UM12047

TEA2376DB1603v2 240 W interleaved PFC + LLC demo board

Rev. 1 — 13 March 2024 User manual

Document information

Information	Content
Keywords	TEA2376, TEA2376DB1603, 240 W, LLC, PFC, interleaved, controller, converter, burst mode, shedding, efficiency, power supply, demo board, TEA2209T, active bridge rectifier, TEA19161 LLC controller, TEA2095 synchronous rectifier controller, programmable settings, I^2C, TEA2016DB1514, RDK1DB1563, TEA2376DB1011.
Abstract	The TEA2376 is a digital configurable two-phase interleaved PFC controller for high-efficiency power supplies. The PFC operates in discontinuous conduction mode (DCM) or quasi-resonant mode (QR) with valley switching to optimize efficiency. The TEA2376 allows the building of an interleaved power factor (PF) converter that is easy to design with a low number of external components. The digital architecture is based on a configurable hardware state machine, ensuring reliable real-time performance. During the power supply development, many PFC controller operation and protection settings can be customized by loading new settings into the device using I^2C to meet specific application requirements. Input current shaping is used for a high power factor and low total harmonic distortion (THD). For a low-load operation with a good efficiency phase, shedding and burst mode operation are included. In burst mode, the power consumption of the IC is reduced. The TEA2376 contains many protections, such as internal and external overtemperature protection (OTP), overcurrent protection (OCP), double overvoltage protections (OVP), inrush current protection (ICP), pin open and pin short protection, and phase fail protection. The protections can be configured independently via programmable parameters. The TEA2376DB1603v2 demo board shows an interleaved PFC converter (TEA2376) with an active bridge rectifier (TEA2209T), an LLC resonant converter (TEA19161), and a synchronous rectifier (TEA2026) without heat sinks. The converter can provide 120 W output power in laboratory conditions without forced cooling. And 240 W with forced cooling for the LLC output section to provide 20 A at 12 V.

1 Important notice

IMPORTANT NOTICE

For engineering development or evaluation purposes only

NXP provides the product under the following conditions:

This evaluation kit or reference design is for use of ENGINEERING DEVELOPMENT OR EVALUATION PURPOSES ONLY.

It is provided as a sample IC pre-soldered to a printed circuit board to make it easier to access inputs, outputs, and supply terminals. This evaluation kit or reference design may be used with any development system or other source of I/O signals by connecting it to the host MCU or computer board via off-the-shelf cables. Final device in an application will be heavily dependent on proper printed circuit board layout and heat sinking design as well as attention to supply filtering, transient suppression, and I/O signal quality.

The product provided may not be complete in terms of required design, marketing, and or manufacturing related protective considerations, including product safety measures typically found in the end device incorporating the product. Due to the open construction of the product, it is the responsibility of the user to take all appropriate precautions for electric discharge. To minimize risks associated with the customers' applications, adequate design and operating safeguards must be provided by the customer to minimize inherent or procedural hazards. For any safety concerns, contact NXP sales and technical support services.

CAUTION

This product has not undergone formal EMC assessment. It is the responsibility of the user to ensure that any finished assembly complies with applicable regulations on EMC interference. EMC testing, and other testing requirements for CE is the responsibility of the user.

FCC NOTICE: This kit is designed to allow:

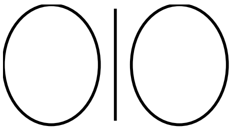
1. Product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and
2. Software developers to write software applications for use with the end product.

This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

2 Safety warning

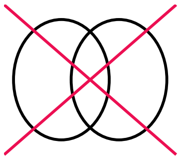
The application board is AC-mains voltage powered. Avoid touching the board while it is connected to the mains voltage and when it is in operation. An isolated housing is obligatory when used in uncontrolled, non-laboratory environments. Galvanic isolation from the mains phase using a fixed or variable transformer is always recommended.

Figure 1 shows the symbols on how to recognize these devices.



019aab173

a. Isolated



019aab174

b. Not isolated

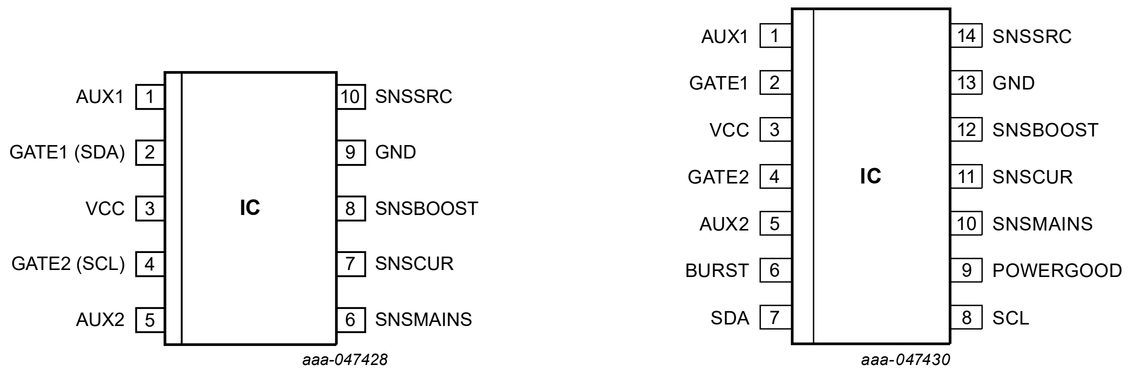
Figure 1. Isolation symbols

3 Introduction

3.1 TEA2376

The TEA2376 provides high efficiency at all power levels. Together with a TEA2209T active bridge rectifier controller, a TEA19161 LLC controller, and a TEA2095 SR controller, a high performance cost-effective resonant power supply can be made, meeting modern power supply efficiency regulations.

Operation modes and protections can be defined by an extensive amount of parameter settings for operation and protections can be stored/programmed in an internal memory. This feature provides flexibility and ease of design to optimize controller properties to application-specific requirements or even optimize/correct performance during power supply production. At start, the IC will load the parameter values for operation. For easy design work during product development the most extended TEA2376DT version can be used to make setting changes on the fly.



a. TEA2376AT (SO10) b. TEA2376DT (SO14)

Figure 2. Pinning diagrams

3.2 TEA2209T

The TEA2209T is an active bridge rectifier controller replacing the traditional diode bridge. Using the TEA2209T with low-ohmic high-voltage external MOSFETs significantly improves the efficiency of the power converter. The reason is that the typical rectifier diode-forward conduction losses are eliminated. In addition, the TEA2209T includes an X-capacitor discharge function. To reduce power consumption at a standby condition, an external signal via the COMP pin can disable the TEA2209T.

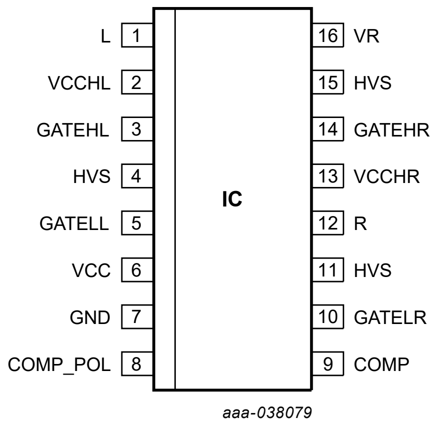


Figure 3. TEA2209T pinning diagram

3.3 TEA19161

The resonant controller TEA19161T is a high-voltage controller for a zero voltage switching LLC resonant converter. The resonant controller includes:

- A high-voltage shift circuit
- A high-voltage internal start-up switch
- Several protection features, like OCP, open-loop protection (OLP), capacitive mode protection (CMP), and a general-purpose latched protection input

To improve the overall performance significantly, the TEA19161 and TEA2376 work together.

With the TEA1995T as a synchronized rectifier controller at the secondary side, MOSFETs can be used instead of rectifying diodes, improving the overall efficiency of the complete system even more.

The combination of an active bridge rectifier controller, an interleaved PFC controller, an LLC resonant controller, and an SR controller makes these devices suitable for all kinds of applications. Especially, for an application that requires high efficiency over the whole power range, from no load to the maximum output load.

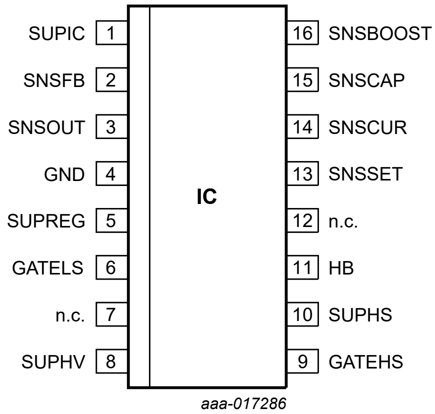


Figure 4. Pinning diagram TEA19161

3.4 TEA2095

The TEA2095T is a synchronous rectifier (SR) controller IC for LLC switched-mode power supplies. It incorporates an adaptive gate-drive method for maximum efficiency at any load.

The TEA2095T is a dedicated controller IC for synchronous rectification on the secondary side of the resonant converters. It includes two driver stages for driving the SR MOSFETs, which rectify the outputs of the central-tap secondary transformer windings. The two-gate driver stages have their own sensing inputs and operate independently.

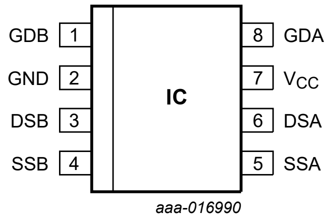


Figure 5. Pinning diagram TEA2095

3.5 Demo board

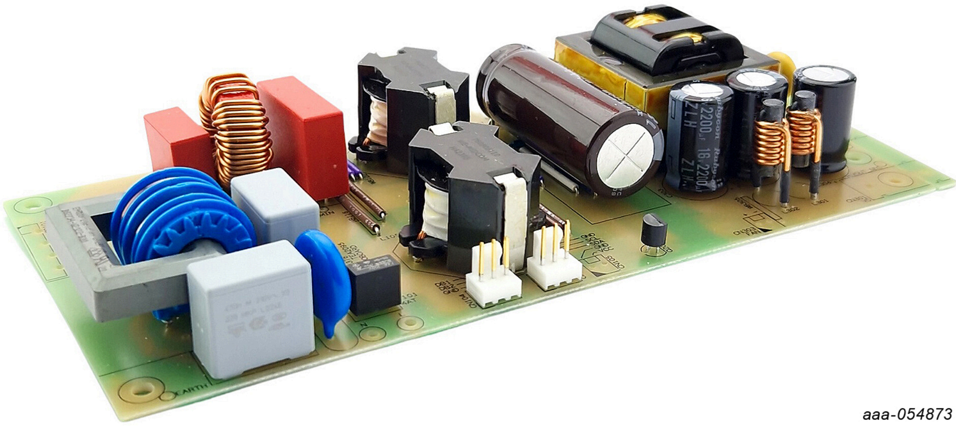


Figure 6. TEA2376DB1603 demo board

The TEA2376DB1603v2 demo board can operate on a mains input voltage between 90 V (RMS) and 264 V (RMS); universal mains voltage.

The TEA2376DB1603V2 demo board contains four subcircuits:

- An active bridge rectifier
- An interleaved PFC converter
- A resonant LLC converter
- A synchronous rectifier

The purpose of the demo board is to demonstrate and evaluate the operation of the TEA2376DT with an LLC converter, including the modes of operation in a typical design. The performance supports common standards, including the current low-load and standby requirements. It can be used as a starting point for developing a power supply using the TEA2376 with the other controllers.

The demo board also demonstrates the built-in system functions of the TEA2376 to work with the TEA19161 via the SNSBOOST. The TEA2376 (interleaved PFC) is an alternative for the TEA19162 (single PFC), which is normally used with the TEA19161 controller.

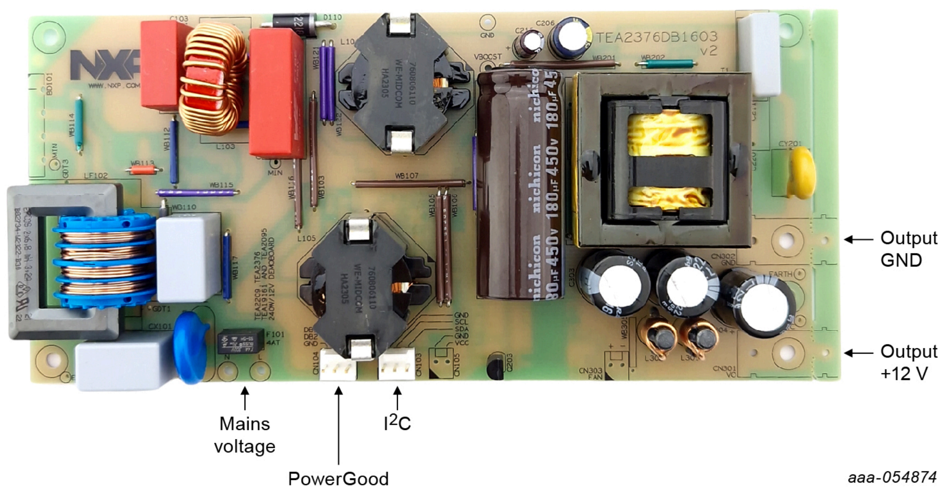


Figure 7. TEA2376DB1603v2 demo board

To show the benefits of an interleaved PFC with an active-bridge rectifier, the TEA2376DB1603V2 board design was made on a single-sided copper PCB with standard MOSFET types and without using heat sinks.

This board setup can be compared to similar 12 V × 20 A NXP demo boards showing a PFC + LLC combination with a single PFC controller: TEA1916DB1262, TEA2016DB1519, or TEA2017DB1580.

3.6 TEA2376 Ringo software and USB-I^{2}C interface

On the TEA2376DB1603v2 board, the TEA2376DT (SO14) version is used. This version includes two dedicated pins for I^{2}C communication that supports access to parameter modification, which is useful for product development work. During the power supply operation, the settings can be modified and the status information of the operation can be monitored.

3.6.1 TEA2376DT: dedicated SDA and SCL pins

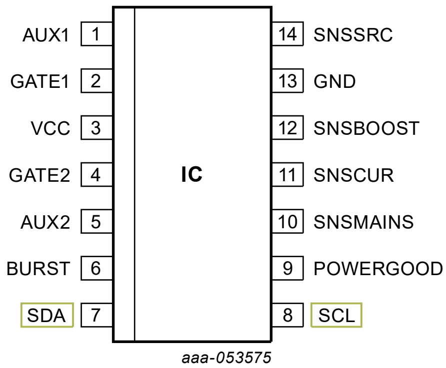


Figure 8. TEA2376DT: I^{2}C connections on pin 7 and pin 8

3.6.2 TEA2376AT: SDA and SCL on combined pins

In the basic TEA2376 version, the I^{2}C interface is available on the combined pins GATE1 (SDA) pin 2 and GATE2 (SCL) pin 4. To program the IC, it must be disabled at start-up with 0 V on SNSMAINS.

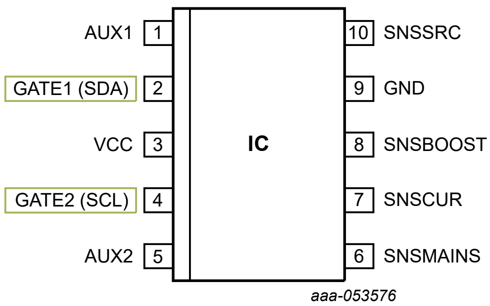


Figure 9. TEA2376AT: I^{2}C connections on pin 2 and pin 4

3.6.3 Ringo software with graphical user interface (GUI) and USB-I^{2}C interface

During power supply development, the communication with the IC can be done using the Ringo software on a Windows OS PC with a USB-I^{2}C interface (TEA2016DB1514 available as part of the RDK1DB1563 kit). The TEA2376 Ringo software with GUI provides the correct protocol and offers several options and tools to work with the IC settings and the readout status information.

The "TEA2376 development software with GUI user manual" (Ref. 5) and the "TEA2016DB1514 USB to I2C hardware interface user manual (Ref. 3) show how to work with it.

a. On the fly

b. Standalone

Figure 10. Two TEA2376 programming setups

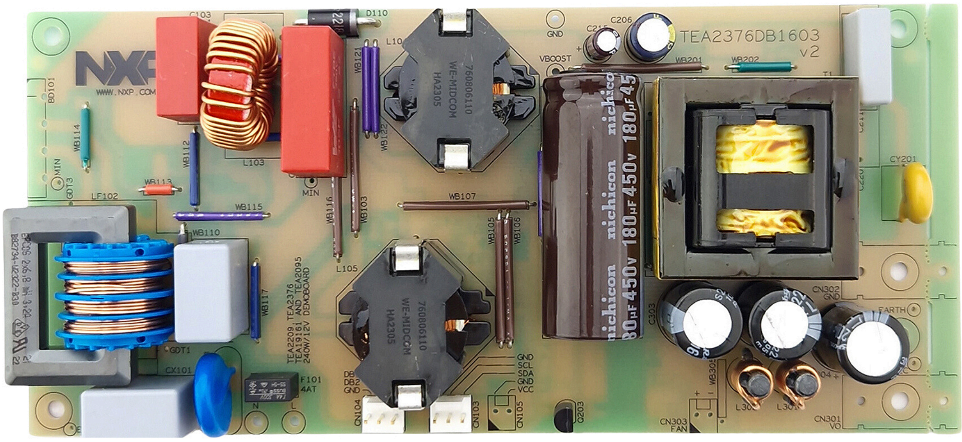
4 Finding kit resources and information on the NXP website

NXP Semiconductors provides information for the devices on the TEA2376DB1603 demo board at www.nxp.com.

5 Getting ready

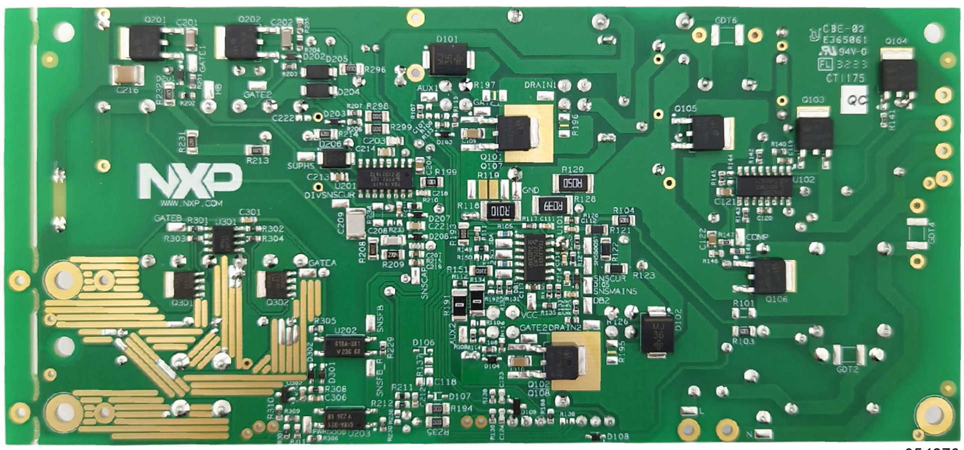
5.1 Box contents

The box contains the TEA2376DB1603v2 demo board. Figure 11 shows the top side and bottom side of the evaluation board.



aaa-054875

a. Top side



aaa-054876

b. Bottom side

Figure 11. TEA2376DB1603 demo board photographs

6 Getting to know the hardware

6.1 Specifications

Table 1. Specifications

Symbol	Description	Conditions	Values	Unit
V_i	input voltage	AC	90 to 264	V (RMS)
F_i	input frequency	-	47 to 63	Hz
$P_{i(no\ load)\_mains}$	no-load input power	at 230 V/50 Hz	< 80	mW
$P_{i(atPout=250mW)}$	standby input power		< 500	mW
V_o	output voltage	normal mode	12	V
$V_{o(min,max)}$	output voltage variations	load-step response	±5	%
I_o	output current	continuous	0 to 20	A
$I_{o(max)}$	maximum output current	OPP level	32	A
$I_{o(peak,max)}$	maximum peak current	t < 50 ms	32	A
t_{start}	start time	115 V/60 Hz, Io = 20 A	< 1500	ms
PF	power factor	I_o = 5 A; I_o = 20 A	> 0.95	-
iTHD	harmonic distortion	I_o = 5 A; I_o = 20 A	< 20	%
η	efficiency	average according to CoC	> 90	%

6.2 TEA2376 features

6.2.1 Distinctive features

- Interleaved PFC controller in an SO10 package (TEA2376AT) or an SO14 package (TEA2376BT and TEA2376DT)
- Programmable phase shedding and burst mode operation
- Dual output over voltage protection
- Inrush current protection
- High power factor (PF) and low total harmonic distortion (THD), also at high input voltages
- Many parameters can be configured during evaluation with the use of a user-friendly graphical user interface (GUI)
- Good phase control over the full input voltage range
- Low audible noise
- TEA2376DT: Power good output and a burst mode input pin
- TEA2376DT: Live monitoring of (internal) IC status values over time with the help of the user-friendly GUI similar to oscilloscope reading
- TEA2376DT: I^2C communication while in operation

6.2.2 Green features

- Valley/zero voltage switching for minimum switching losses
- High efficiency from high load to medium load and low load by phase shedding and burst mode operation

6.2.3 Protection features

- Protections can independently be set to latched, safe restart, or latched after several attempts to restart
- Dual output overvoltage protection (OVP)
- Supply undervoltage protection (UVP) and overvoltage protection (OVP)
- Internal and external overtemperature protection (OTP)
- Overcurrent protection (OCP)
- Inrush current protection (ICP)
- Brownin/brownout protection
- Open and short pin protection
- Coil short protection
- Output diode short protection
- Open control loop protection
- Phase fail protection

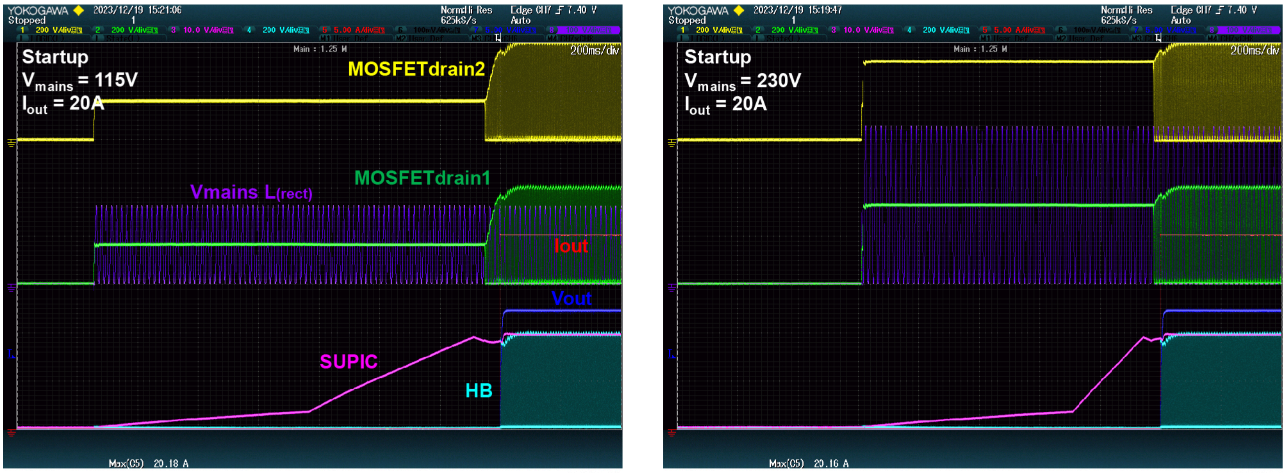
7 Performance measurements

7.1 Test facilities

- Oscilloscope: Yokogawa DLM4038
- AC power source: Agilent 6812B
- Electronic load: Agilent 6060B
- Digital power meter: Yokogawa WT210

7.2 Startup and switch off behavior

7.2.1 Start-up behavior



aaa-054880 aaa-054881

Figure 12. Start-up behavior

When connecting the mains voltage, the TEA19161 HV source charges the SUPIC capacitor to supply the ICs. The time it takes is 1300 ms at 115 V mains voltage and 1000 ms at 230 V mains voltage. For a shorter HV charge time, a capacitor with a lower value can replace the SUPIC capacitor C206 (150 µF).

7.2.2 Output voltage rise time

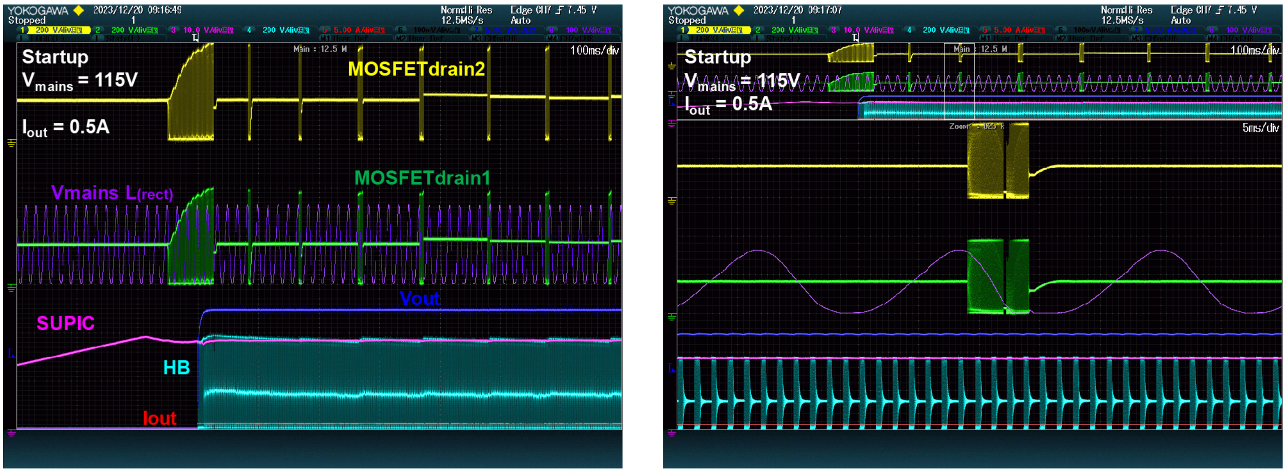
aaa-054882

aaa-054883

Figure 13. Output voltage rise time

The 12 V LLC output rise time is approximately between 4 ms and 10 ms. It depends on the output load condition at start-up.

7.2.3 Start-up and burst mode operation



aaa-054884

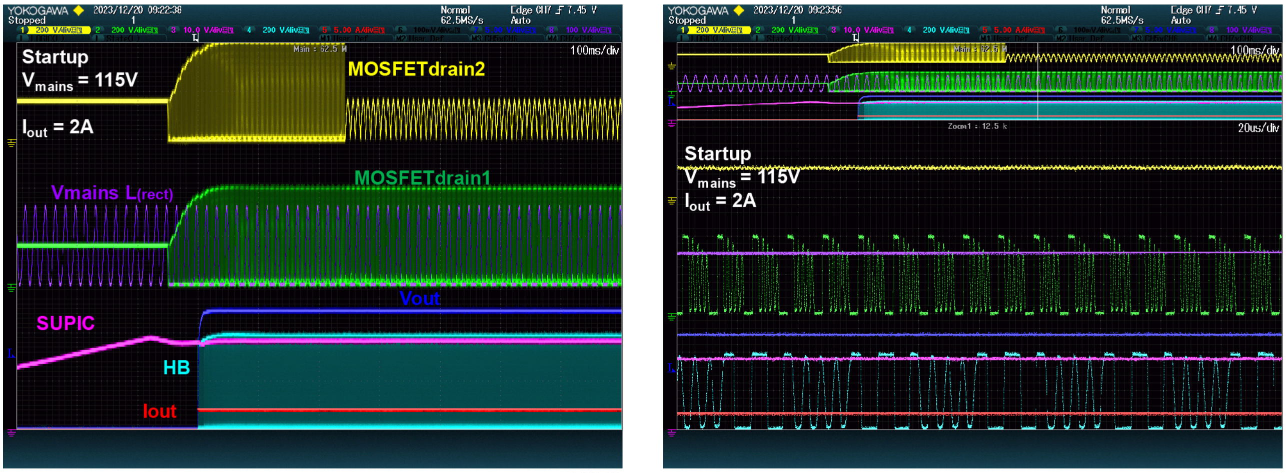
aaa-054885

Figure 14. Start-up followed by PFC and LLC burst mode operation

In the burst mode operation, the TEA19161 also controls the PFC burst via the SNSBOOST connection. The LLC burst repetition is according to the preset BM frequency on the TEA19161. A voltage hysteresis (100 mV) on the SNSBOOST pin start and stops the PFC burst.

7.2.4 Start-up and PFC shedding and LLC low-power mode operation

At lower load conditions, the PFC shedding and the LLC LP mode improve the efficiency. The transition power levels for these modes can be set independently using settings for each controller IC.



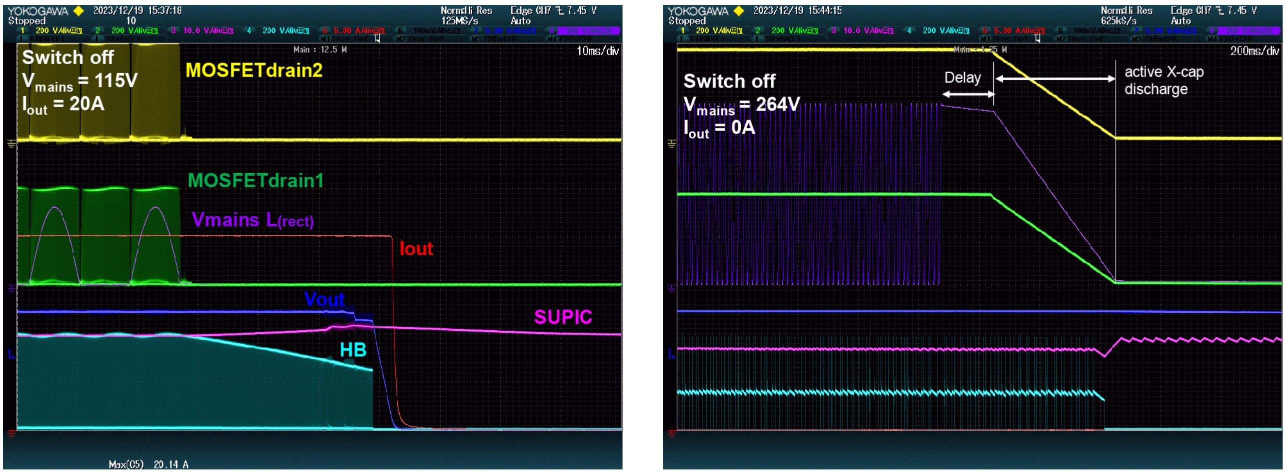
aaa-054886

aaa-054887

Figure 15. Start-up followed by PFC shedding and LLC low-power mode operation

7.2.5 Mains switch-off and X-capacitor discharge

At low-load conditions, the TEA2209T X-capacitor discharge function is activated.



aaa-054888

aaa-054889

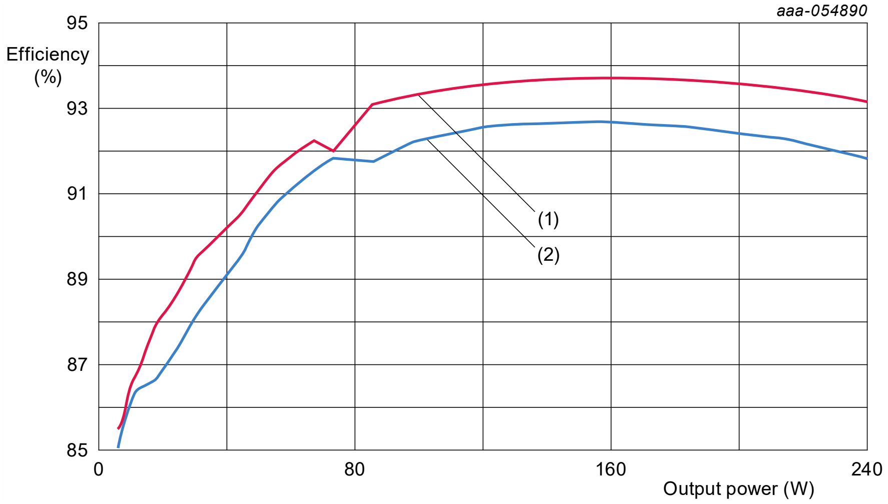
Figure 16. Mains switch-off behavior

7.3 Efficiency

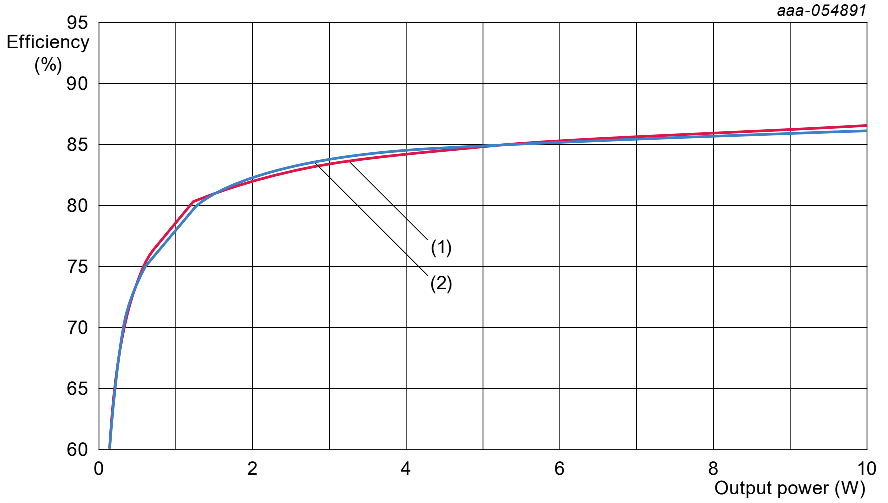
7.3.1 Efficiency characteristics

Table 2. Efficiency results

Condition	Average (%)	25 % load	50 % load	75 % load	100 % load
115 V/60 Hz	92.1	91.2	92.6	92.6	91.8
230 V/50 Hz	93.1	92.0	93.6	93.7	93.1



(1) V_{mains} = 230 V (AC)
(2) V_{mains} = 115 V (AC)



(1) V_{mains} = 230 V (AC)
(2) V_{mains} = 115 V (AC)

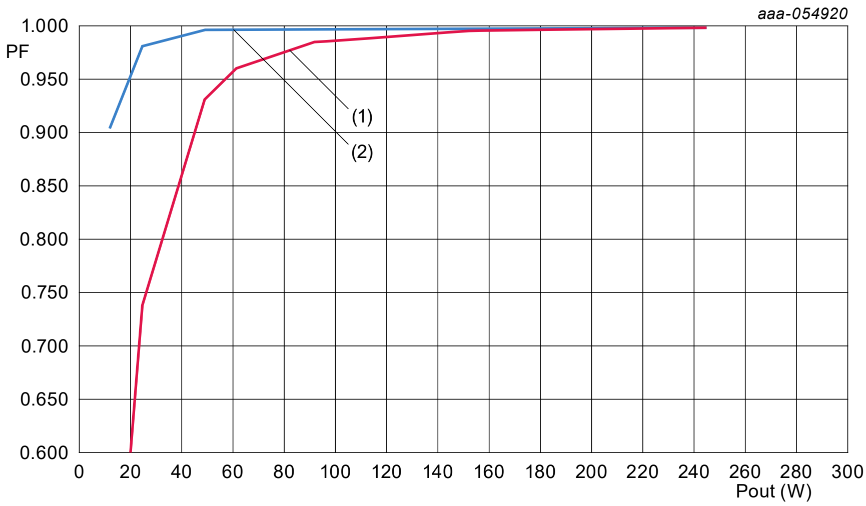
Figure 17. Efficiency graphs

7.3.2 No-load power consumption

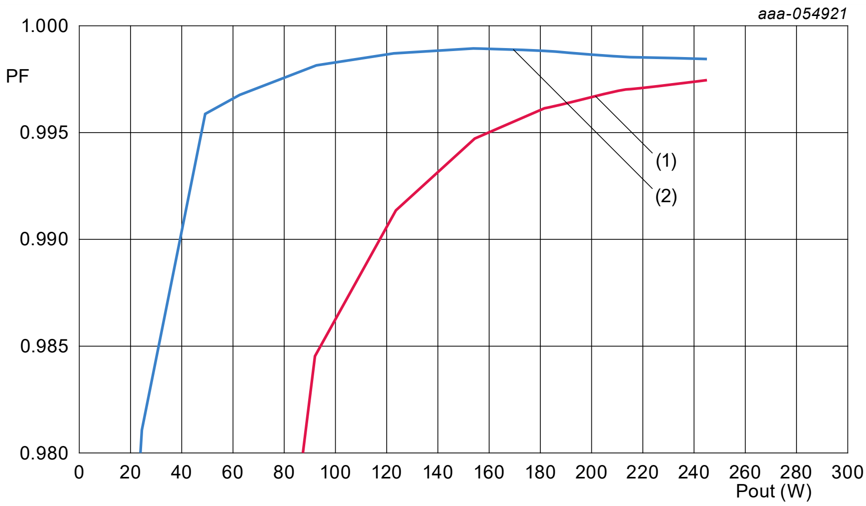
Table 3. Power consumption at no load

Condition	Requirement	No-load power consumption
115 V/60 Hz	≤ 100 mW	60 mW
230 V/50 Hz	≤ 100 mW	65 mW

7.3.3 Power factor



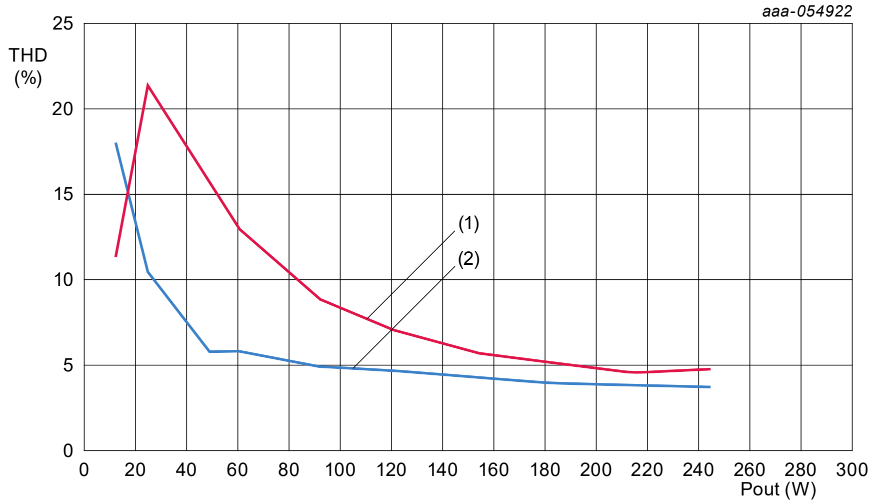
(1) V_{mains} = 230 V (AC)
(2) V_{mains} = 115 V (AC)



(1) V_{mains} = 230 V (AC)
(2) V_{mains} = 115 V (AC)

Figure 18. Power factor graphs

7.3.4 Harmonic distortion



(1) V_{mains} = 230 V (AC)
(2) V_{mains} = 115 V (AC)

Figure 19. Harmonic distortion (iTHD) graph

7.4 Operation mode transitions

There are five modes of operation:

1. PFC normal mode
2. LLC high-power mode
3. PFC phase shedding
4. LLC low-power mode
5. PFC + LLC burst mode (BM)

The transition levels can be modified using settings in the TEA2376 (MTP) and TEA19161 (external resistor settings).

7.4.1 Burst mode transitions

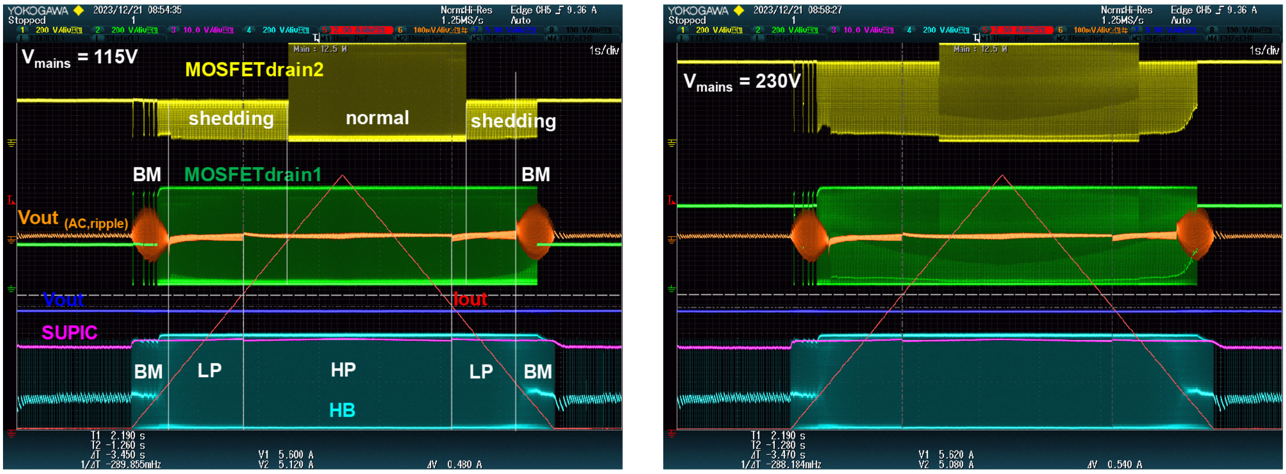
aaa-054923 aaa-054924

Load sweep: slowly varying the output current to observe mode transitions.

Figure 20. LLC BM - LP transition; PFC BM - phase shedding transition

- LLC BM to LP mode: P_{out} = 23 W
- PFC BM to phase shedding: P_{out} = 23 W

7.4.2 LLC LP mode transitions



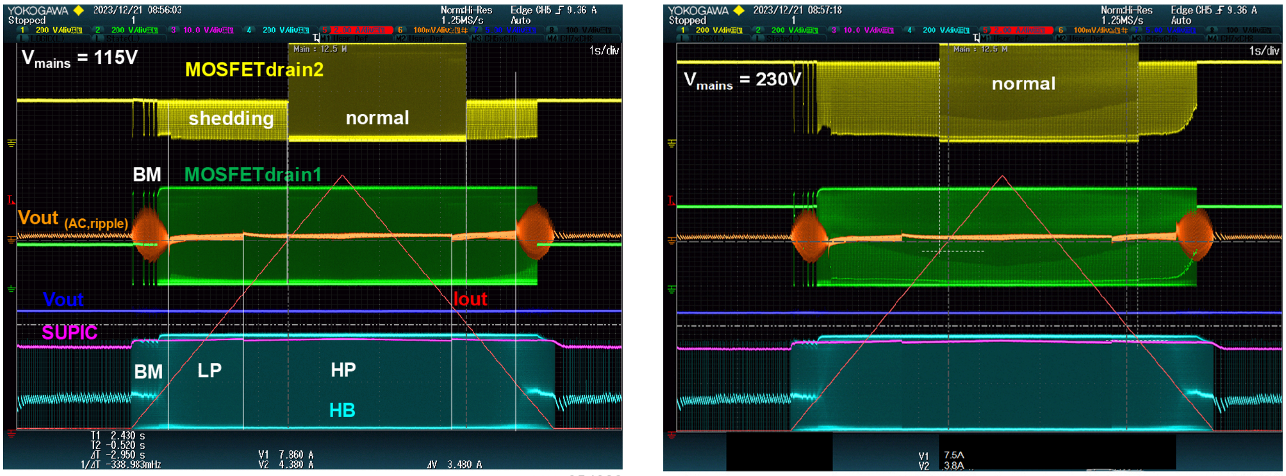
aaa-054925 aaa-054926

Load sweep: Slowly varying the output current to observe mode transitions.

Figure 21. LLC LP - HP transition; LLC HP - LP transition

- LLC LP to HP mode: P_{out} = 67 W
- LLC HP to LP mode: P_{out} = 61 W

7.4.3 PFC shedding mode transitions



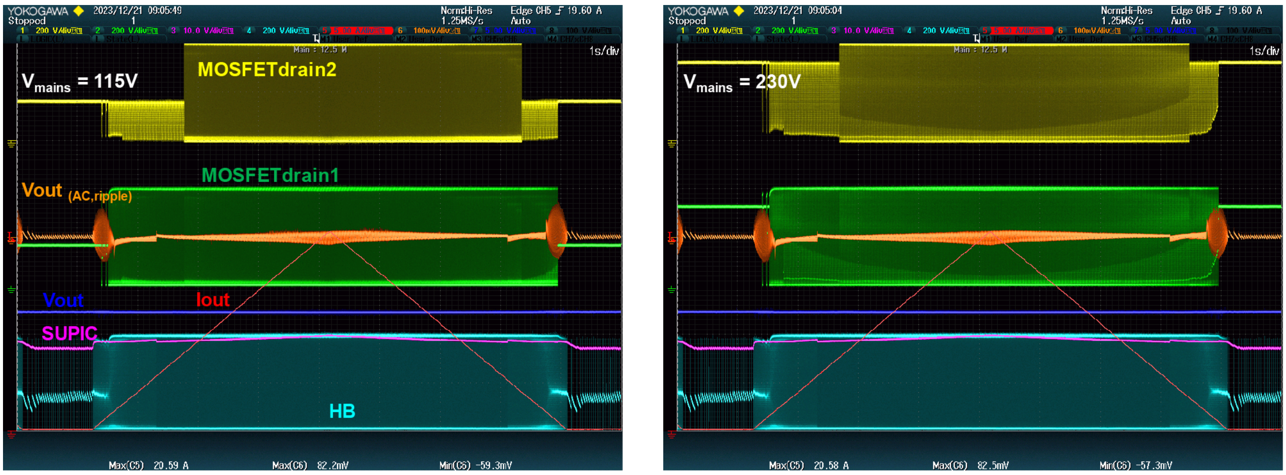
aaa-054929 aaa-054930

Load sweep: Slowly varying the output current to observe mode transitions.

Figure 22. PFC shedding – normal transition; PFC normal - shedding transition

- **V_{mains} = 115 V**
  – PFC shedding to normal mode: P_{out} = 94 W
  – PFC normal to shedding mode: P_{out} = 53 W
- **V_{mains} = 230 V**
  – PFC shedding to normal mode: P_{out} = 90 W
  – PFC normal to shedding mode: P_{out} = 46 W

7.4.4 Load sweep from 0 W to 240 W



aaa-054931 aaa-054932

Load sweep: Slowly varying the output current to observe mode transitions.

Figure 23. Load sweep from 0 W to 240 W

7.4.5 Maximum output voltage ripple

The maximum output voltage ripple is in burst mode operation at 50 % LLC burst duty cycle: 140 mVpp (see Figure 23).

7.5 Dynamic load response

Worse case load steps 0 A (0 %) to 20 A (100 %) show output voltage variations; 1 Hz: Output voltage 11.2 V to 12.6 V (−7 %, +5 %)

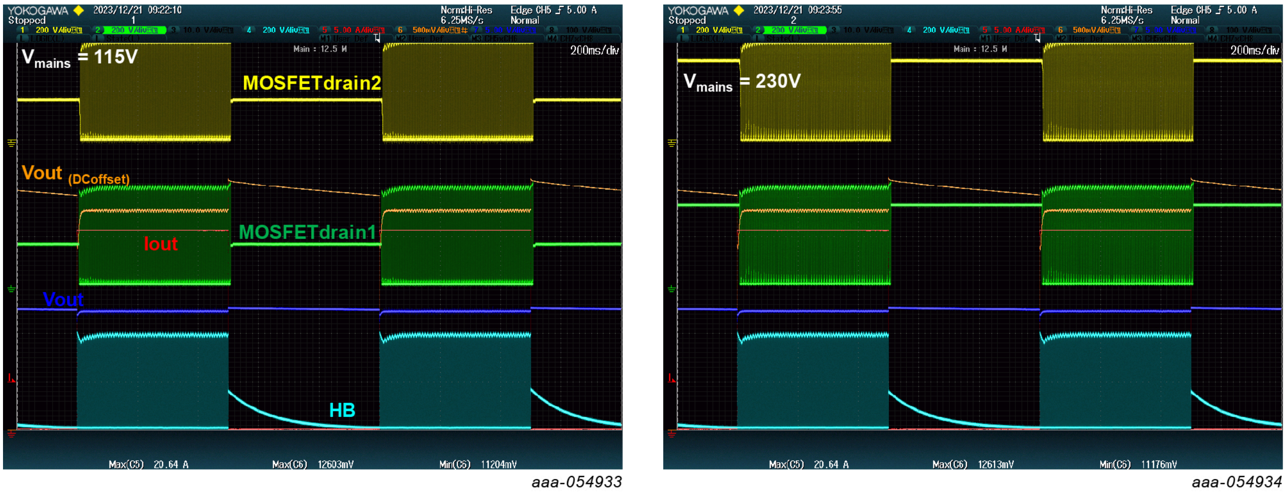


Figure 24. Load step behavior 0 A (500 ms) to 20 A (500 ms)

100 Hz: Output voltage 11.7 V to 12.5 V (−3 %, +4 %)

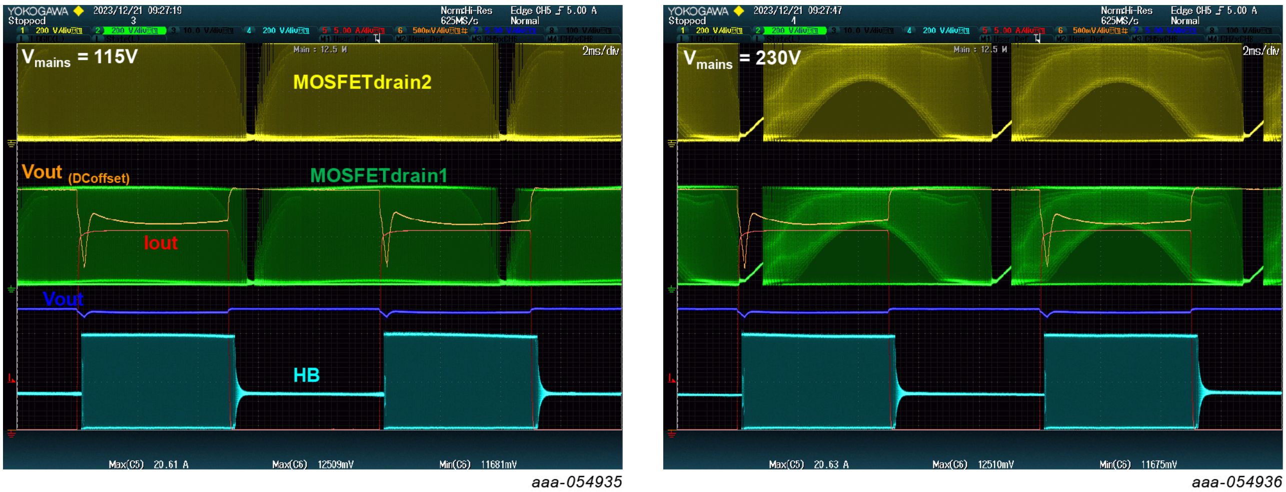
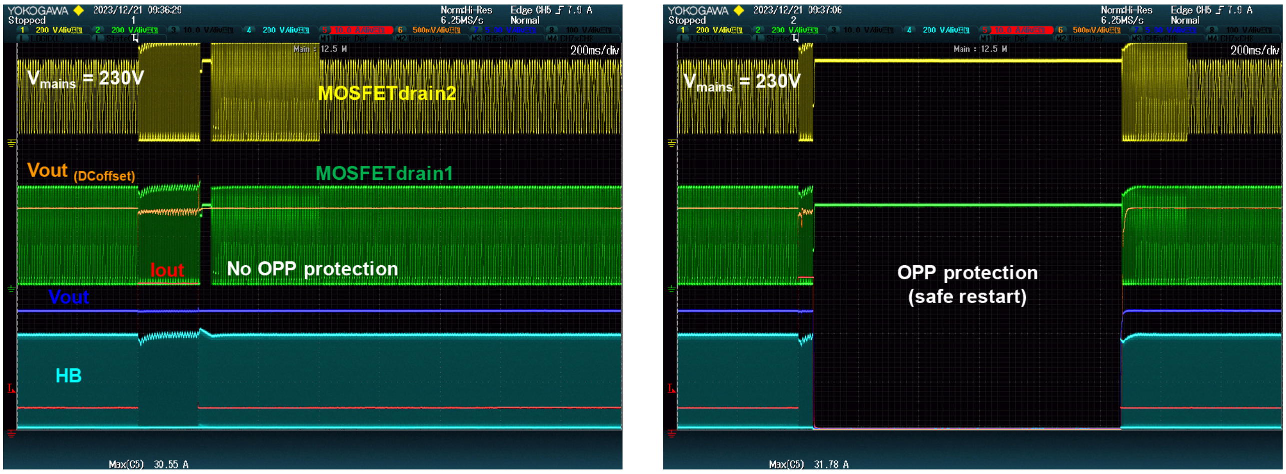


Figure 25. Load step behavior 0 A (5 ms) to 20 A (5 ms)

7.6 Peak output power capability

The maximum peak output power of the LLC converter is limited.

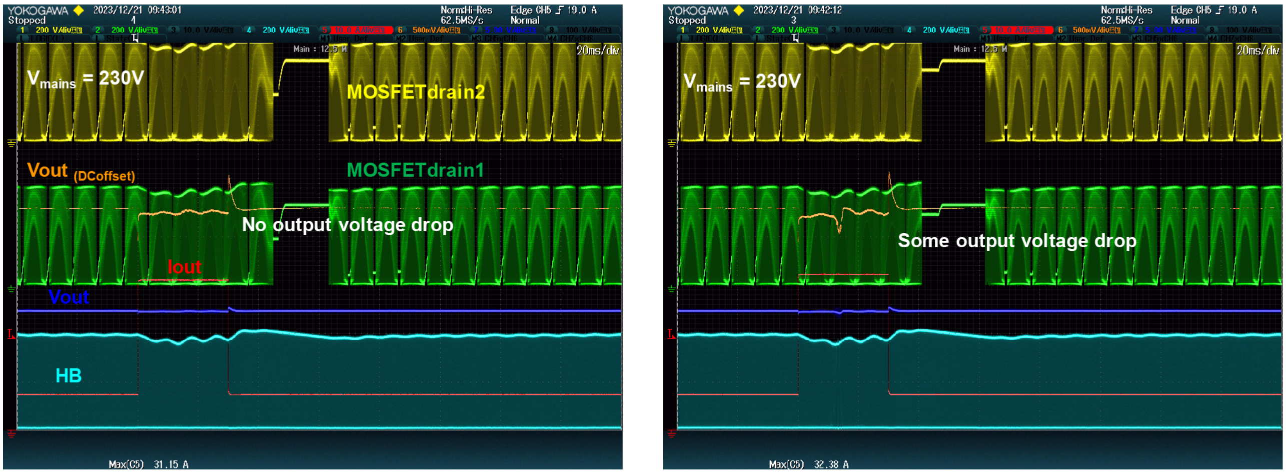
- Nominal P_{out} = 240 W (100 %)
- Overpower protection level = 372 W (155 %)
- Peak power limit = 384 W (160 %)



aaa-054937 aaa-054938

With a load step longer than 50 ms, the OPP output power level can be found; the system stops and safe restarts.

Figure 26. LLC OPP output power level



aaa-054939 aaa-054940

With a short load step, the maximum output power can be found; the output voltage drops.

Figure 27. LLC output power limit

7.7 Thermal information

To show the benefits of an interleaved PFC with an active bridge-rectifier circuit, the TEA2376DB1603v2 board design was made on a single-sided copper PCB with standard MOSFET types and without using heat sinks.

At an output power of 240 W, the temperature of the components remains acceptable with forced cooling (fan). The fan cooling is required for the high-current LLC output stage: 12 V at 20 A.

8 Schematic, bill of materials, layout

8.1 Schematic

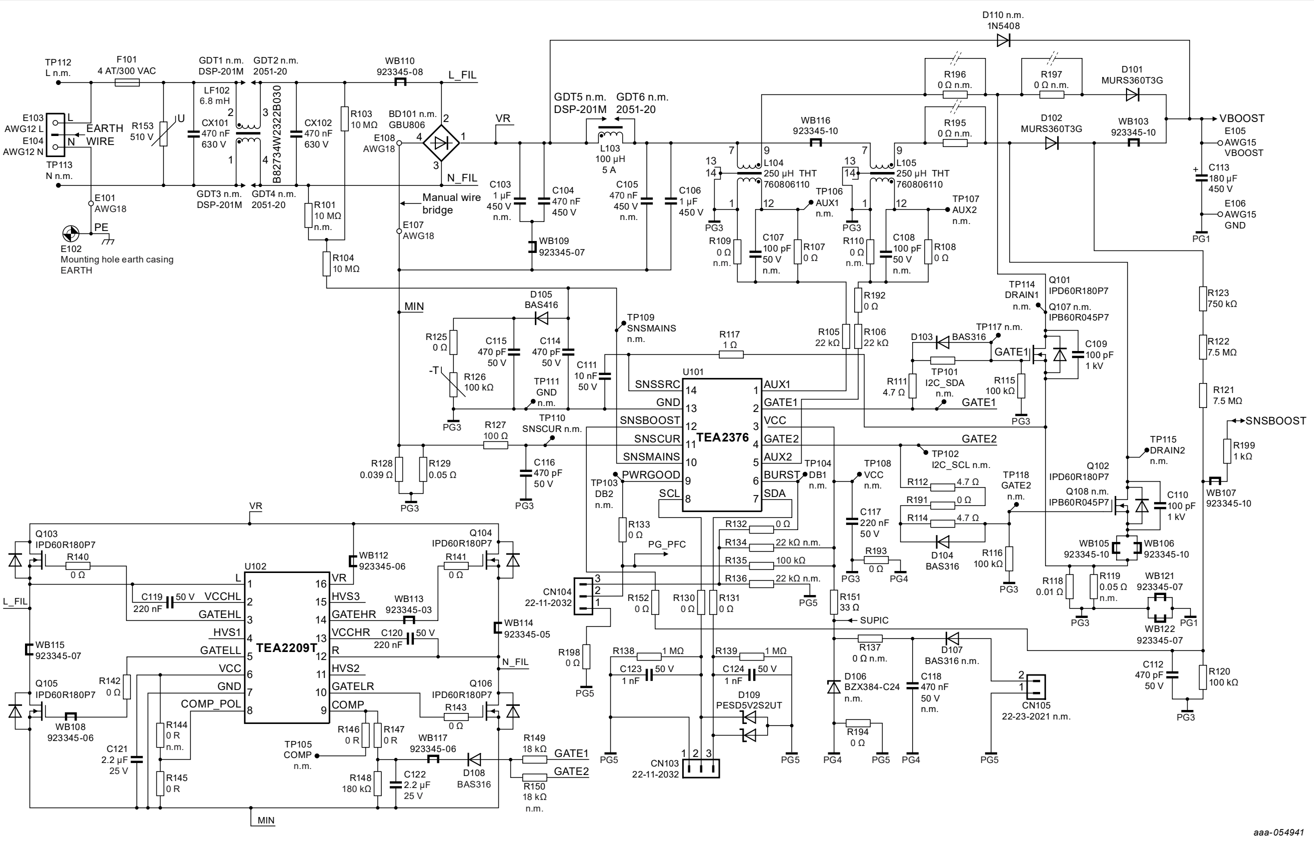


Figure 28. TEA2376DB1603v2 240 W demo board (PFC part)

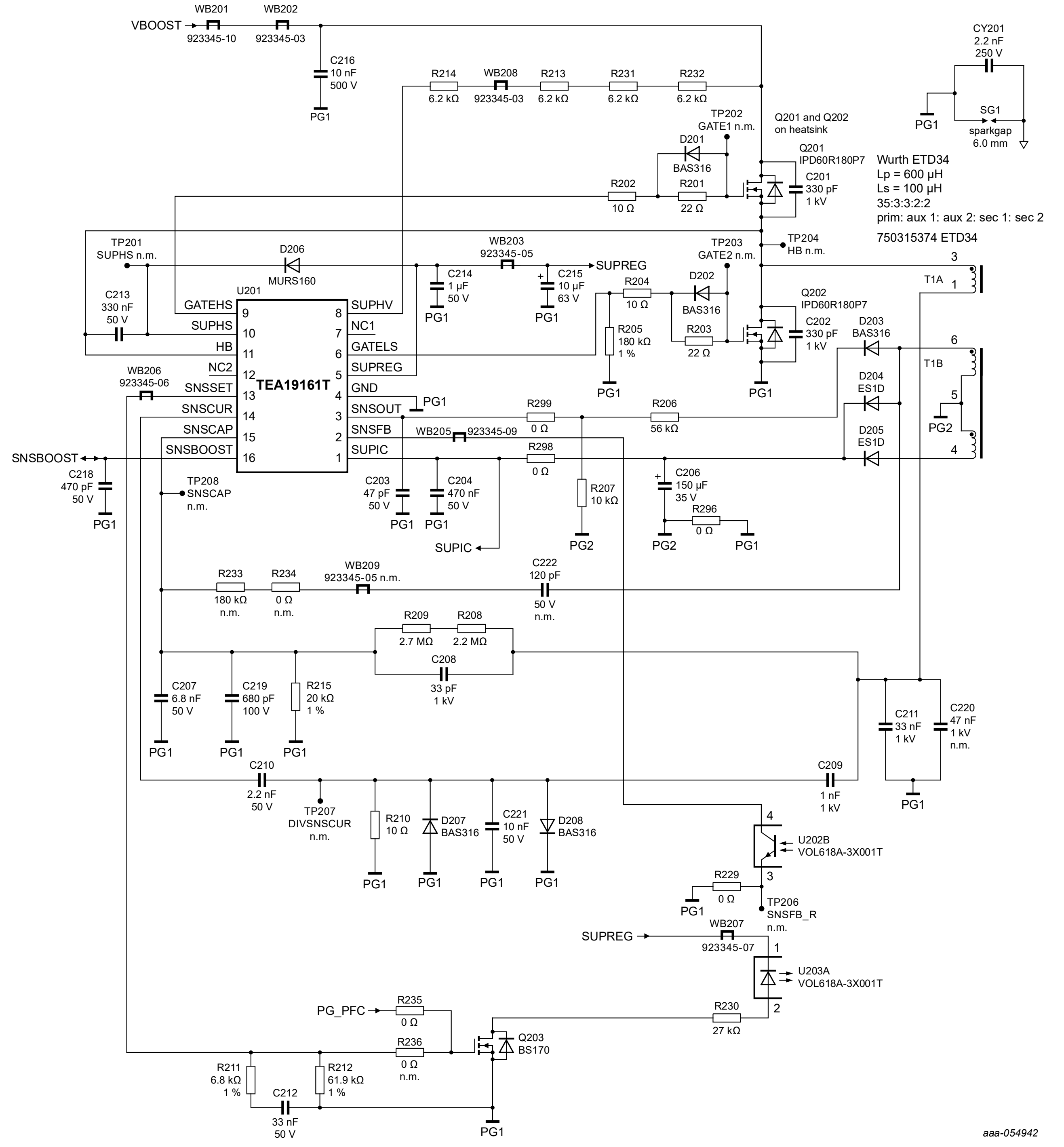


Figure 29. TEA2376DB1603v2 240 W demo board (LLC part)

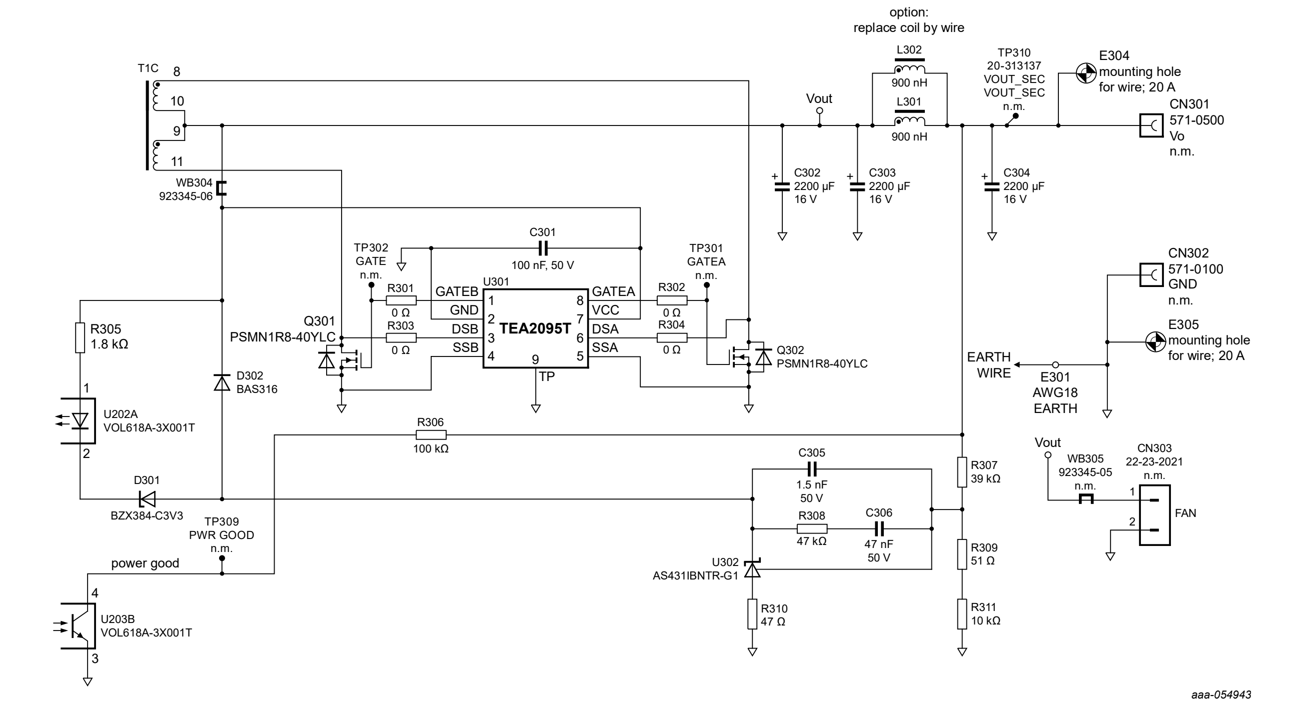


Figure 30. TEA2376DB1603v2 240W demo board (SR part)

8.2 Bill of material (BOM)

Table 4. Bill of materials

Part	Description and values	Part number	Manufacturer
BD101	bridge rectifier; not mounted; 600 V; 8 A	GBU806	Diodes Inc
C103	capacitor; not mounted; 1 μF; 10 %; 450 V; PET; THT	ECQE2W105KH	Panasonic
C104	capacitor; 470 nF; 10 %; 400 V; PET	890334025039	Würth Elektronik
C105	capacitor; not mounted; 470 nF; 10 %; 450 V; PET; THT	ECQE2W474KH	Panasonic
C106	capacitor; 1 μF; 10 %; 400 V; PET	890283426008CS	Würth Elektronik
C107; C108	capacitor; not mounted; 100 pF; 10 %; 50 V; C0G; 0603	-	-
C109; C110	capacitor; 100 pF; 10 %; 1 kV; X7R; 1206	-	-
C111	capacitor; 10 nF; 10 %; 50 V; X7R; 0603	-	-
C112; C114; C115; C116; C204	capacitor; 470 pF; 10 %; 50 V; X7R; 0603	-	-
C113	capacitor; 180 μF; 20 %; 450 V; ALU; THT	UPH2W181MHD	Nichicon Corp
C117; C119; C120	capacitor; 220 nF; 10 %; 50 V; X7R; 0603	-	-
C118	capacitor; not mounted; 470 nF; 10 %; 50 V; X7R; 0805	-	-
C121; C122	capacitor; 2.2 μF; 10 %; 25 V; X7R; 0805	-	-
C123; C124	capacitor; 1 nF; 5 %; 50 V; C0G; 0603	-	-
C201; C202	capacitor; 330 pF; 5 %; 1 kV; C0G; 1206	102R18N331JV4E	Johanson Dielectrics
C203	capacitor; 47 pF; 10 %; 50 V; X7R; 0805	-	-
C206	capacitor; 150 μF; 20 %; 35 V; ALU; THT	EEUFC1V151	Panasonic
C207	capacitor; 6,8 nF; 5 %; 50 V; C0G; 0603	C1608C0G1H561J080AA	TDK
C208	capacitor; 33 pF; 5 %; 1 kV; C0G; 1206	GRM31A5C3A330JW01D	Murata
C209	capacitor; 1 nF; 5 %; 1 kV; C0G; 1812	CC1812JKNPOCBN102	Yageo
C210	capacitor; 2.2 nF; 10 %; 50 V; X7R; 0603	-	-
C211	capacitor; 33 nF; 20 %; 1 kV; MKP; THT; X1	BFC233810333	Vishay
C212	capacitor; 33 nF; 10 %; 50 -V; X7R; 0603	-	-
C213	capacitor; 330 nF; 10 %; 50 V; X7R; 0805	-	-
C214	capacitor; 1 μF; 10 %; 50 V; X7R; 0805	-	-
C215	capacitor; 10 μF; 20 %; 63 V; ALU; THT	UPS1J100MDD1	Nichicon Corp
C216	capacitor; 10 nF; 10 %; 500 V; X7R; 1812	C1812C103KCRACTU	KEMET
C218	capacitor; 470 pF; 5 %; 50 V; C0G; 0603	-	-
C219	capacitor; 680 pF; 5 %; 100 V; C0G; 0603	C0603C681J1GACTU	KEMET
C220	capacitor; not mounted; 47 nF; 5 %; 1 kV; MKP; THT	BFC237520473	Vishay

Table 4. Bill of materials*...continued*

Part	Description and values	Part number	Manufacturer
C221	capacitor; 10 nF; 10 %; 50 V; X7R; 0805	-	-
C222	capacitor; not mounted; 120 pF; 5 %; 50 V; C0G; 0603	0603N121J500CT	Walsin Technology Corp
C301	capacitor; 100 nF; 10 %; 50 V; X7R; 0603	-	-
C302; C303; C304	capacitor; 2200 µF; 20 %; 16 V; ALU; THT	16ZLH2200MEFC12.5X20	Rubycon
C305	capacitor; 1.5 nF; 10 %; 50 V; X7R; 0603	-	-
C306	capacitor; 47 nF; 10 %; 50 V; X7R; 0603	-	-
CN103; CN104	header; straight; 1×3-way; 2.54 mm; gold plated	22-11-2032	Molex
CN105; CN303	header; straight; not mounted; 1×2-way; 2.54 mm; tin plated	22-23-2021	Molex
C301; C302	receptacle; not mounted; R/A; 4 mm; 1×2-way; red; 10 A	571-0500	Deltron Components Ltd
CX101; CX102	capacitor; 470 nF; 20 %; 630 V; MKP; THT; X2	BFC233922474	Vishay
CY201	capacitor; 2.2 nF; 20 %; 250 V; CER; THT	DE1E3KX222MA5B	Murata
D101; D102	diode; 600 V; 3 A	MURS360T3G	ON Semiconductor
D103; D104; D108; D201; D202; D203; D207; D208; D302	diode; 100 V; 250 mA	BAS316	NeXPeria
D105	diode; 85 V; 200 mA	BAS416	NeXPeria
D106	diode; Zener; not mounted; 24 V; 300 mW	BZX384-C24	NeXPeria
D107	diode; not mounted; 100 V; 250 mA	BAS316	NeXPeria
D109	ESD; Unidirectional; 5.2 V; Maximum 15 A; 30 kV	PESD5V2S2UT	NeXPeria
D110	diode; 1 kV; 3 A	1N5408	Vishay
D204; D205	diode; 140 V; 1 A	ES1D-E3	Vishay
D206	diode; 600 V; 1 A	MURS160	Vishay
D301	diode; Zener; 3.3 V; 300 mW	BZX384-C3V3	NeXPeria
F101	fuse; slow blow; 300 V (AC); 4 A	SS-5H-4A-APH	Cooper Bussmann
GDT1; GDT3; GDT5	gas discharge tube; not mounted; 200 V; 20 %; THT	DSP-201M	Mitsubishi Semiconductor
GDT2; GDT4; GDT6	gas discharge tube; not mounted; 200 V; 25 %; SMT	2051-20-SM-RPLF	Bourns Inc.
L103	inductor; 100 µH; 5 A	7447070	Würth Elektronik
L104; L105	inductor; PFC; 250 µH; 5.7 A	760806110	Würth Elektronik
L301; L302	inductor; 900 nH	APS-13903-NL	Axis Power
LF102	inductor; common mode; 6.8 mH; 3.2 A	B82734W2322B030	EPCOS

Table 4. Bill of materials...*continued*

Part	Description and values	Part number	Manufacturer
Q101; Q102; Q103; Q104; Q105; Q106; Q201; Q202	MOSFET-N; 650 V; 11 A	IPD60R180P7	Infineon
Q107; Q108	MOSFET-N; not mounted; 650 V; 38 A	IPB60R045P7	Infineon
Q203	MOSFET-N; 60 V; 500 mA	BS170	Fairchild
Q301; Q302	MOSFET-N; 40 V; 100 A	PSMN1R8-40YLC	NeXPeria
R101	resistor; not mounted; 10 MΩ; 1 %; 250 mW; 1206	-	-
R103; R104	resistor; 10 MΩ; 1 %; 250 mW; 1206	-	-
R105; R106	resistor; 51 kΩ; 1 %; 63 mW; 0603	-	-
R107; R108; R125; R130; R131; R132; R133; R140; R141; R142; R143; R145; R146; R147; R152; R229	resistor; jumper; 0 Ω; 63 mW; 0603	-	-
R109; R110; R144; R236	resistor; jumper;l not mounted; 0 Ω; 63 mW; 0603	-	-
R111; R113; R114	resistor; 4.7 Ω; 1 %; 63 mW; 0603	-	-
R112	resistor; 4.7 Ω; 1 %; 100 mW; 0603	-	-
R115; R116; R120; R135; R306	resistor; 100 kΩ; 1 %; 63 mW; 0603	-	-
R117	resistor; 1 Ω; 1 %; 63 mW; 0603	-	-
R118; R129	resistor; 0.01 Ω; 1 %; 1 W; 2512	RL2512FK-070R01L	Yageo
R119	resistor; not mounted; 0.05 Ω; 1 %; 1 W; 2512	RL2512FK-070R05L	Yageo
R121; R122	resistor; 7.5 MΩ; 1 %; 250 mW; 1206	CRCW12067M50FKEA	Vishay
R123	resistor; 750 kΩ; 1 %; 250 mW; 1206	-	-
R126	resistor; NTC; 100 kΩ; 1 %; 100 mW; 4250 K	NCU18WF104F60RB	Murata
R127	resistor; 100 Ω; 1 %; 63 mW; 0603	-	-
R128	resistor; 0.039 Ω; 1 %; 1 W; 2512	RL2512FK-070R039L	Yageo
R134; R136	resistor; not mounted; 22 kΩ; 1 %; 63 mW; 0603	-	-
R137	resistor; jumper; not mounted; 0 Ω; 125 mW; 0805	-	-
R138; R139	resistor; 1 MΩ; 1 %; 63 mW; 0603	-	-
R148	resistor; 180 kΩ; 1 %; 63 mW; 0603	-	-
R149	resistor; 18 kΩ; 1 %; 63 mW; 0603	-	-
R150	resistor; not mounted; 18 kΩ; 1 %; 63 mW; 0603	-	-

Table 4. Bill of materials*...continued*

Part	Description and values	Part number	Manufacturer
R151	resistor; 33 Ω; 1 %; 250 mW; 1206	-	-
R153	resistor; VDR; 510 V; 125 J	MOV-14D511K	Bourns Inc.
R191; R192	resistor; jumper; 0 Ω; 750 mW; 2010	RC2010JK-070RL	Yageo
R193; R194; R235; R296; R298; R299	resistor; jumper; 0 Ω; 250 mW; 1206	-	-
R195; R196; R197; R234	resistor; jumper; not mounted; 0 Ω; 250 mW; 1206	-	-
R198	resistor; jumper; 0 Ω; 100 mW; 0603	-	-
R199	resistor; 1 kΩ; 1 %; 250 mW; 1206	-	-
R201; R203	resistor; 1 kΩ; 1 %; 250 mW; 1206	-	-
R202; R204; R210	resistor; 22 Ω; 1 %; 63 mW; 0603	-	-
R205	resistor; 180 kΩ; 1 %; 63 mW; 0603	-	-
R206	resistor; 56 kΩ; 1 %; 63 mW; 0603	-	-
R207; R311	resistor; 10 kΩ; 1 %; 63 mW; 0603	-	-
R208	resistor; 2.2 MΩ; 1 %; 250 mW; 1206	-	-
R209	resistor; 2.7 MΩ; 1 %; 250 mW; 1206	-	-
R211	resistor; 6.8 kΩ; 1 %; 63 mW; 0603	-	-
R212	resistor; 61.9 kΩ; 1 %; 63 mW; 0603	-	-
R213; R214; R231; R232	resistor; 6.2 kΩ; 1 %; 250 mW; 1206	-	-
R215	resistor; 20 kΩ; 1 %; 63 mW; 0603	-	-
R230	resistor; 27 kΩ; 1 %; 63 mW; 0603	-	-
R233	resistor; not mounted; 180 kΩ; 5 %; 63 mW; 0603	-	-
R301; R302; R303; R304;	resistor; jumper; 0 Ω; 100 mW; 0603	-	-
R305	resistor; 1.8 kΩ; 1 %; 63 mW; 0603	-	-
R307	resistor; 39 kΩ; 1 %; 63 mW; 0603	-	-
R308	resistor; 47 kΩ; 1 %; 100 mW; 0603	-	-
R309	resistor; 51 Ω; 1 %; 63 mW; 0603	-	-
R310	resistor; 47 Ω; 1 %; 63 mW; 0603	-	-
T1	transformer; ETD34	750315374	Würth Elektronik

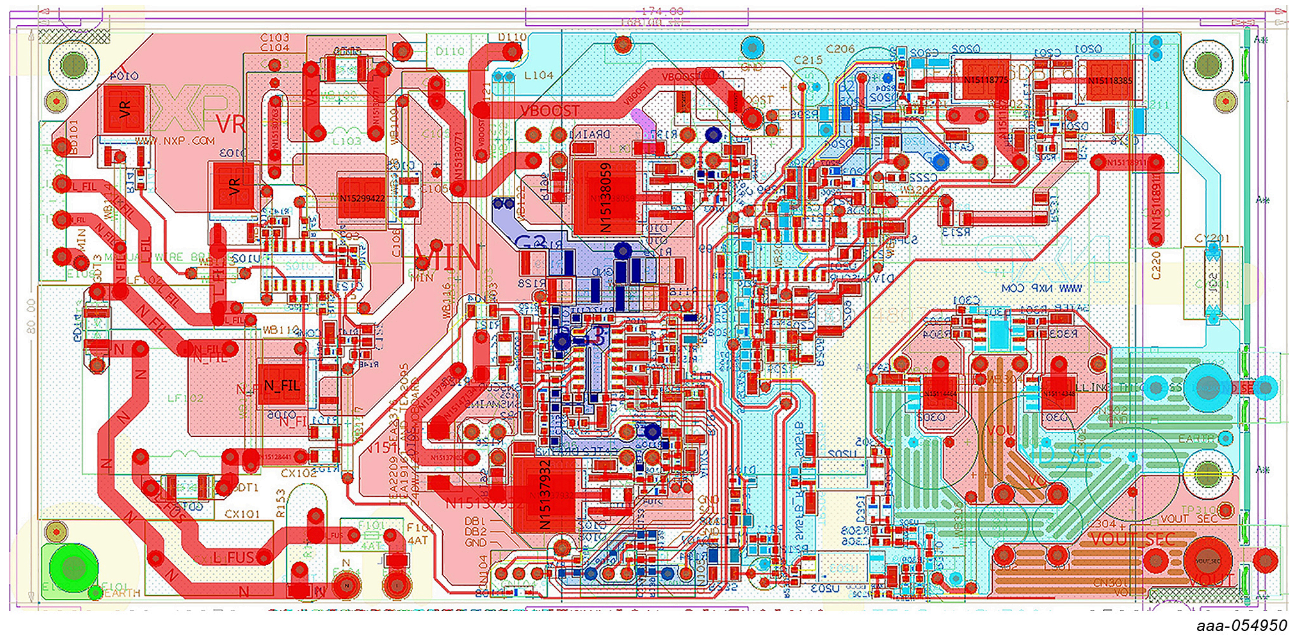
Table 4. Bill of materials*...continued*

Part	Description and values	Part number	Manufacturer
TP101; TP102; TP103; TP104; TP105; TP106; TP107; TP108; TP109; TP110; TP111; TP112; TP113; TP114; TP115; TP116; TP117; TP118; TP201; TP202; TP203; TP204; TP205; TP206; TP207; TP208; TP301; TP302; TP309	Testpoint; not mounted; 0805	RCT-0C	TE Connectivity
TP310	testpoint; Iso.; not mounted; 1.02 mm; red	20-313137	Vero Technologies
U101	interleaved PFC; TEA2376 (SO14)	TEA2376	NXP Semiconductors
U102	active bridge rectifier controller; TEA2209T	TEA2209T	NXP Semiconductors
U201	LLC controller; TEA19161T	TEA19161T	NXP Semiconductors
U202; U203	optocoupler; NPN; 80 V; 60 mA	VOL618A-3X001T	Vishay
U301	sync. rec. cntrl. ; dual ; TEA2095T	TEA2095T	NXP Semiconductors
U302	regulator; AS431	AS431IBNTR-G1	BCD Semi
WB103; WB105; WB106; WN107; WB116; WB201	wirebridge; 0.8 mm; P = 25.40 mm	923345-10	3M
WB108; WB112; WB117; WB206; WB304	wirebridge; 0.8 mm; P = 15.24 mm	923345-06	3M

Table 4. Bill of materials...*continued*

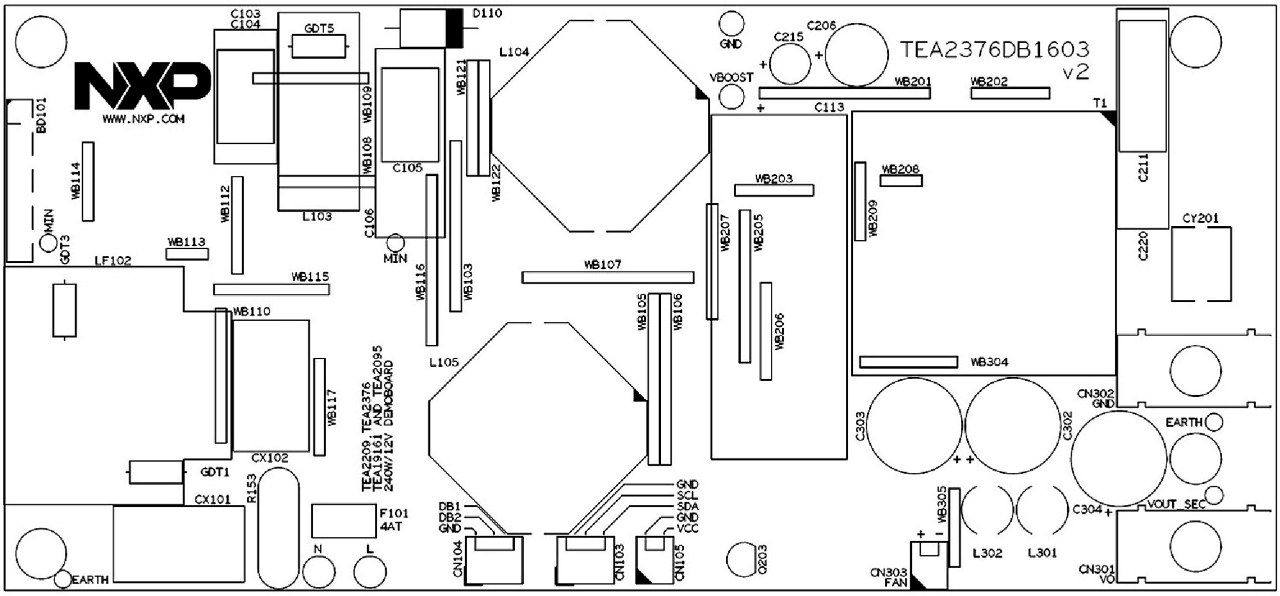
Part	Description and values	Part number	Manufacturer
WB109; WB115; WB121; WB122; WB207	wirebridge; 0.8 mm; P = 17.18 mm	923345-07	3M
WB110	wirebridge; 0.8 mm; P = 20.32 mm	923345-08	3M
WB113; WB208	wirebridge; 0.8 mm; P = 7.62 mm	923345-03	3M
WB114; WB202; WB203; WB209; WB305	wirebridge; 0.8 mm; P = 12.10 mm	923345-05	3M
WB205	wirebridge; 0.8 mm; P = 22.86 mm	923345-09	3M

8.3 PCB layout and board

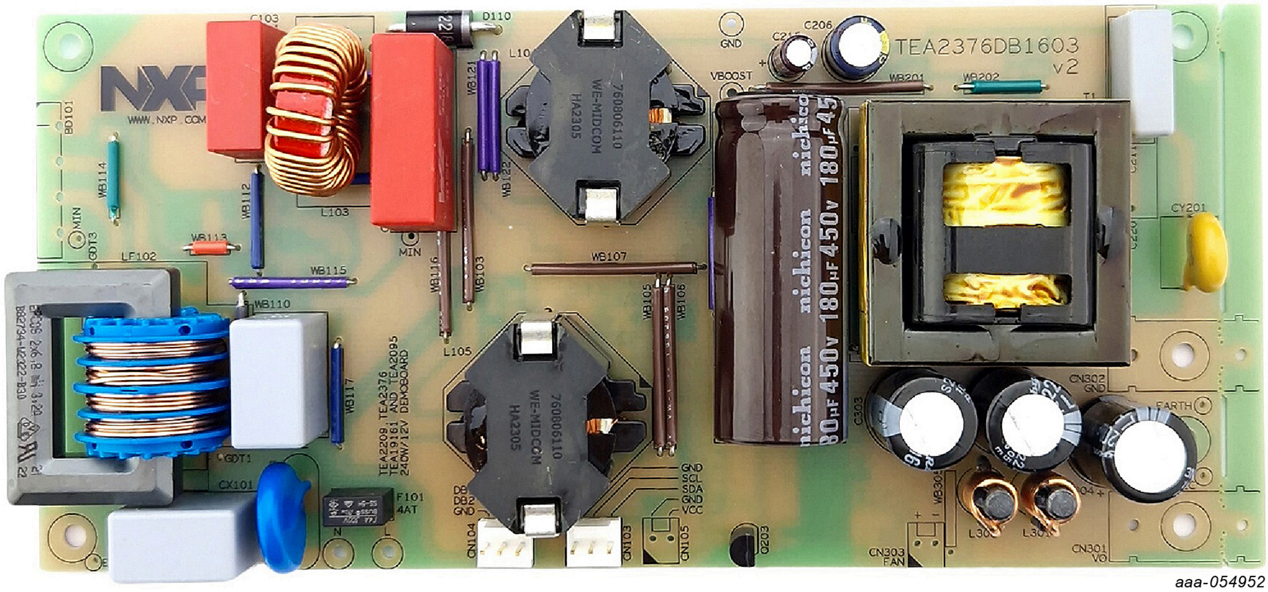


aaa-054950

Figure 31. TEA2376DB1603v2 PCB layout design (single side copper)

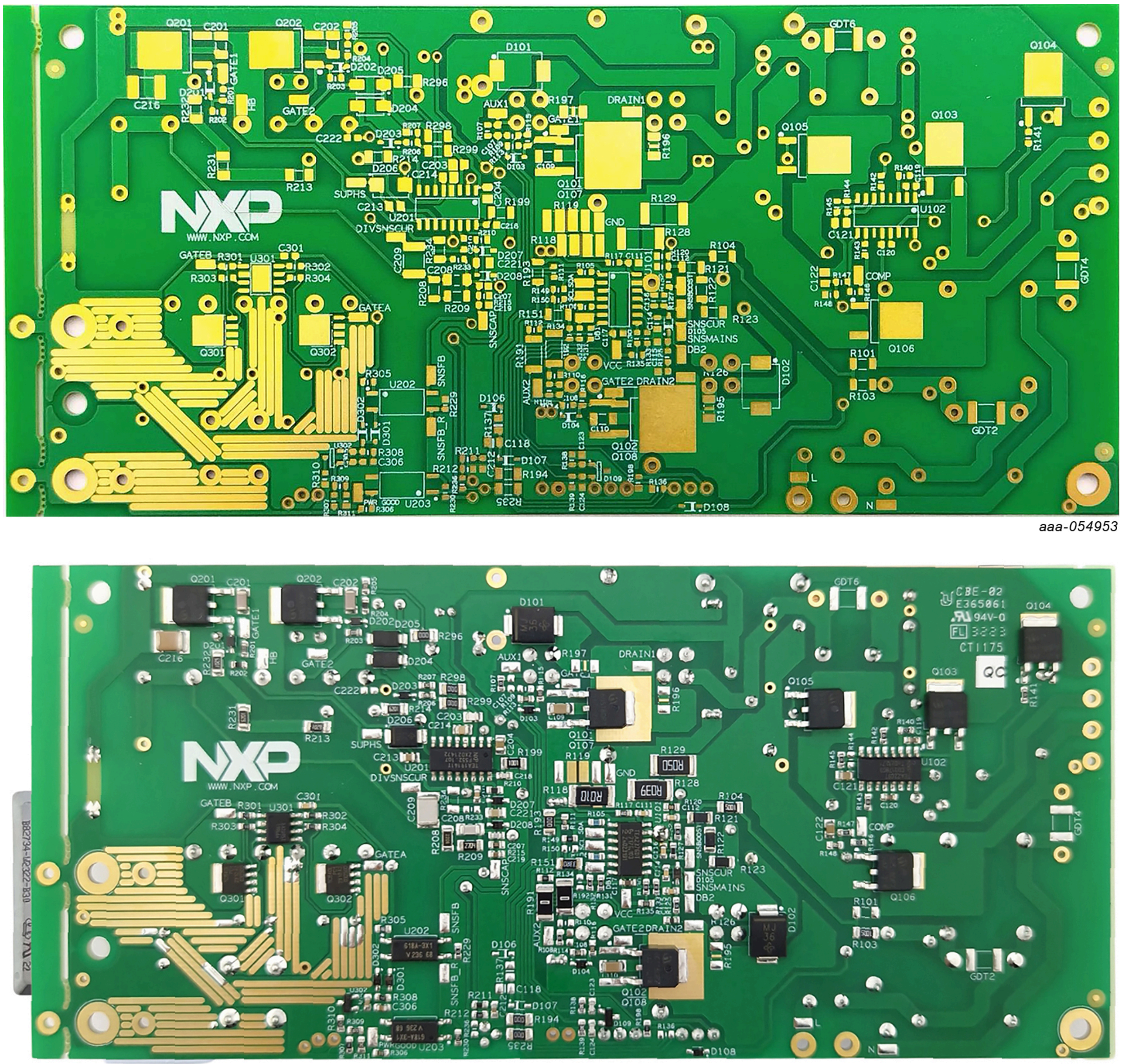


aaa-054951



aaa-054952

Figure 32. TEA2376DB1603v2 PCB pictures top side

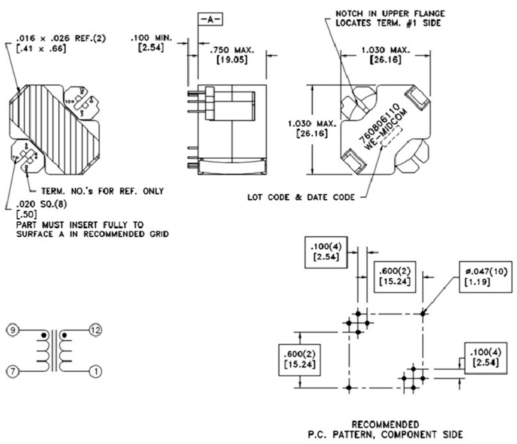


aaa-054953

aaa-054954

Figure 33. TEA2376DB1603v2 PCB pictures bottom side

8.4 PFC coil and LLC transformer specification



ELECTRICAL SPECIFICATIONS @ 25°C unless otherwise noted:

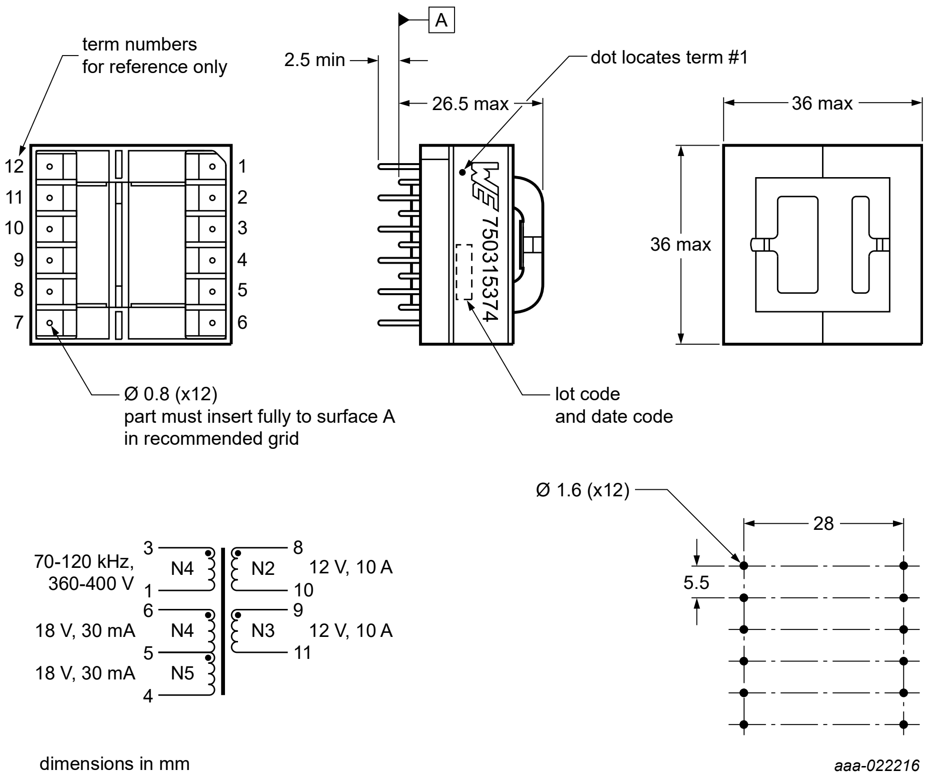
PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	9–7	@20°C	0.15 ohms max.
D.C. RESISTANCE	12–1	@20°C	0.05 ohms max.
INDUCTANCE	9–7	10kHz, 100mVAC, Ls	250uH ±10%
SATURATION CURRENT		20% rolloff from initial	5.7A typ.
DIELECTRIC	9–12	1200VAC, 1 second	1000VAC, 1 minute
TURNS RATIO		(9–7):(12–1)	13.3:1, ±2%

GENERAL SPECIFICATIONS:
OPERATING TEMPERATURE RANGE: −40°C to +125°C including temp rise.

aaa-053665

PFC coil winding (9-7): 40 turns
Auxilary winding (12-1): 3 turns

Figure 34. PFC coil specification



aaa-022216

Figure 35. LLC transformer

Table 5. LLC transformer specifications

Parameter	Values	Test conditions
DC resistance; 3-1	0.152 Ω; ±10	at 20 °C
DC resistance; 8-10	maximum 0.005 Ω	at 20 °C
DC resistance; 9-11	maximum 0.005 Ω	at 20 °C
DC resistance; 6-5	0.122 Ω; ±10	at 20 °C
DC resistance; 5-4	0.122 Ω; ±10	at 20 °C
inductance; 3-1	600 μH; ±10	10 kHz; 100 mV; L_s
saturation current; 3-1	1.7 A	20 % roll-off from initial
leakage inductance; 3-1	100 μH; ±10	tie(4+5+6, 8+9+10+11); 100 kHz; 100 mA; L_s
dielectric; 1-11	3200 V; 1 minute	tie(3-4, 10+11); 4000 V (AC); 1 s

9 TEA2376DT parameter settings

Table 6 provides a list of the parameters in the TEA2376DT MTP, which are available in this demo board. It shows the parameter name and the value. Parameter values that differ from the default programming of the TEA2376DT are highlighted in *italics*.

The Ringo GUI export function can generate a list with the MTP settings of an IC. It provides an overview of the selected values. It can be used for comparison, checking, or sharing the information. In addition to this list, the settings can be stored as a .mif file, which can be reloaded in the Ringo GUI software later or shared with others.

Table 6. TEA2376 MTP parameter settings in TEA2376DB1603v2

	Ringo parameter name	IC parameter name	Value	Unit	Binary value
1	VCC OVP	mtp_vcc_ovp	OK	-	0
2	AUX OVP	mtp_aux_ovp	OK	-	0
3	SNSBOOST short	mtp_snsboost_short	OK	-	0
4	SNSMAINS OVP	mtp_mains_ovp	OK	-	0
5	SNSSRC OCP	mtp_snssrc_ocp	OK	-	0
6	SNSCUR OCP	mtp_snscur_ocp	OK	-	0
7	SNSCUR short	mtp_snscur_short	OK	-	0
8	DIFF PHASE	mtp_diff_phase_fail	OK	-	0
9	POSAUX	mtp_posaux_fail	OK	-	0
10	NEGAUX	mtp_negaux_fail	OK	-	0
11	External OTP	mtp_eotp	OK	-	0
12	Internal OTP	mtp_iotp	OK	-	0
13	MTP read failure	mtp_read_fail	OK	-	0
14	Start up soft start time	mtp_t_start	25.6	ms	0
15	PFC voltage loop gain	mtp_vgain	0.4375	-	9
16	I2C ending delay on GATE	mtp_i2c_mode_to_sel	100	ms	0
17	Protection register logging	mtp_prot_reg_mtp_en	disabled	-	0
18	MTP writing	write_lock	enabled	-	0
19	MTP reading	read_lock	enabled	-	0
20	Brownin Level	mtp_brown_in_lvl	*6.3*	*µA*	*8*
21	Brownin/brownout hysteresis	mtp_brown_in_hys	*0.3*	*µA*	*2*
22	Brownout delay	mtp_brown_out_delay	50	ms	0
23	PFC valley switching	mtp_valleysw	enabled	-	1
24	Filter delay compensation	mtp_t_filt_delay	277	µs	0
25	Mains sensitivity	mtp_mains_sensitivity	low	-	0
26	Mains sensing resistor value	mtp_rmains	20	MΩ	1
27	Notch filter in regulation loop	mtp_notch_en	enabled	-	1
28	PFC gamma value	mtp_pfc_gamma	36	-	36

Table 6. TEA2376 MTP parameter settings in TEA2376DB1603v2*...continued*

	Ringo parameter name	IC parameter name	Value	Unit	Binary value
29	Mains peak zero crossing detection	mtp_pk_pos_detect	enabled	-	1
30	Mains sense wait time after NTC	mtp_t_snsmains_discharge	500	μs	0
31	Disable NTC during startup	mtp_ntc_chk_en	enabled	-	1
32	SNSMAINS phase factor	mtp_phase_factor	0.9375	-	0
33	SNSBOOST level low gain increase	mtp_level_gm_low	off	-	0
34	SNSBOOST low gain increase	mtp_gain_gm_low	2	-	0
35	VCC stop level	mtp_vcc_stop	8	V	0
36	Mains sensing resistors	mtp_nr_resistors	1 resistor	-	0
37	VCC start level	mtp_vcc_start	11	V	0
38	AUX sensing filter	mtp_fc_aux	5	MHz	0
39	AUX blanking time	mtp_t_aux_blank	600	ns	0
40	AUX high time for sec stroke	mtp_t_wait_aux_high	750	ns	0
41	Time slot for measuring NTC	mtp_t_meas_ntc	450	μs	0
42	NTC circuit diode voltage drop	mtp_udiode_dig0	460	mV	0
43	Number of phases controller	mtp_phase1_only	2	phase	0
44	Startup delay for AC/DC detection	mtp_wait_for_acdc	*normal*	-	*0*
45	Phase when no valley switching	mtp_force_phase_valley_dis	phase 180	-	0
46	Min switch on delay between phases	mtp_min_tps_diff_delay	204	ns	0
47	Max switch on delay between phases	mtp_max_tps_diff_delay	2	μs	0
48	Ipfc_peak for Fmin	mtp_vrsense_fmin	55	-	0
49	Delta Ipfc_peak for Fmax-Fmin	mtp_vrsense_fmax_fmin	110	-	0
50	Min PFC freq phase value	mtp_phi_imin	0.18	-	0
51	Max-min PFC freq phase value	mtp_phi_imin_imax	0.14	-	0
52	Minimum switching frequency	mtp_fmin	40	kHz	0
53	Maximum switching frequency	mtp_fmax	130	kHz	0
54	Power level for leaving Shedding	mtp_pshed_high_perc	30	%	3
55	Hysteresis for entering Shedding	mtp_pshed_hys_perc	10	%	0
56	Time delay for entering Shedding	mtp_time_shed	140	ms	0
57	Value of AUX measurement resistor	mtp_raux	33	kΩ	0
58	Duty cycle reduction at OCP	mtp_ocp_red	0.75	-	0
59	Soft start time BM	mtp_softstart_time	normal	-	0
60	Ton steps in soft stop CCM	mtp_softstop_tonstep	normal	-	0
61	Initial on time at startup	mtp_scale_duty_init	normal	-	0
62	Slope current	mtp_cur_limit_dc	0.75	-	0
63	Proportional loop gain	mtp_pgain	10	-	0

Table 6. TEA2376 MTP parameter settings in TEA2376DB1603v2*...continued*

	Ringo parameter name	IC parameter name	Value	Unit	Binary value
64	Regulation Vin compensation	mtp_vincomp	enabled	-	1
65	Regulation Vin current compensation	mtp_cur_vincomp	enabled	-	1
66	Regulation Tring compensation	mtp_tringcomp	enabled	-	1
67	QR mode switching	mtp_en_qr	enabled	-	1
68	CCM allowed	mtp_sel_ipfc_ok	when needed	-	0
69	AUX min oscillation level	mtp_osc_amin	17	V	0
70	AUX scaling oscillation to valley	mtp_osc_scale	1	-	0
71	AUX delay compensation	mtp_osc_offset	93	ns	0
72	AUX valley detection time out	mtp_osc_timeout	3	μs	0
73	AUX valley detection hysteresis	mtp_osc_hys	2	-	0
74	AUX demag time out	mtp_wait_mag	3	μs	0
75	Minimum GATE off time	mtp_toffmin	1	μs	0
76	Notch filter for mains frequency	mtp_ton_fir_filt	enabled	-	1
77	PFC current loop gain	mtp_igain	*25*	-	*0*
78	PFC current scaler	mtp_kdes	2.013	-	13
79	Limit the power at start	mtp_pwr_limit_start	255 no limit	-	0
80	Minimum secondary stroke time	mtp_minsecstroke	1	μs	0
81	Minimum stretch time	mtp_stretchmin	200	ns	0
82	Minimum Ides clamp level	mtp_idesmax_min	13	%	0
83	Ides clamp slope K	mtp_k_idesclamp	1	-	2
84	Ipfc clamp function	mtp_idesclamp_en	enabled	-	1
85	Slope clamp value	mtp_slope_clamp	512	-	0
86	SNSBOOST high gain increase	mtp_gain_gm_high	4	-	0
87	3ms blanking BI after BO	mtp_bi_blank	*enabled*	-	*1*
88	External OTP protection Level	mtp_gotp_limit	88	-	0
89	External OTP delay time	mtp_t_eotp	4	s	0
90	FLR only when protection	mtp_flr_only_at_prot	disabled	-	0
91	SNSBOOST low clears all protections	mtp_snsb_short_clr_prots	disabled	-	0
92	Fast latch reset delay time	mtp_flr_delay	50	ms	0
93	External OTP level multiplier	mtp_mult_gntc	32	-	0
94	Safe Restart Time	mtp_restart_time	1	s	0
95	VCC OVP delay	mtp_vcc_ovp_delay	1000	μs	0
96	AUX OVP level	mtp_aux_ovp_value	*215*	-	*0*
97	SNSMAINS OVP level	mtp_snsmains_ovp_value	420	mV	0

Table 6. TEA2376 MTP parameter settings in TEA2376DB1603v2*...continued*

	Ringo parameter name	IC parameter name	Value	Unit	Binary value
98	SNSBOOST OVP level	mtp_snsboostovp	2.63	V	0
99	VCC OVP level	mtp_vcc_ovp_limit	24	V	0
100	Max pos AUX voltage difference	mtp_min_auxpos_value	*20*	*(dig)*	*0*
101	Fast Latch Reset function	mtp_fast_latch_reset	disabled	-	0
102	PFC shortwinding delay cycles	mtp_max_drain_short_count	2500	-	0
103	OCP blanking time	mtp_ocp_blanking_time	250	ns	0
104	SNSCUR short detection level	mtp_snscur_short_det_lvl	30	-	0
105	Max SNSCUR cycles to show short	mtp_nr_snscur_short_cycles	*100*	*cycles*	*0*
106	Max AUX voltage difference in phases	mtp_max_vout_diff	25	(dig)	3
107	AUX voltage measurement filter	mtp_aux_v_filt_setting	4	cycles	0
108	AUX min time for valid stroke	mtp_tmin_pk_hold	750	ns	0
109	Max missed AUX primary strokes	mtp_max_missed_prim_strokes	100	cycles	0
110	Max missed AUX secondary strokes	mtp_max_missed_sec_strokes	100	cycles	0
111	SNSCUR current ratio	mtp_snscur_ratio	128	-	0
112	SNSBOOST pulldown at brownout	mtp_snsboost_pulldown_brownout	0	ms	0
113	SNSMAINS OVP prot follow up	mtp_mains_ovp_mode	disabled	-	0
114	VCC OVP prot follow up	mtp_vcc_ovp_mode	*disabled*	-	*7*
115	AUX OVP prot follow up	mtp_aux_ovp_mode	*safe restart*	-	*0*
116	SNSBOOST short prot follow up	mtp_snsb_short_mode	auto continue	-	0
117	SNSSRC over current prot follow up	mtp_snssrc_oc_mode	safe restart	-	0
118	Allow startup with mains DC	mtp_allow_startup_dc_load	disabled	-	0
119	SNSCUR over current prot follow up	mtp_snscur_oc_mode	safe restart	-	0
120	SNSCUR short protect follow up	mtp_snscur_short_mode	safe restart	-	0
121	Internal OTP prot follow up	mtp_iotp_mode	safe restart	-	0
122	External OTP prot follow up	mtp_eotp_mode	safe restart	-	0
123	AUX phase fail prot follow up	mtp_pf_vout_diff_mode	safe restart	-	0
124	AUX pos phase fail prot follow up	mtp_pf_pos_aux_mode	safe restart	-	0
125	AUX neg phase fail prot follow up	mtp_pf_neg_aux_mode	safe restart	-	0
126	Duration soft start/stop operation	mtp_bm_end_soft_start_stop	infinite	-	0
127	Burst mode SNSBOOST ripple	mtp_bmripple	105	mV	0
128	BM soft start	mtp_skip_soft_start	softstart	-	0
129	BM soft stop	mtp_skip_soft_stop	softstop	-	0
130	Burst mode delay time	mtp_burstdelay	0	s	0
131	Burst mode level	mtp_bmpth_low	10.9	%	0
132	Burst on/off level on VCC	mtp_bmvccth	10	V	0

Table 6. TEA2376 MTP parameter settings in TEA2376DB1603v2...*continued*

	Ringo parameter name	IC parameter name	Value	Unit	Binary value
133	Burst mode type	mtp_bm	*follow*	-	*2*
134	BM boost recover	mtp_boostrecover	disabled	-	0
135	External BM control pin	mtp_bm_ctrl_sel	*SNSBOOST*	-	*2*
136	BM depending on shedding	mtp_bm1phase	*1 phase only*	-	*1*
137	Burst starts with 1 phase	mtp_single_phase_burst_restart	disabled	-	0
138	BM hysteresis	mtp_bmpth_hys	3.1	%	0
139	SNSBOOST level to stop PG	mtp_pwrgood_stop_pct	0.5	-	0
140	Power good at mains brownout	mtp_pwrgood_bo_stop	*disabled*	-	*0*
141	SNSBOOST level for power good	mtp_pwrgood_start_lvl	*2.2*	*V*	*0*
142	Power Good polarity	tp_pwrgood_pol	normal	-	0
143	PG stopped by SNSBOOST	mtp_pwrgood_lvl_stop	enabled	-	1
144	Vendor code	mtp_code	*0x0000*	-	*0*

10 Abbreviations

Table 7. Abbreviations

Acronym	Description
BM	burst mode
CCM	continuous conduction mode
CMP	capacitive mode protection
DCM	discontinuous conductions mode
ICP	inrush current protection
MOSFET	metal-oxide-silicon field-effect transistor
OCP	overcurrent protection
OLP	open-loop protection
OTP	overtemperature protection
OVP	overvoltage protection
PCB	printed-circuit board
PF	power factor
PFC	power factor correction
QR	quasi-resonant
SR	synchronous rectifier
THD	total harmonic distortion

11 References

Many documents are included in the GUI of the Ringo software that can be downloaded from www.nxp.com.

[1] **TEA2376AT data sheet** — Digital configurable interleaved PFC controller; 2023, NXP Semiconductors

[2] **TEA2376DT data sheet** — Digital configurable interleaved PFC controller; 2023, NXP Semiconductors

[3] **UM11235 user manual** — TEA2016DB1514 USB to I2C hardware interface; 2019, NXP Semiconductors

[4] **AN14200** — TEA2376 application note (working title)

[5] **UM12042** — TEA2376 development software with GUI; 2024, NXP Semiconductors

12 Revision history

Table 8. Revision history

Document ID	Release date	Description
UM12047 v.1.0	13 March 2024	• Initial version

Legal information

Definitions

Draft — A draft status on a document indicates that the content is still under internal review and subject to formal approval, which may result in modifications or additions. NXP Semiconductors does not give any representations or warranties as to the accuracy or completeness of information included in a draft version of a document and shall have no liability for the consequences of use of such information.

Disclaimers

Limited warranty and liability — Information in this document is believed to be accurate and reliable. However, NXP Semiconductors does not give any representations or warranties, expressed or implied, as to the accuracy or completeness of such information and shall have no liability for the consequences of use of such information. NXP Semiconductors takes no responsibility for the content in this document if provided by an information source outside of NXP Semiconductors.

In no event shall NXP Semiconductors be liable for any indirect, incidental, punitive, special or consequential damages (including - without limitation - lost profits, lost savings, business interruption, costs related to the removal or replacement of any products or rework charges) whether or not such damages are based on tort (including negligence), warranty, breach of contract or any other legal theory.

Notwithstanding any damages that customer might incur for any reason whatsoever, NXP Semiconductors' aggregate and cumulative liability towards customer for the products described herein shall be limited in accordance with the Terms and conditions of commercial sale of NXP Semiconductors.

Right to make changes — NXP Semiconductors reserves the right to make changes to information published in this document, including without limitation specifications and product descriptions, at any time and without notice. This document supersedes and replaces all information supplied prior to the publication hereof.

Suitability for use — NXP Semiconductors products are not designed, authorized or warranted to be suitable for use in life support, life-critical or safety-critical systems or equipment, nor in applications where failure or malfunction of an NXP Semiconductors product can reasonably be expected to result in personal injury, death or severe property or environmental damage. NXP Semiconductors and its suppliers accept no liability for inclusion and/or use of NXP Semiconductors products in such equipment or applications and therefore such inclusion and/or use is at the customer's own risk.

Applications — Applications that are described herein for any of these products are for illustrative purposes only. NXP Semiconductors makes no representation or warranty that such applications will be suitable for the specified use without further testing or modification.

Customers are responsible for the design and operation of their applications and products using NXP Semiconductors products, and NXP Semiconductors accepts no liability for any assistance with applications or customer product design. It is customer's sole responsibility to determine whether the NXP Semiconductors product is suitable and fit for the customer's applications and products planned, as well as for the planned application and use of customer's third party customer(s). Customers should provide appropriate design and operating safeguards to minimize the risks associated with their applications and products.

NXP Semiconductors does not accept any liability related to any default, damage, costs or problem which is based on any weakness or default in the customer's applications or products, or the application or use by customer's third party customer(s). Customer is responsible for doing all necessary testing for the customer's applications and products using NXP Semiconductors products in order to avoid a default of the applications and the products or of the application or use by customer's third party customer(s). NXP does not accept any liability in this respect.

Terms and conditions of commercial sale — NXP Semiconductors products are sold subject to the general terms and conditions of commercial sale, as published at https://www.nxp.com/profile/terms, unless otherwise agreed in a valid written individual agreement. In case an individual agreement is concluded only the terms and conditions of the respective agreement shall apply. NXP Semiconductors hereby expressly objects to applying the customer's general terms and conditions with regard to the purchase of NXP Semiconductors products by customer.

Export control — This document as well as the item(s) described herein may be subject to export control regulations. Export might require a prior authorization from competent authorities.

Suitability for use in non-automotive qualified products — Unless this document expressly states that this specific NXP Semiconductors product is automotive qualified, the product is not suitable for automotive use. It is neither qualified nor tested in accordance with automotive testing or application requirements. NXP Semiconductors accepts no liability for inclusion and/or use of non-automotive qualified products in automotive equipment or applications.

In the event that customer uses the product for design-in and use in automotive applications to automotive specifications and standards, customer (a) shall use the product without NXP Semiconductors' warranty of the product for such automotive applications, use and specifications, and (b) whenever customer uses the product for automotive applications beyond NXP Semiconductors' specifications such use shall be solely at customer's own risk, and (c) customer fully indemnifies NXP Semiconductors for any liability, damages or failed product claims resulting from customer design and use of the product for automotive applications beyond NXP Semiconductors' standard warranty and NXP Semiconductors' product specifications.

Translations — A non-English (translated) version of a document, including the legal information in that document, is for reference only. The English version shall prevail in case of any discrepancy between the translated and English versions.

Security — Customer understands that all NXP products may be subject to unidentified vulnerabilities or may support established security standards or specifications with known limitations. Customer is responsible for the design and operation of its applications and products throughout their lifecycles to reduce the effect of these vulnerabilities on customer's applications and products. Customer's responsibility also extends to other open and/or proprietary technologies supported by NXP products for use in customer's applications. NXP accepts no liability for any vulnerability. Customer should regularly check security updates from NXP and follow up appropriately.

Customer shall select products with security features that best meet rules, regulations, and standards of the intended application and make the ultimate design decisions regarding its products and is solely responsible for compliance with all legal, regulatory, and security related requirements concerning its products, regardless of any information or support that may be provided by NXP.

NXP has a Product Security Incident Response Team (PSIRT) (reachable at PSIRT@nxp.com) that manages the investigation, reporting, and solution release to security vulnerabilities of NXP products.

NXP B.V. — NXP B.V. is not an operating company and it does not distribute or sell products.

Trademarks

Notice: All referenced brands, product names, service names, and trademarks are the property of their respective owners.

NXP — wordmark and logo are trademarks of NXP B.V.

GreenChip — is a trademark of NXP B.V.

Contents

Date of release: 13 March 2024
Document identifier: UM12047