ICL8810 high power density PSU for LED lighting

High power density, QR flyback solution



About this doucment

Scope and purpose

High power density and miniaturization are becoming a reality. High switching frequency helps to shrink the size of magnetic components and some passive components, but it also leads to system complexity. A higher power density design needs higher efficiency, so it dissipates less heat from the closed, non-ventilated box. Increasing the frequency does not result in a proportional size reduction of the power supply. Every system contains components that cannot be reduced in size, such as an EMI filter, input and output connectors, etc. These components can take up to 30 percent of the space in low-power systems. Previously, high-switching operations were mainly limited by MOSFET switching losses. Meanwhile, modern P7, G7 and GaN devices allow operation at an exceptionally high frequency, more than 300 kHz, with relatively low switching losses even in non-ZVS topologies. Therefore the challenge now lies in accurate MOSFET control, such as valley detection, minimal delays and EMI compatibility. The latter is a serious challenge when a quasi-resonant (QR) flyback operates as a single stage. A compact design with tightly placed magnetics may lead to unwanted coupling and resonant effects.

Achieving a high power density design at a low power level that is also iTHD and EMI compliant for lighting applications is a complex task, requiring various optimization strategies. This document provides design hints and a reference design overview.

Intended audience

This document is intended for engineers designing a high power density LED driver based on ICL88xx.

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1 System description

Lighting applications are subject to stricter regulations than AC-DC chargers and adapters:

- Harmonic EMC standard EN IEC 61000-3-2 requires a power factor correction (PFC) function. This means that using bulky electrolytic capacitance after the input rectifier is impossible. A two-stage solution automatically increases size and cost. A one-and-a-half-stage solution with a single-stage PFC flyback and output linear ripple filter has relatively low efficiency and slow dynamic reaction. An electrolytic low-voltage capacitor on the secondary side is much bigger than it could be on the high-voltage primary side, since the energy stored in the capacitance $\frac{CU^2}{2}$ is squared, depending on voltage.
- Meanwhile, the dynamic load requirement, which is very important for lighting applications with an entertainment feature, contradicts the first requirement for good PFC functionality. A possible implementation would be using a high-energy electrolytic capacitor on the output, but due to the size limitation and a high-frequency crossover feedback loop, single-stage PFC functionality is not a valid option.
- Conversely, EMI standard EN IEC 55015 has a relatively tolerant requirement below 150 kHz. So, operating at a much higher switching frequency at the single stage in critical conduction mode (CrCM) may affect EMI. A design packed with magnetic components placed close together leads to magnetic coupling that needs additional shielding, changing the axis so that it is perpendicular between the magnetics, for example.

Solving the puzzle of these contradictory requirements leads to the following concept:

- Such a low-power application, with input power from 5 W up to 25 W according to the EN IEC 61000-3-2 standard, can have a passive PFC filter, the so-called 2C-3D circuit. This allows storing energy on the high-voltage primary side, which reduces the size of the capacitors.
- The passive PFC function based on a 2C-3D circuit allows the implementation of a single-stage solution with high crossover feedback frequency. An excellent dynamic load response can be achieved.
- Soft-switching topologies such as QR flyback help improve EMI, but a broad spectrum of switching frequencies, due to the large bus voltage changes on the passive PFC, makes the task challenging. For this application, it is recommended to keep the switching frequency below 150 kHz. Moving to a higher switching frequency increases filter size and does not result in advantages such as power density or increased efficiency.

The topology based on these multiple requirements is shown in **Figure 1**.

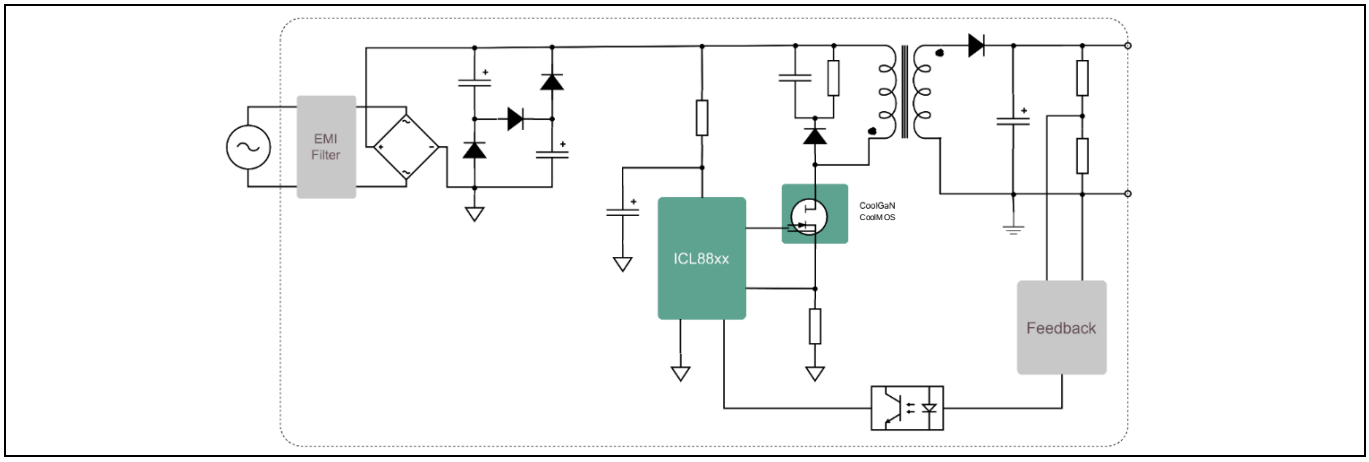


Figure 1 The topology selected

At the same time, increased power density needs a higher efficiency to dissipate heat from the now smaller, closed, non-ventilated LED driver box. Efficiency vs. power density is shown in **Figure 2**.

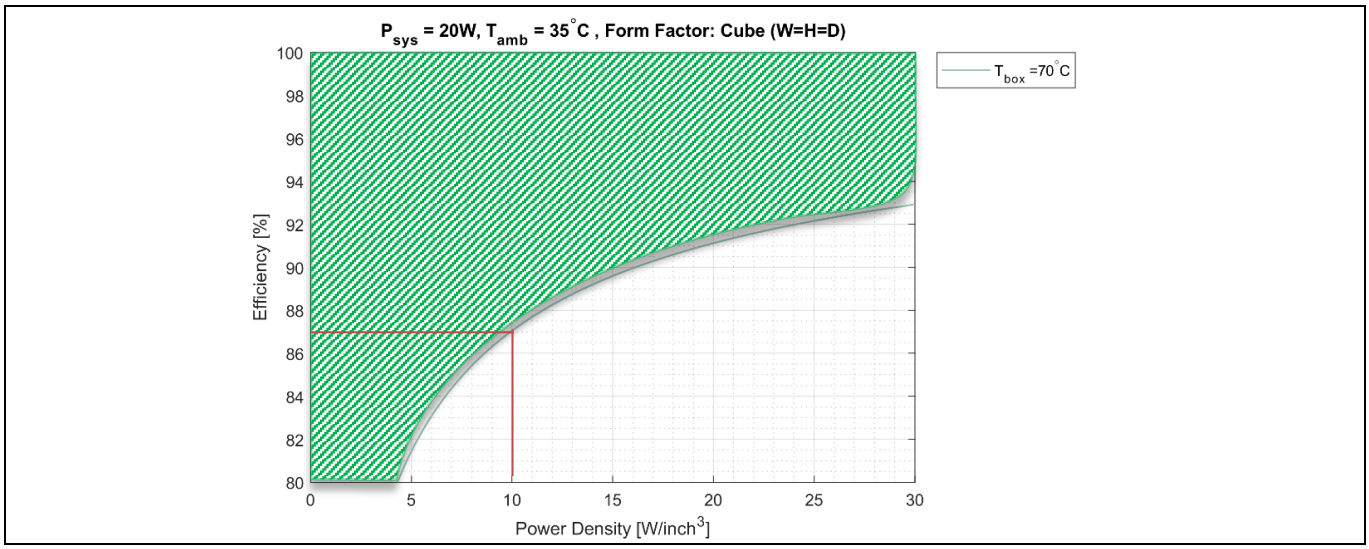


Figure 2 Efficiency vs. power density for 20 W LED driver

Figure 2 shows that efficiency must be higher than 87 percent at a power density of 10 W/inch^3 and T_{box} = 70°C; that's already critical. The target efficiency is 89 to 90 percent to reduce the enclosure temperature.

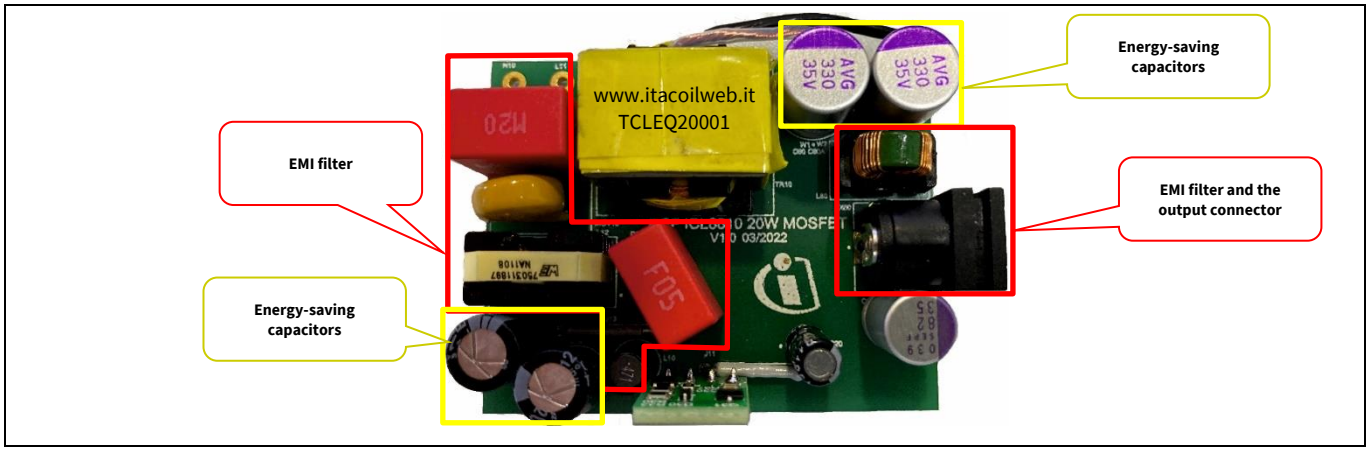


Figure 3 Design structure with relatively constant-size parts

Figure 3 shows the design structure. An EMI filter and the output connector are constant-size parts. EMI filters may be more complicated and even increase in size with a switching frequency higher than 150 kHz.

The bus capacitance and the output capacitance are split to store more energy. The capacitor's size is defined by the power level and peak load current.

2 Design hints

- The IC has propagation delay, T_{delay}, between zero crossing detection (ZCD) and gate drive (GD). It is the minimum time within which the controller can react and switch on the MOSFET. T_{delay} should be considered as ~300 to 400 ns. This means the condition must be fulfilled to achieve proper valley detection:

$$\frac{T_{oscill}}{4} > T_{delay}, \text{ there: } T_{oscill} = \frac{1}{F_{oscill}},$$

$$F_{oscill} = \frac{1}{2\pi\sqrt{L_{prim}C_{sum}}}, C_{sum} = C_{OSS}(V) + C_{trans} + \frac{C_{diode}(V)}{n^2}$$

L_{prim} is the primary transformer inductance; C_{sum} is the sum of the output MOSFET capacitance $C_{OSS}(V)$, transformer capacitance C_{trans} and reflected output diode capacitance $\frac{C_{diode}(V)}{n^2}$.

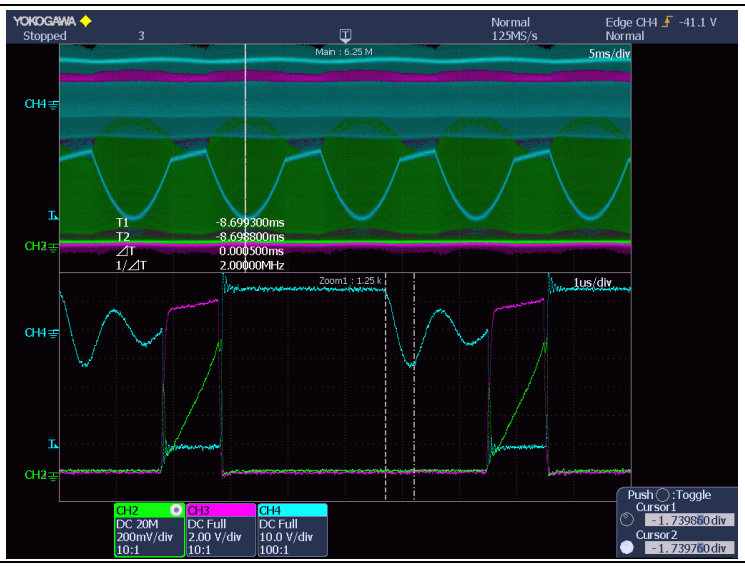


Figure 4 ICL88xx valley detection: pink – gate, blue – drain, green – shunt

If $\frac{T_{oscill}}{4}$ is shorter than T_{delay} the IC cannot detect valleys anymore. This leads to low switching frequency at N (e.g., 10 -15th valley) or hard switching with a delay. It is recommended to set the minimum possible resistance on the TD pin as the first step. Then check the oscillation frequency, L_{prim} and C_{sum}, which should be in the range in which the IC can detect it correctly.

- The signal at the V_{in} pin must be adequately filtered. The filtering capacitors must be placed close to the V_{in} pin.

- Because the IC operates in voltage mode, it lags between output voltage change and the pulse reaction. When bus voltage changes rapidly with the constant on-time operation, the MOSFET's peak current increases a few times, as shown in **Figure 5**. This may lead to transformer saturation and additional losses in the transformer.

  For this reason, a feedforward circuit R30 and D30 was implemented, which adds an inversely proportional signal with information about the bus voltage. As you can see in **Figure 6**, this helps to change the pulse width according to the bus voltage change. The MOSFET's current is less affected by the feedforward signal.

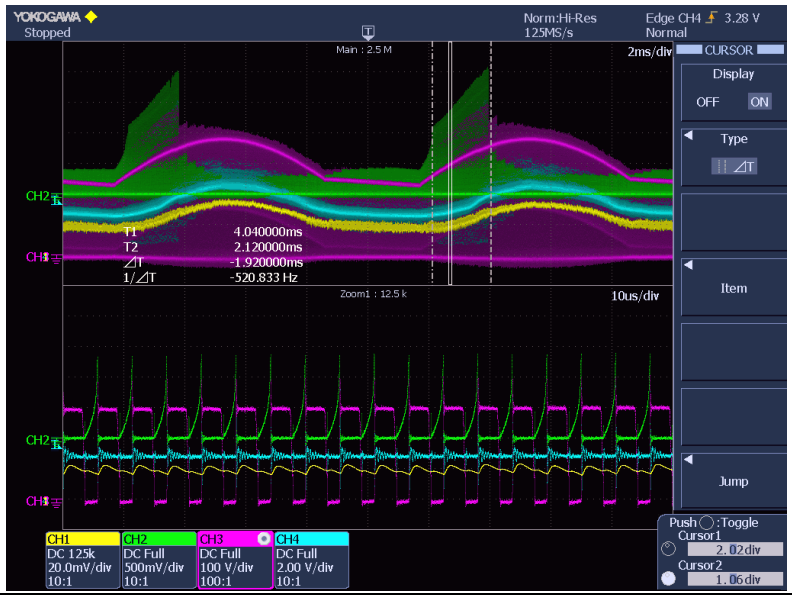


Figure 5 **Voltage mode control, transformer saturation: pink – drain, blue – secondary-side feedback, yellow – primary-side feedback, green – shunt**



Figure 6 **Voltage mode control with feedforward signal: pink – drain, blue – secondary-side feedback, yellow – primary-side feedback, green – shunt**

- High power density designs have stringent demands in terms of PCB layout. High-switching dV/dt creates radiated noise that can affect noise-sensitive paths and pins, especially V_{in}, VS and ZCD. High dI/dt may cause a negative gate signal voltage defined by a parasitic ground inductance. In turn, this can lead to incorrect operation and additional losses in the MOSFET. A layout design with critical loops is shown in **Figure 7**.

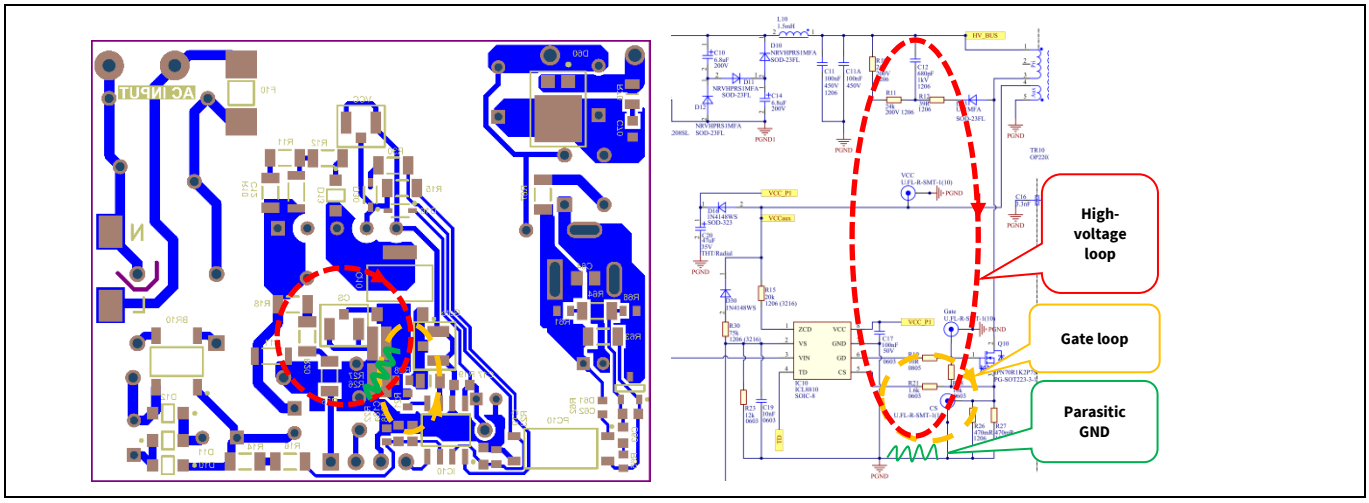


Figure 7 ICL88xx high power density layout explanation

Component placement and cross-interaction in the EMI scope can be challenging. When magnetic components are placed close to each other, the design will need special measures such as shielding, and orienting the EMI choke and the transformer on a different axis. For example, here the flyback transformer is vertically oriented and the EMI filter is horizontally oriented.

3 Schematics and performance

Table 1 Board specifications

Specification	Symbol	Value	Unit
Standard operational AC input voltage	$V_{AC,norm}$	176 to 264	V_{rms}
Nominal operational AC input frequency	F_{line}	47 ~ 63	Hz
CV output setpoint	$V_{out,setpoint}$	24	V
Output load current range	I_{out}	0 ~ 830	mA
Maximum output power	$P_{out,max}$	20	W
Maximum efficiency at $P_{out,max}$	$\eta_{max.at,P,out.max}$	90	%
Target maximum switching frequency at $P_{out,full}$	$f_{sw.max,at,P,out.max}$	150	kHz
Standard compliance			
Harmonics	–	EN 61000-3-2 class C	–
Board dimensions			
Size	L x B x H	Main board: 58 x 44.5 x 12.5	mm
Size	L x B	Plug-in TL: 36.5 x 27	mm

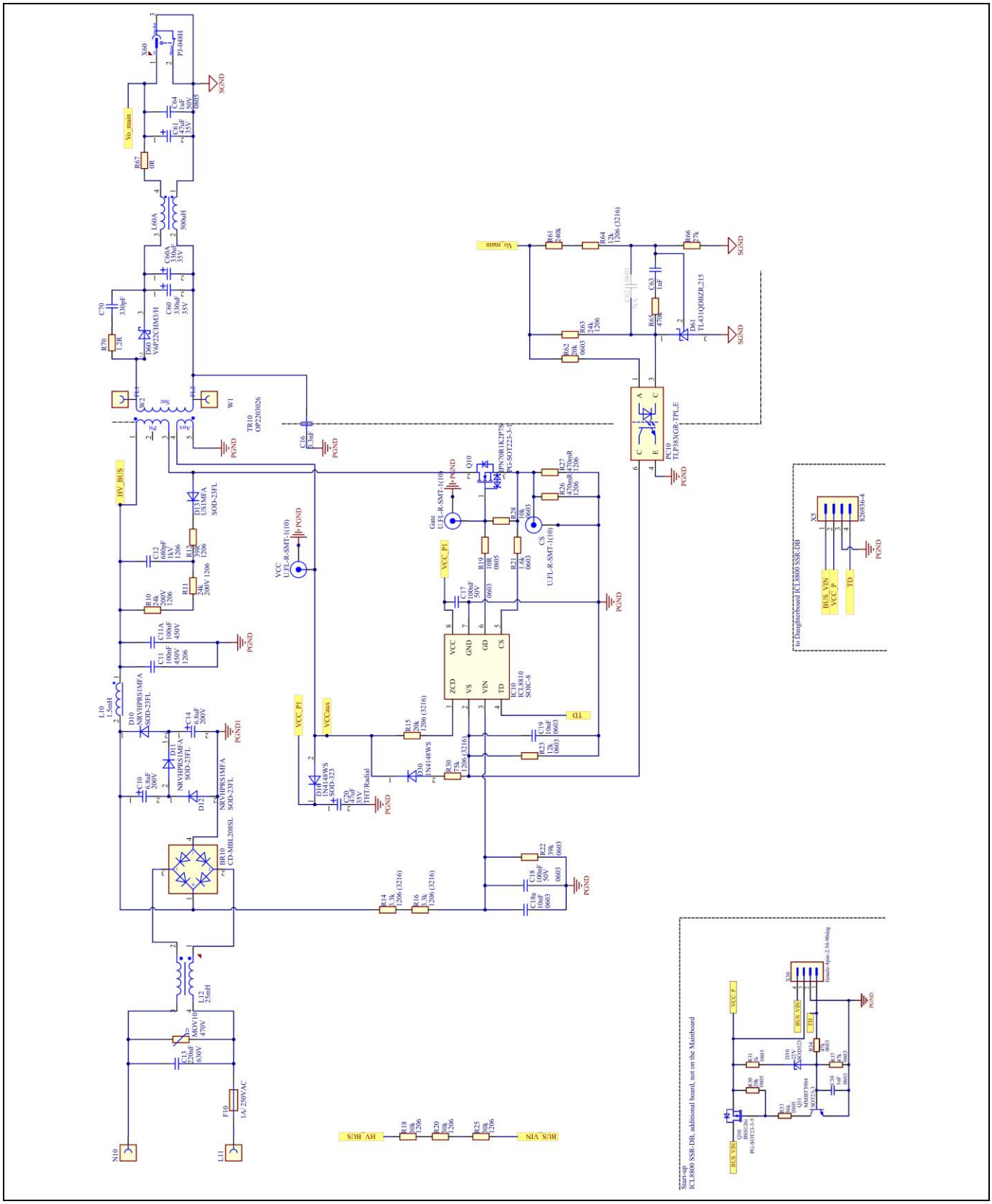


Figure 8 Schematic of the ICL88xx high power density reference design

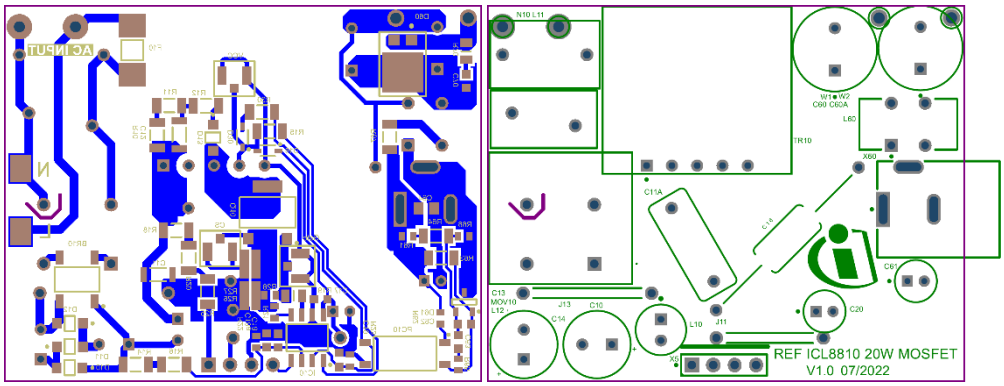


Figure 9 **Layout of the ICL88xx high power density reference design**



Figure 10 **ICL88xx high power density reference design**



Figure 11 **ICL88xx high power density load response: pink – gate, blue – output voltage, yellow – output current, green – shunt**

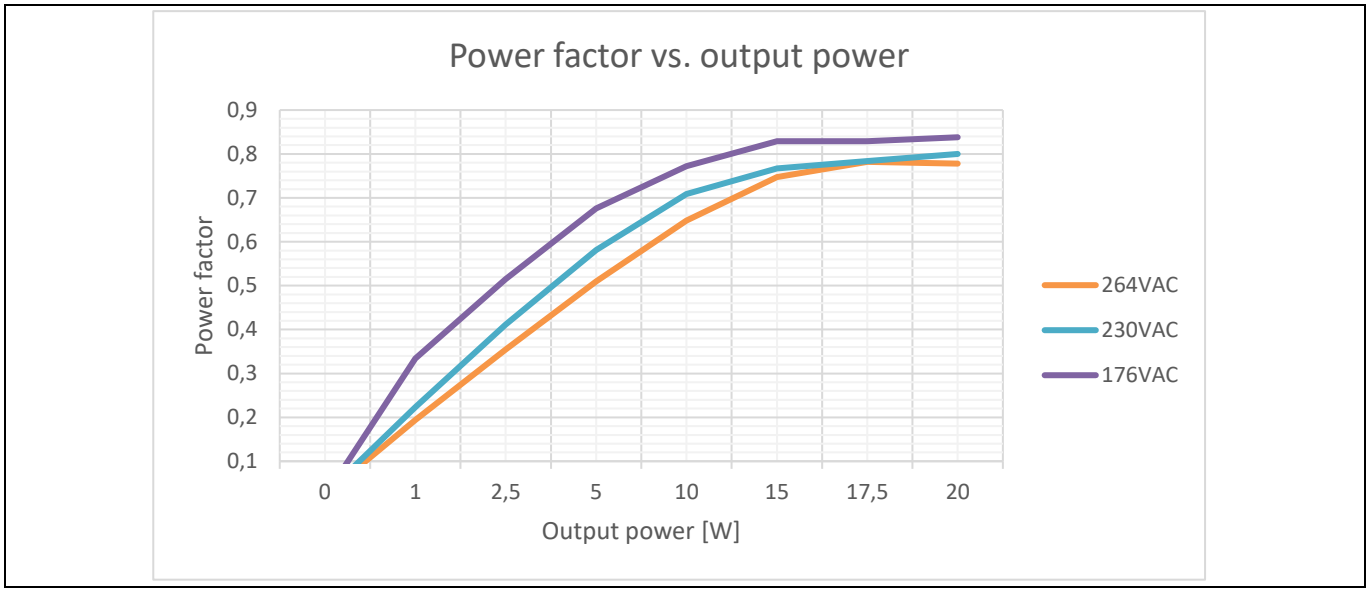


Figure 12 ICL88xx high power density power factor

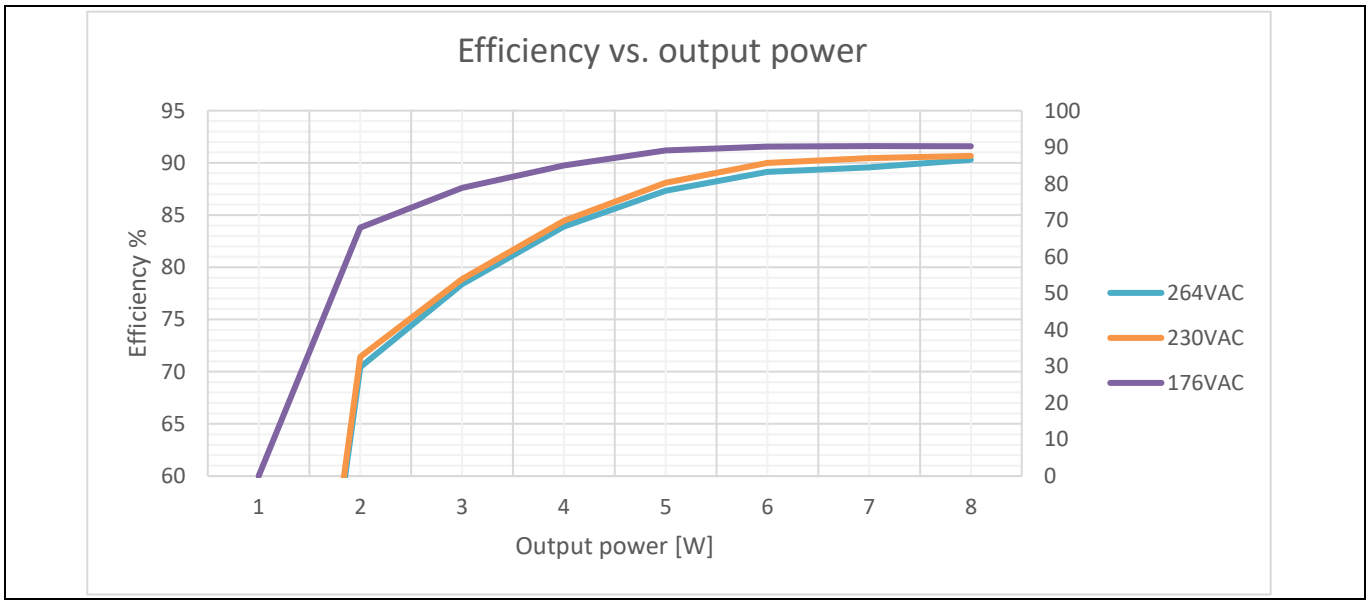


Figure 13 ICL88xx high power density efficiency

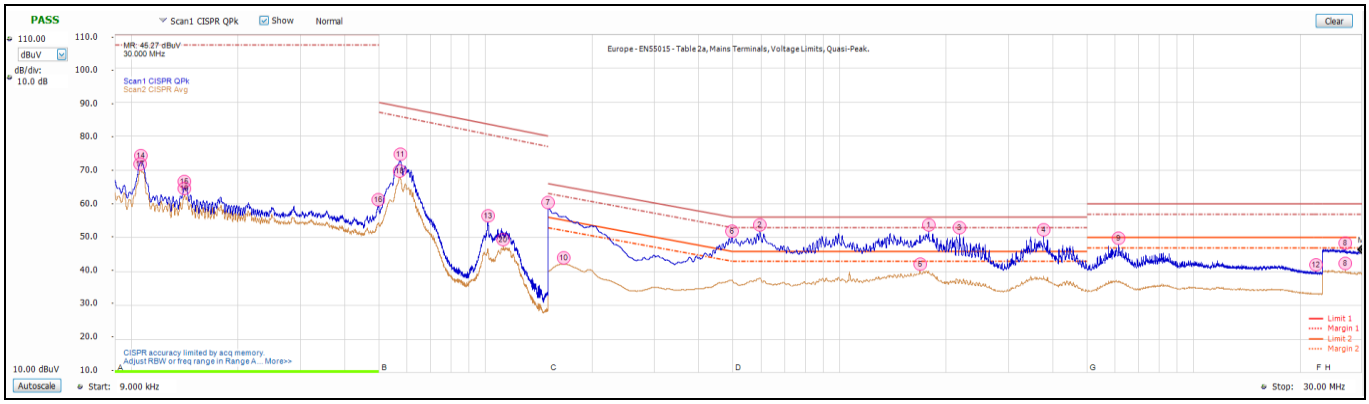


Figure 14 ICL88xx high power density, at full load EMI measurement

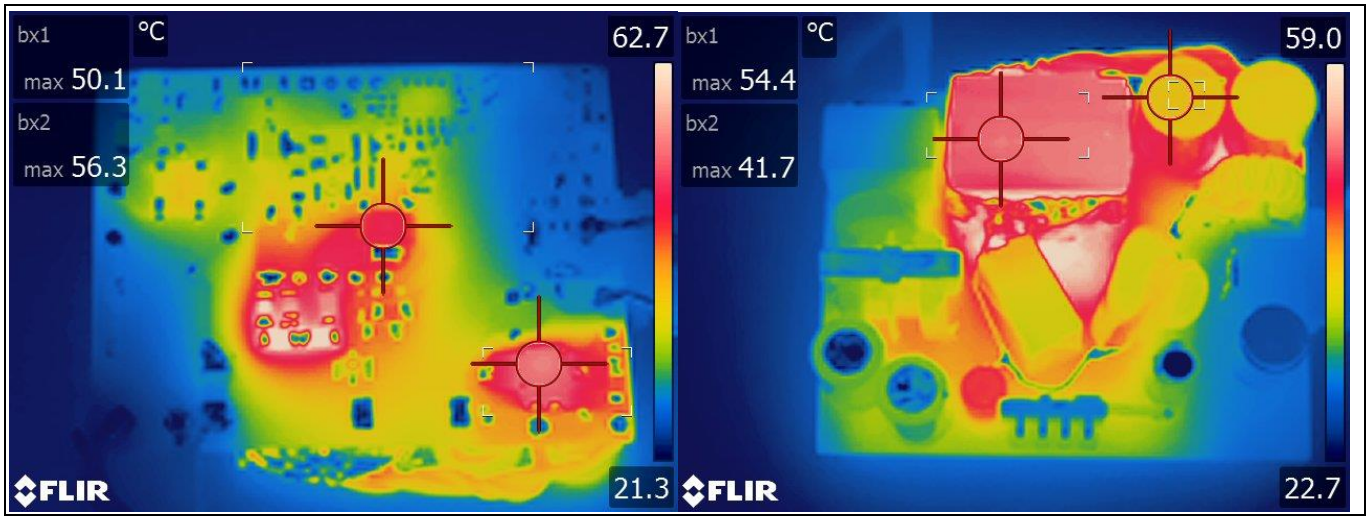


Figure 15 ICL88xx high power density, thermal measurement

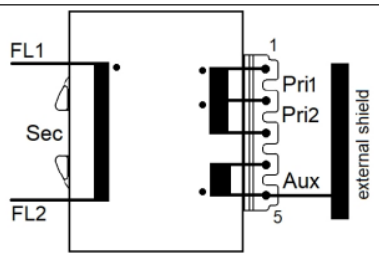
itacoilweb	**DATASHEET**	19/10/2022	**REV**	02	
	EDITED	Davide Maida	**APPROVED**	Dario Radaelli	
FINAL P/N	TCLEQ20001	**REV**	00	**SAMPLING CODE**	
PRELIMINARY P/N	OP2203026			**CUSTOMER P/N**	
CUSTOMER	INFINEON TECHNOLOGIES AG (Munich)				

DESCRIPTION	PFC flyback transformer EQ20

TEST/FEATURES			
Inductance Pri1+Pri2	1100 µH ±10,0%	100KHz / 1V	
Leakage Inductance Pri	TBD	100KHz/100mV	
Dielectric Strenght	Pri1+Pri2+Aux+CORE / Sec	3,0KVac / 2sec.	

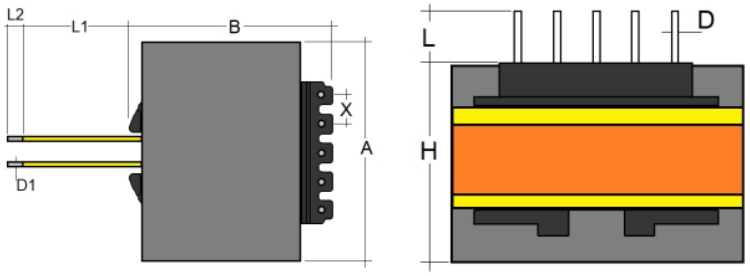
WINDINGS		
Pri1+Pri2	65ts - litz wire gr.1 155° (2UEW-F)	2 Ts PET ad.tape 0,06mm 130° yellow
Sec	13ts - litz wire gr.1 155° (2UEW-F)	2 Ts PET ad.tape 0,06mm 130° yellow
Aux	8ts - gr.2 130° (1UEW-B)	2 Ts PET ad.tape 0,06mm 130° yellow

LAYOUT (bottom view)



FL1=transparent tube
FL2= black tube

DRAWING



DIMENSIONS (mm)									
A	22,3 max	**B**	19,8 max	**H**	13,0 typ	**X**	3,0 typ	**DØ**	0,6 typ
DØ	0,6 typ	**L**	3,0 min	**L1**	27,0 typ	**L2**	4,0 min		

NOTES

RoHS compliant [Directives 2011/65/EU and 2015/863/EU] see https://www.itacoilweb.com/files/RoHS.pdf
REACH compliant [Regulation (EC)1907/2006] see https://www.itacoilweb.com/regulatory-compliance/

Figure 16 Transformer specification

Table 2 Bill of materials

#	Quantity	Designator	Description	Manufacturer	Manufacturer part number
1	1	BR10	Diode CD-MBL208SL//SMD//	Bourns	CD-MBL208SL
2	2	C10, C14	Capacitor 6.8 µF/200 V/P3.5, D8xH9//20%	Rubycon	200LLE6R8MEFC8X9
3	1	C11	Capacitor 100 nF/450 V/1206//10%	TDK Corporation	C3216X7T2W104K160AA
4	1	C11A	Capacitor 100 nF/450 V/ECW-FE//10%	Panasonic	ECW-FE2W104KA
5	1	C12	Capacitor 680 pF/1 kV/1206/X7R/10%	Murata	GRM31BR73A681KW01
6	1	C13	Capacitor 220 nF/630 V/P10xL13xW7xH13//10%	Würth Elektronik	890334023028CS
7	1	C16	Capacitor 3.3 nF//THT/Radial//20%	Murata	DE2E3SA332MA3BY02F
8	2	C17, C18	Capacitor 100 nF/50 V/0603/X7R/10%	AVX	06035C104K4Z2A
9	2	C18a, C19	Capacitor 10 nF/50 V/0603/X7R/5%	Murata	GRM188R71H103JA01
10	2	C20, C61	Capacitor 47 µF/35 V/THT/Radial//20%	Würth Elektronik	860020572006
11	2	C60, C60A	Capacitor 330 µF/35 V/p5 D10xH12//20%	Cornell Dubilier	337AVG035MGBJ
12	1	C63	Capacitor 1 nF/50 V/0603/X7R/10%	Murata	GRM188R71H102KA01
13	1	C64	Capacitor 1 µF/50 V/0805/X7R/10%	TDK Corporation	CGA4J3X7R1H105K125AB
14	1	C70	Capacitor 330 pF/50 V/0603/C0G/2%	Murata	GRM1885C1H331GA01
15	3	CS, gate, V_{CC}	Connector U.FL-R-SMT-1(10)//CON-SMA-U.FL-R-SMT-1(10)//	Hirose Connectors	U.FL-R-SMT-1(10)
16	3	D10, D11, D12	Diode NRVHPRS1MFA//SOD-23FL//	ON Semiconductor	NRVHPRS1MFA
17	1	D13	Diode US1MFA//SOD-23FL//	ON Semiconductor	US1MFA
18	2	D16, D30	Diode 1N4148WS//SOD-323//	Diodes Incorporated	1N4148WS-7-F
19	1	D60	Diode V6P22CHM3/H//TO-277A//	Vishay	V6P22CHM3/H
20	1	D61	Int. TL431QDBZR,215//SOT-23//	Nexperia	TL431QDBZR,215
21	1	F10	Resistor 1 A/250 V AC/125 V/SMD 2410//	Bourns	SF-2410FP100W-2
22	1	IC10	ICL8810//SOIC-8//	Infineon	ICL8810
23	1	J11	Connector JL-500-25-T//JP-THT-JL-500-25-T//	Samtec	JL-500-25-T
24	1	J13	Connector JL-600-25-T//JP-THT-JL-600-25-T//	Samtec	JL-600-25-T
25	1	L10	Inductor 1.5 mH//THT//5%	Würth Elektronik	7447462152
26	4	L11, N10, W1, W2	Connector IFX_Testhole_1.32mm_2mm pad//testhole_1.32mm_2mm pad//	Infineon Technologies	IFX_Testhole_1.32mm_2mm pad
27	1	L12	Inductor 25 mH//THT//50%	Würth Elektronik	744861250
28	1	L60	Inductor 500 µH//THT//	–	71353-00076-01
29	1	MOV10	Resistor 470 V//Radial//10%	Würth Elektronik	820513011
30	1	PC10	Int. TLP383(GR-TPL,E)//SO-6-4//	Toshiba	TLP383(GR-TPL,E
31	1	Q10	Transistor IPN70R1K2P7S//PG-SOT223-3-1//	Infineon Technologies	IPN70R1K2P7S
32	2	R10, R11	Resistor 24k/200 V/1206//1%	Vishay	CRCW120624K0FK
33	1	R12	Resistor 39 R/200 V/1206//1%	Vishay	CRCW120639R0FK
34	2	R14, R16	Resistor 3.3k/200 V/1206//1%	Vishay	CRCW12063K30FK
35	1	R15	Resistor 20k/200 V/1206//1%	Vishay	CRCW120620K0FK
36	3	R18, R20, R25	Resistor 30k/200 V/1206//1%	Vishay	CRCW120630K0FK
37	1	R19	Resistor 10 R/150 V/0805//1%	Vishay	CRCW080510R0FK
38	1	R21	Resistor 1.6k/75 V/0603//1%	Vishay	CRCW06031K60FK
39	1	R22	Resistor 39k/75 V/0603//1%	Vishay	CRCW060339K0FK
40	1	R23	Resistor 12k/75 V/0603//1%	Vishay	CRCW060312K0FK
41	2	R26, R27	Resistor 470 mR/200 V/1206//1%	Panasonic	ERJB2BFR47V
42	1	R28	Resistor 10k/75 V/0603//1%	Vishay	CRCW060310K0FKEA
43	1	R30	Resistor 75k/200 V/1206//1%	Vishay	CRCW120675K0FK
44	1	R61	Resistor 240k/75 V/0603//1%	Vishay	CRCW0603240KFK
45	1	R62	Resistor 20k/75 V/0603//1%	Vishay	CRCW060320K0FK
46	1	R63	Resistor 24k/200 V/1206//1%	Vishay	CRCW120624K0FK

#	Quantity	Designator	Description	Manufacturer	Manufacturer part number
47	1	R64	Resistor 12k/200 V/1206//1%	Vishay	CRCW120612K0FK
48	1	R65	Resistor 470k/75 V/0603//1%	Vishay	CRCW0603470KFK
49	1	R66	Resistor 27k/75 V/0603//1%	Vishay	CRCW060327K0FK
50	1	R67	Resistor 0 R/200 V/1206//0%	Vishay	CRCW12060000Z0EA
51	1	R70	Resistor 1.2 R/150 V/0805//1%	Vishay	CRCW08051R20FK
52	1	TR10	Transformer TCLEQ20001//THT//	ITACOIL	TCLEQ20001
53	1	X5	Connector 826936-4//CON-M-THT-826936-4//	TE Connectivity	826936-4
54	1	X60	Connector PJ-048H//THT//	CUI	PJ-048H
55	0	C62	Capacitor NA/50 V/0603/C0G/5%	Murata	GRM1885C1H681JA01

Revision history

Document version	Date of release	Description of changes
V 1.0	2022-10-28	First release
V 1.1	2022-12-13	Added transformer markings to figures 3 and 10; BOM transformer part number changed

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