UM11234

TEA2016DB1519v2 240 W demo board

Rev. 1 — 5 November 2019 User manual

Document information

Information	Content
Keywords	TEA2016DB1519, 240 W, 12V x 20A, PFC, LLC, resonant, controller, converter, burst mode, power supply, demo board, programmable settings, I2C
Abstract	The TEA2016 is a controller IC for resonant power supplies that include a PFC. It provides high efficiency at all power levels. Together with the TEA1995T dual LLC resonant SR controller, a high performance cost-effective resonant power supply can be made. To reach a high efficiency at all power levels the TEA2016 provides a low-power operation mode (LP) and extensive burst mode configuration options. Operation modes and protections can be defined by parameter setting in an internal multi times programmable memory. For product development an IC version is available to make setting changes on the fly. The TEA2016 provides extra functions like active X-cap discharge, external OTP sensing and Power Good signal. Protections can be configured to provide the correct handling. The efficiency at high power levels is well above 90%. No-load power consumption is below 100 mW. At 250 mW output power, the input power is well below 500 mW for easily meeting the EUP lot6 standby requirement. The TEA2016DB1519 board shows a single output (12 V) desktop PC application that needs forced cooling (by fan) at high output power (above 120 W)

Revision history

Revision history

Rev	Date	Description
v.1	20191105	Initial version

1 Introduction

1.1 TEA2016

The TEA2016 provides high efficiency at all power levels. Together with the TEA1995T, a dual LLC resonant SR controller, a high-performance cost-effective resonant power supply can be designed. The power supply designed can meet 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.

In general, resonant converters show an excellent efficiency at high power levels, while at lower levels their efficiency reduces because of the relatively high magnetizing current losses. To reach a high efficiency at all power levels, the TEA2016 provides a low-power operation mode (LP) and extensive burst mode configuration options.

Most LLC resonant converter controllers regulate the output power by adjusting the operating frequency. The TEA2016 regulates the output power by adjusting the voltage across the primary resonant capacitor for accurate state control and a linear power control.

The primary resonant capacitor voltage provides accurate information about the output power to the controller using a voltage divider. The voltage divider sets the output power levels. It determines when the system switches from the high-power mode to low-power mode and when it switches from low-power mode to burst mode.

An extensive number of parameter settings for operation can define operation modes and protections. 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-up, the IC loads the parameter values for operation. For easy design work during product development, an IC version is available to change settings on the fly.

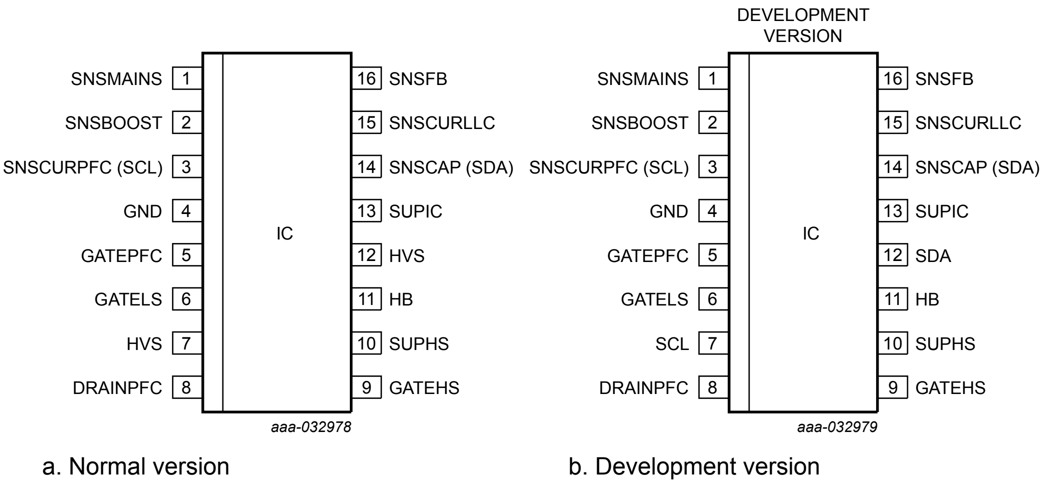

Figure 1. TEA2016AAT pinning

Note: *The TEA2016DB1519 demo board contains the development version.*

1.2 TEA1995T

The TEA1995T 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 TEA1995T is a dedicated controller IC for synchronous rectification on the secondary side of 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.

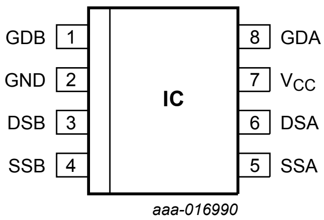

Figure 2. TEA1995T pinning

1.3 Demo board

The TEA2016DB1519 demo board can operate at a mains input voltage between 90 V (RMS) and 264 V (RMS; universal mains).

The TEA2016DB1519 demo board contains three sub circuits (see Section 8):

- A BCM-type PFC converter
- A resonant LLC-type HBC converter
- An SR resonant LLC-type output stage

The purpose of the demo board is to show and evaluate the operation of the TEA2016 and TEA1995T in a single output supply, which includes the operation modes in a typical design. The performance passes general standards, including the EuP lot6 requirements. It can be used as a starting point for power supply design using the TEA2016 and TEA1995T controller ICs.

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Figure 3. TEA2016DB1519v2 demo board

1.4 TEA2016 GUI and USB-I^{2}C interface

In addition to the normal TEA2016 ICs, NXP Semiconductors provides special IC versions for product development. The difference is that the development IC samples include a second I^{2}C interface for easy modification of settings while the IC is operating ("on the fly" changing). The TEA2016DB1519 demo board uses the development version of the TEA2016.

1.4.1 Development IC samples: SDA and SCL on spacer pins

Connections to the IC second I^{2}C interface are provided on high-voltage spacer pins 7 and 12. Normally, these pins are not connected.

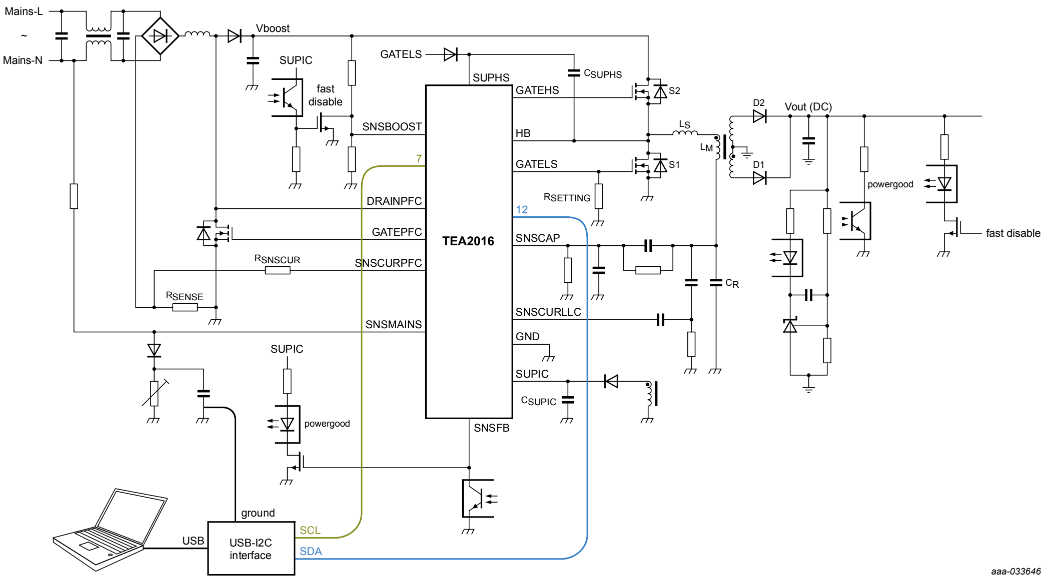


Figure 4. Development IC: I^{2}C connections with spacer pins

1.4.2 Production IC samples: SDA and SCL on combined pins

In the production version of the TEA2016, the I^{2}C interface is available on the combined pins SNSCURPFC (SCL) and SNSCAP (SDA). To program the IC, it must be put in the disabled condition pulling SNSBOOST to GND. During programming, SUPIC must supply the IC.

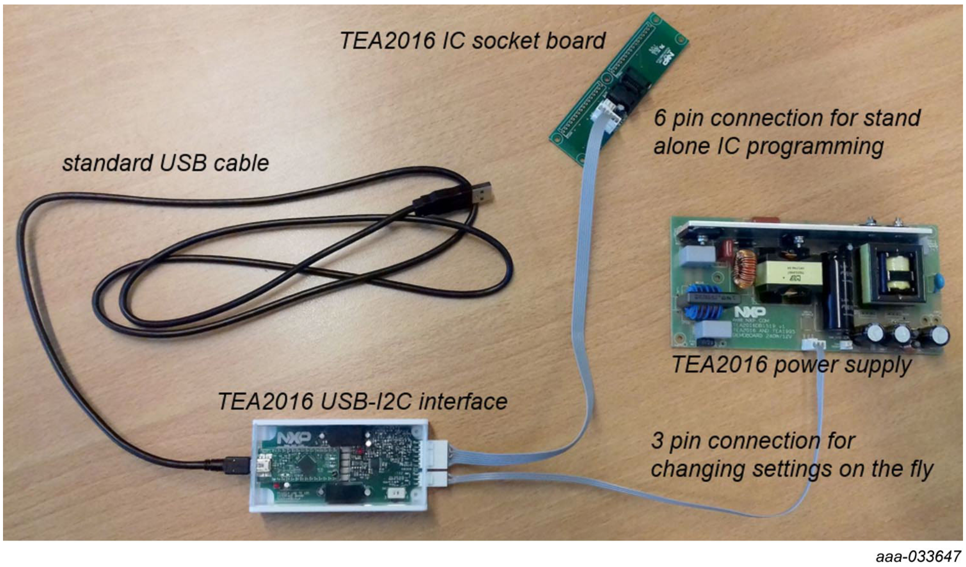


Figure 5. Two TEA2016 programming setups: on the fly and standalone

1.5 Graphical user interface (GUI) and USB-I²C interface

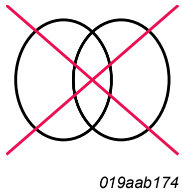
During power supply development, a GUI program on a computer communicates with the IC via a USB-I2C interface. The Ringo TEA2016 software with GUI provides the correct protocol and offers several options and tools to work with the IC settings.

For more information on the Ringo TEA2016 GUI, see the UM11219 user manual (Ref. 3). For more information on the USB-I²C interface, see the UM11235 user manual (Ref. 4).

2 Safety warning

The board must be connected to mains voltage. Avoid touching the demo board while it is connected to the mains voltage. An isolated housing is obligatory when used in uncontrolled, non-laboratory environments. Galvanic isolation of the mains phase using a variable transformer is always recommended. Figure 6 shows the symbols that identify the isolated and non-isolated devices.

a. Isolated



b. Not isolated

Figure 6. Isolation symbols

3 Specifications

Table 1. TEA2016DB1519 board specification

Symbol	Description	Value	Conditions
Input			
V_i	input voltage	90 V (RMS) to 264 V (RMS)	AC
f_i	input frequency	47 Hz to 63 Hz	
$P_{i(noload)}$	no-load input power	< 100 mW	at 230 V/50 Hz
$P_{i(load\text{-}250mW)}$	standby power consumption	< 450 mW	at 230 V/50 Hz
Output			
V_o	output voltage	12 V	
I_o	output current	0 A to 20 A	continuous
$I_{o(max)}$	maximum output power	24 A	OPP level
$I_{o(peak)max}$	maximum peak output current	30 A	t < 50 ms; limited by power limit setting (155 %)
t_{hold}	hold time	> 10 ms	at 115 V/60 Hz
t_{start}	start time	< 0.5 s	at 115 V/60 Hz
η	efficiency	≥ 89 %	average according to CoC

Note: *The TEA2016DB1519v2 board shows a single output (12 V) desktop PC application that requires forced cooling (fan) at high output power (when 120 W is exceeded).*

4 Board photographs

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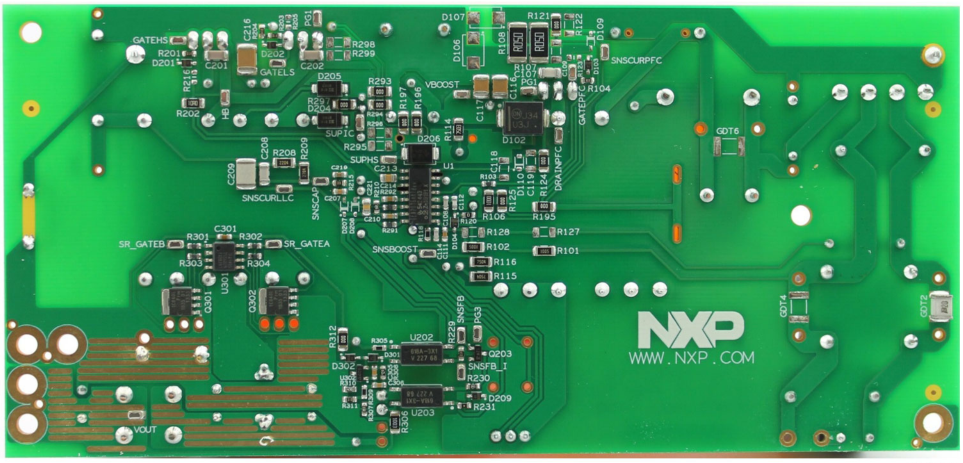
a. Top



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b. Bottom

Figure 7. TEA2016DB1519v2 board photographs

5 Performance measurements

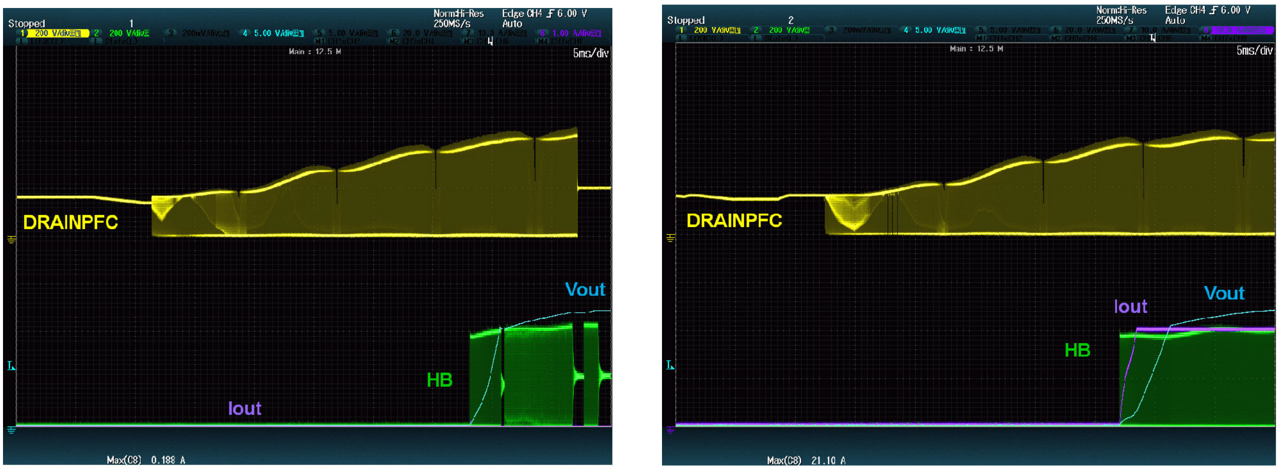
5.1 Test facilities

- Oscilloscope: Yokogawa DLM4038
- AC Power Source: Agilent 6812B
- Electronic load: Agilent 6063B
- Digital power meter: Yokogawa WT210

5.2 Start-up and switch-off behavior

5.2.1 Output voltage rise time

The rise time of the output voltage (measured from 10 % to 90 % point of the nominal output) is between 3 ms and 6 ms (see Figure 8. The rise time depends on the output current load.



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a. V_{mains} = 115 V; I_{out} = 0 A

b. V_{mains} = 115 V; I_{out} = 20 A

Figure 8. Start-up behavior

5.2.2 Start-up time

The total start-up time from mains switch-on until the output voltage reaches 12 V is approximately 200 ms (see Figure 9).

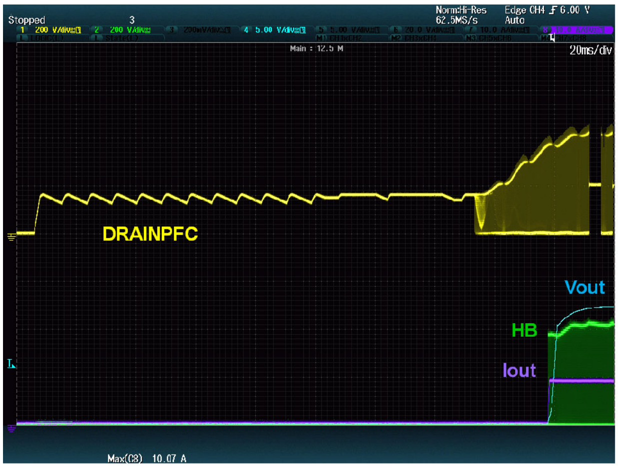
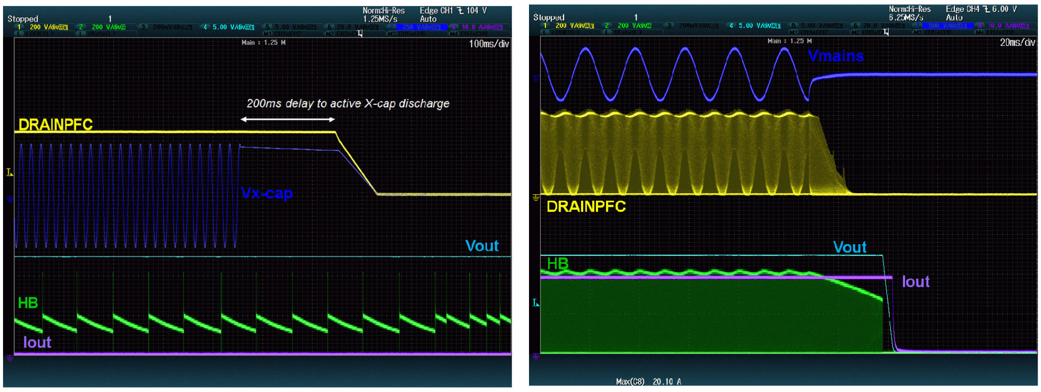


Figure 9. Total start-up time - V_{mains} = 115 V; I_{out} = 10 A

5.2.3 Mains switch-off and X-capacitor discharge



a. V_{mains} = 230 V; I_{out} = 0 A

b. V_{mains} = 230 V; I_{out} = 20 A

Figure 10. Mains switch-off behavior

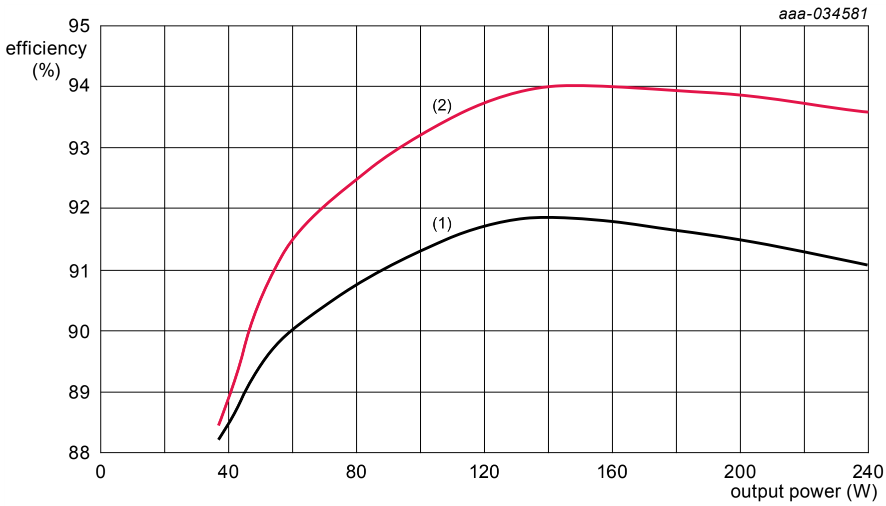
5.3 Efficiency

5.3.1 Efficiency characteristics

To determine the efficiency, the output voltage (not taking into account the losses in an output connection cable) on the TEA2016DB1519v2 demo board was measured.

Table 2. Efficiency results

Condition	COC efficiency requirement (%)	Efficiency (%)				
		Average	25 % load	50 % load	75 % load	100 %
115 V/60 Hz	> 89	91.1	90.1	91.8	91.6	91.0
230 V/50 Hz	> 89	93.3	91.6	93.8	94.0	93.6



(1) 115 V (AC)/60 Hz

(2) 230 V (AC)/50 Hz

Figure 11. Efficiency graph

5.3.2 No-load power consumption

Table 3. Output voltage and power consumption at no load

Condition	Requirement (mW)	Output voltage (V)	No load power consumption (mW)
115 V/60 Hz	≤ 100 mW	12.3	60
230 V/50 Hz	≤ 100 mW	12.3	70

5.3.3 Standby power consumption

Results depend on parameter settings for BM operation. A lower LLC BM repetition frequency and a higher energy per cycle result in a lower power consumption. Output voltage ripple increases as a consequence.

Table 4. Output voltage and power consumption at standby

Condition	Output power (mW)	Output voltage (V)	Standby power consumption (mW)
115 V/60 Hz	250 mW	12.3	440
230 V/50 Hz	250 mW	12.3	440
EuP lot6 requirement	250 mW		< 500

5.3.4 Power factor

Table 5. Power Factor Correction

Condition	Requirement	Output Power (W)	Power Factor
115 V/60 Hz	≥ 0.9	240	0.99
230 V/50 Hz		240	0.93

5.4 Operation mode transitions

There are three modes of operation

- High-power mode (HP)
- Low-power mode (LP)
- Burst mode (BM)

A parameter setting can modify the levels of the transition between operation modes.

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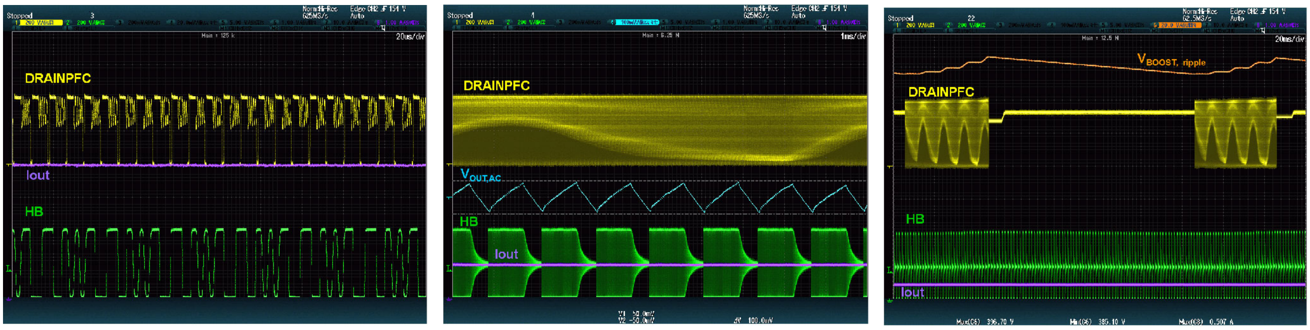
Load sweep: slowly varying the output current to observe mode transitions

Figure 12. Operating mode transitions BM-LP-HP

- HP to LP transition: I_{out} = 5.9 A
- LP to HP transition: I_{out} = 7.0 A
- BM transition: I_{out} = 1.6 A



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a. LP mode (I_{out} = 4 A) a. BM mode (I_{out} = 1 A) a. BM mode (I_{out} = 0.5 A)

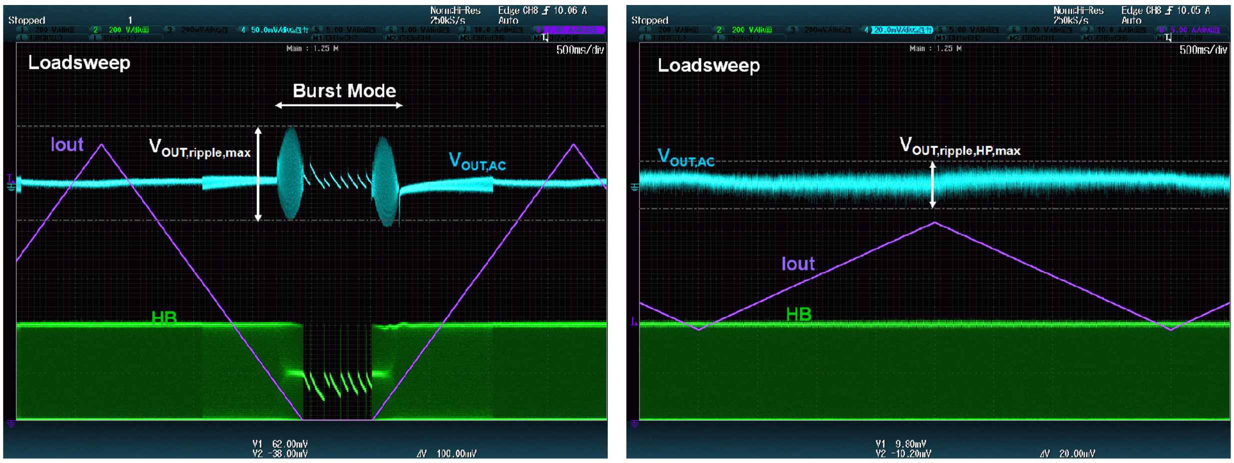
Figure 13. LP and BM (LLC and LLC+PFC) behavior

5.5 Output voltage ripple

Maximum output voltage ripple is approximately 100 mVpp during BM operation.

At maximum output power in HP mode, the output voltage ripple is less than 20 mV.

The amount of ripple in BM operation can be modified using parameter settings, for example, BM repetition frequency.



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Normally, the maximum output voltage ripple is at an LLC BM 50 % duty cycle.

Figure 14. Output voltage ripple

5.6 Dynamic load response

The dynamic load response test shows the result of a series of load steps on the output. The output current of the converter is changed in steps between 0 A and 20 A at a repetition frequency of 1 Hz, 10 Hz, 100 Hz, and 1000 Hz with a duty cycle of 50 %.

- The maximum voltage varies between 12.49 V and 12.60 V
- The minimum voltage varies between 11.11 V and 11.87 V
- The output voltage can be defined as 12 V (+5 %/−7.5 %)

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Load step (0 A - 20 A - 0 A) at 1 Hz; duty cycle = 50 %

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Load step (0 A - 20 A - 0 A) at 10 Hz; duty cycle = 50 %

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Load step (0 A - 20 A - 0 A) at 100 Hz; duty cycle = 50 %

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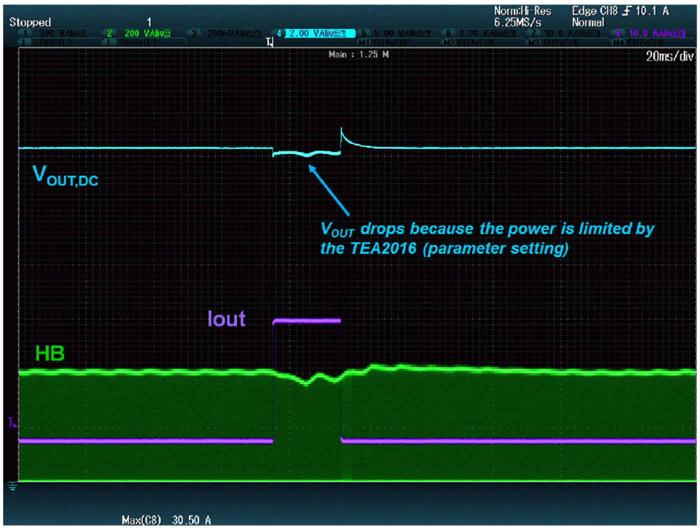
Load step (0 A - 20 A - 0 A) at 1000 Hz; duty cycle = 50 %

Figure 15. Load step behavior

5.7 Power limit

The output power is limited at 30.5 A at 12 V (P_{out} = 366 W = 153 %).

The power limit can be modified with the parameter settings (155 % selected).



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The power limit can be checked with a short load step (to avoid OPP protection). The output voltage drops because the power is limited by the TEA2016 a parameter setting.

Figure 16. Power limit; load step (7 A - 30.5 A - 7 A)

5.8 Overpower protection (OPP)

The overpower protection (OPP1) is at 24 A. It stands for 24 A × 12.3 V = 295 W.

The selected setting is on −20 %. It corresponds to P_{limit} − 20 % = 0.8 × 155 % = 124 %. 124 % power stands for 1.24 × 240 W = 298 W.

The OPP1 level can be modified with parameter settings.

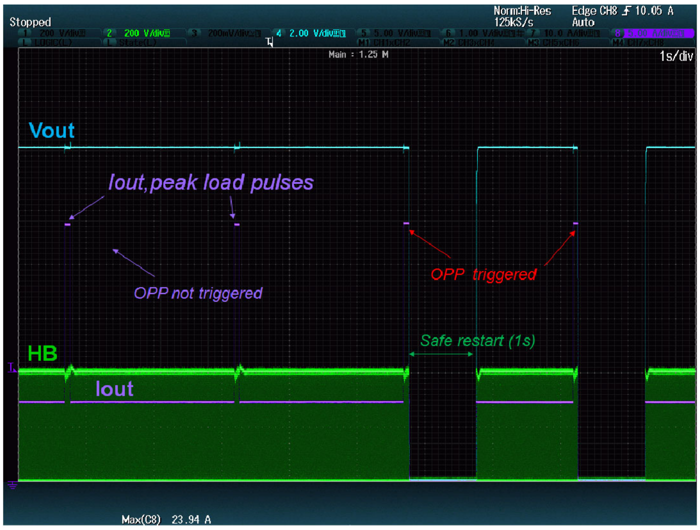


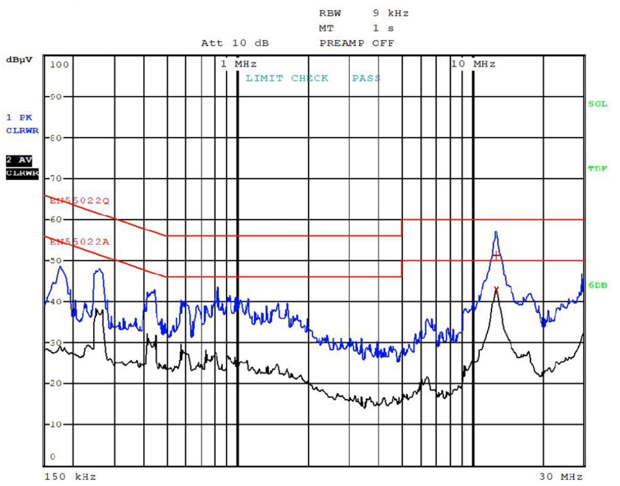
Figure 17. OPP with safe restart

5.9 EMI

The conducted electromagnetic interference (EMI) of the TEA2016DB1519v2 demo board was measured under the following conditions:

- Load resistor: 0.6 Ω; V_{out} = 12 V; I_{out} = 20 A
- V_{line} = 230 V/50 Hz or 115 V/50 Hz

The conducted EMI was measured both in the line and neutral. The product complies with the EMC standard.



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EDIT PEAK LIST (Final Measurement Results)			
Trace1:	EN55022Q		
Trace2:	EN55022A		
Trace3:	- - -		
TRACE	FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
1 Quasi Peak	12.702 MHz	51.34 L1	-8.65
2 Average	12.742 MHz	42.57 N	-7.52

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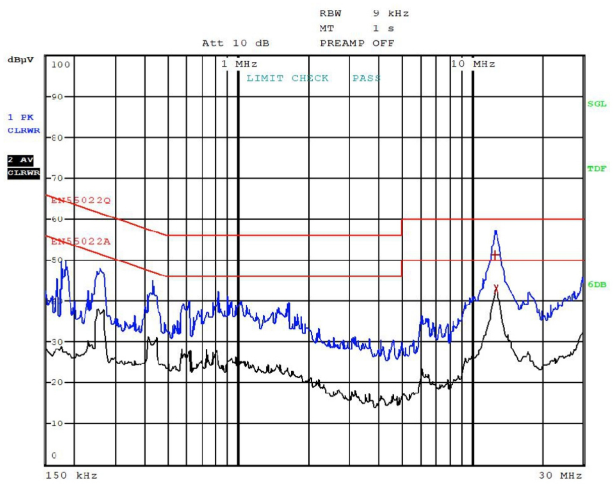
a. Line



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EDIT PEAK LIST (Final Measurement Results)			
Trace1:	EN55022Q		
Trace2:	EN55022A		
Trace3:	- - -		
TRACE	FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
1 Quasi Peak	12.642 MHz	51.33 N	-8.67
2 Average	12.738 MHz	42.84 N	-7.15

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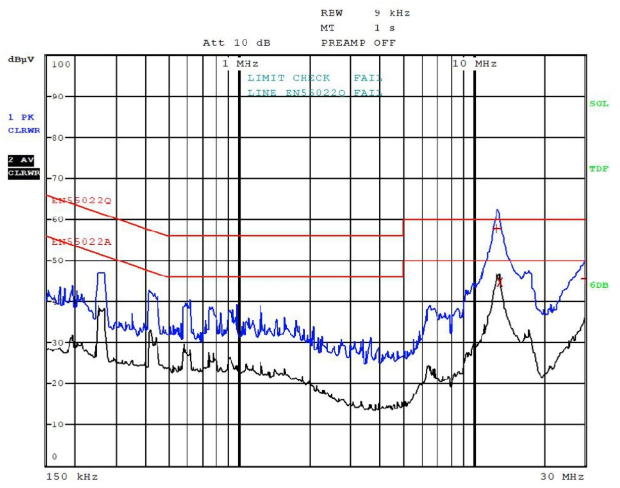
b. Neutral

Figure 18. Conducted EMI at V_{line} = 230 V (RMS)



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EDIT PEAK LIST (Final Measurement Results)			
Trace1:	EN55022Q		
Trace2:	EN55022A		
Trace3:	- - -		
TRACE	FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
1 Quasi Peak	12.594 MHz	57.95 N	-2.04
2 Average	12.95 MHz	44.68 L1	-5.31
1 Quasi Peak	29.918 MHz	45.47 N	-14.52

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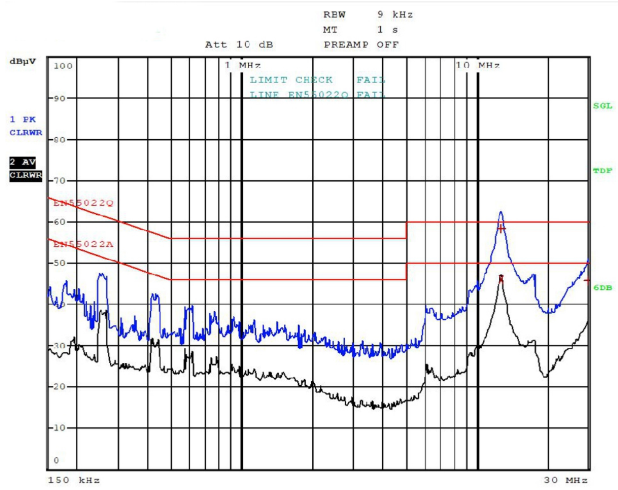
a. Line



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EDIT PEAK LIST (Final Measurement Results)			
Trace1:	EN55022Q		
Trace2:	EN55022A		
Trace3:	- - -		
TRACE	FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
1 Quasi Peak	12.722 MHz	58.38 N	-1.62
2 Average	12.722 MHz	46.05 L1	-3.94
1 Quasi Peak	29.826 MHz	45.68 N	-14.31

aaa-035603

b. Neutral

Figure 19. Conducted EMI at V_{line} = 115 V (RMS)

6 MTP settings

For good performance, the IC in the TEA2016DB1519 demo board contains a set of standard settings.

These settings can be modified to improve a certain performance subject. Or, using a file (.mif) that contains the settings information, the Ringo GUI can load and save a set of settings.

In the original board, the settings of the IC are the default TEA2016AATdev programming values. Table 9 shows a list of all settings.

7 Thermal information

The TEA2016DB1519v2 board shows a single output (12 V) desktop PC application that requires forced cooling (fan) at high output power (when 120 W is exceeded).

8 Circuit diagrams

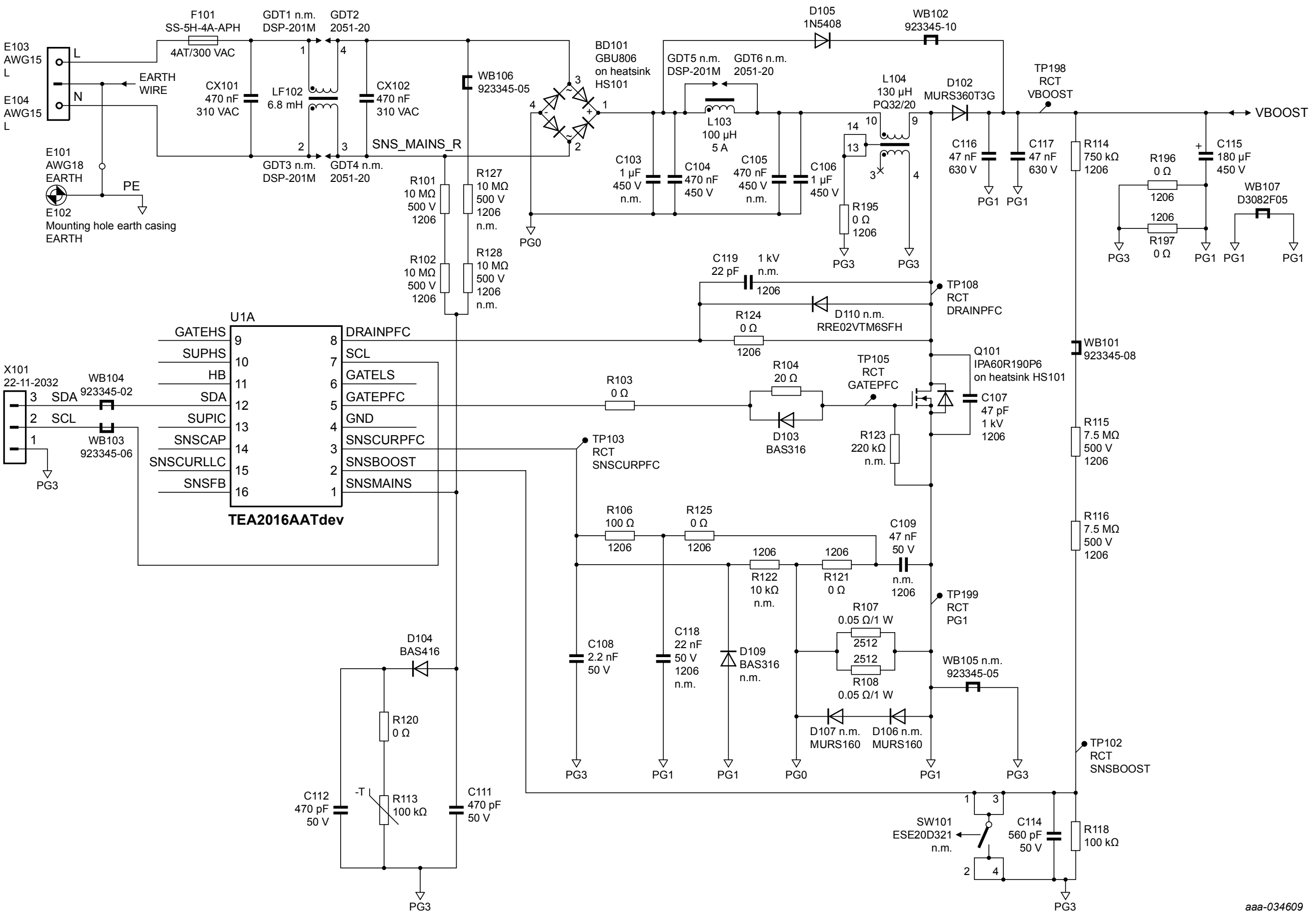


Figure 20. TEA2016DB1519v2 240 W demo board (PFC part)

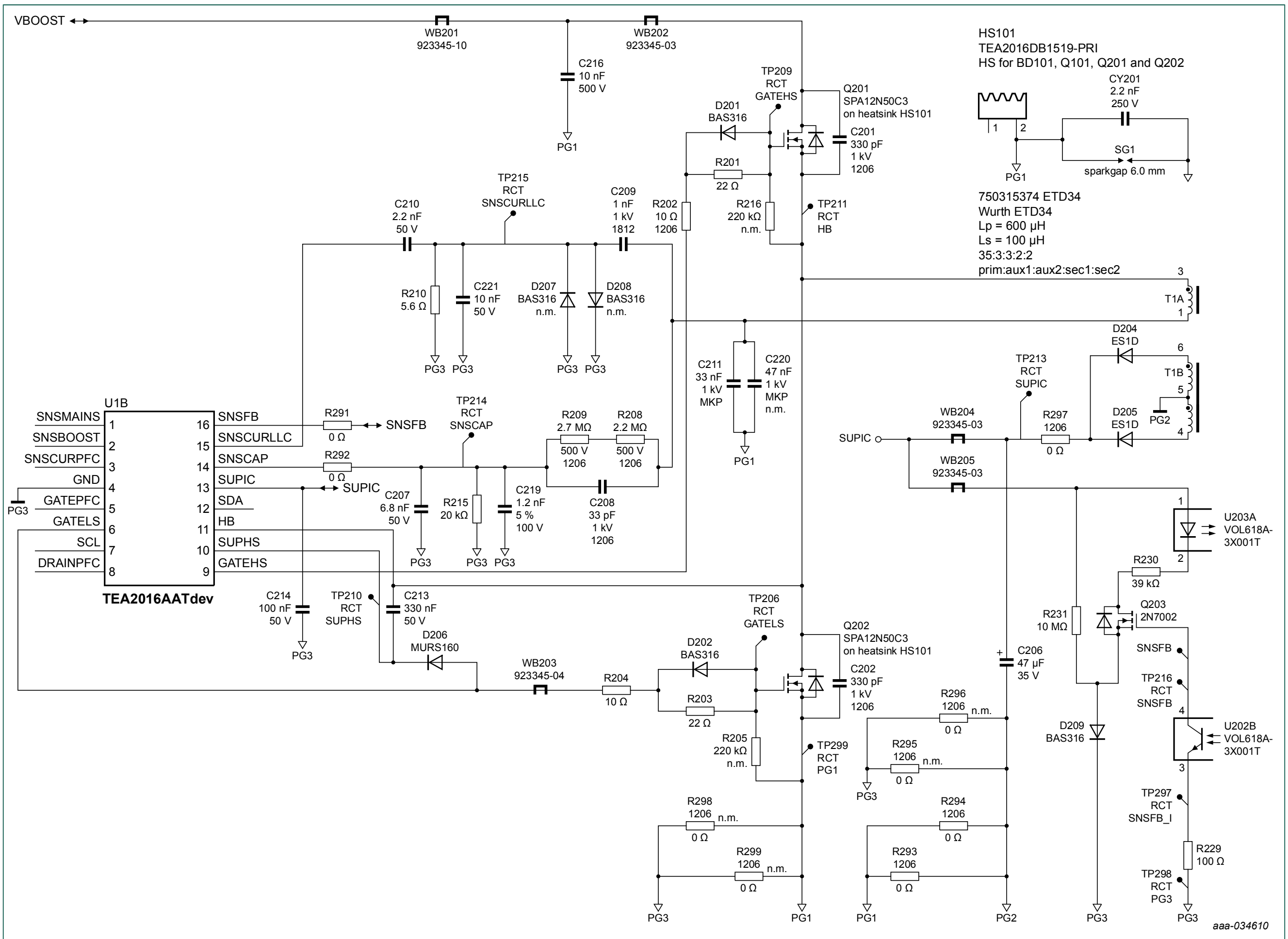


Figure 21. TEA2016DB1519v2 240 W demo board (LLC part)

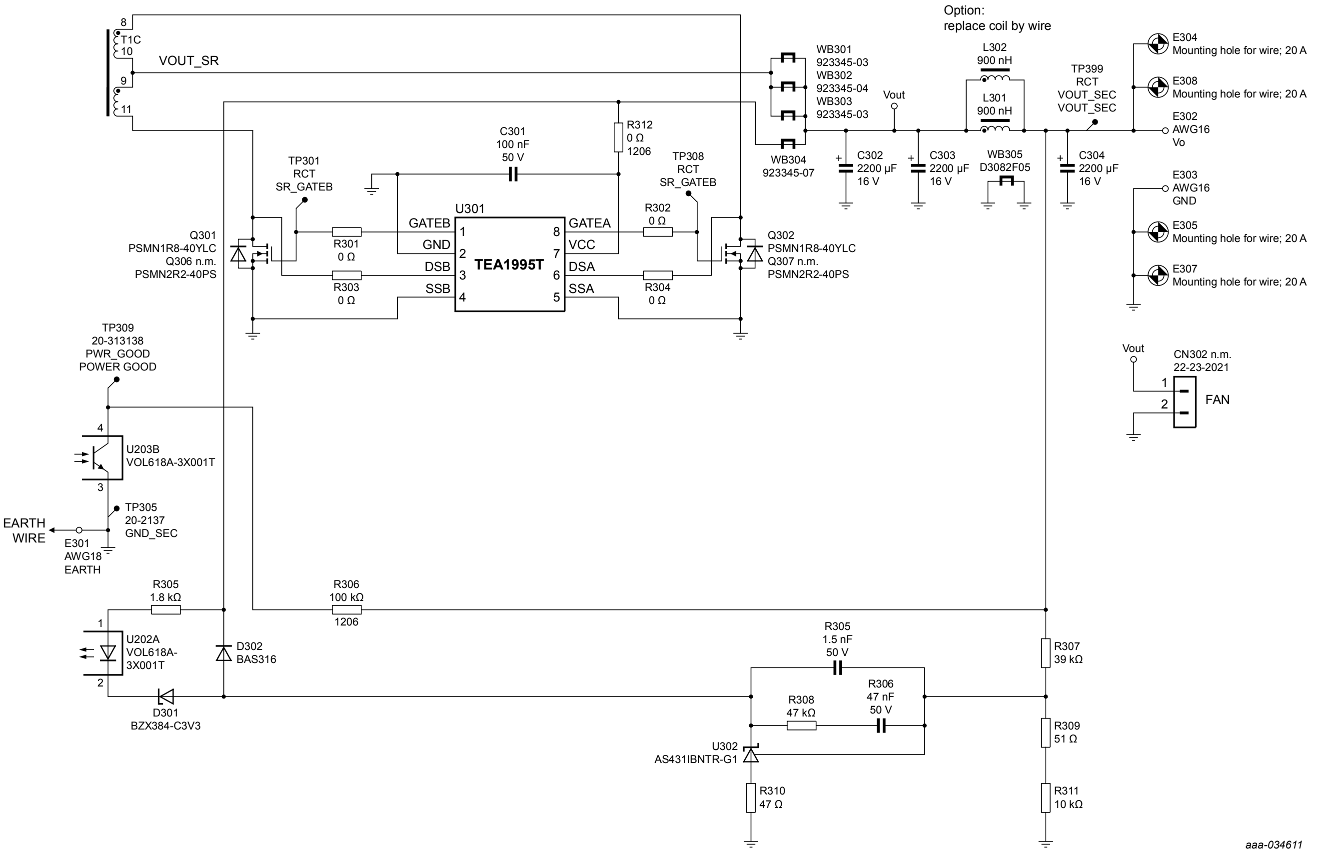


Figure 22. TEA2016DB1519v2 240 W demo board (SR part TEA1995T)

9 Circuit diagrams with comments

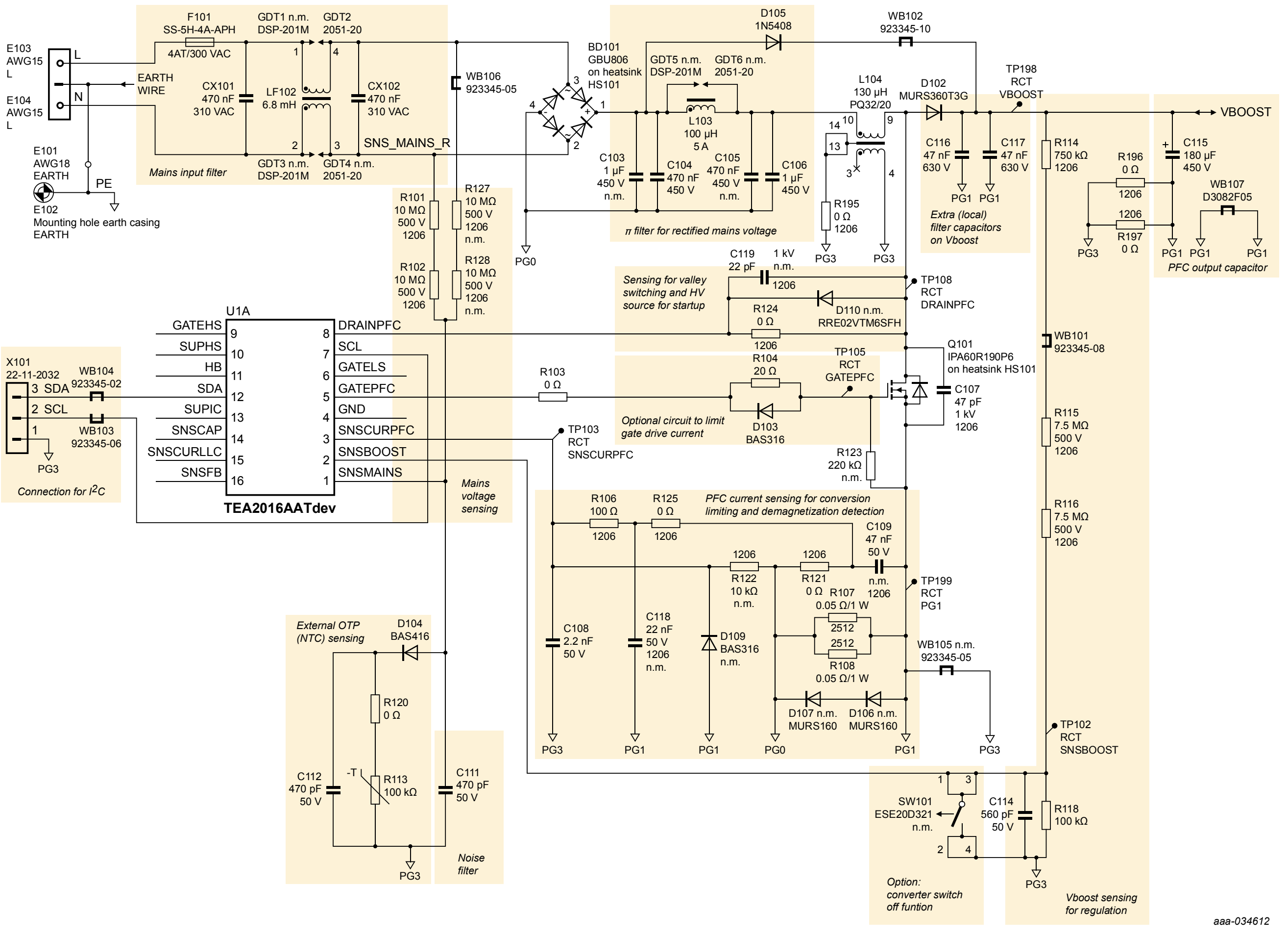


Figure 23. TEA2016DB1519v2 240 W demo board (PFC part) with comments

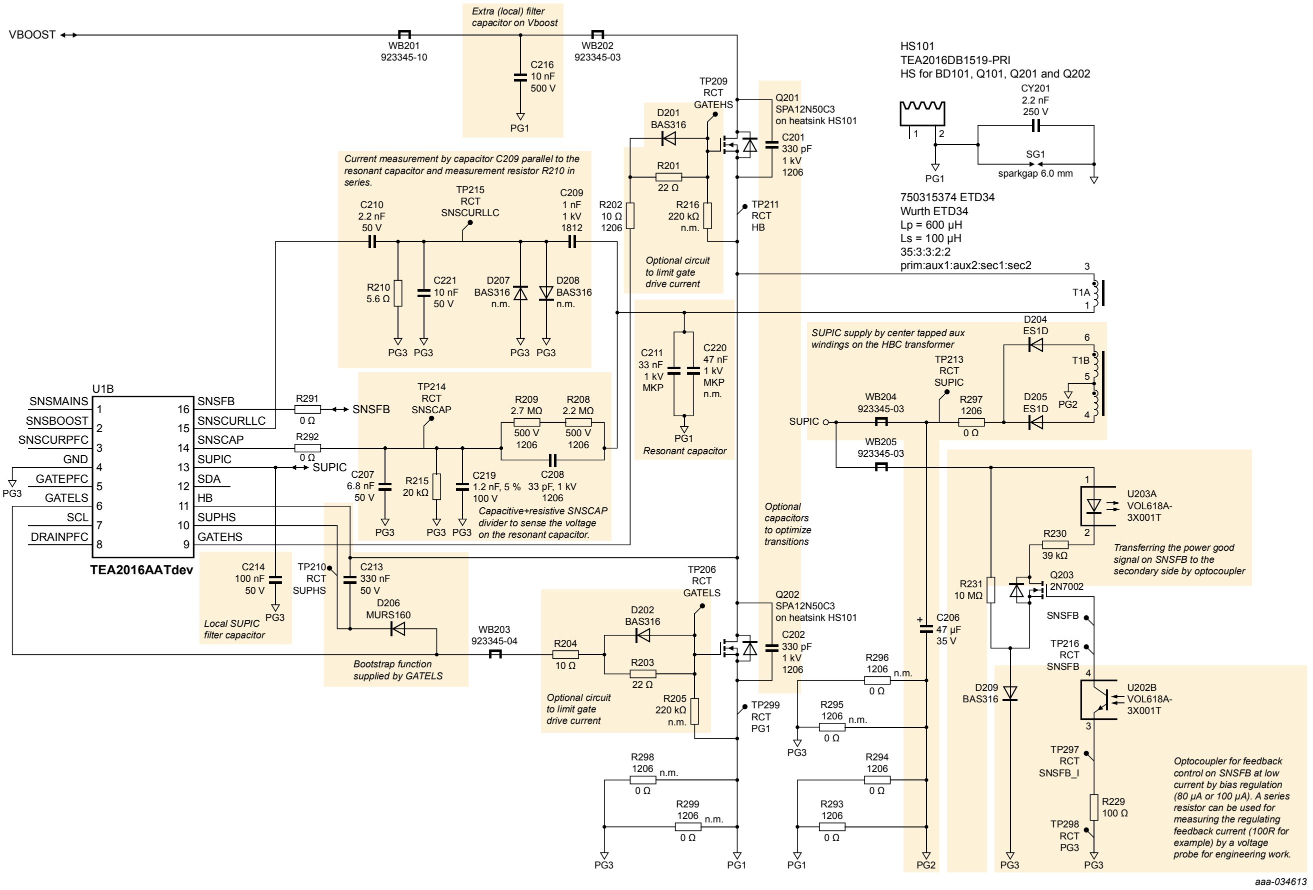


Figure 24. TEA2016DB1519v2 240 W demo board (LLC part) with comments

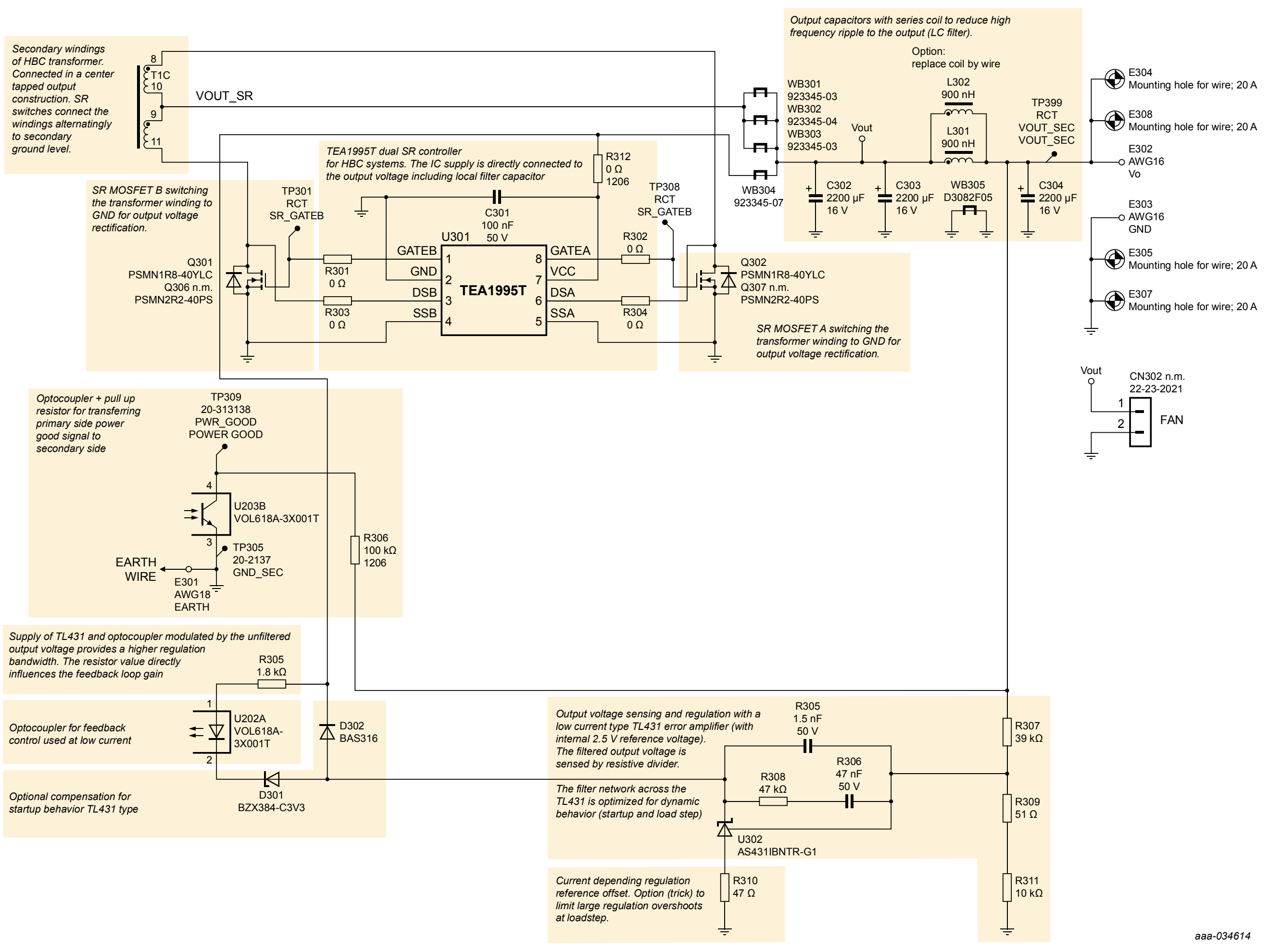


Figure 25. TEA2016DB1519v2 240 W demo board (SR part TEA1995T) with comments

10 Bill of materials (BOM)

Table 6. TEA2016DB1519v2 bill of materials

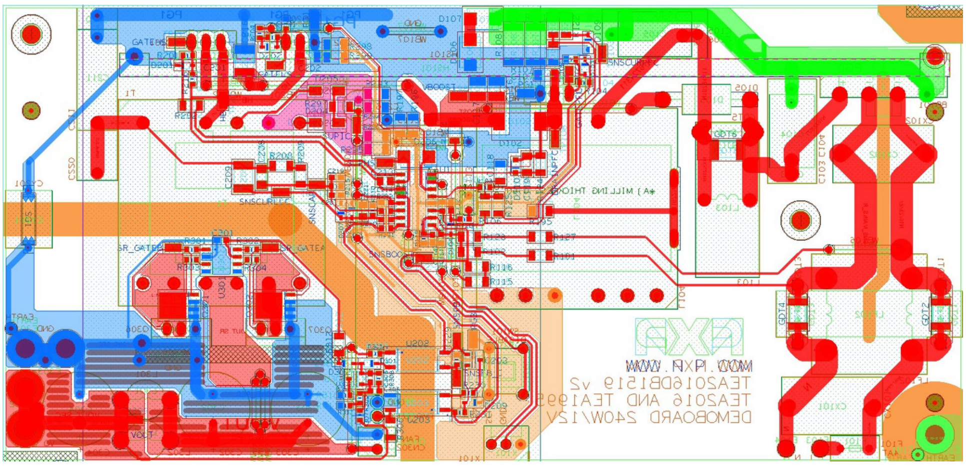
Reference	Description and values	Part number	Manufacturer
BD101	bridge rectifier; 600 V; 8 A	GBU806	Diode Inc.
C103	capacitor; not mounted; 1 μF; 10 %; 450 V; PET; THT	ECQE2W105KH	Panasonic
C104	capacitor; 470 nF; 10 %; 450 V; PET; THT	ECQE2W474KH	Panasonic
C105	capacitor; not mounted; 470 nF; 10 %; 450 V; PET; THT	ECQE2W474KH	Panasonic
C106	capacitor; 1 μF; 10 %; 450 V; PET; THT	ECQE2W105KH	Panasonic
C107	capacitor; 47 pF; 5 %; 1 kV; C0G; 1206	GRM31A5C3A470JW01D	Murata
C108	capacitor; 2.2 nF; 5−%; 50 V; C0G; 0603	-	-
C109	capacitor; no mounted; 47 nF; 10 %; 50 V; X7R; 1206	-	-
C111	capacitor; 470 pF; 5 %; 50 V; C0G; 0603	-	-
C112	capacitor; 470 pF; 5 %; 50 V; C0G; 0603	C1608C0G1H471J080AA	TDK
C114	capacitor; 560 pF; 5 %; 50 V; C0G; 0603	C1608C0G1H561J080AA	TDK
C115	capacitor; 180 μF; 20 %; 450 V; ALU; THT	450QXW180MEFC18X45	Rubycon
C116; C117	capacitor; 47 nF; 10 %; 630 V; X7R; 1210	MC1210B473K631CT	Multicomp
C118	capacitor; not mounted; 10 pF; 10 %; 50 V; X7R; 1206	-	-
C119	capacitor; not mounted; 22 pF; 5 %; 1 kV; C0G; 1206	C0603C122J1GACTU	KEMET
C201; C202	capacitor; 330 pF; 5 %; 1 kV; C0G; 1206	102R18N331JV4E	Johanson Dielectrics
C206	capacitor; 47 μF; 20 %; 35 V; ALU; THT	35ZLJ47MTA5X11	Rubycon
C207	capacitor; 6.8 nF; 10 %; 50 V; X7R; 0603	-	-
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	BFC233810333	Vishay
C213	capacitor; 330 nF; 10 %; 50 V; X7R; 0805	-	-
C214; C301	capacitor; 100 nF; 10 %; 50 V; X7R; 0603	-	-
C216	capacitor; 10 nF; 10 %; 500 V; X7R; 1812	C1812C103KCRACTU	KEMET
C219	capacitor; 1.2 nF; 5 %; 100 V; C0G; 0603	C0603C122J1GACTU	KEMET
C220	capacitor; not mounted; 47 nF; 5 %; 1 kV; MKP	BFC237520473	Vishay
C221	capacitor; 10 nF; 10 %; 50 V; X7R; 0805	-	-
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	-	-

Reference	Description and values	Part number	Manufacturer
CN302	header; straight; not mounted; 1x2-way; 2.54 mm	22-23-2021	Molex
CX101; CX102	capacitor; 470 nF; 20 %; 310 V (AC); MKP; THT	BFC233922474	Vishay
CY201	capacitor; 2.2 nF; 20 %; 250 V; CER; THT	DE1E3KX222MA5B	Murata
D102	diode; 600 V; 3 A	MURS360T3G	On Semi
D103; D201; D202; D209; D302	diode; 100 V; 250 mA	BAS316	NXP Semiconductors
D104	diode; 85 V; 200 mA	BAS416	NXP Semiconductors
D105	diode; 1 kV; 3 A	1N5408	Vishay
D106; D107	diode; not mounted; 600 V; 1 A	MURS160	Vishay
D109	diode; not mounted; 100 V; 250 mA	BAS316	NXP Semiconductors
D204; D205	diode; 140 V; 1 A	ES1D-E3	Vishay
D206	diode; 600 V; 1 A	MURS160	Vishay
D207; D208	diode; not mounted; 100 V; 250 mA	BAS316	NXP Semiconductors
D301	diode; Zener diode; 3.3 V; 250 mA	BZX384-C3V3	NXP Semiconductors
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; THT	DSP-201M	Mitsubishi
GDT2	gas discharge tube; 200 V; SMT	2051-20-SM-RPLF	Bourns
GDT4; GDT6	gas discharge tube; not mounted; 200 V; SMT	2051-20-SM-RPLF	Bourns
HS101	heat sink; primary	TEA2016DB1519-PRI	NXP Semiconductors
L103	inductor; 100 μH; 5 A	7447070	Würth Elektronik
L104	coil former; PQ32/20	CPV-PQ32/20-1s-12p	Ferroxcube
L301; L302	inductor; 900 nH	-	-
LF102	inductor; common mode; 6.8 mH; 3.2 A	B82734R2322B30	EPCOS
MCL1; MCL2; MCL3; MCL4; MCL5	fixing kit; nut and bolt	MK3311	Multicomp
MCL6; MCL7; MCL8; MCL9	screw; CSK; POZI; M3X12	CP3M12	Duratool
Q101	MOSFET-N; 650 V; 20.2 A	IPA60R190P6	Infineon
Q201; Q202	MOSFET-N; 560 V; 11.6 A or MOSFET-N; 650 V; 20.2 A	SPA12N50C3 or IPA60R190P6	Infineon
Q203	MOSFET-N; 60 V; 300 mA	2N7002	NXP Semiconductors
Q301; Q302	MOSFET-N; 40 V; 100 A	PSMN1R8-40YLC	NXP Semiconductors
Q306; Q307	MOSFET-N; not mounted; 40 V; 100 A	PSMN2R2-40PS	NXP Semiconductors
R101; R102	resistor; 10 MΩ; 1 %; 250 mW; 500 V; 1206	KTR18EZPF1005	ROHM

Reference	Description and values	Part number	Manufacturer
R103; R291; R292; R301; R302; R303; R304	resistor; jumper; 0 Ω; 63 mW; 0603	-	-
R104	resistor; 20 Ω; 1 %; 63 mW; 0603	-	-
R106	resistor; 100 Ω; 1 %; 250 mW; 1206	-	-
R107; R108	resistor; 0.05 Ω; 1 %; 1 W; 2512	RL2512FK-070R05L	Yageo
R113	resistor; NTC; 100 kΩ; 5 %; 100 mW; 4190 K	NTCLE100E3104JB0	Vishay
R114	resistor; 750 kΩ; 1 %; 250 mW; 1206	-	-
R115; R116	resistor; 7.5 MΩ; 1 %; 250 mW; 500 V; 1206	KTR18EZPF7504	ROHM
R118	resistor; 100 kΩ; 1 %; 63 mW; 0603	-	-
R120	resistor; jumper; 0 Ω; 100 mW; 0603	-	-
R121; R124; R125; R195; R196; R197; R293; R294; R297; R312	resistor; jumper; 0 Ω; 250 mW; 1206	-	-
R122	resistor; not mounted; 10 kΩ; 1 %; 250 mW; 1206	-	-
R123	resistor; not mounted; 220 kΩ; 1 %; 63 mW; 0603	-	-
R127; R128	resistor; 10 MΩ; 1 %; 250 mW; 500 V; 1206	KTR18EZPF1005	ROHM
R201; R203	resistor; 22 Ω; 1 %; 63 mW; 0603	-	-
R202	resistor; 10 Ω; 1 %; 250 mW; 1206	RC1206FR-0710RL	Yageo
R204	resistor; 10 Ω; 1 %; 63 mW; 0603	-	-
R205; R216	resistor; not mounted; 220 kΩ; 1 %; 63 mW; 0603	-	-
R208	resistor; 2.2 MΩ; 1 %; 250 mW; 500 V; 1206	KTR18EZPF2204	ROHM
R209	resistor; 2.7 MΩ; 1 %; 250 mW; 500 V; 1206	KTR18EZPF2704	ROHM
R210	resistor; 5.6 Ω; 1 %; 63 mW; 0603	-	-
R215	resistor; 20 kΩ; 1 %; 63 --mW; 0603	-	-
R229	resistor; 100 Ω; 1 %; 63 mW; 0603	-	-
R230; R307	resistor; 39 kΩ; 1 %; 63 mW; 0603	-	-
R231	resistor; 10 MΩ; 1 %; 63 mW; 0603	-	-
R295; R296; R298; R299	resistor; jumper; not mounted; 0 Ω; 250 mW; 1206	-	-
R305	resistor; 1.8 kΩ; 1 %; 63 mW; 0603	-	-
R306	resistor; 100 kΩ; 1 %; 250 mW; 1206	-	-
R308	resistor; 47 kΩ; 1 %; 63 mW; 0603	-	-
R309	resistor; 51 Ω; 1 %; 63 mW; 0603	-	-
R310	resistor; 47 Ω; 1 %; 63 mW; 0603	-	-
R311	resistor; 10 kΩ; 1 %; 63 mW; 0603	-	-
SW01	switch; push; not mounted; SPST; off-on; 1-way	ESE20D321	Panasonic

Reference	Description and values	Part number	Manufacturer
T1	transformer; ETD34	750315374	Würth Elektronik
TP102; TP103; TP105; TP108; TP198; TP199; TP206; TP209; TP210; TP211; TP213; TP214; TP215; TP216; TP297; TP298; TP299; TP301; TP308; TP399	test point; 0805	RCT-0C	TE Connectivity
TP305	test point; isolated; 1.02 mm; black	20-2137	Vero Technologies
TP309	test point; isolated; 1.02 mm; Green	20-313138	Vero Technologies
U1	PFC + LLC controller	TEA2016AATdev	NXP Semiconductors
U202; U203	optocoupler; NPN; 80 V; 60 mA	VOL618A-3X001T	Vishay
U301	synchronous rectifier Controller; dual	TEA1995T	NXP Semiconductors
U302	regulator; AS431	AS431IBNTR-G1	BCD Semi
WB101	wire bridge; 0.8 mm; P = 20.32 mm	923345-08	3M
WB102; WB201	wire bridge; 0.8 mm; P = 25.40 mm	923345-10	3M
WB103	wire bridge; 0.8 mm; P = 15.24 mm	923345-06	3M
WB104	wire bridge; 0.8 mm; P = 5.08 mm	923345-02	3M
WB105	wire bridge; not mounted; 0.8 mm; P = 12.10 mm	923345-05	3M
WB106	wire bridge; 0.8 mm; P = 12.10 mm	923345-05	3M
WB107; WB305	wire bridge; bare; 1 mm; P = 10.16 mm	D3082F05	Harwin
WB202; WB204; WB205; WB301; WB303	wire bridge; 0.8 mm; P = 7.62 mm	923345-03	3M
WB203; WB302	wire bridge; 0.8 mm; P = 10.16 mm	923345-04	3M
WB304	wire bridge; 0.8 mm; P = 17.18 mm	923345-07	3M
X101	header; straight; 1 x 3-way; 2.54 mm	22-11-2032	Molex

11 PCB layout



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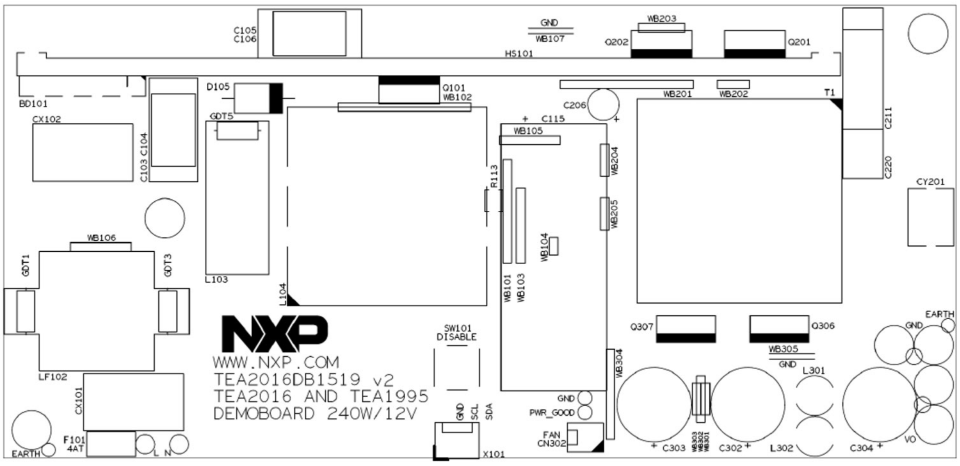
a. PCB layout



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b. PCB components

Figure 26. TEA2016DB1519v2 PCB layout and components

12 Transformer specifications

12.1 LLC transformer

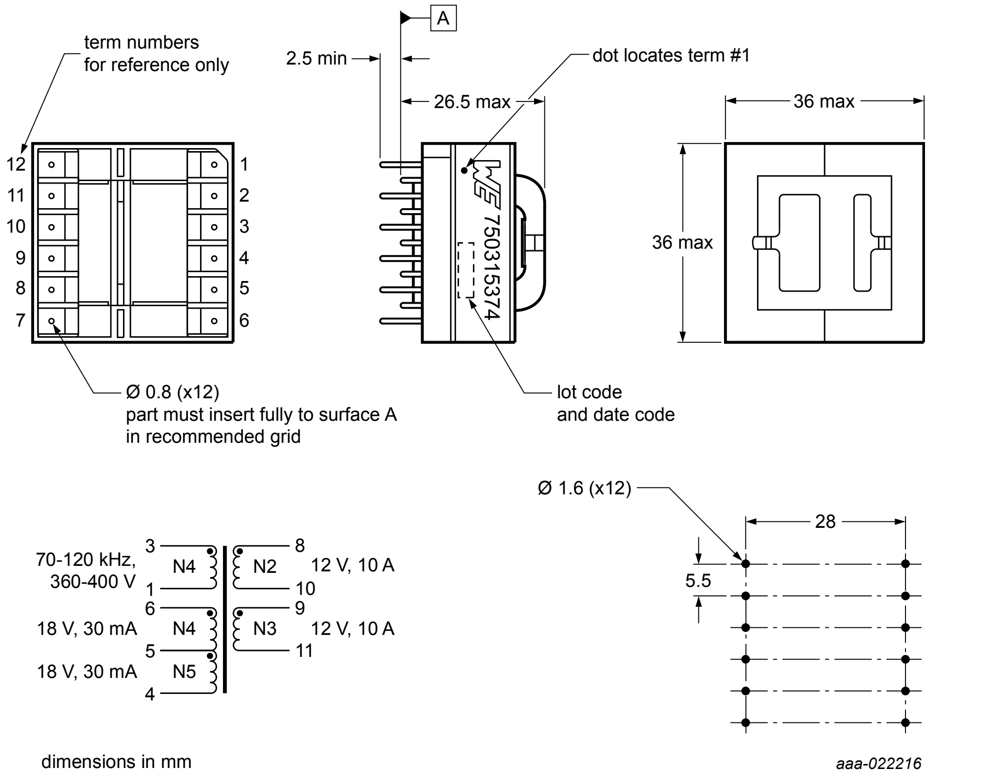
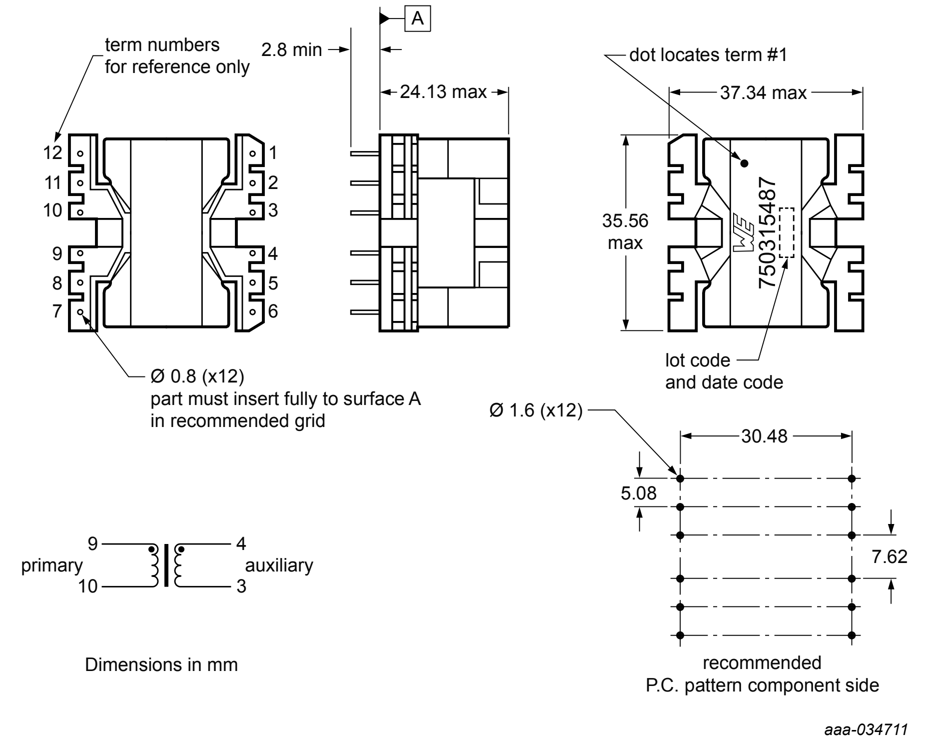


Figure 27. LLC transformer

Table 7. 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 (AC); 1 minute	tie(3=4, 10+11); 4000 V (AC); 1 s

12.2 PFC coil



Note: *Pin 4 is connected to the core. The auxiliary winding is not used.*

Figure 28. PFC coil

Table 8. PFC coil specifications

Parameter	Value	Conditions
Electric specifications		
DC resistance; 3-4	0.048 Ω; ±20 %	at 20 °C
DC resistance; 9-10	0.060 Ω; ±20 %	at 20 °C
inductance; 9-10	130 μH; ±5 %	10 kHz; 100 mV; L_s
saturation current; 9-10	13 A	20 % roll-off from initial
leakage current; 9-10	52 μH (typical); maximum 75 μH	tie(3+4); 100 kHz; 100 mV; L_s
dielectric; 3-10	-	1500 V (AC); 1 s
turns ratio	30:1; ±1 %	(9-10):(4-3)
General specifications		
operating temperature	−40 °C to +125 °C	including temperature rise

13 TEA2016dev parameter settings

Table 9 shows a list of the parameters in the MTP. It shows the Ringo GUI parameter names, the NXP Semiconductors parameter names, and their values.

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

Table 9. Ringo parameter/IC parameter settings

	Ringo parameter name	IC parameter name	Value	Unit	Binary value
1	PFC OCP	pfc_ocp	OK	-	0
2	PFC OVP (drainPFC)	pfc_ovp_suphv	OK	-	0
3	PFC OVP (SNSBOOST)	pfc_ovp_snsboost	OK	-	0
4	LLC OPP 1	llc_opp1	OK	-	0
5	LLC OPP 2	llc-opp2	OK	-	0
6	LLC maximum start-up time	llc_max_startup_time	OK	-	0
7	LLC OCP	llc_ocp	OK	-	0
8	LLC OVP	llc_ovp_prot	OK	-	0
9	external OTP	ext_otp	OK	-	0
10	internal OTP	int_otp	OK	-	0
11	fast disable	fast_disable	OK	-	0
12	LLC maximum on-time	llc_max_on_time	OK	-	0
13	LLC maximum I_{opto}	llc_max_iopto	OK	-	0
14	LLC capacitor mode	llc_cap_mode	OK	-	0
15	MTP read failure	mtp_read_fail	OK	-	0
16	OPP via SUPIC UVP	opp_via_supic_uvp	OK	-	0
17	read lock	read_lock	reading is enabled	-	0
18	write lock	write-lock	writing is enabled	-	0
19	SUPIC start level	sup_start	19	V	0
20	low SUPIC during energy save	dis_vlow	enabled	-	0
21	X-capacitor discharge delay-time after AC-off	t_xcap_disch	200	ms	0
22	mains resistor value	rmains	20	MΩ	0
23	PFC maximum switching frequency	max_pfc_freq	125	kHz	2
24	PFC burst mode SNSBOOST ripple	vburst_ripple	70	mV	0
25	PFC soft-stop time burst mode	t_burst_stop	normal	-	0
26	dV/dt ratio switch-on/maximum	ratio_valley_detect	0.5	-	0
27	mains SNS filtering	mains_filter	2	-	0

	Ringo parameter name	IC parameter name	Value	Unit	Binary value
28	PFC gain	pfc_gain	0.75	-	0
29	power factor improvement	pf_compensation	off	-	0
30	mains SNS resistors	nr_mains_resistors	1 resistor	-	0
31	PFC soft-start time burst mode	t_burst_start	normal	-	0
32	maximum (start-up) frequency	max_llc_startup	350	kHz	0
33	LLC soft-start speed	llc_tsoftstart	7x	-	0
34	LLC soft-start current limit	max_llc_istartup	0.75	V	0
35	V_{dump} level	vdump	2.6	V	0
36	minimum non-overlap time	t_no_min	200	ns	0
37	maximum non-overlap time	t_no_max	1.1	μs	0
38	maximum on-time	llc_max_on	20	μs	0
39	capacitive mode regulation level	capm_lvl	100	mV	0
40	optocoupler current level	iopto	80	μA	0
41	HP-LP transition level	hp_lp_lev	30	%	0
42	LP-BM transition level	lp_bm_lev	10	%	0
43	HP-LP hysteresis	hp_lp_hys	20	%	0
44	dV_{cap} offset	vcap_offset	0	mV	0
45	zero power slope	min_slope	6	mV/μs	0
46	LP-BM delay time	lp_bm_del	0	s	0
47	BM-LP hysteresis	bm_lp_hys	50	%	0
48	BM-LP hysteresis filter	bm_lp_filt	4	-	0
49	BM frequency	bm_freq	800	Hz	0
50	BM energy-per-cycle increase	bm_incr	1	-	0
51	number of soft-start cycles	start_cycle_sel	0	-	0
52	number of soft-stop cycles	stop_cycle_sel	0	-	0
53	safe restart timer 1	sr_time__r1_	1	s	0
54	safe restart timer 2	sr_time__r2_	1	s	0
55	safe restart timer 3	sr_time__r3_	1	s	0
56	safe restart timer 4	sr_time__r4_	1	s	0
57	slope of the 4^{th} BM soft-stop cycle	stop_cycle4	180	-	0
58	slope of the 3^{rd} BM soft-stop cycle	stop_cycle3	1	-	1
59	slope of the 2^{nd} BM soft-stop cycle	stop_cycle2	84	-	0
60	slope of the 1^{st} BM soft-stop cycle	stop_cycle1	36	-	0
61	slope of the 4^{th} BM soft-start cycle	start_cycle4	36	-	0
62	slope of the 3^{rd} BM soft-start cycle	start_cycle3	84	-	0
63	slope of the 2^{nd} BM soft-start cycle	start_cycle2	1	-	1

	Ringo parameter name	IC parameter name	Value	Unit	Binary value
64	slope of the 1st BM soft-start cycle	start_cycle1	180	-	0
65	number of BM soft-stop cycles	nr_bm_sstop	2	-	2
66	number of BM soft-start cycles	nr_bm_sstart	2	-	2
67	minimum cycles in burst	min_nr_cycl	3	-	0
68	burst-on end by optocurrent	iopto_bm_end	2.5	-	0
69	LP number of peaks	lp_nr_peaks	2	-	0
70	SNSBOOST compensation	snsb_comp	−1.4	-	0
71	fast latch reset delay time	t_flr	50	ms	0
72	external OTP current level	eotp_lvl	600	μA	0
73	external OTP delay time	t_eotp	4	s	0
74	OTP	otp_ltch__r1_	safe restart	-	0
75	OTP	otp_ltch__r2_	latched	-	1
76	OTP	otp_ltch__r3_	latched	-	1
77	OTP	otp_ltch__r4_	latched	-	1
78	OTP number of restarts to latch	otp_nr_rest	0	-	0
79	brownin level	brownin_lvl	5.7	μA	0
80	brownin/brownout hysteresis	brownin_hys	0.75	μA	0
81	brownout delay	t_brownout	50	ms	0
82	PFC OCP blanking time	ocp_tblank	300	ns	0
83	PFC maximum on-time	ton_max	50	μs	0
84	PFC OVP level	ovp_lvl	2.63	V	0
85	OVP-drainPFC protection level	ovpprot_lvl	475	V	0
86	OVP-drainPFC protection delay	t_ovpprot	infinite	ms	3
87	PFC OVP-drainPFC	ovp_ltch__r1_	safe restart	-	0
88	PFC OVP-drainPFC	ovp_ltch__r2_	safe restart	-	0
89	PFC OVP-drainPFC	ovp_ltch__r3_	safe restart	-	0
90	PFC OVP-drainPFC	ovp_ltch__r4_	safe restart	-	0
91	OVP-drainPFC number of restarts before latched	ovp_nr_rest	0	-	0
92	PFC maximum ringing time (½)	max_tring_pfc	10	μs	0
93	PFC minimum off-time	tmin_off	1500	ns	0
94	maximum start-up time	t_start_max	100	ms	0
95	LLC maximum ringing time	max_tring_llc	5	μs	0
96	LLC brownout level (SNSBOOST)	snsb_stop	1.65	-	3
97	LLC brownin level (SNSBOOST)	snsb_start	2.3	V	2
98	disable LLC after mains brownout	llc_dis_bo	250	ms	0
99	disable LLC after SNSBOOST OVP	dis_ovp_snsb	off	-	3

	Ringo parameter name	IC parameter name	Value	Unit	Binary value
100	power limitation level	pow_lim	155	%	0
101	start OPP timer 1	opp1_lvl	−20	%	0
102	OPP time 1 to protect	opp1_time__r1_	50	ms	0
103	OPP time 1 to protect	opp1_time__r2_	50	ms	0
104	OPP time 1 to protect	opp1_time__r3_	100	ms	2
105	OPP time 1 to protect	opp1_time__r4_	50	ms	0
106	count down value at 1 cycle below OPP	opp_nr_dwn	1	-	0
107	start OPP timer 2	opp2_lvl	−10	%	0
108	OPP time 2 to protect	opp2_time	infinite	-	0
109	OPP	opp_ltch__r1_	safe restart	-	0
110	OPP	opp_ltch__r2_	safe restart	-	0
111	OPP	opp_ltch__r3_	safe restart	-	0
112	OPP	opp_ltch__r4_	latched	-	1
113	OPP restarts to latch	opp_nr_rest	0	-	0
114	OVP level	llc_ovp	10	V	0
115	OVP delay	llc_tovp	50	μs	0
116	down counts per up count OVP	llc_ovp_nr_dwn	1	-	0
117	OVP	llc_ovp_ltch__r1_	safe restart	-	0
118	OVP	llc_ovp_ltch__r2_	latched	-	1
119	OVP	llc_ovp_ltch__r3_	latched	-	1
120	OVP	llc_ovp_ltch__r4_	latched	-	1
121	OVP restarts to latch	llc_ovp_nr_rest	0	-	0
122	LLC OCP	llc_ocp_ltch__r1_	safe restart	-	0
123	LLC OCP	llc_ocp_ltch__r2_	safe restart	-	0
124	LLC OCP	llc_ocp_ltch__r3_	safe restart	-	0
125	LLC OCP	llc_ocp_ltch__r4_	latched	-	1
126	OCP restarts to latch	llc_ocp_nr_rest	0	-	0
127	fast disable by SNSBOOST	llc_fast_disable	latched	-	3
128	power good signal before protection	pgd_tim	4	ms	0
129	enable power good at OTP	pgd_otp	yes	-	0
130	enable power good at OPP	pgd_opp	yes	-	0
131	power good SNSBOOST reset level	pgd_lvl	1.75	V	0
132	delay power good	pgd_del	5	ms	0
133	power good signal edge (SNSFB)	pgd_tr	2	ms	0
134	disable power good signal at SNSBOOST OVP	pgd_ovp_sbo	yes	-	0

	Ringo parameter name	IC parameter name	Value	Unit	Binary value
135	PFC operation	pfc_dis_dev	enabled	-	0
136	overcurrent protection filter LLC	llc_tocp__r1_	5	-	0
137	overcurrent protection filter LLC	llc_tocp__r2_	5	-	0
138	overcurrent protection filter LLC	llc_tocp__r3_	5	-	0
139	overcurrent protection filter LLC	llc_tocp__r4_	5	-	0
140	vendor code	mtp_code	0x0002	-	1

14 Abbreviations

Table 10. Abbreviations

Acronym	Description
BCM	boundary conduction mode
BM	burst mode
EMI	electromagnetic interference
GUI	graphical user interface
HBC	half-bridge converter
HP	high power
LLC	resonant tank or converter (Lm+Lr+Cr in series)
LP	low power
MOSFET	metal–oxide–semiconductor field-effect transistor
MTP	multi times programmable
OPP	overpower protection
OTP	overtemperature protection
OVP	overvoltage protection
PCB	printed-circuit board
PFC	power factor correction
SR	synchronous rectification

15 References

[1] **TEA2016AAT data sheet** — Digital controller for high-efficiency resonant power supply; 2019, NXP Semiconductors

[2] **AN12330 application note** — TEA2016 PFC + LLC controller IC; 2019, NXP Semiconductors

[3] **UM11219 user manual** — Ringo TEA2016 development software with GUI; 2019, NXP Semiconductors

[4] **UM11235 user manual** — TEA2016DB1514 USB to I^2C hardware interface; 2019, NXP Semiconductors

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