UM12272

TEA2376DB1647 2.5 kW battery charger design example

Rev. 1.0 — 21 March 2025 User manual

Document information

Information	Content
Keywords	TEA2376DB1647, TEA2376, TEA2095T, TEA2226AT, TEA2209T, TEA19361T, TEA2096T, LPC5506JHI48, TJA1042, TEA2095DB1574, LLC converter, dual synchronous rectifier (SR) driver, SO8, high efficiency, power supply, 2.5 kW, PFC, interleaved, LLC, SR, Flyback, controller, converter, burst mode, shedding, active bridge rectifier, programmable settings, I^2C, battery charger
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 critical conduction mode with valley switching to optimize efficiency. The TEA2376 enables the building of an interleaved power factor converter, which is easy to design with a low external component count. The digital architecture is based on a configurable hardware state machine ensuring reliable real-time performance. To meet specific application requirements, many operation and protection settings of the PFC controller can be adjusted by loading new settings into the device with I^2C during the power supply development. Input current shaping is used for a high-power factor and a low THD. For a low-load operation, a good efficiency phase shedding and burst mode operation are included. In the burst mode operation, the power consumption of the IC is reduced. The TEA2376 contains many protections, like internal and external overtemperature protection (OTP), overcurrent protection (OCP), dual overvoltage protection (OVP), inrush current protection (ICP), pin open and pin short protection, and phase-fail protection. The protections can be configured independently, using programmable parameters. The TEA2376DB1647 design example shows an interleaved PFC converter (TEA2376) with an active bridge rectifier (TEA2209T), an LLC resonant converter (TEA2226AT), and a synchronous rectifier (TEA2096T), and a flyback controller (TEA19361T), an MCU (LPC5506JHI48), a CAN communication controller (TJA1042). The design example can provide maximum 2.5 kW output power in laboratory conditions. It is a suitable design for battery charger applications, which require constant voltage and constant current control.

1 Important notice

IMPORTANT NOTICE

For engineering development or evaluation purposes only

NXP provides this evaluation product under the following conditions:

Evaluation kits or reference designs are intended solely for technically qualified professionals, specifically for use in research and development environments to facilitate evaluation purposes. This evaluation kit or reference design is not a finished product, nor is it intended to be a part of a finished product. Any software or software tools provided with an evaluation product are subject to the applicable terms that accompany such software or software tool.

The evaluation kit or reference design 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. This evaluation kit or reference design 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 evaluation product. Due to the open construction of the evaluation 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:

- Product developers to evaluate electronic components. circuitry, or software associated with the kit to determine if such items are incorporated in a finished product.
- Software developers to write the software applications for use with the end product.

This kit is not a finished product. When assembled, it cannot be resold or otherwise marketed unless all required FCC equipment authorizations are obtained first. Operation is subject to the condition that this product does not cause harmful interference to licensed radio stations and that this product accepts 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. When used in uncontrolled, non-laboratory environments, an isolated housing is obligatory. 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.

a. Isolated

b. Not isolated

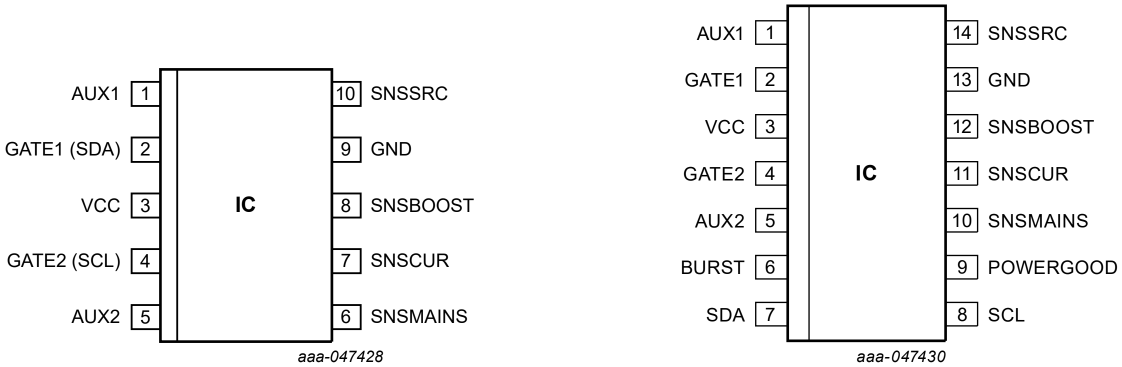
Figure 1. Isolation symbols

3 Introduction

3.1 TEA2376

The TEA2376 provides high efficiency at all power levels. Together with a TEA2209T active bridge-rectifier controller, a TEA2226AT LLC controller. and a TEA2096T SR controller, a high-performance, cost-effective resonant power supply can be designed, which meets modern power supply efficiency regulations.

An extensive number of parameter settings for operation and protections, which can be stored/programmed in an internal memory define the operation modes and protections. This feature provides flexibility and ease of design to optimize the controller properties to application-specific requirements or even optimize/correct the performance during power supply production. At start-up, the IC loads the parameter values for operation. For easy design work during product development, the TEA2376DT version is available 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 as 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.

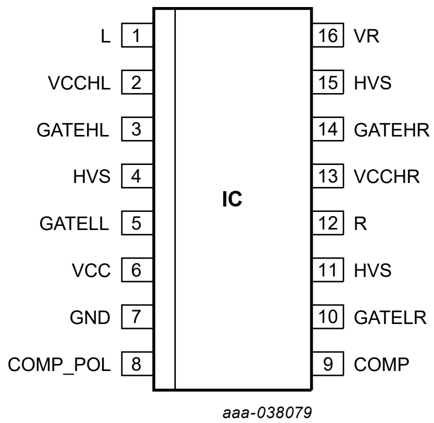


Figure 3. TEA2209T pinning diagram

3.3 TEA2226AT

The TEA2226AT is a digital configurable controller for high-efficiency resonant power supplies. The power supply is easy to design and has a very low component count. It meets the efficiency regulations of Energy Star, the Department of Energy (DoE), the Eco-design directive of the European Union, the European Code of Conduct, and other guidelines. So, no auxiliary low-power supply is required. To increase the efficiency of a low-voltage supply output, the TEA2095T dual SR controller can be added on the secondary side.

In contrast to traditional resonant topologies, the TEA2226AT achieves a high efficiency at low loads due to the low-power mode. This mode operates in the power region between continuous switching (also called high-power mode) and the burst mode.

Because the TEA2226AT is regulated via the primary capacitor voltage, it has accurate information about the power delivered to the output. The measured output power defines the mode of operation (burst mode, low-power mode, or high-power mode).

The TEA2226AT LLC controller enables the building of an easy to design, highly efficient, and reliable power supply. The power supply can provide 90 W to 1000 W output power with a minimum of external components. It has a very low no-load input power (< 75 mW) and a high efficiency from minimum to maximum load. So, no additional low-power supply is required, which ensures a significant system cost saving and a highly simplified power supply design, while meeting the latest power supply guidelines and regulations.

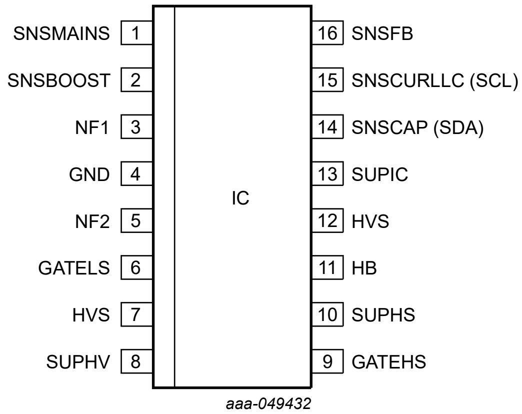


Figure 4. TEA2226AT pinning diagram

3.4 TEA2096T

The TEA2096T is a synchronous rectifier (SR) controller IC for switched-mode power supplies. It incorporates an adaptive gate drive method for maximum efficiency at any load.

The TEA2096T is a dedicated controller IC for synchronous rectification on the secondary side of resonant converters. It has 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.

The TEA2096T is optimized for efficient operation with very low-ohmic MOSFETs and switching at high frequencies.

The TEA2096T is fabricated in a silicon-on-insulator (SOI) process.

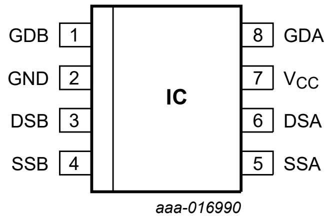


Figure 5. TEA2096T pinning diagram

3.5 TEA19361T

The TEA19361T is a member of the GreenChip family of controller ICs for switched-mode power supplies. It is intended for flyback topologies. The built-in green functions provide high efficiency at all power levels.

At high power levels, the flyback converter operates in quasi-resonant (QR) mode. At lower power levels, the controller switches to frequency reduction (FR) in discontinuous conduction mode (DCM) operation. The peak current is limited to a minimum level. Valley switching is used in all operating modes.

At very low power levels, the controller uses burst mode to regulate the output power. A special optocoupler current reduction regulation, which reduces the average optocoupler current in all modes to a minimum level, has been integrated. This reduction ensures high efficiency at low power and an excellent no-load power performance. As the switching frequency in this mode is never less than $f_{sw(min)}$ and the burst repetition rate is regulated to a low value, the audible noise is minimized. During the non-switching phase of the burst mode, the internal IC supply current is minimized for further efficiency optimization.

The TEA19361T includes a wide set of protections that are safe-restart protections. One of these protections is an accurate overpower protection (OPP). If the output is shorted, the system stops switching and restarts. The output power is then limited to a lower level.

The TEA19361T is manufactured in a high-voltage silicon-on-insulator (SOI) process. The SOI process combines the advantages of a low-voltage process (accuracy, high-speed protection, functions, and control). However, it also maintains the high-voltage capabilities (high-voltage start-up, low standby power, and brownin/ brownout sensing at the input).

The TEA19361T enables low-cost, highly efficient, and reliable supplies for power requirements up to 75 W using a minimum number of external components.

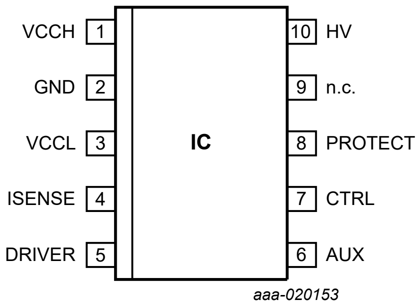


Figure 6. TEA19361T pinning diagram

3.6 LPC5506JHI48

The LPC55S0x/LPC550x is an Arm Cortex-M33-based microcontroller for embedded applications. These devices include:

- CASPER crypto engine
- Up to 256 KB on-chip flash
- Up to 96 KB of on-chip SRAM
- PRINCE module for on-the-fly flash encryption/decryption
- Code watchdog
- CAN FD
- Five general-purpose timers
- One SCTimer/PWM
- One RTC/alarm timer
- One 24-bit multirate timer (MRT)
- Windowed watchdog timer (WWDT)
- Nine flexible serial communication peripherals (which can be configured as a USART, SPI, high-speed SPI, I^2C, or I^2S interface)
- Programmable logic unit (PLU)
- One 16-bit 2.0 Msamples/sec ADC capable of simultaneous conversions
- Comparator
- Temperature sensor

The Arm Cortex-M33 provides a security foundation, offering isolation to protect valuable IP and data with Trustzone technology. It simplifies the design and the software development of digital signal control systems with the integrated digital signal processing (DSP) instructions. To support security requirements, the LPC55S0x/LPC550x also offers support for secure boot, HASH, AES, RSA, UUID, DICE, dynamic encrypt and decrypt, debug authentication, and TBSA compliance.

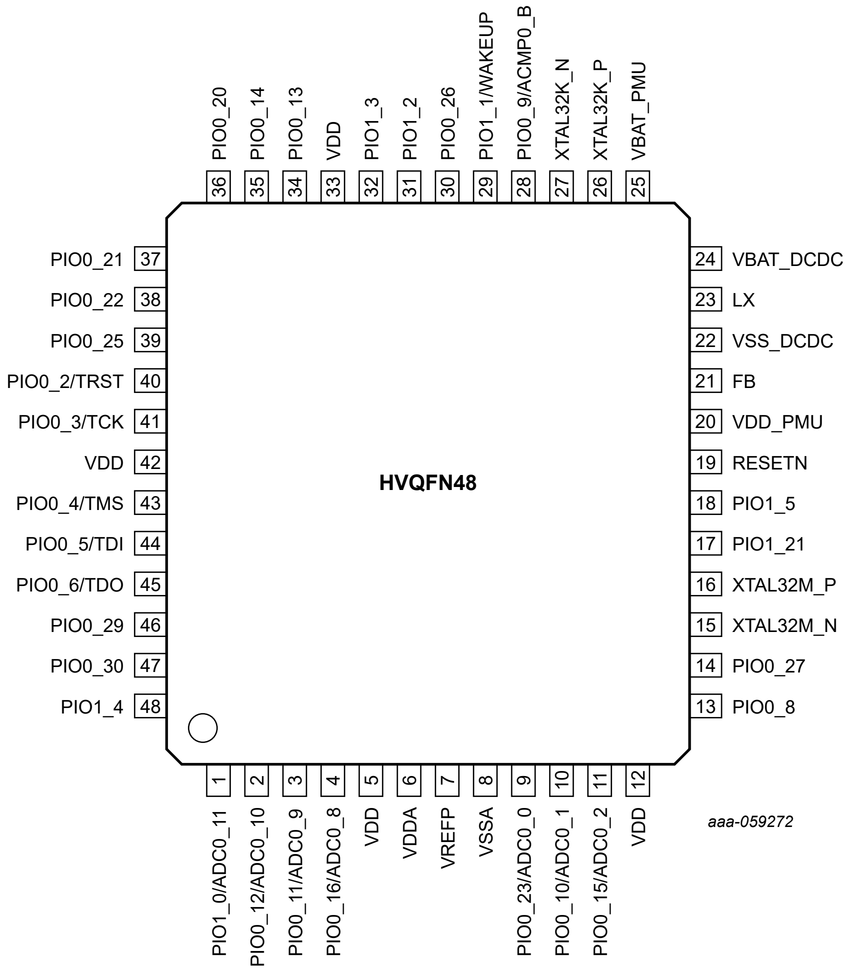


Figure 7. LPC5506JHI48 pin configuration diagram

3.7 TJA1042

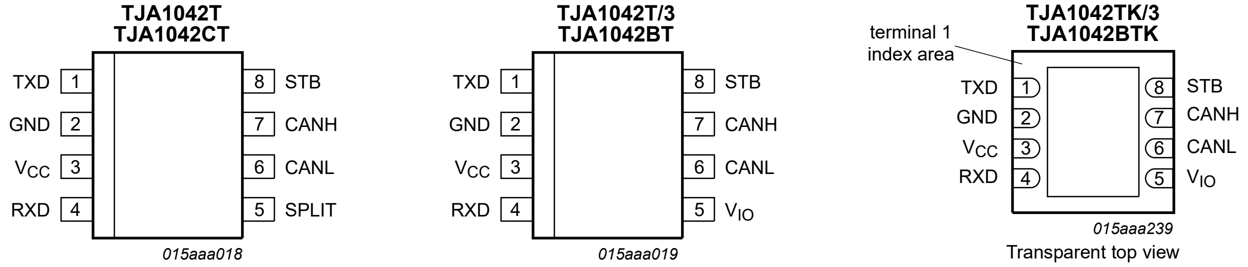
The TJA1042 high-speed CAN transceiver provides an interface between a controller area network (CAN) protocol controller and the physical two-wire CAN bus. The transceiver is designed for high-speed CAN applications in the automotive industry, providing the differential transmit and receive capability to (a microcontroller with) a CAN protocol controller.

The TJA1042 belongs to the third generation of high-speed CAN transceivers from NXP Semiconductors, offering significant improvements over first-generation and second-generation devices, such as the TJA1040. It offers improved electromagnetic compatibility (EMC) and electrostatic discharge (ESD) performance, and also features:

- Ideal passive behavior to the CAN bus when the supply voltage is off.
- A very low-current Standby mode with bus wake-up capability.
- Variants with a VIO pin can be interfaced directly with microcontrollers with supply voltages from 3.3 V to 5 V.

The TJA1042 implements the CAN physical layer as defined in ISO 11898-2:2016 and SAE J2284-1 to SAE J2284-5. This implementation enables reliable communication in the CAN FD fast phase at data rates up to 5 Mbit/s. The TJA1042B and TJA1042C feature shorter propagation delay, supporting larger network topologies.

These features make the TJA1042 an excellent choice for all types of HS-CAN networks, in nodes that require a low-power mode with wake-up capability via the CAN bus.



a. SO8 b. SO8 c. HVSON8

Figure 8. TJA1042 pinning diagrams

4 Finding kit resources and information on the NXP website

NXP Semiconductors provides online resources for this user manual and its supported devices at https://www.nxp.com.

4.1 Collaborate in the NXP community

In the NXP community you can share ideas and tips, ask and answer technical questions, and receive input on any embedded design topic. The NXP community can be found at https://community.nxp.com.

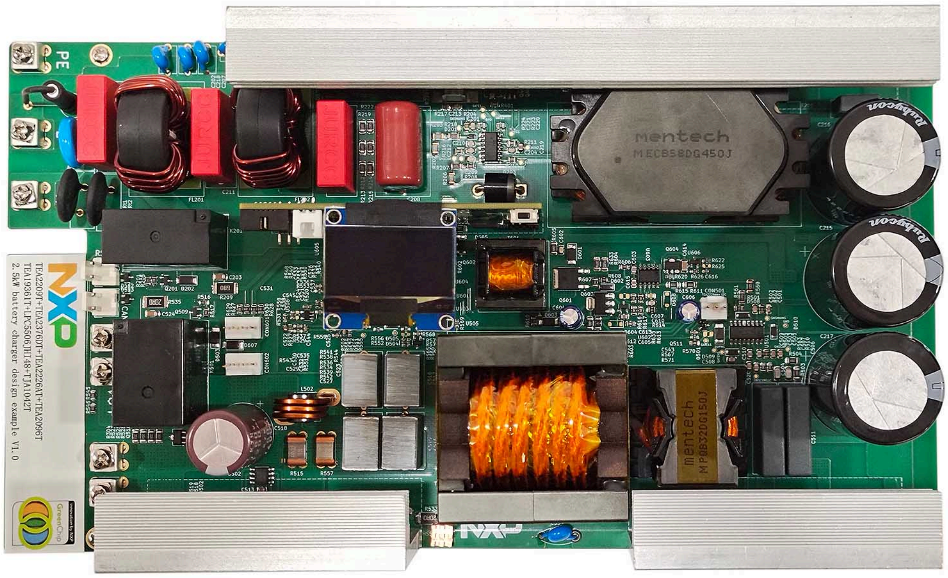
5 Getting ready

5.1 Box contents

The box contains the TEA2376DB1647 evaluation board. Figure 10 shows the top side and bottom side of the evaluation board.

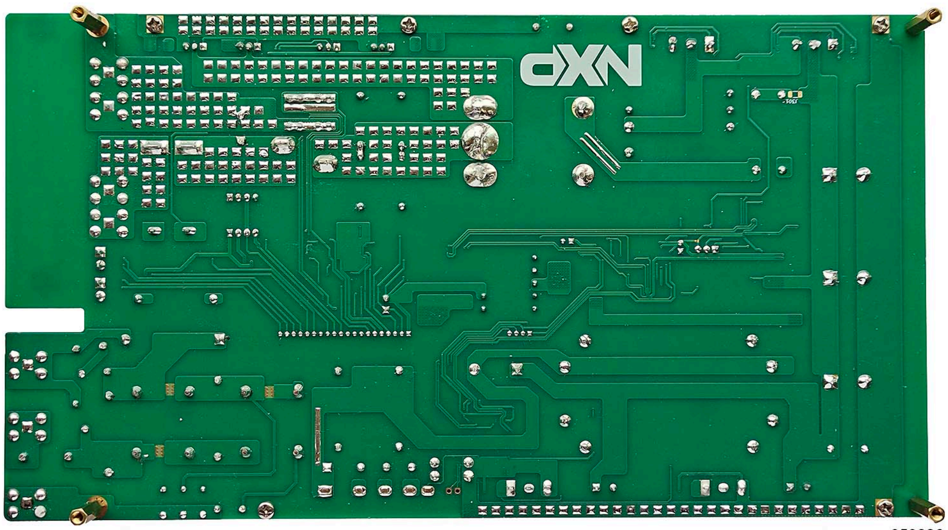
aaa-059284

Figure 9. Board photograph with a case



aaa-059285

a. Top side



aaa-059286

b. Bottom side

Figure 10. Board photographs without a case

6 Getting to know the hardware

6.1 Specifications

Table 1. Specifications

Symbol	Description	Conditions	Values	Unit
Input				
V_{mains}	AC mains voltage	AC	90 to 264	V
f_{mains}	mains frequency		47 to 63	Hz
PF	power factor	90 V (AC) ~ 180 V (AC), P_{out} = 1.5 kW	> 0.99	-
		170 V (AC) ~ 264 V (AC), P_{out} = 2.5 kW	> 0.99	-
Output				
$V_{out\_max\_cv}$	maximum output voltage in constant voltage regulation		60	V
$V_{out\_range\_cc}$	output voltage range in constant current regulation		30 to 60	V
$I_{out\_max\_cc}$	maximum output current in constant current regulation	90 V (AC) ~ 180 V (AC)	27	A
		170 V (AC) ~ 264 V (AC)	41	A
$\eta_{100\%}$	maximum load efficiency	at 115 V/60 Hz; P_{out} = 1.5 kW; V_{out} = 48 V	> 92	%
		at 230 V/50 Hz; P_{out} = 2.5 kW; V_{out} = 48 V	> 94	%
Temperature				
T_{comp}	components temperature	at room temp with fan operation	see Section 7.12	°C
Conduction EMI				
CE	conduction EMI	Class B at 115 V/60 Hz, P_{out} = 1.5 kW	> 3 (margin)	dB
		Class B at 230 V/50 Hz, P_{out} = 2.5 kW	> 3 (margin)	dB

7 Performance measurement

7.1 Test facilities

- Oscilloscope: DSOX3034T, PicoScope 6000 Series
- AC power source: SP300VAC4000W
- Electronic load: EL1200VDC6600W
- Digital power meter: PA333H

7.2 Test setup

Figure 11 shows test setup. When the AC mains input (90 V (AC) ~ 264 V (AC)) is applied, a flyback converter (TEA19361T) starts to operate and the flyback converter output voltage supplies the VCC of the MCU. When the MCU starts up, the LCD panel turns on. It is ready to acknowledge a battery voltage via the output connectors (between output + and output –). When a correct battery (between 30 V and 60 V) is connected to the output connectors, the output relay is enabled. It starts charging a battery (see Section 7.11).

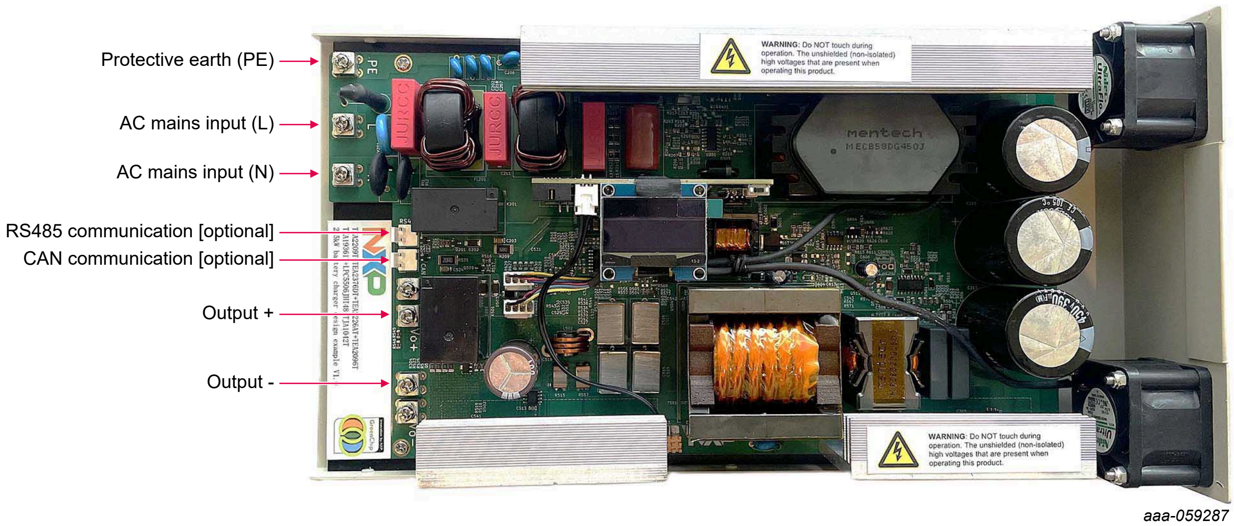


Figure 11. Test setup

For a lab test without a battery, test modes are implemented as well. When pressing the button for three seconds and releasing the button, the PSU enters these test modes. When it enters the test modes, the different constant output voltages (48 V or 60 V) can be selected by pressing the button. In these test modes, the constant output current levels are fixed as 27 A for low mains and 41 A for high mains. Pressing the button for three seconds and releasing the button again leaves the test mode and enters the battery charging mode.

The "battery charging curves" and the "start-up and off sequences" tests use the charging modes. And others use the test modes.

Figure 12 shows how to select different charging curves. Details of charging curves are given in the sections below.

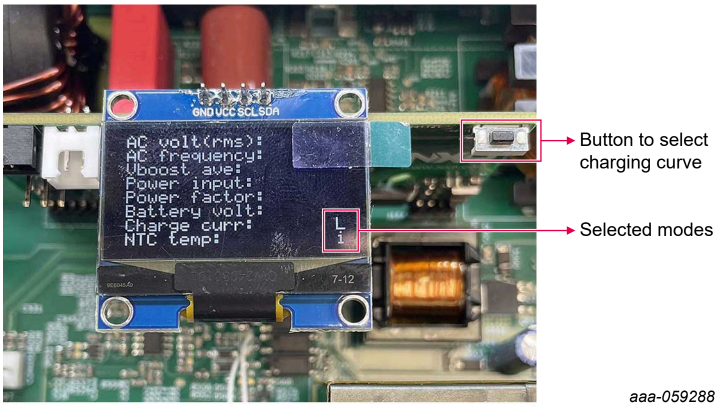


Figure 12. How to select different charging modes

List of battery charging modes; push the button to select one of the curves below.

1. Start-up default charging curve for Li-ion battery; first line “L”, second line “i”.
2. Charging curve for Lead-acid battery; first line “L”, second line “a”.

Note: *Charging the curve test section can be referred for more detail of charging curve information (see Section 7.8.2.*

List of test modes; push the button to select one of the curves below

1. Enter test mode: Press the button longer than three seconds and release the button. The default test mode is at a 48 V constant voltage and maximum constant current level (first lie “T”, second line “4”).
2. Change test mode: Press the button once again, it enters the 60 V test mode (first lie “T”, second line “6”) for a 60 V constant voltage and maximum constant current level. Whenever the button is pushed once, the test mode toggles between 48 V and 60 V.
3. Leave test mode: Press the button longer than three seconds and release the button. It leaves test modes and enters battery charging mode.

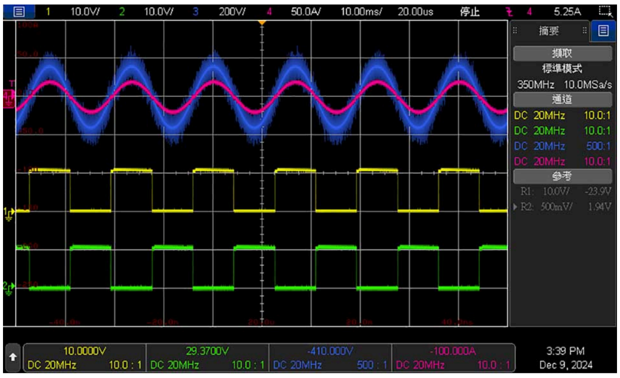
Note: *The maximum CC levels in the test modes are 27 A fixed CC for low mains and 41 A fixed CC for high mains. These test modes are only for steady-state conditions tests. Using battery charging mode to see the overall features is recommended.*

List of information on LCD display

1. Information based on the live functionality of the TEA2376DT: AC mains voltage, AC mains frequency, average boost voltage, input power, and power factor.
2. Information from the MCU monitoring; Battery voltage (output voltage), battery charging current, and external temperature (via NTC on MCU expansion board).

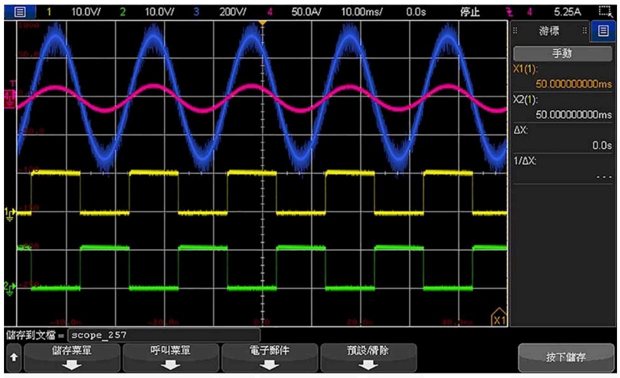
7.3 Active bridge (TEA2209T) operation

The TEA2226AT has four gates (GATELL, GATELR, GATEHL, and GATEHR). When the AC mains voltage is positive, GATEHL and GATELR are enabled. When the AC mains voltage is negative, GATEHR and GATELL are enabled.



aaa-059303

At 115 V mains and 1.5 kW
- CH1: GATELR (10 V/div)
- CH2: GATELL (10 V/div)
- CH3: V_{MAINS} (200 V/div)
- CH4: I_{MAINS} (50 A/div)
- Time: 10 ms/div



aaa-059304

At 230 V mains and 2.5 kW
- CH1: GATELR (10 V/div)
- CH2: GATELL (10 V/div)
- CH3: V_{MAINS} (200 V/div)
- CH4: I_{MAINS} (50 A/div)
- Time: 10 ms/div

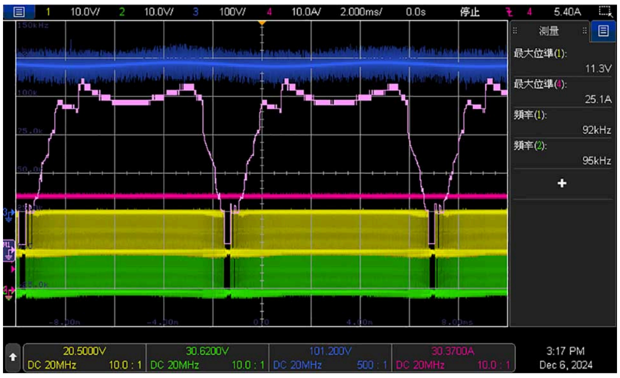
Figure 13. Active bridge operation at maximum output power

7.4 Interleaved PFC (TEA2376) operation

The TEA2376DT incorporates an average current-mode control. To achieve good power factor and total harmonic distortion performances, the TEA2376DT controls the average PFC inductor current as a sinusoidal waveform. To compensate a phase shift between the AC mains voltage and the average inductor current due to AC mains filter capacitors, the PFC starts switching after a time delay in every mains voltage cycle. Since the mains filter capacitor varies at different power levels, the MTP can select the shift factor.

The TEA2376DT frequency clamping and the foldback functions to achieve the best efficiency. The minimum frequency and the maximum frequency can be set via MTP. This design example sets 130 kHz maximum frequency and 30 kHz minimum frequency.

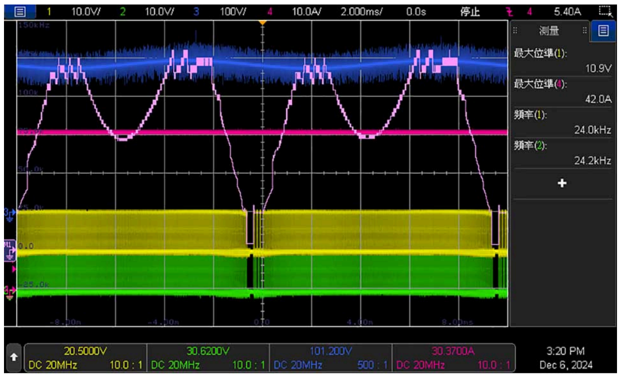
The TEA2376DT phase control method regulates the phase difference of two PFC channels to 180 degrees, although the switching frequency varies in the half-main cycle.



aaa-059305

PFC frequency at 115 V mains and 1.5 kW

CH1: GATE1 (10 V/div)
CH2: GATE2 (10 V/div)
CH3: V_{BOOST} (100 V/div)
CH4: I_{OUT} (10 A/div)
F1: FreqPHASE1 (25 kHz/div)
Time: 2 ms/div

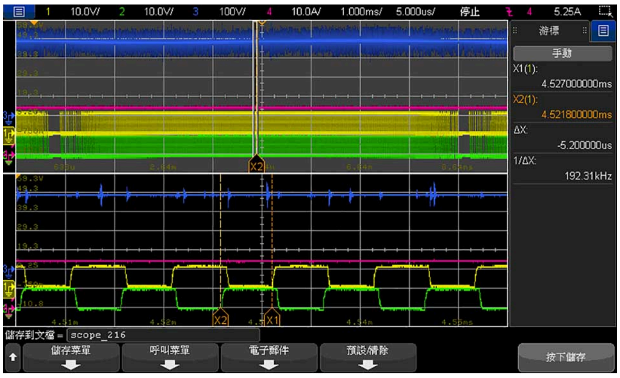


aaa-059306

PFC frequency at 230 V mains and 2.5 kW

CH1: GATE1 (10 V/div)
CH2: GATE2 (10 V/div)
CH3: V_{BOOST} (100 V/div)
CH4: I_{OUT} (10 A/div)
F1: FreqPHASE1 (25 kHz/div)
Time: 2 ms/div

Figure 14. PFC operation at maximum output power



aaa-059307

Interleaving performance at 115 V mains and 1.5 kW

CH1: GATE1 (10 V/div)
CH2: GATE2 (10 V/div)
CH3: V_{BOOST} (100 V/div)
CH4: I_{OUT} (10 A/div)
Time: 1 ms/div and 5 μs/div

aaa-059308

Interleaving performance at 230 V mains and 2.5 kW

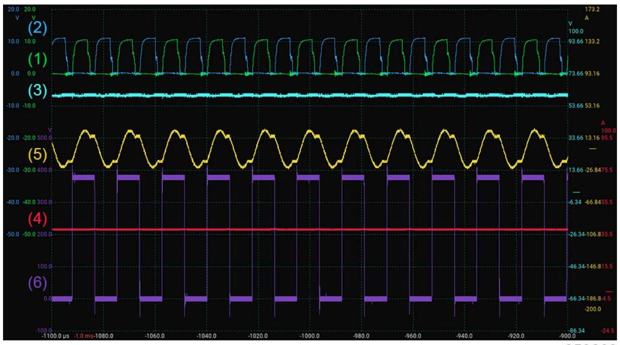
CH1: GATE1 (10 V/div)
CH2: GATE2 (10 V/div)
CH3: V_{BOOST} (100 V/div)
CH4: I_{OUT} (10 A/div)
Time: 2 ms/div and 5 μs/div

Figure 15. PFC operation at maximum output power

7.5 LLC half-bridge (TEA2226) and SR (TEA2096T) operation

The TEA2226AT regulates the output power by adjusting the voltage across the primary capacitor. Compared to a standard frequency-control loop, the advantage is that the control loop has a constant gain and the IC has information about the output power. So, the operation mode transition levels are derived from the output power.

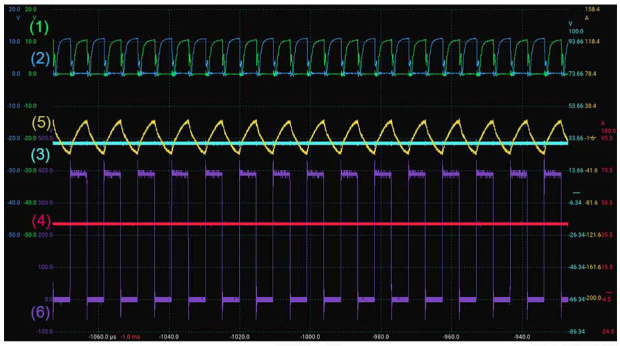
The LLC switching frequency varies according to different output voltages. At 60 V and a maximum output current condition, the switching frequency is approximately 58 kHz. At 30 V and a maximum output current condition, the switching frequency is approximately 105 kHz.



aaa-059309

LLC operation at 230 V mains and 60 V

(1) CH1: SR GATE1 (10 V/div)
(2) CH2: SR GATE2 (10 V/div)
(3) CH3: V_{OUT} (20 V/div)
(4) CH4: I_{OUT} (10 A/div)
(5) CH5: Resonant current (40 A/div)
(6) CH6: HB (100 V/div)
Time: 20 μs/div



aaa-059310

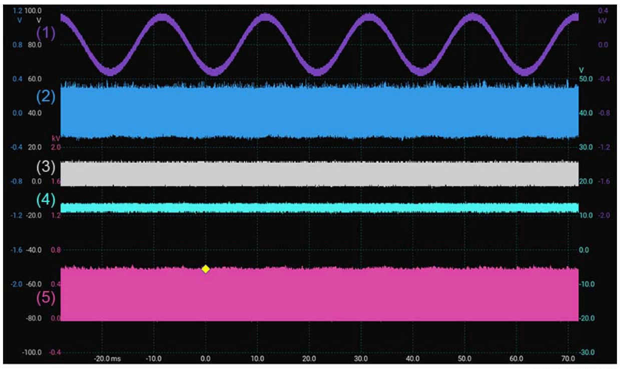
LLC operation at 230 V mains and 30 V

(1) CH1: SR GATE1 (10 V/div)
(2) CH2: SR GATE2 (10 V/div)
(3) CH3: V_{OUT} (20 V/div)
(4) CH4: I_{OUT} (10 A/div)
(5) CH5: Resonant current (40 A/div)
(6) CH6: HB (100 V/div)
Time: 20 μs/div

Figure 16. LLC and SR operation

7.6 Flyback (TEA19361T) operation

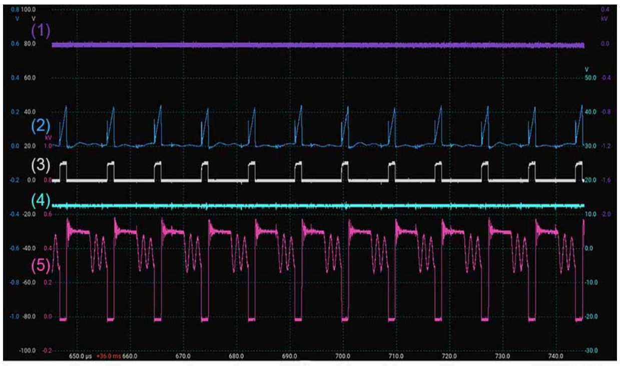
At high power levels, the flyback converter operates in quasi-resonant (QR) mode. At lower power levels, the controller switches to frequency reduction (FR) in discontinuous conduction mode (DCM) operation.



aaa-059311

Flyback operation at 230 V mains with fan operation; Zoom out

(1) CH1: V_{AC} (400 V/div)
(2) CH2: V_{SENSE} (0.4 V/div)
(3) CH3: GATE (20 V/div)
(4) CH4: $V_{OUT\_Flyback}$ (10 V/div)
(5) CH5: V_{DS} (400 V/div)
Time: 10 ms/div



aaa-059312

Flyback operation at 230 V mains with fan operation; Zoom in

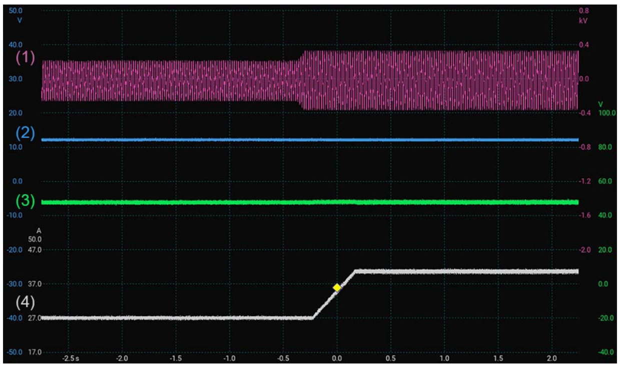
(1) CH1: V_{AC} (400 V/div)
(2) CH2: V_{SENSE} (0.4 V/div)
(3) CH3: GATE (20 V/div)
(4) CH4: $V_{OUT\_Flyback}$ (10 V/div)
(5) CH5: V_{DS} (400 V/div)
Time: 10 μs/div

Figure 17. Flyback operation

7.7 AC mains voltage transition

The design example supports different output power (1.5 kW for low mains condition, and 2.5 kW for high mains condition) for different mains conditions. The TEA2376 always transfers the mains input voltage to the MCU using I^2C communication. When the AC mains voltage exceeds 180 V_{AC}, the MCU increases the maximum power level to 2.5 kW. And when mains voltage decreases to below 170 V_{AC}, the MCU decreases the maximum power level to 1.5 kW.

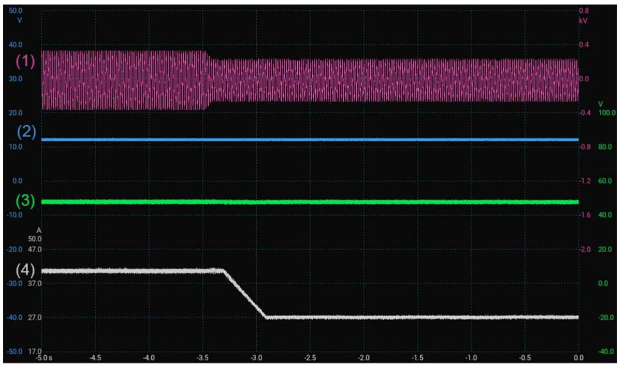
Figure 18 shows the practical test results of AC mains voltage change. When a mains voltage change happens, the output current is gradually increased or decreased.



aaa-059313

AC mains voltage change from 160 V_{AC} to 230 V_{AC}

(1) CH1: V_{MAINS} (400 V/div)
(2) CH2: $V_{OUT\_FLYBACK}$ (10 V/div)
(3) CH3: V_{OUT} (20 V/div)
(4) CH4: I_{OUT} (10 A/div)
Time: 500 ms/div



aaa-059314

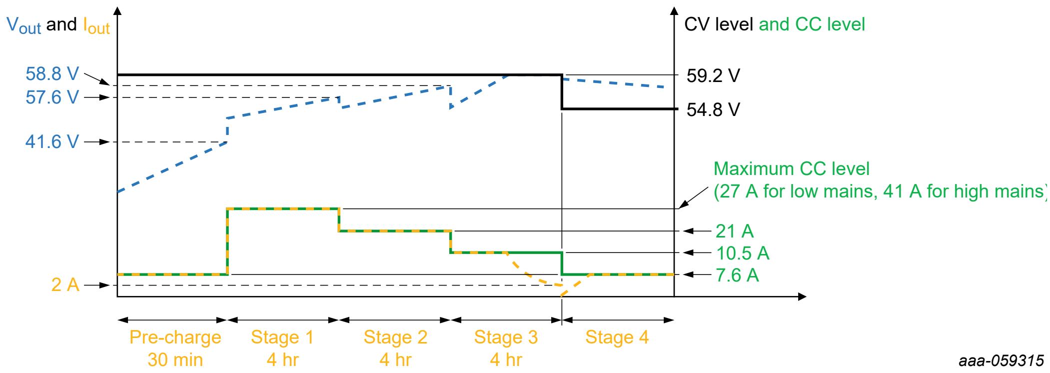
AC mains voltage change from 230 V_{AC} to 160 V_{AC}

(1) CH1: V_{MAINS} (400 V/div)
(2) CH2: $V_{OUT\_FLYBACK}$ (10 V/div)
(3) CH3: V_{OUT} (20 V/div)
(4) CH4: I_{OUT} (10 A/div)
Time: 500 ms/div

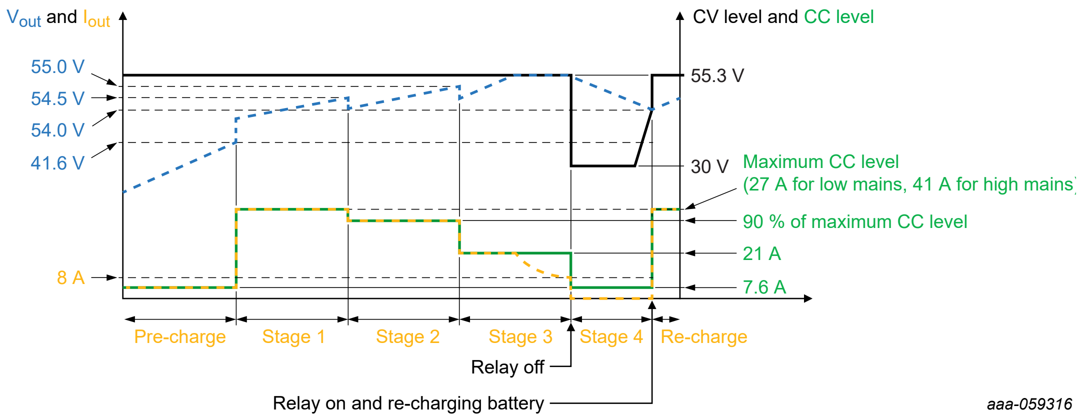
Figure 18. AC mains voltage transitions

7.8 Battery charging curves

This design example implements two different battery charging curves. Figure 19 shows the implemented charging curves.



a. Charging curve 1



b. Charging curve 2

Figure 19. Battery charging curve concept

Note: *The implemented charging curves can be modified through reprogramming the MCU. Users can program their own charging curve. For more information, contact NXP.*

7.8.1 TEA2226AT operation modes

The TEA2226AT LLC controller implements different operation modes (high-power mode, low-power mode, and burst mode) for better light-load efficiency. The burst-mode entry power level selects the minimum of recommended MTP setting (6 %). The minimum power levels of both charging curves do not enter the burst-mode operation.

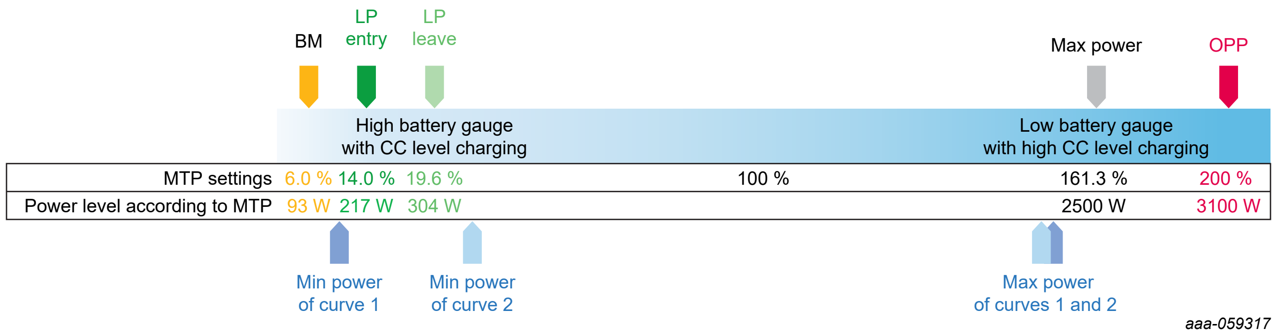
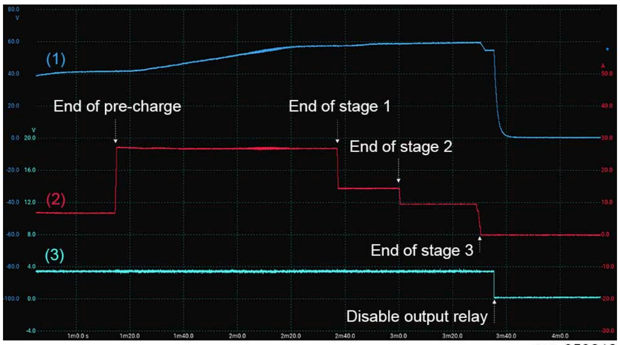


Figure 20. TEA2226AT operation modes and charging status

7.8.2 Battery charging curve test

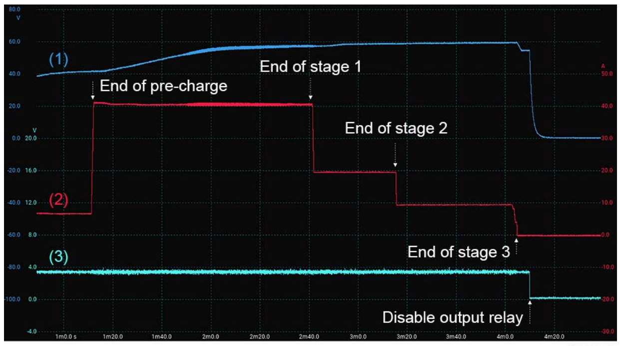
Figure 21 shows practical test result of different charging curves at different AC mains condition. An electronic load (Constant voltage mode) is used to simulate battery voltages.



aaa-059318

Charging curve 1 at 115 V mains

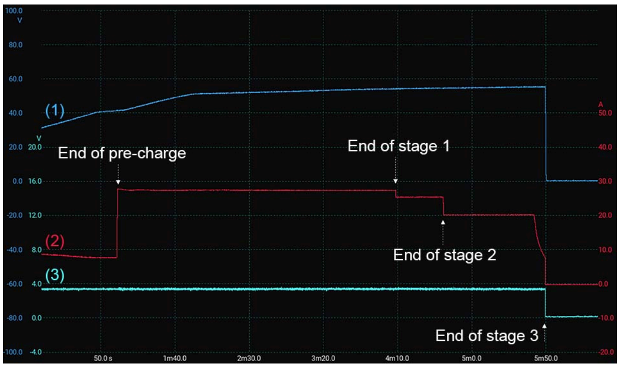
(1) CH1: V_{OUT} (20 V/div)
(2) CH2: I_{OUT} (10 A/div)
(3) CH3: Control signal of output relay (4 V/div)
Time: 20 s/div



aaa-059319

Charging curve 1 at 230 V mains

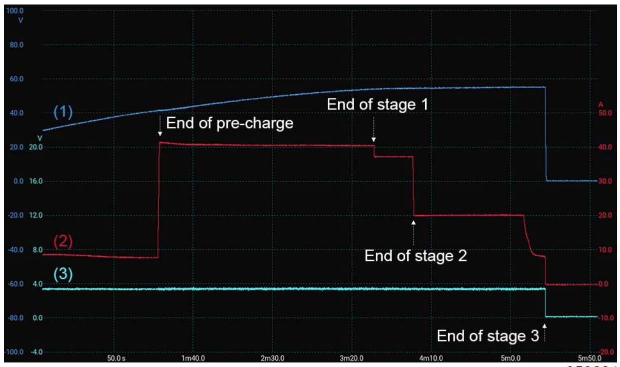
(1) CH1: V_{OUT} (20 V/div)
(2) CH2: I_{OUT} (10 A/div)
(3) CH3: Control signal of output relay (4 V/div)
Time: 20 s/div



aaa-059320

Charging curve 2 at 115 V mains

(1) CH1: V_{OUT} (20 V/div)
(2) CH2: I_{OUT} (10 A/div)
(3) CH3: Control signal of output relay (4 V/div)
Time: 50 s/div



aaa-059321

Charging curve 2 at 230 V mains

(1) CH1: V_{OUT} (20 V/div)
(2) CH2: I_{OUT} (10 A/div)
(3) CH3: Control signal of output relay (4 V/div)
Time: 50 s/div

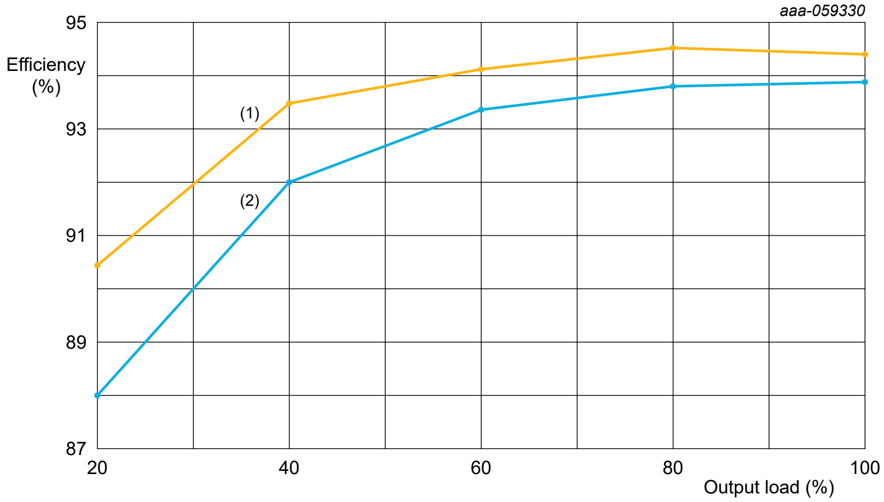
Figure 21. Battery charging curve test results

7.9 Efficiency test result

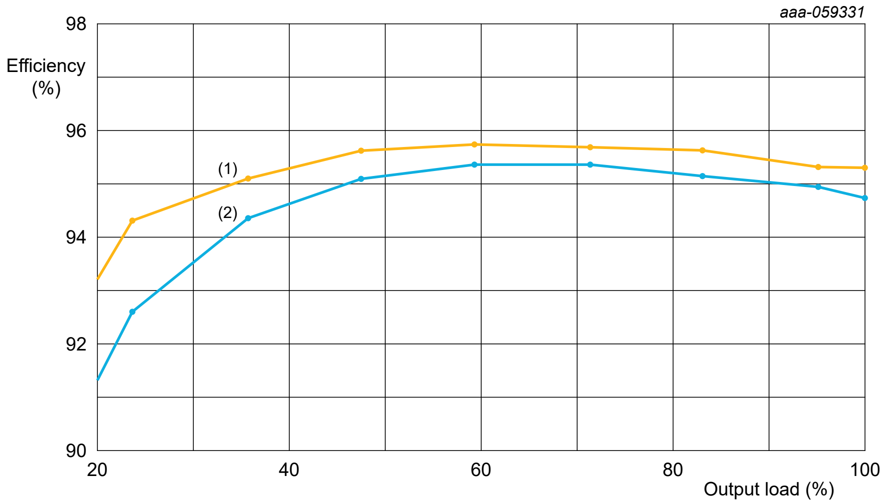
Efficiency is measured at the maximum power rating. It exceeds 95 % at high mains. Figure 22 shows the efficiency test result at each mains condition and different load conditions. The 100 % output load percentage is based on the maximum output current (27 A for 115 V (AC) and 41 A for 230 V (AC)).

Table 2. Efficiency test results

Mains condition	Output condition	Specification	Test result
115 V/60 Hz	48 V; 27 A	> 92 %	94.4 %
230 V/50 Hz	48 V; 41 A	> 94 %	95.3 %



a. At 115 V (AC)



b. At 230 V (AC)

(1) Output voltage at 48 V
(2) Output voltage at 60 V

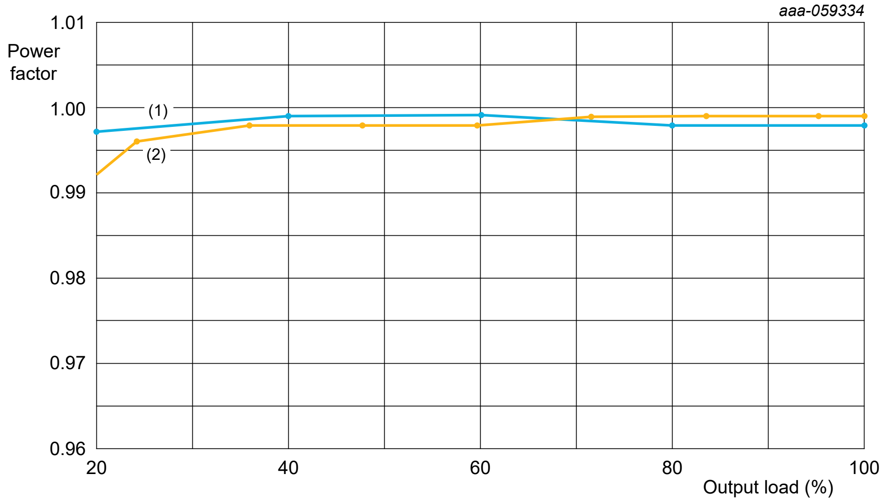
Figure 22. Efficiency

7.10 Power factor test result

Table 3 gives the power factor correction specification and its results. Figure 23 shows additional power factor test results at each mains condition and different load conditions. The 100 % output load percentage is based on the maximum output current (27 A for 115 V (AC) and 41 A for 230 V (AC)).

Table 3. Efficiency test results

Mains condition	Output condition	Specification	Test result
115 V/60 Hz	1.5 kW; load = 100 %	> 0.99	0.999
230 V/50 Hz	2.5 kW; load = 100 %	> 0.99	0.998

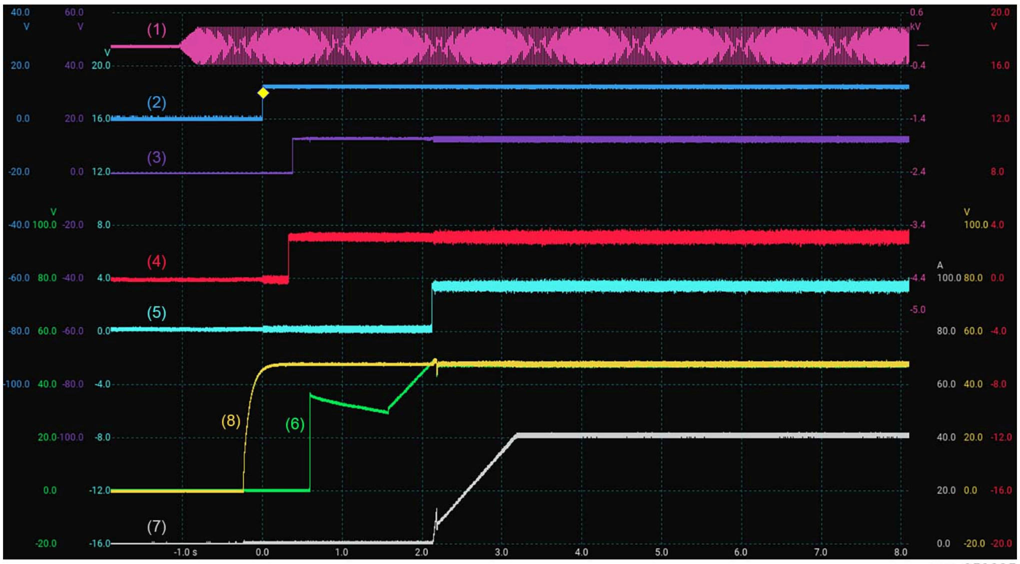


(1) PF at 115 V (AC)
(2) PF at 230 V (AC)

Figure 23. Power factor at 60 V output

7.11 Start-up and off sequences

To start charging safely and to terminate charging a battery, this design example includes start-up and AC mains power-off sequences. Figure 24 and Figure 25 show the start-up sequence and the AC mains power-off sequence.



(1) CH1: AC mains input (1 kV/div)

(2) CH2: Flyback output voltage (20 V/div)

(3) CH3: VCC for TEA2376/TEA2226 (20 V/div)

(4) CH4: Control signal for input relay (4 V/div)

(5) CH5: Control signal for output relay (4 V/div)

(6) CH6: Output voltage before output relay (20 V/div)

(7) CH7: Output current (20 A/div)

(8) CH8: Output voltage after output reply, V_{bat} (20 V/div)

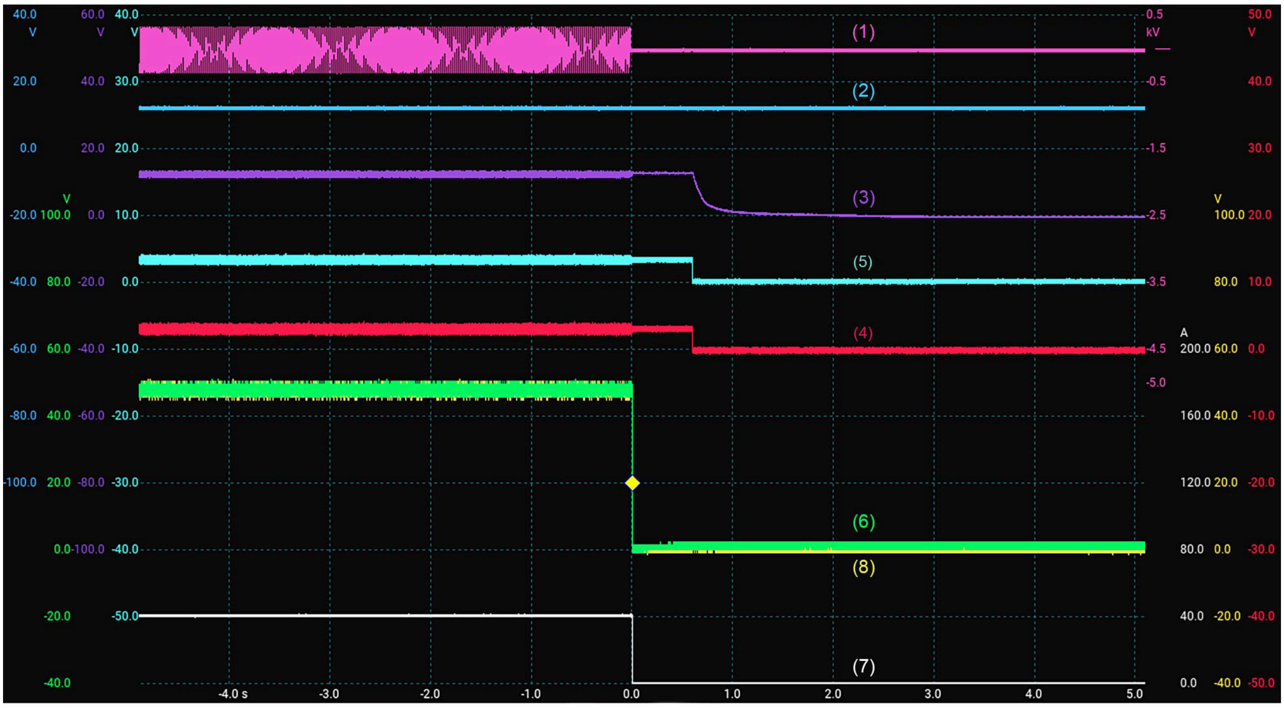
Time: 1 s/div

Sequence explanation:

AC mains ON → Flyback output ON (12 V) → MCU is ON → Acknowledging correct battery level (30 V ~ 60 V) → Input relay ON → Supply VCC for TEA2376 and TEA2226AT → Output voltage of LLC (before output relay) is slowly increased from 30 V → When the output voltage of LLC is 2 V higher than the battery voltage (after output reply), output reply is ON → Starts to charge a battery.

Note: *The DC source and the E-load are used to simulate the battery load. So, the test results can be slightly different with an actual battery.*

Figure 24. Start-up sequence with attaching 48 V battery voltage at 230 V (AC)



(1) CH1: AC mains input (1 kV/div)
(2) CH2: Flyback output voltage (20 V/div)
(3) CH3: VCC for TEA2376/TEA2226AT (20 V/div)
(4) CH4: Control signal for input relay (10 V/div)
(5) CH5: Control signal for output relay (10 V/div)
(6) CH6: Output voltage before output relay (20 V/div)
(7) CH7: Output current (40 A/div)
(8) CH8: Output voltage after output reply, V_{bat} (20 V/div)
Time: 1 s/div

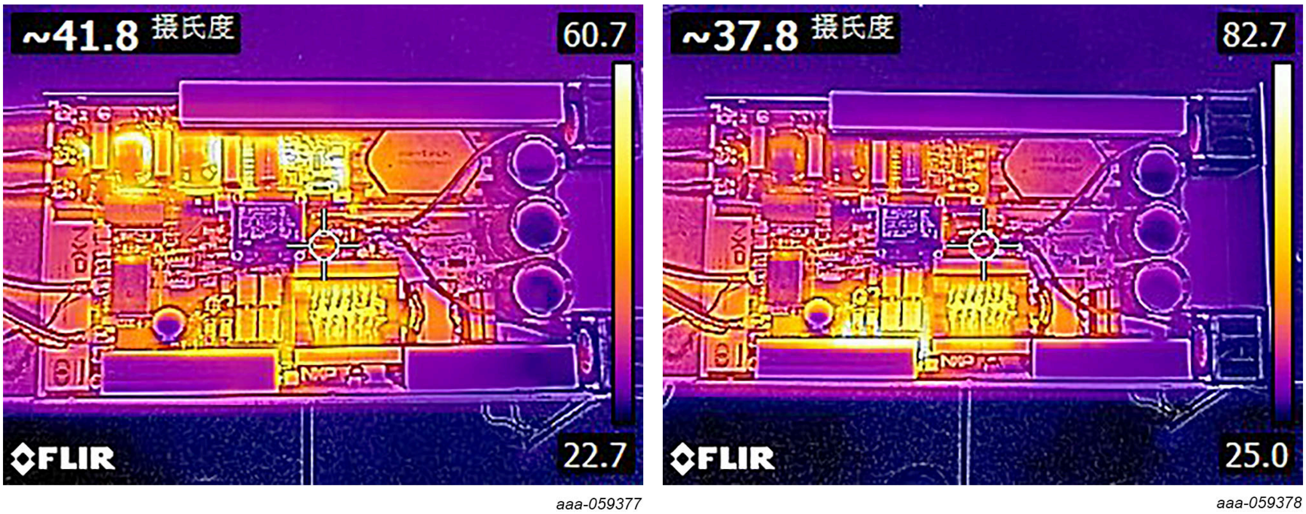
Sequence explanation:
AC mains OFF → PFC stops operation after AC brownout delay time → LLC stops operation after DC brownout → After 500 ms delay time after AC brownout, the MCU disables the input relay → Output relay off → Disable VCC for TEA2376 and TEA2226AT

Note: *The DC source and the E-load are used to simulate the battery load. So, the test results can be slightly different with an actual battery.*

Figure 25. AC mains power-off sequence; 48 V battery voltage at 230 V_{AC}

7.12 Components temperature performance

The temperature is measured at room temperature condition with the implemented two fans. It is measured after 1 hour aging time.



At 90 V (AC), 60 V, and 1.5 kW

At 180 V (AC), 60 V, and 2.5 kW

Figure 26. Temperature performance

Table 4. Temperature test result at 1.5 kW and 90 V mains condition

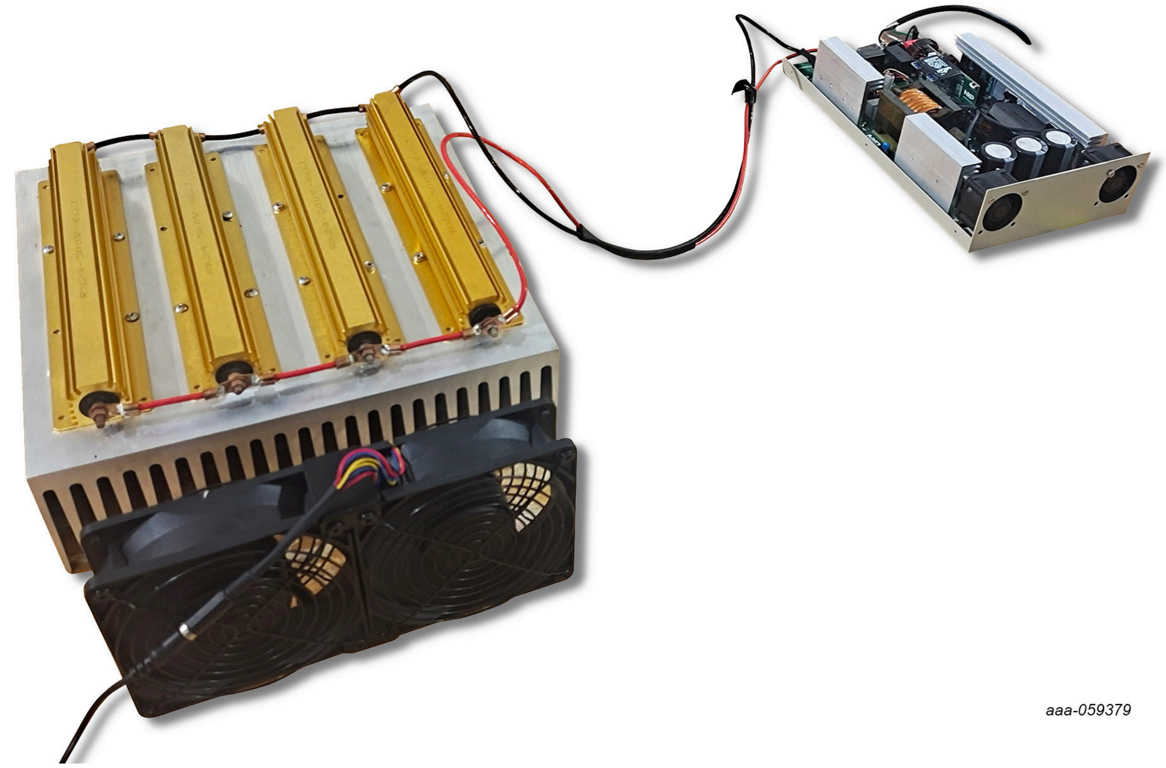
Components	Specification	Test results at 90 V (AC), 60 V, and 1.5 kW	Test results at 180 V (AC), 60 V, and 2.5 kW
Input common mode choke	< 105 °C	66 °C	51 °C
active bridge MOSFET	< 120 °C	75 °C	58 °C
TEA2209T	< 100 °C	44 °C	38 °C
PFC phase 2 MOSFET	< 120 °C	51 °C	46 °C
PFC phase 2 diode	< 120 °C	43 °C	36 °C
PFC inductor core	< 105 °C	41 °C	40 °C
PFC inductor wire	< 110 °C	51 °C	48 °C
PFC current sense resistor	< 120 °C	62 °C	49 °C
TEA2376DT controller	< 100 °C	59 °C	49 °C
LLC MOSFET (low side)	< 120 °C	34 °C	45 °C
SR MOSFET	< 120 °C	37 °C	50 °C
LLC transformer core	< 105 °C	55 °C	76 °C
LLC transformer wire	< 110 °C	53 °C	73 °C
LLC resonant inductor core	< 105 °C	39 °C	46 °C
LLC resonant inductor wire	< 110 °C	49 °C	72 °C
output current sensing resistor	< 120 °C	55 °C	100 °C

Table 4. Temperature test result at 1.5 kW and 90 V mains condition*...continued*

Components	Specification	Test results at 90 V (AC), 60 V, and 1.5 kW	Test results at 180 V (AC), 60 V, and 2.5 kW
output capacitor	< 105 °C	53 °C	52 °C
SR MOSFET RC snubber resistor	< 120 °C	71 °C	87 °C
TEA2226AT controller	< 100 °C	33 °C	34 °C
TEA2096T controller	< 100 °C	51 °C	84 °C
flyback MOSFET	< 120 °C	39 °C	40 °C
flyback output rectifier diode	< 120 °C	52 °C	50 °C
flyback transformer core	< 105 °C	38 °C	39 °C
flyback transformer wire	< 110 °C	43 °C	45 °C
TEA19361T controller	< 100 °C	32 °C	33 °C

7.13 Conduction EMI

The conduction EMI is measured with a fixed resistive load at the certification lab. Figure 27 shows the test setup. Figure 28 shows the conduction EMI test result. The conduction EMI can meet Class B with more than 3 dB margin.

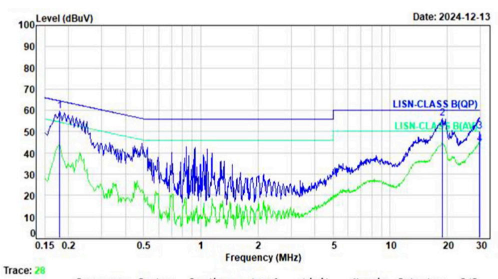


aaa-059379

Figure 27. Conduction EMI test setup; PSU with a fixed resistive load

Note: *A fan is used to avoid too much high temperature of the resistive load. The AC input power of the fan is not connected to the same AC mains. So, there is no impact on conduction EMI test result.*

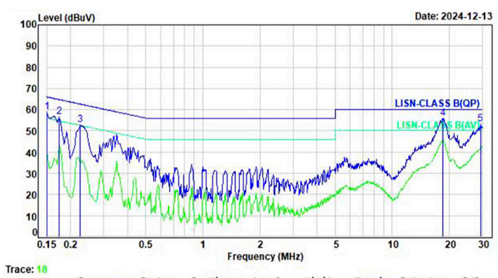
Note: *To pass Class B, the V18012 snap on the ferrite cores is required on input and output cables.*



No.	Frequency (MHz)	Factor (dB)	Reading (dBuV)	Level (dBuV)	Limit (dBuV)	Margin (dB)	Detector	P/F
1	0.18	10.48	49.12	59.60	64.50	-4.90	Peak	P
2	18.82	10.43	45.70	56.13	60.00	-3.87	Peak	P
3	29.60	10.82	39.53	50.35	60.00	-9.65	QP	P
4	29.60	10.82	33.24	44.06	50.00	-5.94	Average	P

aaa-059380

Conduction EMI at 1.5 kW/48 V and 115 V (AC): Line



No.	Frequency (MHz)	Factor (dB)	Reading (dBuV)	Level (dBuV)	Limit (dBuV)	Margin (dB)	Detector	P/F
1	0.15	10.48	48.44	58.92	66.00	-7.08	Peak	P
2	0.17	10.48	46.04	56.52	64.72	-8.20	Peak	P
3	0.23	10.47	42.25	52.72	62.61	-9.89	Peak	P
4	18.43	10.42	45.50	55.92	60.00	-4.08	Peak	P
5	29.22	10.80	42.34	53.14	60.00	-6.86	Peak	P

aaa-059381

Conduction EMI at 2.5 kW/60 V and 230 V (AC): Line

Figure 28. Conduction EMI test results

8 Schematic and bill of materials

8.1 Schematic

8.1.1 Design example overall schematic

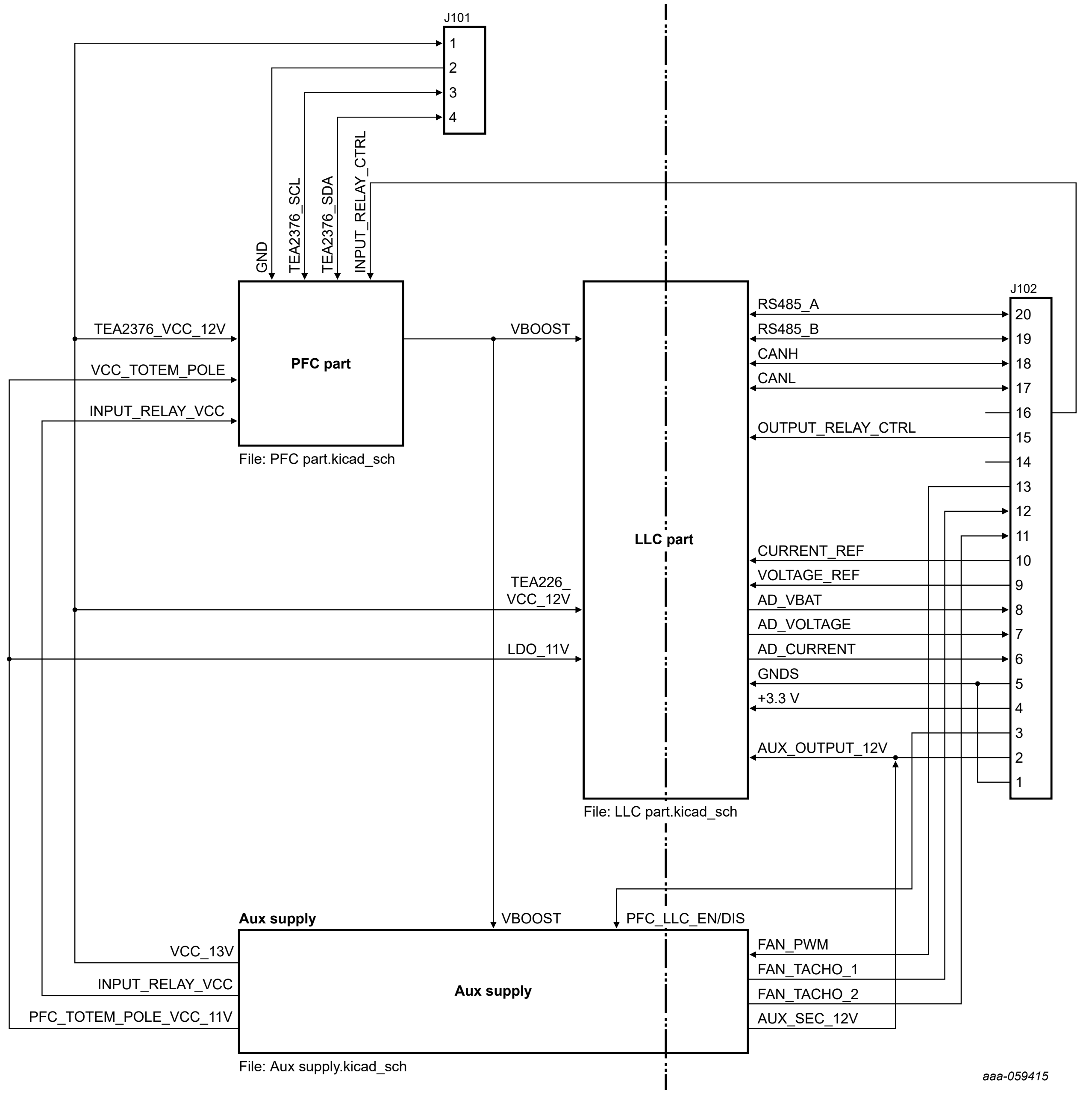


Figure 29. Design example schematic (Overall block diagram)

8.1.2 AC mains and PFC parts

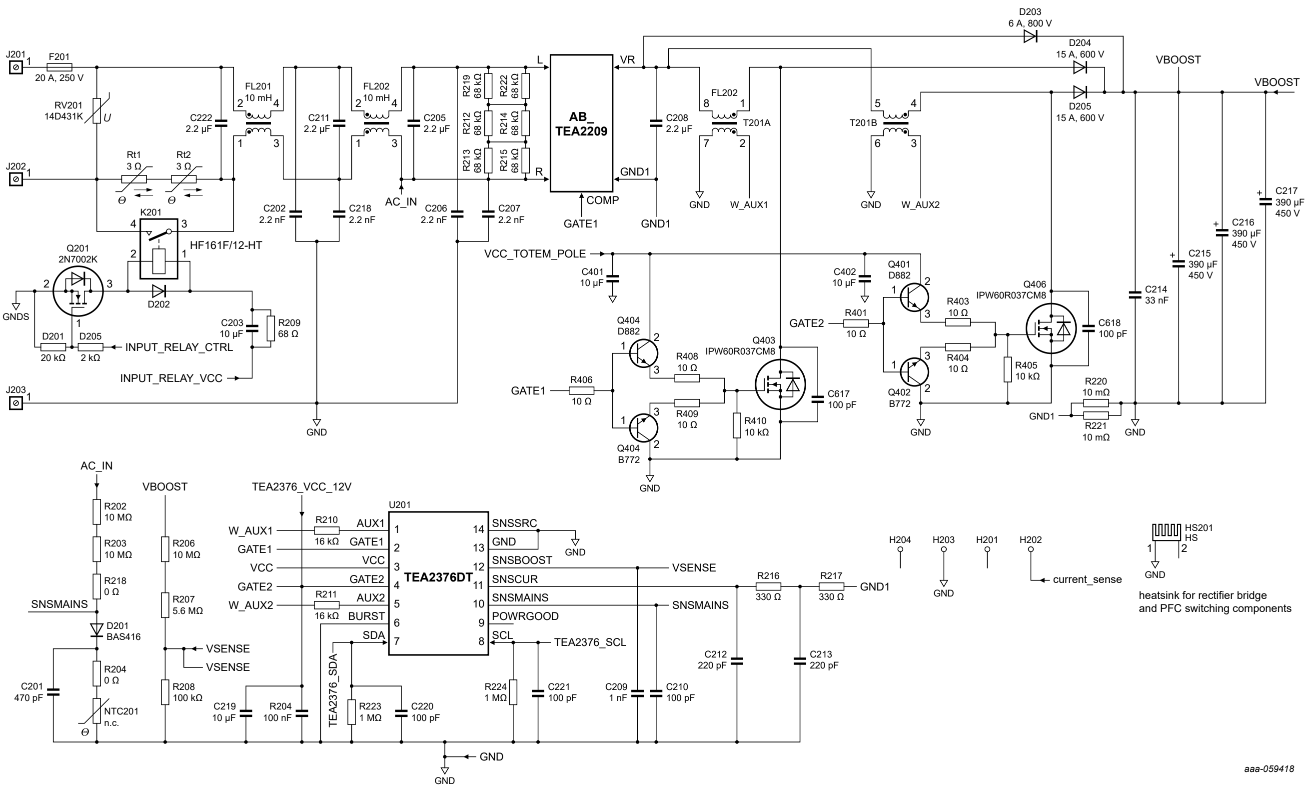


Figure 30. AC mains and PFC parts

8.1.3 LLC and SR parts

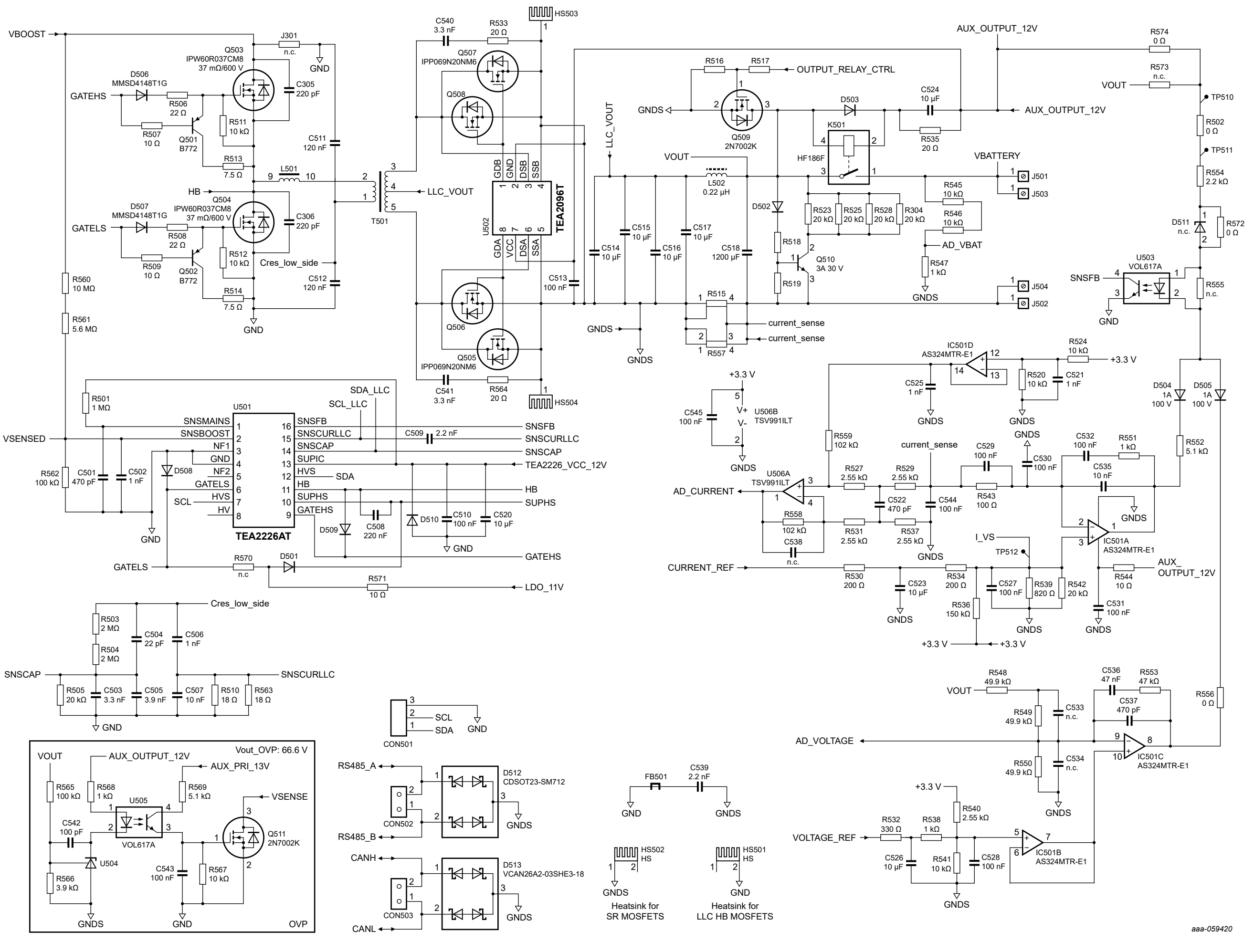


Figure 31. LLC and SR parts

8.1.4 Active bridge part

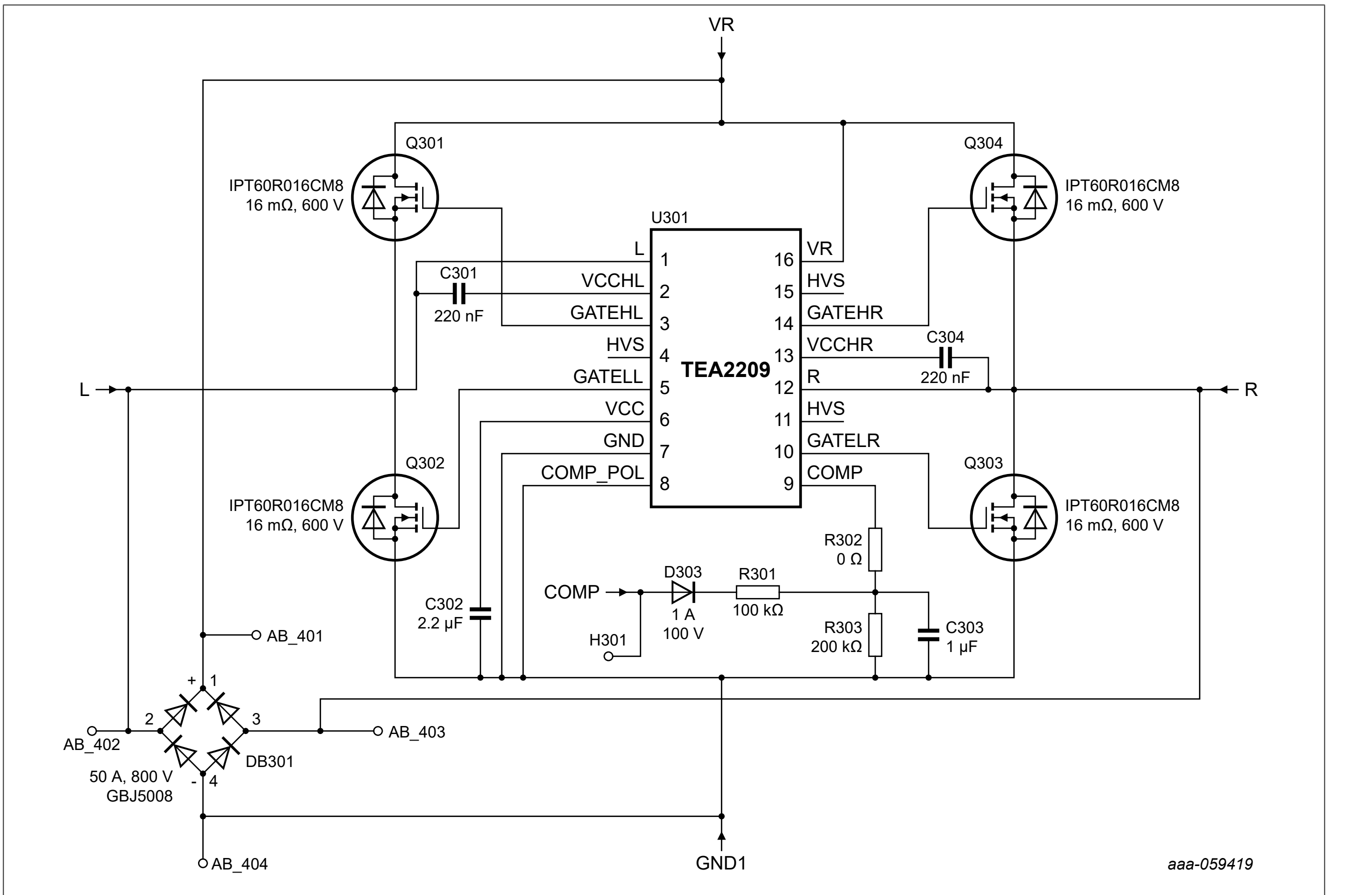


Figure 32. Active bridge part

8.1.5 Flyback part

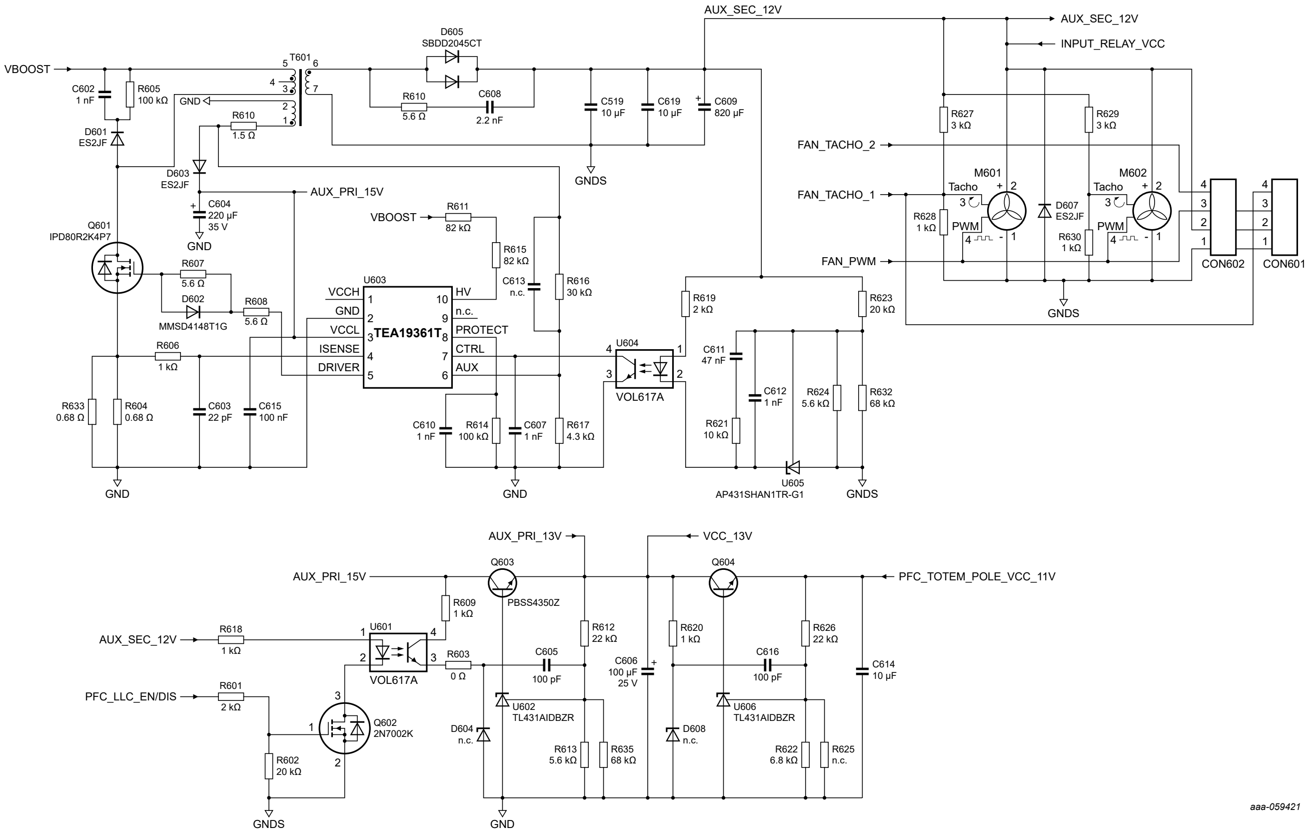


Figure 33. Flyback part

8.1.6 MCU daughter board part

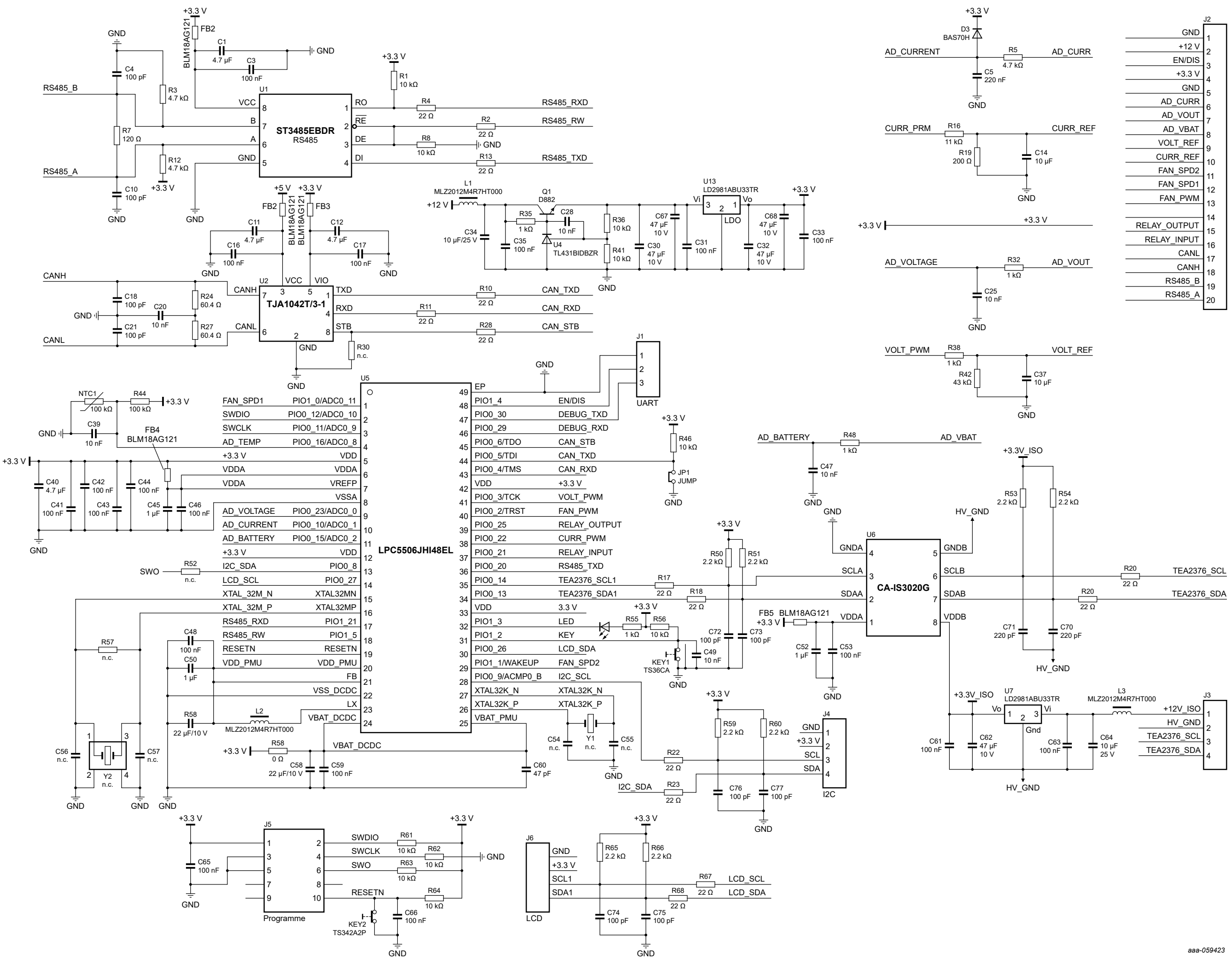


Figure 34. MCU daughter board part

8.2 Bill of materials (BOM)

8.2.1 TEA2376DB1647: Main board

Table 5. TEA2376DB1647 bill of materials (BOM); main board

Part	Description and values	Part number	Manufacturer
C201	capacitor; 470 pF; 50 V; 0805; X7R; 10 %	0805B471K500NT	FH
C202; C206; C207; C218	capacitor; 2.2 nF; 20 %; 250 V; THT	Y26F1E222M	HEL
C203; C401; C402; C519; C524; C614; C619	capacitor; 10 µF; 50V; 1206; X5R; 10%	CL31A106KBHNNNE	Samsung
C204; C510; C513; C615	capacitor; 100 nF; 50 V; 0805; X7R; 10 %	CGA4J2X7R1H104KT0Y0N	TDK
C205; C211; C222	capacitor; 2.2 µF; 10 %; THT; X2	JY00002	JURCC
C208	capacitor; 2.2 µF; 5 %; 630 V; THT	ECWFA2J225J	Panasonic
C209; C502; C607; C610	capacitor; 1 nF; 50 V; 0805; X7R; 10 %	CL21B102KBCNNNC	Samsung
C210; C605	capacitor; 100 pF; 50 V; 0805; C0G; 5 %	CL21C101JBANNNC	Samsung
C212; C213	capacitor; 220 pF; 50 V; 0805; X7R; 10 %	CC0805KRX7R9BB221	Yageo
C214	capacitor; 33 nF; 5 %; 630 V; THT	MPBH333J2J1001	KYET
C215; C216; C217	capacitor; 390 µF; 20 %; 450 V; THT	450VXH390MEFCSN30X45	Rubycon
C219; C520	capacitor; 10 µF; 25 V; 0805; X5R; 10 %	CL21A106KAYNNNE	Samsung
C220; C221; C542; C616	capacitor; 100 pF; 50V; 0603; C0G; 5 %	CL10C101JB8NNNC	Samsung
C301; C304	capacitor; 220 nF; 50 V; 0805; X7R; 10 %	CL21B224KBFNNNE	Samsung
C302	capacitor; 2.2 µF; 50 V; 0805; X7R; 10 %	CC0805KKX7R9BB225	Yageo
C303	capacitor; 1 µF; 50 V; 0805; X7R; 10 %	CL21B105KBFNNNE	Samsung
C305; C306	capacitor; 220 pF; 1 kV; 1206; NP0; 5 %	CC1206JKNPOCBN221	Yageo
C501; C522; C537	capacitor; 470 pF; 50 V; 0603; X7R; 10 %	0603B471K500NT	FH
C503	capacitor; 3.3 nF; 50 V; 0805; X7R; 10 %	FCC0805B332K500DT	FOJAN
C504	capacitor; 22 pF; 1 kV; 1206; NP0; 5 %	CC1206JKNPOCBN220	Yageo
C505	capacitor; 3.9 nF; 100 V; 0805; X7R; 10 %	0805B392K101CT	Walsin
C506	capacitor; 1 nF; 630 V; 1206; C0G; 5 %	GRM31B5C2J102JW01L	Murata
C507	capacitor; 10 nF; 50 V; 0805; X7R; 10 %	CL21B103KBANNNC	Samsung
C508	capacitor; 220 nF; 50 V; 0805; X7R; 10 %	C2012X7R1H224KT000N	TDK
C509; C608	capacitor; 2.2 nF; 50 V; 0805; C0G; 5 %	CL21C222JBFNNNE	Samsung
C511; C512	capacitor; 120 nF; 5 %; 630 V; THT	MMKP124J2J2201	KYET

Table 5. TEA2376DB1647 bill of materials (BOM); main board...*continued*

Part	Description and values	Part number	Manufacturer
C514; C515; C516; C517	capacitor; 10 µF; 5 %; 100 V; THT	C252A106J60C350	Faratronic
C518	capacitor; 1200 µF; 20 %; 80 V; THT	EKZN800ELL122MMN3S	NCC
C521; C525; C612	capacitor; 1 nF; 50 V; 0603; X7R; 10 %	CL10B102KB8NNNC	Samsung
C523; C526	capacitor; 10 µF; 25 V; 0603; X5R; 20 %	CL10A106MA8NRNC	Samsung
C527, C528, C529, C530, C531, C532; C543; C544; C545	capacitor; 100 nF; 50 V; 0603; X7R; 10 %	CC0603KRX7R9BB104	Yageo
C533; C534; C538	capacitor; not mounted; 0603	-	-
C535	capacitor; 10 nF; 50 V; 0603; X7R; 10 %	0603B103K500NT	FH
C536; C611	capacitor; 47 nF; 50 V; 0603; X7R; 10 %	CL10B473KB8NNNC	Samsung
C539	capacitor; 2.2 nF; 20 %; 400 V; THT	Y16F1D222M	HEL
C540; C541	capacitor; 3.3 nF; 250 V; 0805; NP0	CC0805JKNPOYBN332	Yageo
C602	capacitor; 1 nF; 500 V; 0805; X7R; 10 %	FM21X102K501PXG	PSA
C603	capacitor; 22 pF; 50 V; 0805; C0G; 5 %	CL21C220JBANNNC	Samsung
C604	capacitor; 220 µF; 20 %; 35 V; THT	ERR1VM221E16OT	Aishi
C606	capacitor; 100 µF; 20 %; 25 V; THT	ERS1EM101E11OT	Aishi
C609	capacitor; 820 µF; 20 %; 16 V; THT	APSG160ELL821MH16S	NCC
C613	capacitor; not mounted; 0805	-	-
C617; C618	capacitor; 100 pF; 1 kV; 1206; NP0; 5 %	CC1206JKNPOCBN101	Yageo
CON501	header; not mounted; pitch = 2.54 mm; vertical with friction lock	22112032	Molex
CON502; CONS503	header; pitch = 3.96 mm; vertical with friction lock	A3963WV-2P-GWT	CJT
CONS601; CONS602	header; pitch = 2.54 mm; vertical with friction lock	22112042	Molex
D201	diode; 200 mA; 100 V; low-leakage; SOD-323	BAS416	Yangjie
D202; D501; D503; D601; D603; D607	diode; superfast; 2 A; 600 V; DO-214AD	ES2JF	CJ
D203	diode; general-purpose rectifier; 6 A; 800 V	6A8	MDD
D204; D205	diode; ultrafast rectifier diode; 15 A; 600 V	BYT79-600,127	WeEn
D303; D502; D504; D505; D506; D507; D602	diode; switching diode; 200 mA; 100 V; SOD-123	MMSD4148T1G	ON Semiconductor
D508; D510	diode; Schottky barrier rectifier; 1A; 30V; SOD-123W	PMEG3010ER,115	Nexperia

Table 5. TEA2376DB1647 bill of materials (BOM); main board*...continued*

Part	Description and values	Part number	Manufacturer
D509	diode; Schottky barrier rectifier; 1 A; 30 V; SOD-123	PMEG3010ER-QX	Nexperia
D511; D604; D608	diode; not mounted; SOD-123	-	-
D512	diode; TVS diode; 400 W; 7.5 V; SOT-23	CDSOT23-SM712	Bourns
D513	diode; superfast; 2 A; 600 V; DO-214AD	ESDA25L	SLKOR
D605	diode; Schottky barrier rectifier; 20 A; 45 V; TO-252	SBDD2045CT	CJ
DB301	diode; bridge rectifier; 50 A; 800 V	GBJ5008	LGE
F201	fuse; time-lag type; 20 A	0215020.MXEP	Littelfuse
FB501	ferrite bead; 64 Ω; 100 MHz; RH = 3.5 mm * 3.1 mm * 1.5 mm	-	-
FL201; FL202	inductor; common-mode choke; 10 mH; 20 A	-	-
HS201	heat sink; 188 mm * 50 mm * 20 mm; AL F type	-	-
HS501; HS502	heat sink; 80 mm * 50 mm * 20 mm; AL F type	-	-
HS503; HS504	heat sink; Copper cube; 6 mm * 6 mm * 5 mm	-	-
IC501	operational amplifier; 4-channel; SOIC-14	AS324MTR-E1	Diodes
J101	header; vertical; female; 2.00 mm; 1*4	2.0-1*4P	BOOMELE
J102	header; vertical; female; 2.00 mm; 1*20	2.0-1*20P	BOOMELE
J201; J202; J203; J501; J502; J503; J504	PCB soldering terminal; M3	T34001	XFCN
J301	Resistor; not mounted; 1206	-	-
K201	power relay	HF161F/12-HT	HF
K501	power relay	HF186F/12-HTF	HF
L501	LLC resonant inductor	MPQB32DG150J	Mentech
L502	Inductor; 0.22 µH; 80 A; DCR = 0.5 mΩ	-	-
M601; M602	DC fan; 12 V; 0.73 A	W40S12BS4A5-07	NIDEC
NTC201	not mounted	-	-
Q201; Q509; Q511; Q602	N-channel MOSFET; 1.6 Ω; 60 V; SOT-23	2N7002K	ON Semiconductor
Q301; Q302; Q303; Q304	MOSFET; 16 mΩ; 600 V; TOLL	IPT60R016CM8	Infineon
Q401; Q404; Q510; Q604	BJT; NPN; 3A; 30V; SOT-89-3	D882(RANGE:160-320)	CJ
Q402; Q405; Q501; Q502	BJT; NPN; 3A; 30V; SOT-89-3	B772(RANGE:160-320)	CJ

Table 5. TEA2376DB1647 bill of materials (BOM); main board...*continued*

Part	Description and values	Part number	Manufacturer
Q403; Q406; Q503; Q504	MOSFET; 37 mΩ; 600 V	IPW60R037CM8	Infineon
Q505; Q506; Q507; Q508	MOSFET; 6.9 mΩ 200 V; TO220	IPP069N20NM6	Infineon
Q601	N-channel MOSFET; 2.4 Ω; 800 V; TO-252-3	IPD80R2K4P7	Infineon
Q603	BJT; NPN; 3 A; 50 V; SOT-223-3	PBSS4350Z,135	Nexperia
R201; R505; R516	resistor; 20 kΩ; 0805; 1 %	0805W8F2002T5E	UNI-ROYAL
R202; R203; R206; R560	resistor; 10 MΩ; 1206; 1 %	RC1206FR-0710ML	Yageo
R204; R302	resistor; 0 Ω; 0805; 1 %	0805W8F0000T5E	UNI-ROYAL
R205; R517	resistor; 2 kΩ; 0805; 1 %	0805W8F2001T5E	UNI-ROYAL
R207	resistor; 5.6 MΩ; 1206; 1 %	1206W4F5604T5E	UNI-ROYAL
R208; R301; R562; R614	resistor; 100 kΩ; 0805; 1 %	0805W8F1003T5E	UNI-ROYAL
R209	resistor; 68 Ω; 2512; 5 %	25121WJ0680T4E	UNI-ROYAL
R210; R211	resistor; 16 kΩ; 0805; 1 %	0805W8F1602T5E	UNI-ROYAL
R212; R213; R214; R215; R219; R222	resistor; 68 kΩ; 1206; 1 %	1206W4F6802T5E	UNI-ROYAL
R216; R217	resistor; 330 Ω; 0805; 1 %	0805W8F3300T5E	UNI-ROYAL
R218; R603	resistor; 0 Ω; 1206; 1 %	1206W4F0000T5E	UNI-ROYAL
R220; R221	resistor; 10 mΩ; 1 %; 5 W	J5-10-10F	Shenzen Yezhan Electronics
R223; R224	resistor; 1 MΩ; 0603; 1 %	0603WAF1004T5E	UNI-ROYAL
R303	resistor; 200 kΩ; 0805; 1 %	0805W8F2003T5E	UNI-ROYAL
R304; R523; R525; R528	resistor; 20 kΩ; 1206; 5 %	1206W4J0203T5E	UNI-ROYAL
R401;R403; R404; R406; R408; R409; R509; R571	resistor; 10 Ω; 0805; 1 %	0805W8F100JT5E	UNI-ROYAL
R405; R410; R511; R512; R518; R519; R545; R546	resistor; 10 Ω; 0805; 1 %	0805W8F1002T5E	UNI-ROYAL
R501	resistor; 1 MΩ; 0805; 1 %	0805W8F1004T5E	UNI-ROYAL
R502; R556; R572; R574	resistor; 0 Ω; 0603; 1 %	0603WAF0000T5E	UNI-ROYAL
R503; R504	resistor; 2 MΩ; 1206; 1 %	1206W4F2004T5E	UNI-ROYAL
R506; R508	resistor; 22 Ω; 0805; 1 %	0805W8F220JT5E	UNI-ROYAL
R510; R563	resistor; 18 Ω; 0805; 1 %	0805W8F180JT5E	UNI-ROYAL

Table 5. TEA2376DB1647 bill of materials (BOM); main board...*continued*

Part	Description and values	Part number	Manufacturer
R513, R514	resistor; 7.5 Ω; 0805; 1 %	0805W8F750KT5E	UNI-ROYAL
R515; R557	resistor; 2 mΩ; 1 %; 5 W	HOBH3820-5W-2mR-1%	Shenzen Milliohm Electronics
R520; R524; R541; R567; R621	resistor; 10 kΩ; 0603; 1 %	0603WAF1002T5E	UNI-ROYAL
R527; R529; R531; R537; R540	resistor; 2.55 kΩ; 0603; 1 %	0603WAF2551T5E	UNI-ROYAL
R530; R534	resistor; 200 Ω; 0603; 1 %	0603WAF2000T5E	UNI-ROYAL
R532	resistor; 330 Ω; 0603; 1 %	0603WAF3300T5E	UNI-ROYAL
R533; R564	resistor; 20 Ω; 2512; 3 W	352220RFT	TE Connectivity
R535	resistor; 20Ω; 2512; 1 %	RC2512FK-7W20RL	Yageo
R536	resistor; 150 kΩ; 0603; 1 %	0603WAF1503T5E	UNI-ROYAL
R538; R551; R568; R618; R620	resistor; 1 kΩ; 0603; 1 %	0603WAF1001T5E	UNI-ROYAL
R539	resistor; 820 Ω; 0603; 1 %	0603WAF8200T5E	UNI-ROYAL
R542; R555; R573; R625	resistor; not mounted; 0603	-	-
R543	resistor; 100 Ω; 0603; 1 %	0603WAF1000T5E	UNI-ROYAL
R544	resistor; 10 Ω; 0603; 1 %	0603WAF100JT5E	UNI-ROYAL
R547; R609	resistor; 1 kΩ; 1206; 1 %	1206W4F1001T5E	UNI-ROYAL
R548; R549	resistor; 49.9 kΩ; 0603; 1 %	0603WAF4992T5E	UNI-ROYAL
R550	resistor; 4.99 kΩ; 0603; 1 %	0603WAF4991T5E	UNI-ROYAL
R552; R569	resistor; 5.1 kΩ; 0603; 1 %	0603WAF5101T5E	UNI-ROYAL
R553	resistor; 47 kΩ; 0603; 1 %	0603WAF4702T5E	UNI-ROYAL
R554	resistor; 2.2 kΩ; 0603; 1 %	0603WAF2201T5E	UNI-ROYAL
R558; R559	resistor; 102 kΩ; 0603; 1 %	0603WAF1023T5E	UNI-ROYAL
R561	resistor; 5.6 MΩ; 1206; 5 %	RS-06L565JT	FH
R565	resistor; 100 kΩ; 0603; 1 %	0603WAF1003T5E	UNI-ROYAL
R566	resistor; 3.9 kΩ; 0603; 1 %	0603WAF3901T5E	UNI-ROYAL
R570	resistor; not mounted; 0805	-	-
R601; R619	resistor; 2 kΩ; 0603; 1 %	0603WAF2001T5E	UNI-ROYAL
R602; R623	resistor; 20 kΩ; 0603; 1 %	0603WAF2002T5E	UNI-ROYAL
R604; R633	resistor; 0.68 Ω; 1206; 1 %	FRL1206FR680TS	FOJAN
R605	resistor; 100 kΩ; 1206; 1 %	1206W4F1003T5E	UNI-ROYAL
R606; R628; R630	resistor; 1 kΩ; 0805; 1 %	0805W8F1001T5E	UNI-ROYAL

Table 5. TEA2376DB1647 bill of materials (BOM); main board...*continued*

Part	Description and values	Part number	Manufacturer
R607; R608	resistor; 5.6 Ω; 0805; 1 %	0805W8F560KT5E	UNI-ROYAL
R610	resistor; 1.5 Ω; 0805; 1 %	0805W8F150KT5E	UNI-ROYAL
R611; R615	resistor; 82 kΩ; 1206; 1 %	206W4F8202T5E	UNI-ROYAL
R612	resistor; 22 kΩ; 0805; 1 %	0805W8F2202T5E	UNI-ROYAL
R613	resistor; 5.6 kΩ; 0805; 1 %	0805W8F5601T5E	UNI-ROYAL
R616	resistor; 30 kΩ; 0805; 1 %	0805W8F3002T5E	UNI-ROYAL
R617	resistor; 4.3 kΩ; 0805; 1 %	0805W8F4301T5E	UNI-ROYAL
R622	resistor; 6.8 kΩ; 0603; 1 %	0603WAF6801T5E	UNI-ROYAL
R624	resistor; 5.6 kΩ; 0603; 1 %	0603WAF5601T5E	UNI-ROYAL
R626	resistor; 22 kΩ; 0603; 1 %	0603WAF2202T5E	UNI-ROYAL
R627; R629	resistor; 3 kΩ; 0805; 1 %	0805W8F3001T5E	UNI-ROYAL
R631	resistor; 5.6 Ω; 1206; 5 %	FRC1206J5R6 TS	FOJAN
R632	resistor; 68 kΩ; 0603; 1 %	0603WAF6802T5E	UNI-ROYAL
R635	resistor; 68 kΩ; 0805; 1 %	0805W8F6802T5E	UNI-ROYAL
Rt1; Rt2	NTC; 3 Ω; 3.9 W; THT	B57238S0309M000	TDK
RV201	varistors; 275 V (AC)	STE14D431K1EN0FQB0R0	STE
T201	PFC inductor	MEC5833DG201J	Mentech
T501	LLC transformer	TTPQ50-2800DG	Mentech
T601	Flyback transformer	TTEF20-2802DG	Mentech
U201	DCM/QR interleaved PFC controller; SO14	TEA2376DT	NXP Semiconductors
U301	active bridge controller; SO16	TEA2209T	NXP Semiconductors
U501	digital LLC controller; SO16	TEA2226AT	NXP Semiconductors
U502	LLC synchronous recitifier controller; SOIC-8	TEA2096T	NXP Semiconductors
U503; U505; U601; U604	optocoupler; CTR = 63 % ~ 125 %; LSOP-4	VOL617A-2X001T	Vishay
U504; U602; U606	shunt regulator; V_{ref} = 2.495 V; SOT-23	TL431AIDBZR	TI
U506	operational amplifier rail-to-rail; SOT-23-5	TSV991ILT	ST
U603	DCM/QR flyback controller; SOIC-10	TEA19361T	NXP Semiconductors
U605	shunt regulator low current; V_{ref} = 2.495 V; SOT-23	AP431SHAN1TR-G1	Diodes

8.2.2 TEA2376DB1647: MCU board

Table 6. TEA2376DB1647 bill of materials (BOM): MCU board

Part	Description and values	Part number	Manufacturer
C1; C11; C12; C40	capacitor; 4.7 µF; 16 V; 0603; X5R; 10 %	CL10A475KO8NNNC	Samsung
C3, C16, C17, C31, C33, C35, C41, C42, C43, C44, C46, C48, C53, C59, C61, C63, C65, C66	capacitor; 100 nF; 50 V; 0603; X7R; 10 %	CC0603KRX7R9BB104	Yageo
C4; C10; C18; C21; C72; C73; C74; C75; C76; C77	capacitor; 100 pF; 50 V; 0603; C0G; 5 %	CL10C101JB8NNNC	Samsung
C5	capacitor; 220 nF; 25 V; 0603; X7R; 10 %	CL10B224KA8NNNC	Samsung
C14; C37	capacitor; 10 µF; 25 V; 0603; X5R; 20 %	CL10A106MA8NRNC	Samsung
C20; C25; C28; C39; C47; C49	capacitor; 10 nF; 50 V; 0603; X7R; 10 %	0603B103K500NT	FH
C30; C32; C62; C67; C68	capacitor; 47 µF; 10 V; 0805; X5R; 20 %	CGA0805X5R476M100MT	HRE
C34; C64	capacitor; 10 µF; 50 V; 1206; X5R; 10 %	CL31A106KBHNNNE	Samsung
C45; C50; C52	capacitor; 1 µF; 50 V; 0603; X5R; 10 %	CL10A105KB8NNNC	Samsung
C51; C58	capacitor; 22 µF; 25 V; 0805; X5R;20 %	CL21A226MAQNNNE	Samsung
C54; C55; C56; C57	capacitor; not mounted; 0603	-	-
C60	capacitor; 47 pF; 50 V; 0603; C0G; 5 %	CL10C470JB8NNNC	Samsung
C70;C71	capacitor; 220 pF; 50 V; 0603; C0G; 5 %	CL10C221JB8NNNC	Samsung
D3	diode; switching diode; 150 mA; 75 V; SOD-123	1N4148W	ST
FB1; FB2; FB3; FB4; FB5	bead; 120 Ω; 800 mA; 0603	BLM18AG121SN1D	Murata
J1	header; 3-pin; pitch = 2.0 mm	2.54-1*3	ZHOURI
J2	header; 20-pin; pitch = 2.0 mm; reversing type	2.0-1*20P	BOOMELE
J3	header; 4-pin; pitch = 2.0 mm; reversing type	2.0-1*4P	BOOMELE
J4	header; 4-pin; pitch = 2.54 mm; reversing type	2.54-1*4P	BOOMELE
J5	connector; IDC type; 10-pin; pitch = 1.27 mm	X1270WV-2x05A-6TV01	XKB Connection
J6	not mounted	-	-

Table 6. TEA2376DB1647 bill of materials (BOM): MCU board...*continued*

Part	Description and values	Part number	Manufacturer
JP1	not mounted	-	-
KEY1	push-bottom; 12 V; 8.4 mm × 3.2 mm	TS36CA-0.6 250gf 031	SHOU HAN
KEY2	push-bottom; 12 V; 4 mm × 3 mm	TS342A2P	SHOU HAN
L1; L2; L3	inductor; 4.7 μH; 300 mA; 0805	MLZ2012M4R7HT000	TDK
LED1	optical fiber diode; LED; 20 mA; 0603	KT-0603R	KENTO
NTC1	NTC with connector; 100 kΩ; B 3950; XH 2.54	-	-
OLED	OLED display; 1.3 inch; 128*64 pixels; I^2C connector	-	-
Q1	BJT; NPN; 3A; 30V; SOT-89-3	D882(RANGE:160-320)	CJ
R1, R8, R36, R41, R46, R56, R61, R62, R63, R64	resistor; 10 kΩ; 0603; 1 %	0603WAF1002T5E	UNI-ROYAL
R2; R4; R10; R11; R13; R17; R18; R20; R21; R22; R23; R28; R67; R68	resistor; 22 Ω; 0603; 1 %	0603WAF220JT5E	UNI-ROYAL
R3; R5; R12	resistor; 4.7 kΩ; 0603; 1 %	0603WAF4701T5E	UNI-ROYAL
R5; R32; R35; R48; R55	resistor; 1 kΩ; 0603; 1 %	0603WAF1001T5E	UNI-ROYAL
R7	resistor; 120 Ω; 0805; 1 %	0805W8F1200T5E	UNI-ROYAL
R16	resistor; 11 kΩ; 0603; 1 %	0603WAF1102T5E	UNI-ROYAL
R19	resistor; 200 Ω; 0603; 1 %	0603WAF2000T5E	UNI-ROYAL
R24; R27	resistor; 60.4 Ω; 0805; 1 %	0805W8F604JT5E	UNI-ROYAL
R30; R52; R57	resistor; not mounted; 0603	-	-
R42	resistor; 43 kΩ; 0603; 1 %	0603WAF4302T5E	UNI-ROYAL
R44	resistor; 100 kΩ; 0603; 1 %	0603WAF1003T5E	UNI-ROYAL
R50, R51, R53, R54, R59, R60, R65, R66	resistor; 2.2 kΩ; 0603; 1 %	0603WAF2201T5E	UNI-ROYAL
R58	resistor; 0 Ω; 0603; 1 %	0603WAF0000T5E	UNI-ROYAL
U1	RS485/RS422 transceiver; 12 Mbps; SOP-8	ST3485EBDR	ST
U2	high-speed CAN transceiver; 5 Mbps; SOIC-8	TJA1042T/3/1J	NXP Semiconductors
U4	shunt regulator; V_{ref} = 2.5 V; SOT-23	TL431	Hottech Electronics
U5	MCU; 32-bit Arm, HVQFN-48	LPC5506JHI48	NXP Semiconductors

Table 6. TEA2376DB1647 bill of materials (BOM): MCU board*...continued*

Part	Description and values	Part number	Manufacturer
U6	bidirectional I^2C isolator; SOIC-8-WB	CA-IS3020G	Chipanalog Microelectronics
U7; U13	positive voltage regulator; 3.3 V; 100 mA; SOT-89-3	LD2981ABU33TR	ST
Y1	not mounted	-	-
Y2	not mounted	-	-

8.3 Layout

8.3.1 Main board

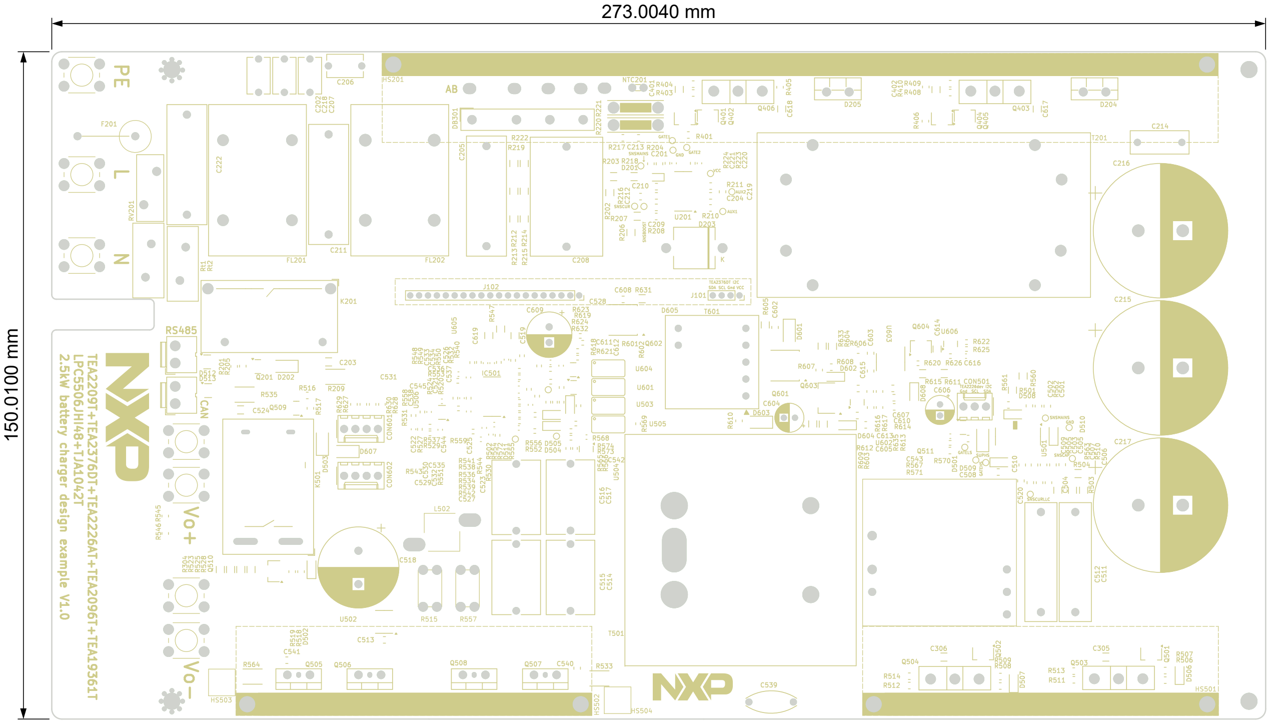


Figure 35. Main board - Top silk

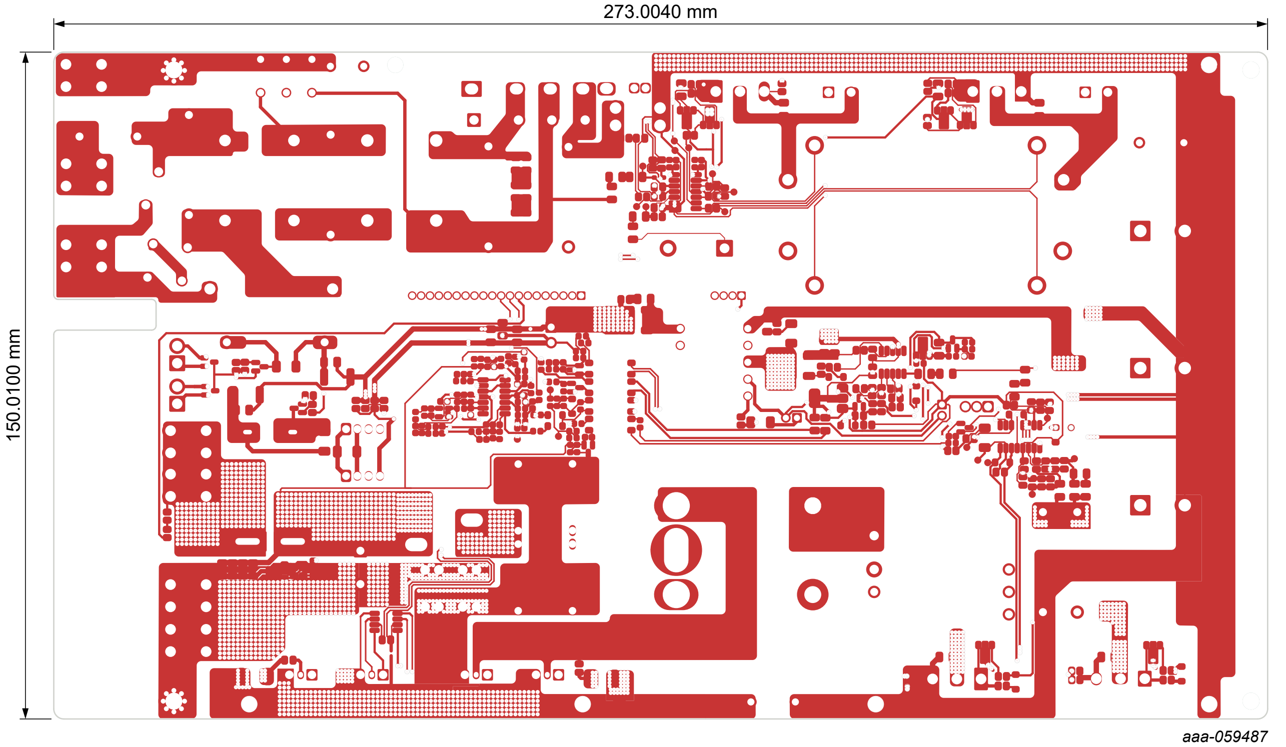


Figure 36. Main board - Top

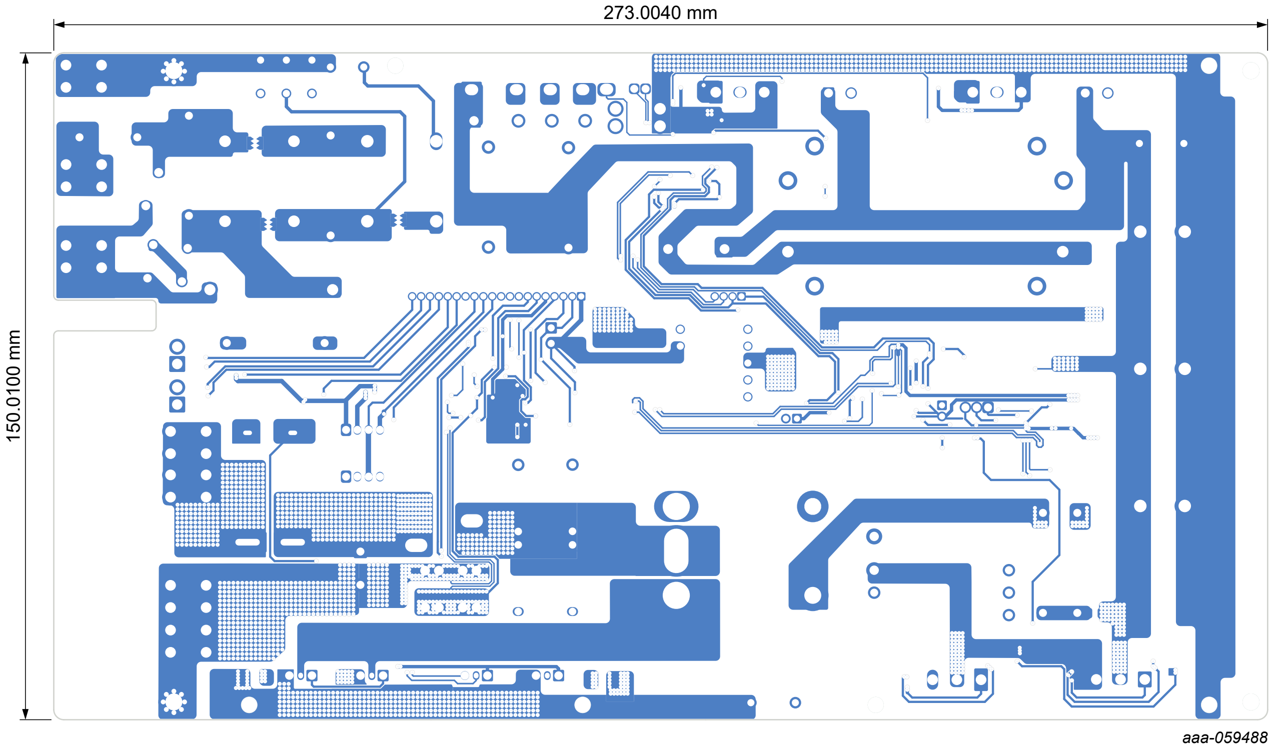


Figure 37. Main board - Bottom

8.3.2 Active bridge board

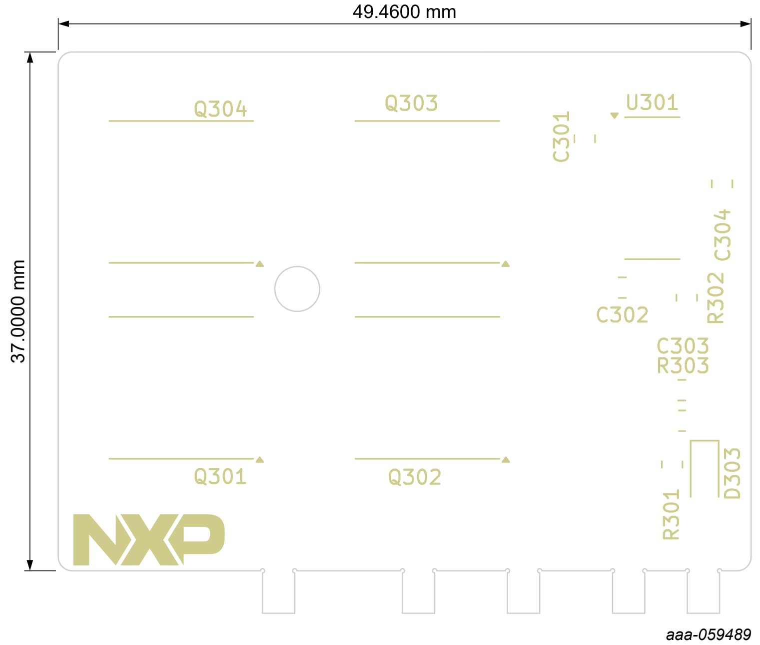


Figure 38. Active bridge board - Top silk

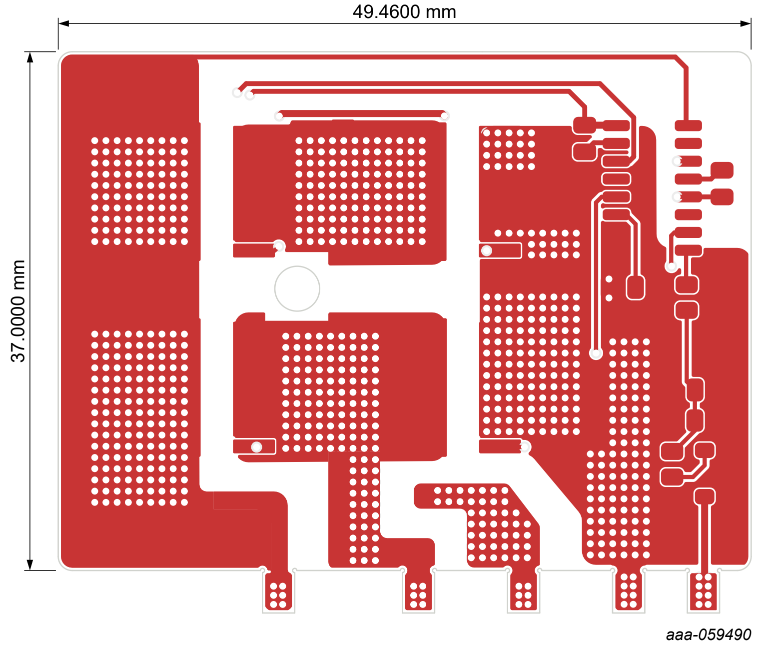


Figure 39. Active bridge board - Top

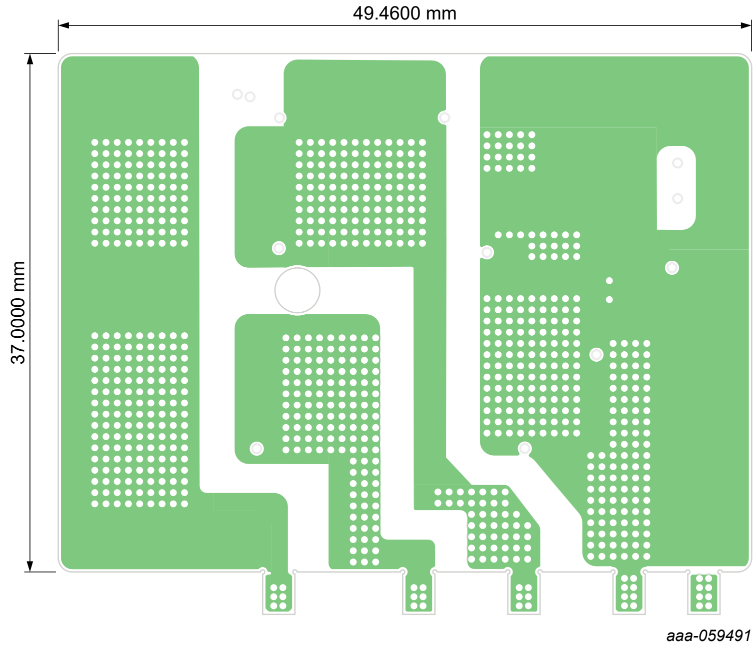


Figure 40. Active bridge board - Inner 1

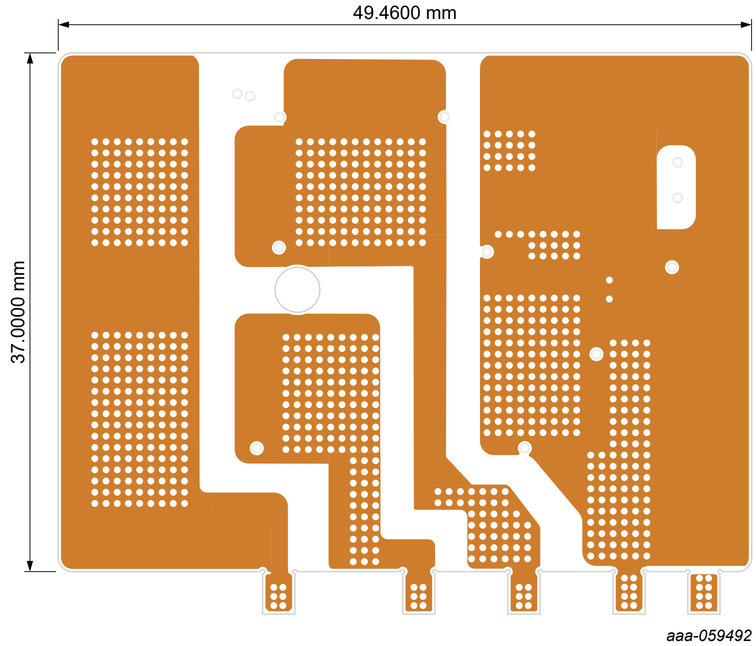


Figure 41. Active bridge board - Inner 2

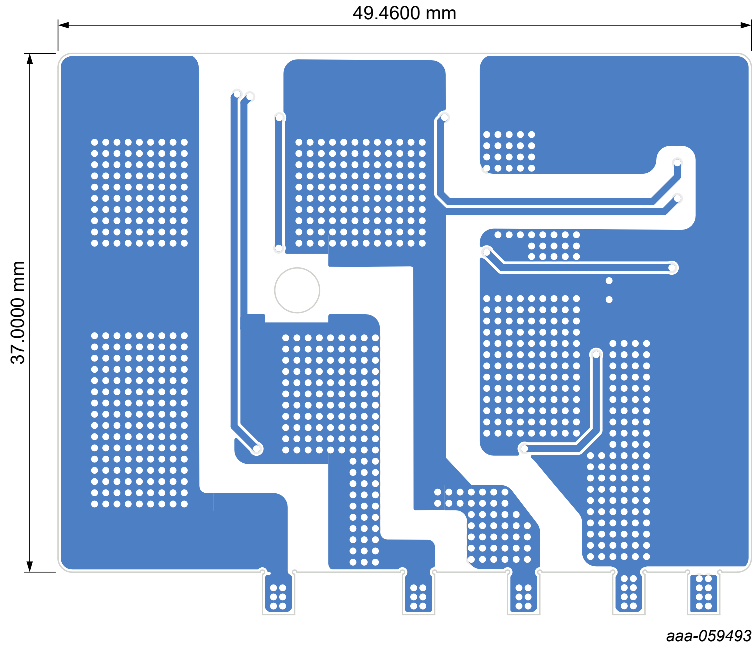


Figure 42. Active bridge board - Bottom

8.3.3 MCU board

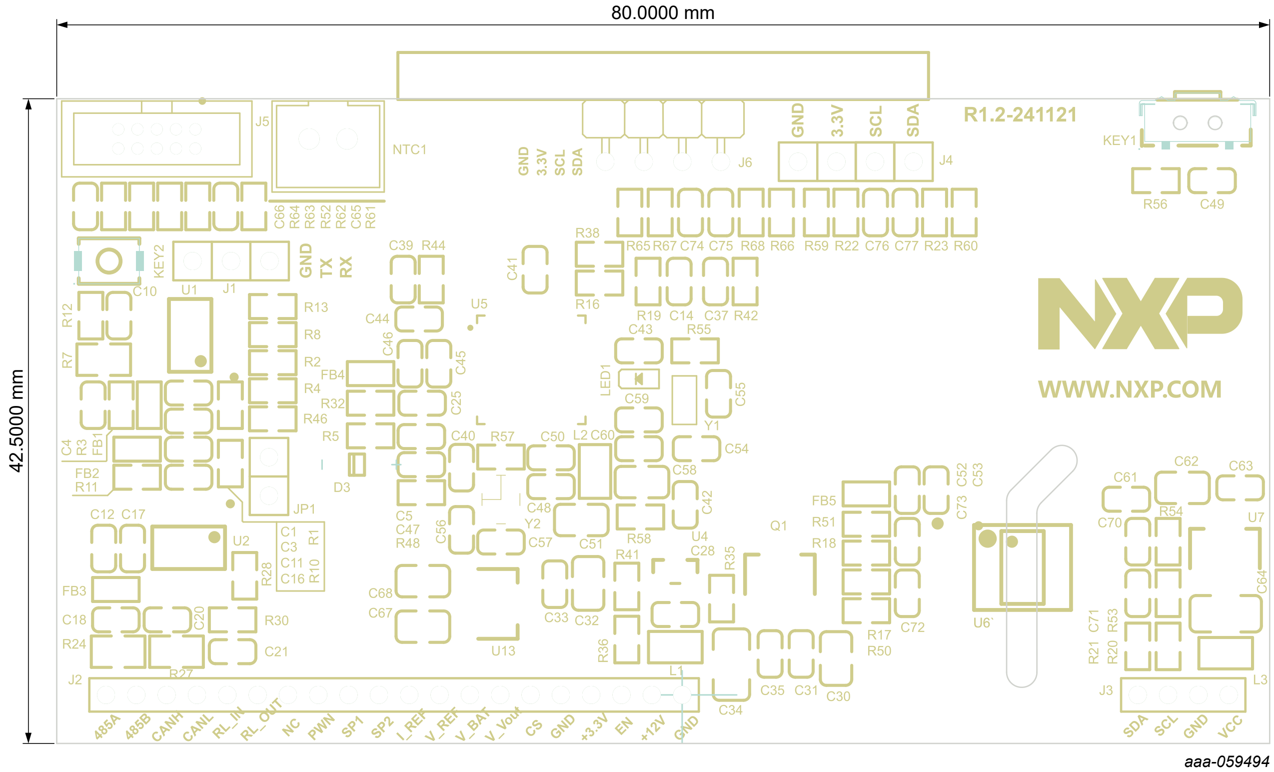


Figure 43. MCU board - Top silk

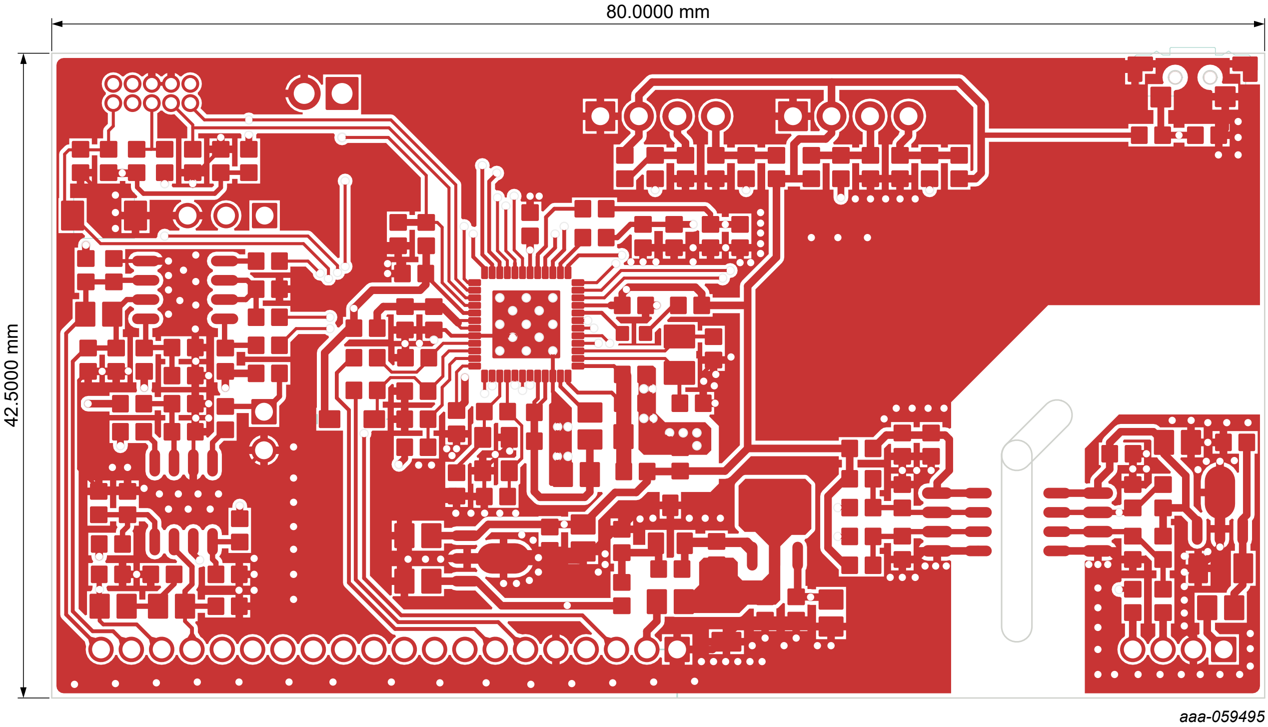


Figure 44. MCU board - Top

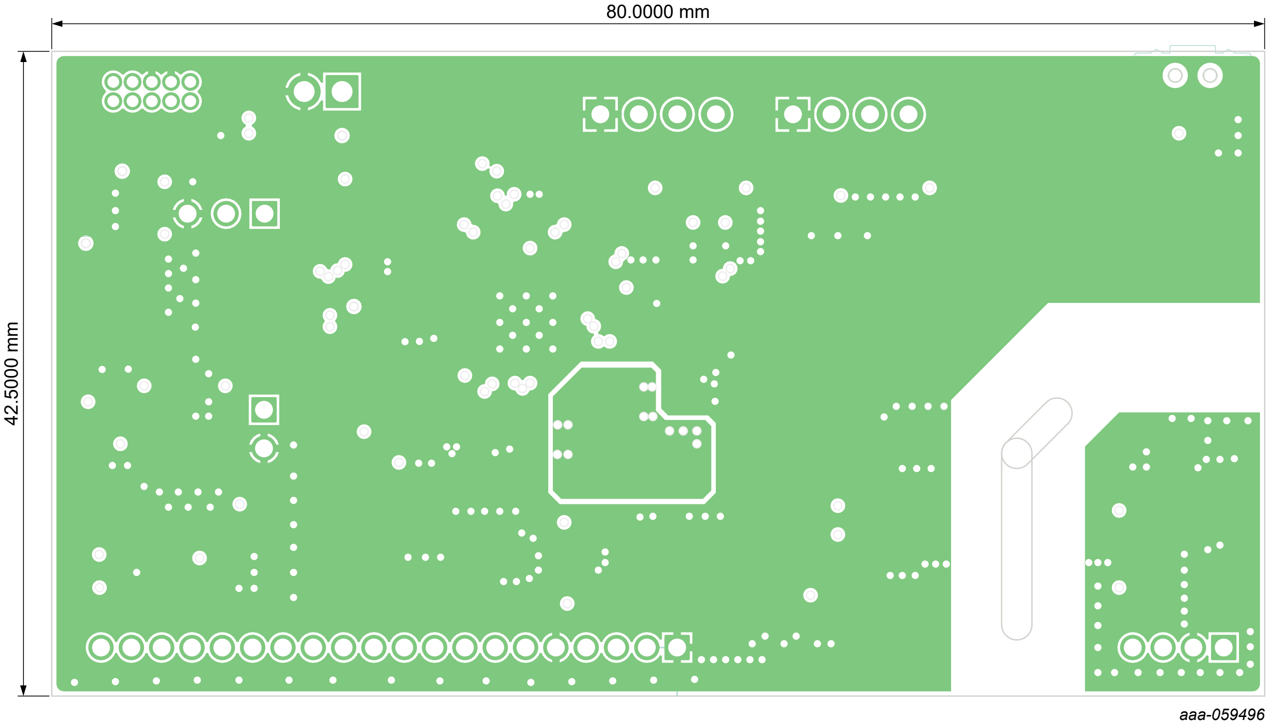


Figure 45. MCU board - Inner 1

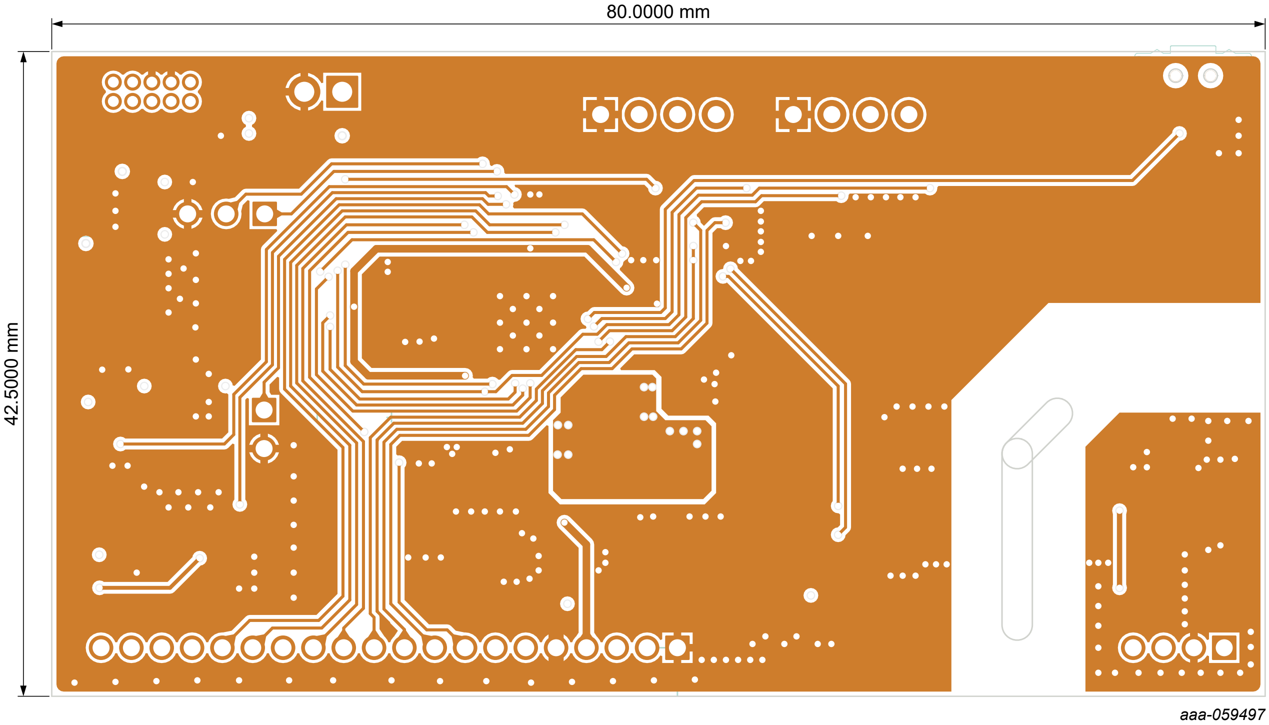


Figure 46. MCU board - Inner 2

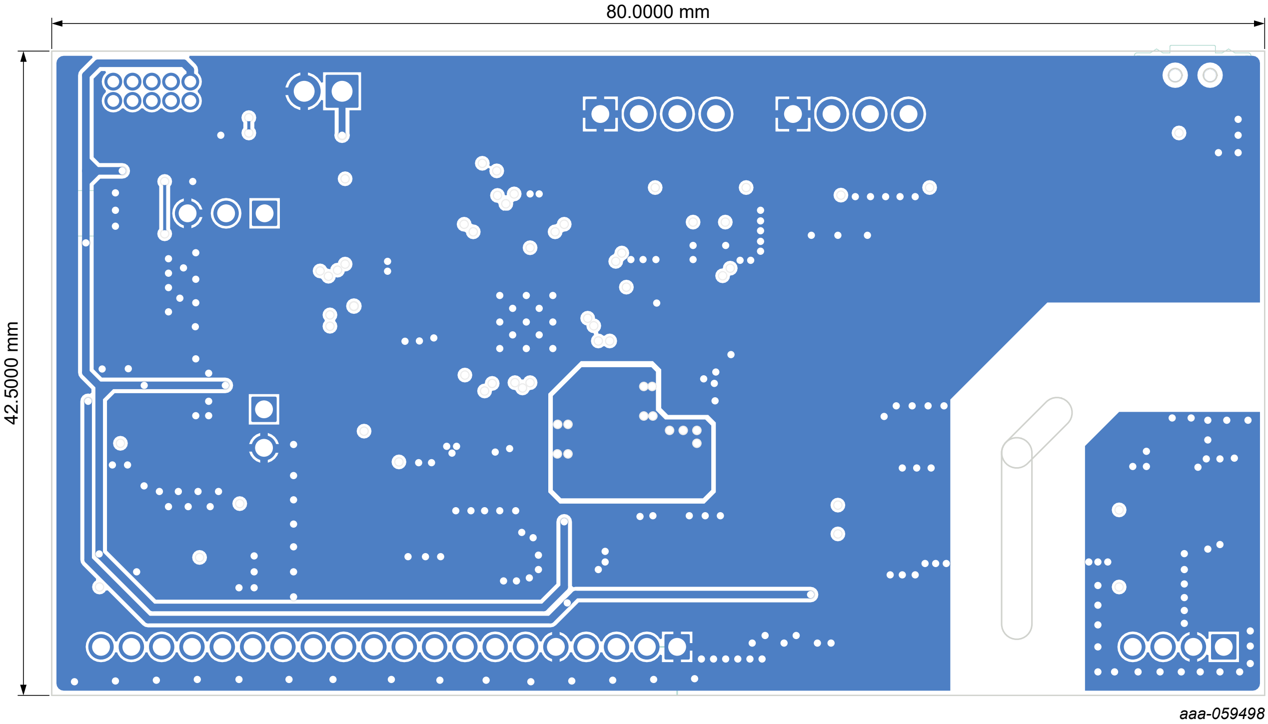


Figure 47. MCU board - Bottom

8.4 Transformers and inductors specifications

8.4.1 PFC inductor specification

- IEC62368-1 compliant
- RoHS compliant

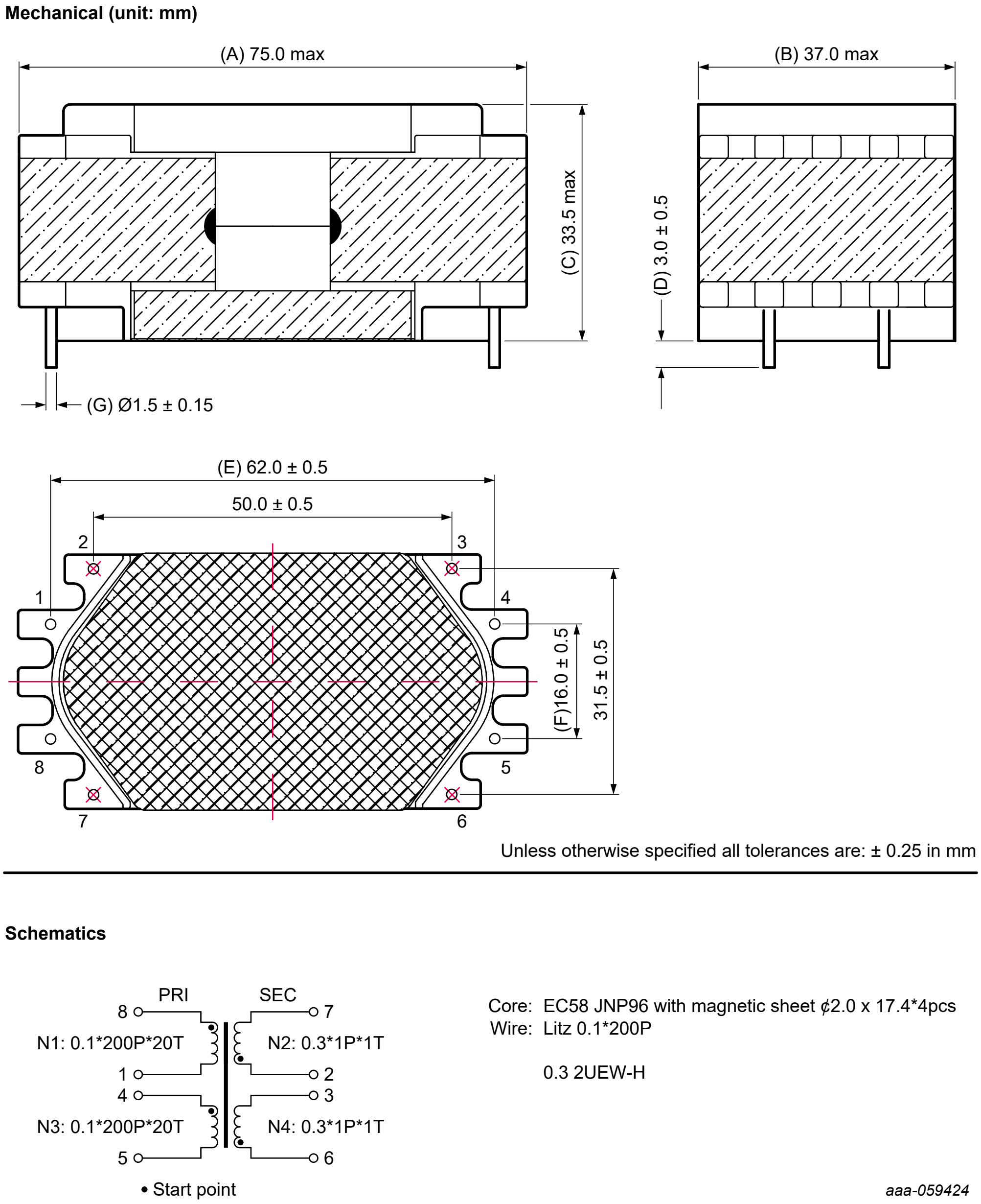


Figure 48. PFC inductor specification

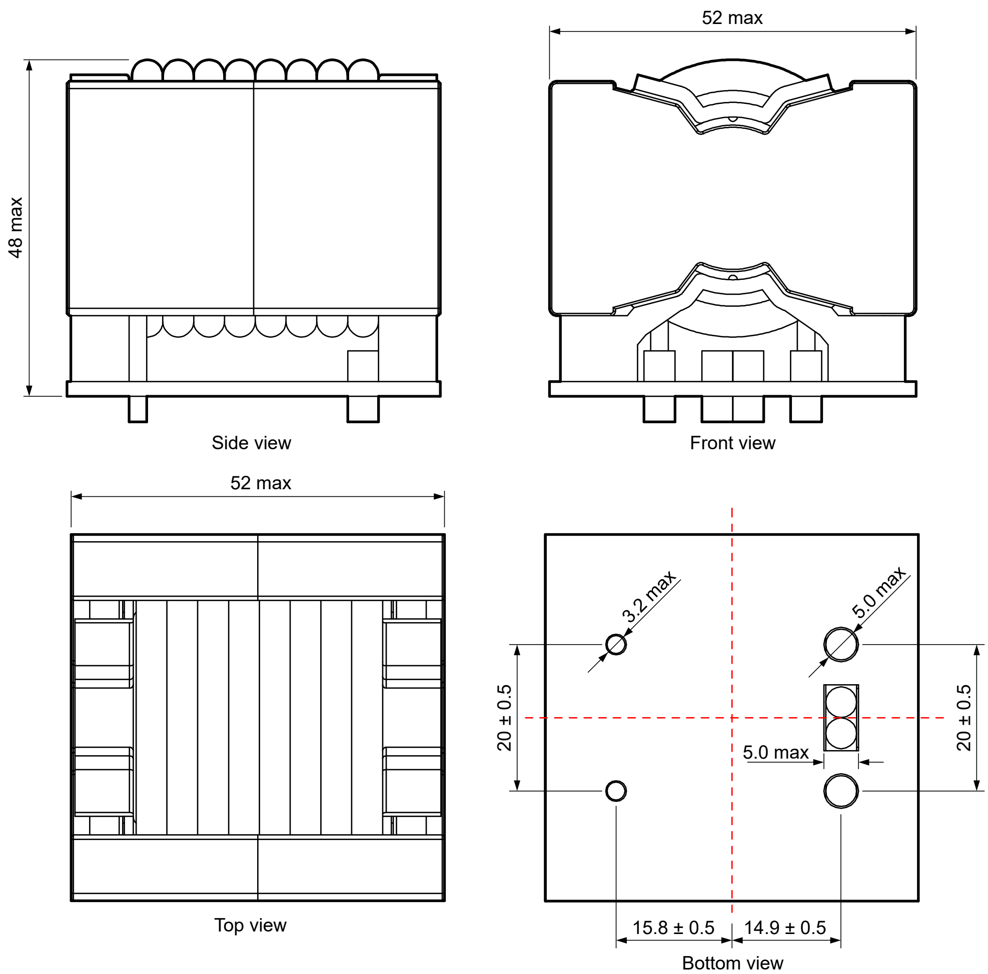
Table 7. PFC inductor specifications

<table>
<tr><th colspan="7">Electrical specifications at 25 °C</th></tr>
<tr><td rowspan="2">Part number</td><td>Turns ratio at 20 kHz and 1 V</td><td>OCL at 100 kHz and 1 V</td><td colspan="2">DCR (mΩ; maximum</td><td colspan="2">Hi-Pot at 2 mA and 5 s</td></tr>
<tr><td>8-1; 7-2/4-5; 3-6</td><td>8-1/4-5</td><td>8-1/4-5</td><td>7-2/3-6</td><td>Coil-core</td><td>pin 8,1 - pin 7,1/pin 4,5 - pin 3,6</td></tr>
<tr><td>MECB58DG450J</td><td>20:1; ±3 %</td><td>45 µH; ±6 %</td><td>20</td><td>32</td><td>600 V (AC)</td><td>600 V (AC)</td></tr>
<tr><th colspan="7">Temperature specifications</th></tr>
<tr><td colspan="2">Storage temperature range</td><td colspan="2">−40 °C to +125 °C</td><td colspan="3" rowspan="2"></td></tr>
<tr><td colspan="2">Operating temperature range</td><td colspan="2">−40 °C to +125 °C</td></tr>
</table>

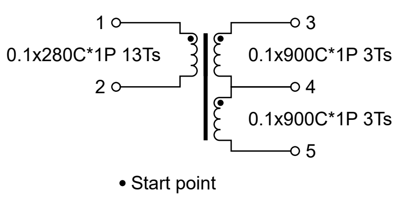
8.4.2 LLC transformer specification

- IEC62368-1 compliant
- RoHS compliant

Mechanical (unit: mm)



Schematics



Core: PQ50/51+4.0xØ20mm*2pcs magnetic sheet HE7F/LP10 or equivalent 96 material

Wire: 0.1x280P 2UEW-H PI wrapped, overlapping rate of more than 50%.
0.1x900P 2UEW-H PI wrapped, overlapping rate of more than 50 %.

aaa-059425

Figure 49. LLC transformer specification

Table 8. PFC transformer specifications

Electrical specification at 25 °C									
Part number	Turns ratio at 20 kHz and 1 V	OCL at 100 kHz and 1 V	LK (µH MAX) at 100 kHz and ,1 V; SHORT(3,4,5)	DCR (mΩ)			Hi-Pot at 2 mA and 5 s		Layer short
	1-2; 3-4; 4-5	1-2	1-2	1-2	3-4/4-5	pin 3,4,5 - core	pin 1,2 - pin 3,4,5	Pin 1, 2 - core	Pin 1,2/ Pin 3,4
TTPQ50-2800DG	13:3; 3 ±0.5 Ts	59.0	3.0	11	1.35	3600 V (AC)	3600 V (AC)	3600 V (AC)	(2000 Vp-p)
Temperature specifications									
Operating temperature range (including self-temperature increase)		−40 °C to +125 °C							

8.4.3 LLC resonant inductor specification

- IEC62368-1 compliant
- RoHS Compliant

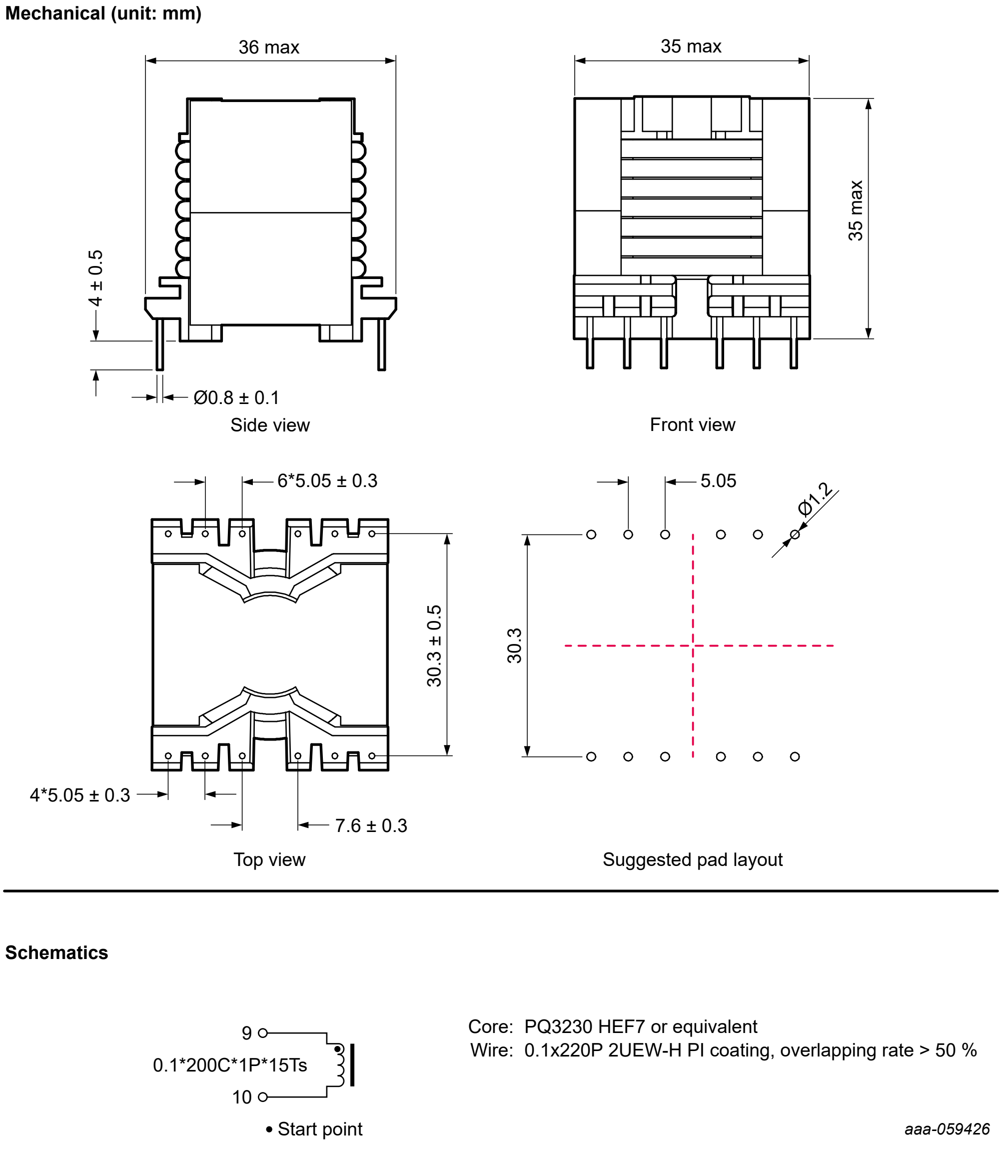


Figure 50. LLC resonant inductor specification

Table 9. LLC resonant inductor specification

Electrical specifications at 25 °C					
Part number	Turns ratio at 20 kHz and 1 V	OCL (μH; ±6 %) at 100 kHz and 1 V	DCR（mΩ)	HI-POT at 2 mA and 5 s	Layer short
	9-10	9-10	9-10	pin 9,10 - core	pin 9 - pin 10
MPQB32DG150J	15; ±0.5 Ts	15	12.5	2000 V (AC)	(1500 Vp-p)
Temperature specifications					
Operation temperature range (including self-temperature increase		−40 °C to +125 °C			

8.4.4 Flyback transformer specification

- IEC62368-1 compliant
- RoHS compliant

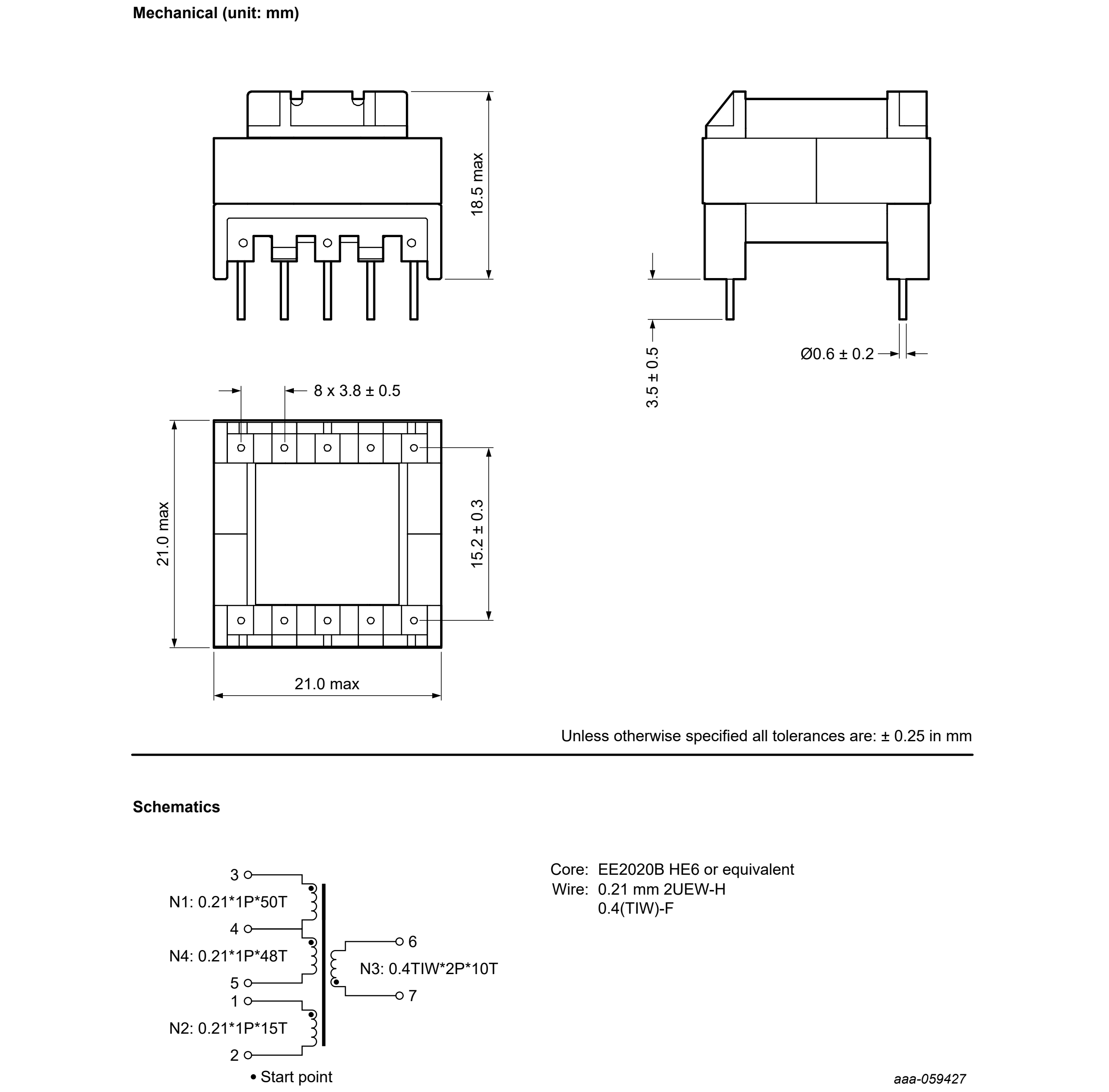


Figure 51. Flyback transformer specification

Table 10. Flyback transformer specification

Electrical specifications at 25 °C									
Part number	Turns ratio at 20 kHz and 1 V	OCL at 100 kHz and 0.1 V	LK at 100 kHz and 0.1 V short other terminals	DCR (mΩ; maximum)			Hi-Pot at 2 mA and 5 s		
	3-5; 1-2; 6-7	3-5	3-5	3-5	1-2	6-7	Pri-core	Sec-core	Pri-Sec
TTEF20-2802DG	98; 15; 10	700 µH; ±12 %	16 µH; maximum	1950	285	32	1000 V (AC)	3600 V (AC)	3600 V (AC)
Temperature specifications									
Storage temperature range		−40 °C to +125 °C							
Operating temperature range		−40 °C to +125 °C							

9 Abbreviations

Table 11. Abbreviations

Abbreviation	Description
DCM	discontinuous conduction mode
DSP	digital signal processing
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ESD	electrostatic discharge
FR	frequency reduction
IC	integrated circuit
ICP	inrush current protection
LCD	liquid crystal display
MOSFET	metal-oxide semiconductor field-effect transistor
MCU	microcontroller unit
MTP	multitime programmable (memory)
NTC	negative temperature coefficient
OCP	overcurrent protection
OPP	overpower protection
OTP	overtemperature protection
OVP	overvoltage protection
PCB	printed-circuit board
PSU	power supply unit
PF	power factor
PFC	power factor correction
QR	quasi-resonant
SOI	silicon-on-insulator
SR	synchronous rectifier
THD	total harmonic distortion
UVP	undervoltage protection

10 References

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

[2] **AN14200 application note** — TEA2376 interleaved PFC controller IC; 2025, NXP Semiconductors

[3] **TEA2209T data sheet** — Active bridge rectifier controller; 2021, NXP Semiconductors

[4] **TEA2226AT data sheet** — Digital configurable LLC controller; 2023, NXP Semiconductors

[5] **AN13140 application note** — TEA2017 CCM/DCM/QR PFC + LLC controller IC; 2022, NXP Semiconductors

[6] TEA2096T data sheet — GreenChip dual synchronous rectifier controller; 2022, NXP Semiconductors

[7] **TEA19361T data sheet** — GreenChip SMPS primary side control IC with QR/DCM operation; 2020, NXP Semiconductors

[8] **LPC5506JHI48 data sheet** — 32-bit Arm Cortex®-M33, TrustZone, PRINCE, CASPER, 96 KB SRAM; 256 KB flash, Flexcomm Interface, CAN FD, 32-bit counter/ timers, SCTimer/PWM, PLU, 16-bit 2.0 Msamples/sec ADC, Comparator, Temperature Sensor, AES, PUF, SHA, CRC, RNG; 2023, NXP Semiconductors

[9] **TJA1042 data sheet** — High-speed CAN transceiver with Standby mode; 2023, NXP Semiconductors

[10] **PCB layout** — Contact NXP Semiconductors

[11] **TEA2376DT MTP setting** — Contact NXP Semiconductors; www.nxp.com

[12] **TEA2226AT MTP setting** — Contact NXP Semiconductors; www.nxp.com

11 Revision history

Table 12. Revision history

Document ID	Release date	Description
UM12272 v.1.0	21 March 2025	• 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.

HTML publications — An HTML version, if available, of this document is provided as a courtesy. Definitive information is contained in the applicable document in PDF format. If there is a discrepancy between the HTML document and the PDF document, the PDF document has priority.

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.

Contents

1 Important notice ... 2
2 Safety warning ... 3
3 Introduction ... 4
3.1 TEA2376 ... 4
3.2 TEA2209T ... 4
3.3 TEA2226AT ... 5
3.4 TEA2096T ... 5
3.5 TEA19361T ... 6
3.6 LPC5506JHI48 ... 7
3.7 TJA1042 ... 9
4 Finding kit resources and information on the NXP website ... 10
4.1 Collaborate in the NXP community ... 10
5 Getting ready ... 11
5.1 Box contents ... 11
6 Getting to know the hardware ... 13
6.1 Specifications ... 13
7 Performance measurement ... 14
7.1 Test facilities ... 14
7.2 Test setup ... 14
7.3 Active bridge (TEA2209T) operation ... 16
7.4 Interleaved PFC (TEA2376) operation ... 17
7.5 LLC half-bridge (TEA2226) and SR (TEA2096T) operation ... 19
7.6 Flyback (TEA19361T) operation ... 20
7.7 AC mains voltage transition ... 21
7.8 Battery charging curves ... 22
7.8.1 TEA2226AT operation modes ... 23
7.8.2 Battery charging curve test ... 24
7.9 Efficiency test result ... 25
7.10 Power factor test result ... 26
7.11 Start-up and off sequences ... 27
7.12 Components temperature performance ... 29
7.13 Conduction EMI ... 31
8 Schematic and bill of materials ... 32
8.1 Schematic ... 32
8.1.1 Design example overall schematic ... 32
8.1.2 AC mains and PFC parts ... 33
8.1.3 LLC and SR parts ... 34
8.1.4 Active bridge part ... 35
8.1.5 Flyback part ... 36
8.1.6 MCU daughter board part ... 37
8.2 Bill of materials (BOM) ... 38
8.2.1 TEA2376DB1647: Main board ... 38
8.2.2 TEA2376DB1647: MCU board ... 44
8.3 Layout ... 47
8.3.1 Main board ... 47
8.3.2 Active bridge board ... 49
8.3.3 MCU board ... 51
8.4 Transformers and inductors specifications ... 54
8.4.1 PFC inductor specification ... 54
8.4.2 LLC transformer specification ... 56
8.4.3 LLC resonant inductor specification ... 58
8.4.4 Flyback transformer specification ... 60
9 Abbreviations ... 62
10 References ... 63
11 Revision history ... 64
Legal information ... 65

Date of release: 21 March 2025
Document identifier: UM12272