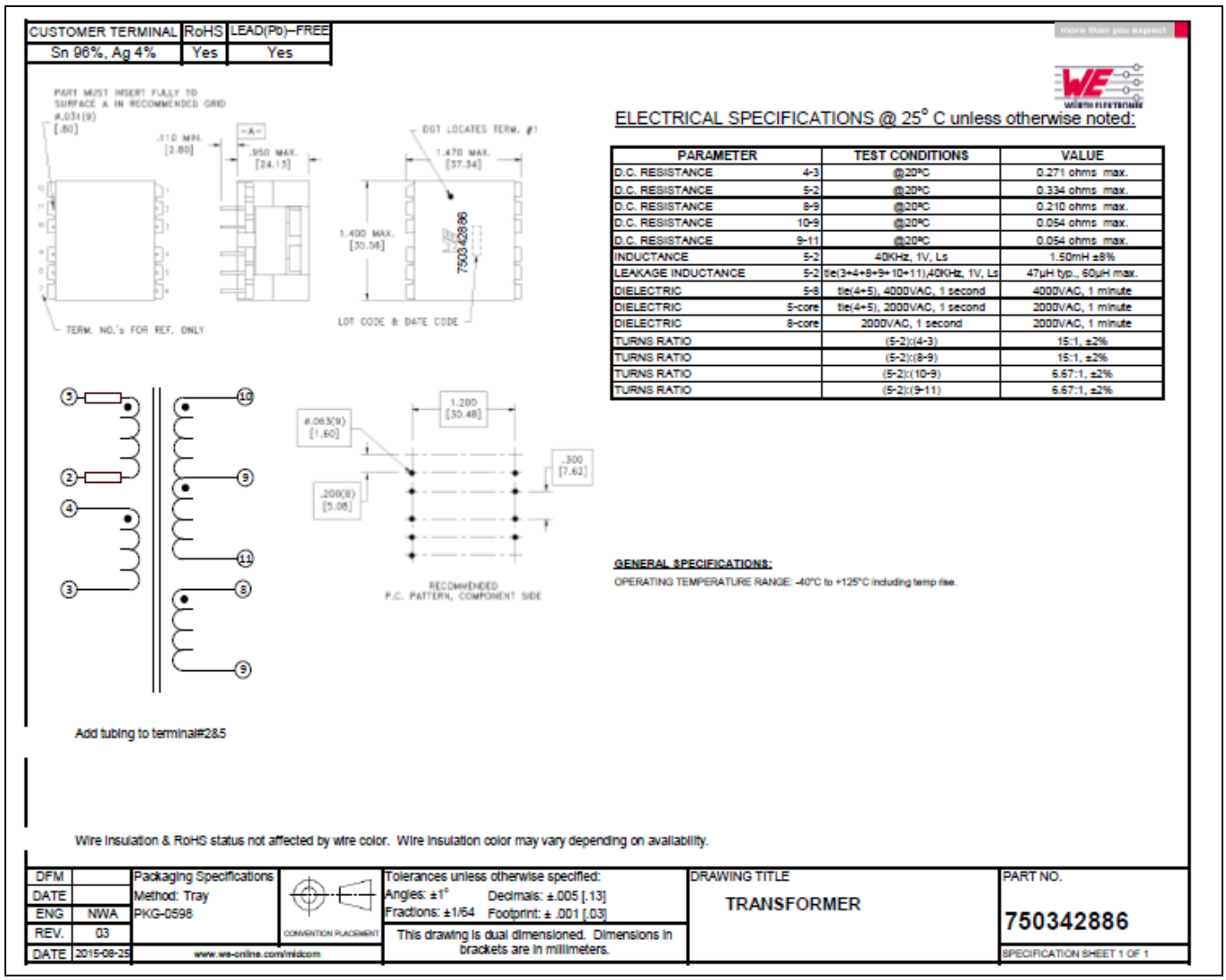


Figure 23 LLC transformer

7 Board layout

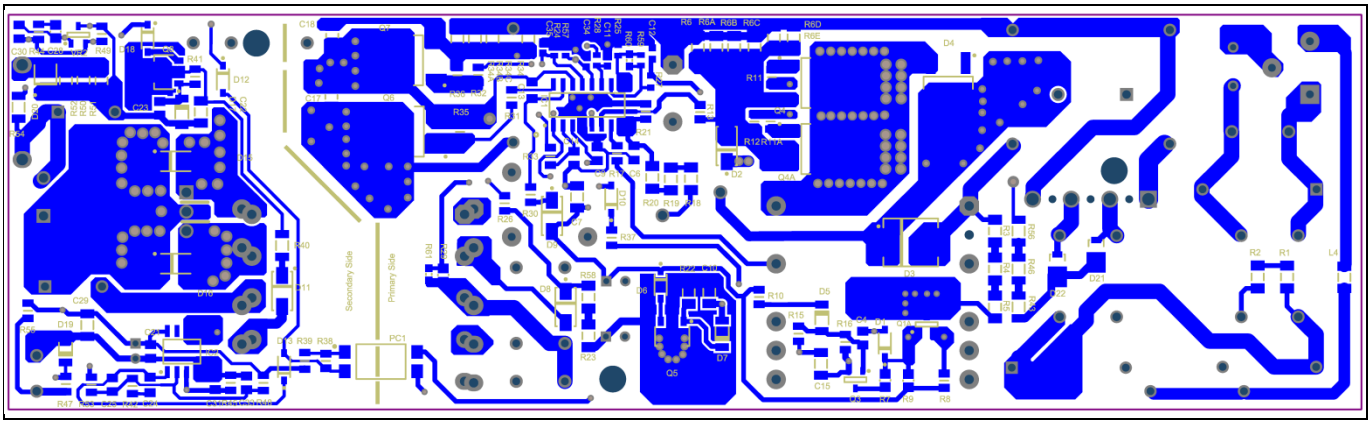


Figure 24 Layout (bottom view)

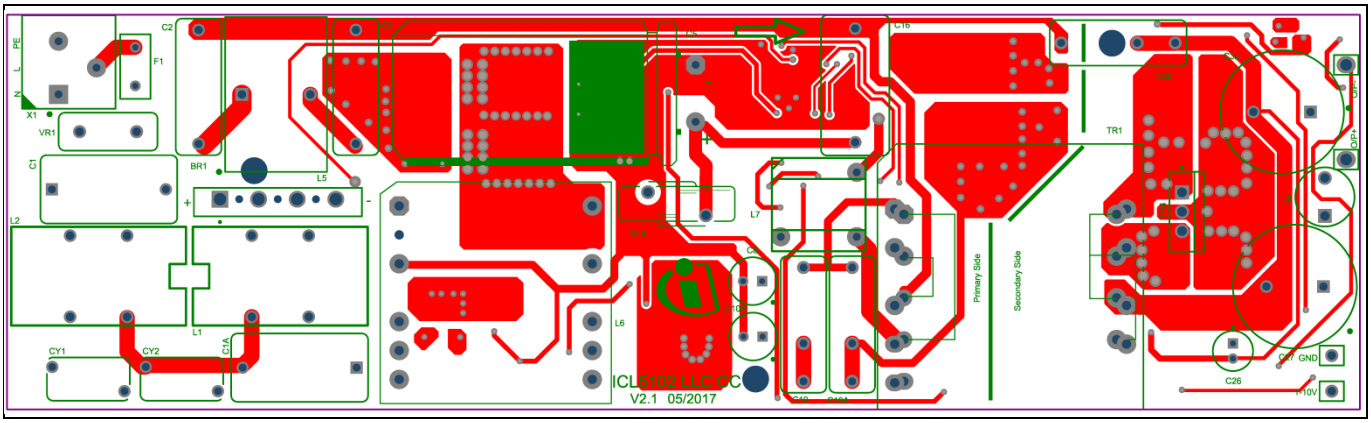


Figure 25 Assembly print (top view)

8 BOM

Designator	Type	PackageReference	Manufacturer	ManufacturerPartNumber
1-10V	AWG24, 200mm, striped 10mm, violet		Manufacturer	
BR1	1000V, 8A	SIP-4	Taiwan Semiconductor	GBU807
C1	470n/305VAC	CAPRR1500W80L1800T900H1750B	EPCOS	B32922C3474M000
C1A	680n/305VAC	CAPRR1500W80L1800T900H1750B	EPCOS	B32922C3684M000
C3	0.68u/450Vdc	CAPRR1500W80L1800T600H1200B	TDK	B32672P4684K000
C4, C9, C13, C21, C23	100n/50V	0805	TDK	C2012X7R1H104K085AA
C5	56u/500V	CAPPR750D80D1825H2700	Nichicon	UCY2H560MHD
C6	2.2n/50V	0805	Kemet	C0805C222K5RACTU
C7, C10, C22	1u/50V/X7R	1206	TDK	C3216X7R1H105K160AB
C8	220u/25Vdc	CAPPRD250W50D630H1220B	Wuerth	860010473011
C12	2.2n/25V/C0G	0603	Kemet	C0603C222J3GACTU
C15	220n/25V/X7R	1206	AVX	12063C224K4Z2A
C16	0.22u/630Vdc	CAPRR1500W80L1850T900H1750B	Panasonic	ECQE6224JF
C19	6.8n/600Vac/1600Vdc	CAPRR1000W60L1300T600H1200B	TDK	B32672L1682J000
C19A	4.7n/600Vac/1600Vdc	CAPRR1000W60L1300T600H1200B	TDK	B32671L0472J000
C20	2200p/760Vac	DISC, Pitch 10-15	Vishay	440LD22-R
C24	68n/50Vdc	0805	muRata	GCM21BR71H683KA37#
C26	33u/35V	CAPPRD200W50D525H1200B	Wuerth	860010472004
C27, C32	220u/100V	CAPPRD750W80D1625H2200B	Rubycon	100YXF220MEFC16X25
C28	56n/50V/X7R	0805	Kemet	C0805C563K5RACTU
C29	100n/50V/X7R	1206	Kemet	C1206C104J5RAC
C30	100p/50V	0805	muRata	GCM2165C1H101JA16#
C31	330n/50V	0805	AVX	08055C334K4Z2A
C33	1n/50Vdc	0805	muRata	GCM2195C1H102JA16#
C34	220n/25V/X7R	0603	Kemet	C0603C224K3RACAUTO
C35	100n/25V/X7R	0603	Kemet	C0603C104K3RAC
C36	2.2n/630Vdc	1206	muRata	GRM31BR72J222KW01L
C37	10n/50V	0805	muRata	GCM21B5C1H103JA16#
CY1, CY2	2200p/760Vac	CAPRR950W81L1090T570H1410B	Vishay	440LD22-R
D4	600V/5A	DPAK-3	STMICROELECTRONICS	STTH5L06B-TR
D5	ZD/17V	SOD80C	Vishay General Semiconductor	TZM5247B-GS18
D6, D10, D12, D13, D18	1N4148W-7-F	SOD123	Diodes Incorporated	1N4148W-7-F
D7	ZD/16V	SOD80C	Vishay General Semiconductor	TZM5246B-GS18
D8	S100	DO-214AC (SMA)	Fairchild	S100
D9, D11	US1M-E3/61T	DO-214AC (SMA)	Vishay General Semiconductor	US1M-E3/61T
D14	UF-Diode/200V/20A	TO-220AB	Vishay General Semiconductor	BYV32-200G
D17	ZD/12V	SOD80C	Vishay General Semiconductor	BZT55B12
D20	Shottky, 20V	DO-214AC	Vishay General Semiconductor	SS12HE3_A/H
D21, D22	D, 1kV, 1A	DO-220AA	Vishay General Semiconductor	S1PM-M3/84A
F1	3.15A, 300V	FUSRR508W60L850T400H800B	Littelfuse	36913150000
Glue Pad	4016-1/2"x36yd		3M	4016-1/2"x36yd
GND	AWG24, 200mm, striped 10mm, grey		Manufacturer	
Heat shrink	Heat shrink tube for C5 L:40mm		eg. Alpha Wire	
IC1	ICL5102 RES Controller PFC LLC	PG-DSO-16	Infineon	ICL5102
IC2	IC Dual OP-AMP ± 1.5V bis ± 16V	SOIC−8	Texas Instruments	LM358ADR
L1, L2	744823305	WE-CMB Type M	Wurth Elektronik	744823305
L4	500R/±25%	1206	Yageo	RC1206FR-070RL
L5	180uH	INDR900W120L2032T1580H2134	Wurth Elektronik	750315755 Rev06A
L6	750343180	PQ2620	Wuerth	750343180 Rev06A
L7	750342805	EE13-3	Wuerth	750342805 Rev06A
L8	4.7uH/±20%	INDPRD500W70D780H950B	Wurth Elektronik	744772047
O/P+	AWG18, 200mm, stripped 10mm, red		Manufacturer	
O/P-	AWG18, 200mm, stripped 10mm, black		Manufacturer	
PC1	SFH617A-3X007T	SMD-4,1016LS254P650W458L440H	Vishay	SFH617A-3X007T
PCB			Manufacturer	
Q1A	N-CH, 600V	PG-SOT23-3-5	Infineon Technologies	BSS126
Q3	NPN, 40V	SOT23 - 3	NXP Semiconductors	MMBT3904,215
Q4, Q4A, Q6, Q7	N-Ch, CE, 600V, 0.4Ohm	PG-TO252-3 (DPAK)	Infineon Technologies	IPD60R400CE
Q5, Q8	NPN 80V, 500mW, 1A,	SOT89	NXP	BCX56-16
R1, R2, R18, R19, R20	1.5M/200V/1%	1206	Yageo/Phycomp	RC1206FR-071M5L
R3, R4, R5	2k/200V/1%	1206	Yageo/Phycomp	RC1206FR-072K
R6A, R6B, R6C, R6D, R6E, R23	1.0/200V/1%	1206	Panasonic	ERJ8RQF1R0V

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Designator	Type	PackageReference	Manufacturer	ManufacturerPartNumber
1-10V	AWG24, 200mm, striped 10mm, violet		Manufacturer	
R7, R9	20k/150V/1%	0805	Yageo/Phycomp	RC0805FR-0720K
R8, R13	0R/150V	0805	Multicomp	MCMR08X000 PTL
R10, R38	1.0k/150V/1%	0805	Bourns	CR0805-FX-1001ELF
R11, R11A, R30	10R/150V/1%	0805	Vishay	CRCW080510R0FKEA
R12, R35, R36	47k/150V/1%	0805	Vishay	CRCW080547K0FKEA
R14	5R/20%	CAPRR525W60L950T600H1400B	Epcos	B57235S0509M000
R15, R16	510k/150V/1%	0805	Vishay	CRCW0805510KFKEA
R17	56k/150V/1%	0805	Vishay	CRCW080556K0FKEA
R21	24.9k/150V/1%	0805	Vishay	CRCW080524K9FKEA
R22	3k/200V/1%	1206	Vishay	CRCW12063K00FKEA
R24	12k/75V/1%	0603	Vishay	CRCW060312K0FKEA
R25	220k/75V/1%	0603	Vishay	CRCW0603220KFKEA
R26	180k/150V/1%	0805	Vishay	CRCW0805180KFKEA
R27, R67	0R/75V/1%	0603	Yageo/Phycomp	RC0603FR-070RL
R28	0R/75V/20mOhm	0603	Vishay	CRCW06030000Z0EA
R29	NTC100k/5%	0805	Epcos	B57471V2104J62
R31, R32	22R/150V/1%	0805	Vishay	CRCW080522R0FKEA
R33	200R/150V/1%	0805	Vishay	CRCW0805200RFKEA
R34A	1.5/200V/1%	1206	Yageo	RC1206FR-071R5L
R34B, R34C	1.8/200V/1%	1206	Yageo/Phycomp	AC1206FR-071R8L
R37	330R/150V/1%	0805	Vishay	CRCW0805330RFKEA
R39	3.3k/150V/1%	0805	Vishay	CRCW08053K30FKEA
R40	10R/200V/1%	1206	Vishay	CRCW120610R0FKEA
R41, R45	3.6k/150V/1%	0805	Vishay	CRCW08053K60FKEA
R42, R44	20k/150V/1%	0805	Vishay	CRCW080520K0FKEA
R43, R46, R56	2.2M/200V/1%	1206	Vishay	CRCW12062M20FKEA
R47	360k/150V/1%	0805	Vishay	CRCW0805360KFKEA
R48	3.9M/150V/1%	0805	Vishay	CRCW08053M90FKEA
R49	4.7k/150V/1%	0805	Vishay	CRCW08054K70FKEA
R50, R51, R52	0.15R/675mV/1%	1206	Bourns	CRL1206-FW-R150ELF
R53	2.0k/150V/1%	0805	Vishay	CRCW08052K00FKEA
R54	150k/200V/1%	1206	Vishay	CRCW1206150KFKEA
R55	33k/150V/1%	0805	Vishay	CRCW080533K0FKEA
R57	100k/75V/1%	0603	Vishay	CRCW0603100KFKEA
R59	2.7k/75V/1%	0603	Vishay	CRCW06032K70FKED
R62	330k/150V/1%	0805	Vishay	CRCW0805330KFKEA
TR1	750342886	EER35	Wuerth	750342886 Rev06A
VR1	10D561K/560V/10%	VARRR750W80L1300T500H1600B	Bourns	MOV-10D561K
VR2	TLE431/2.495V - 36V	SOT23-3	Texas Instruments	TL431CDBZR
X1	WAGO_250-203		WAGO	250-203
C2	0.68u/450Vdc	CAPRR1500W80L1800T600H1200B	TDK	B32672P4684K000
C10A	220u/25Vdc	CAPPRD250W50D630H1220B	Wuerth	860010473011
C11	100n/25V/X7R	0603	Kemet	C0603C104K3RAC
not assembled				
C14, C25	not assembled			
C17, C18	not assembled			
D1	not assembled			
D2	not assembled			
D3	not assembled			
D15, D16	not assembled			
D19	not assembled			
HS	not assembled			
R6	not assembled			
R34	not assembled			
R60	not assembled			
R61	not assembled			

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V1.0	2018-01-04	Initial version
V1.1	2018-11-07	Updated BOM table

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