User Guide

TDAIO250P200: All-in-one PFC + LLC Evaluation Board

Introduction

The TDAIO250P200 is a complete 250W power supply evaluation board designed specifically to meet the requirements for an all-in-one computer. The power supply combines a PFC input stage with an LLC DC-DC converter and uses ON Semiconductor control ICs (NCP4810, NCP1654, NCP1397, NCP432) with three Transphorm 600V 290mΩ GaN FETs (TPH3202PS).

Designed to switch at 200-250kHz, the compact-size board showcases the GaN devices' advantage in delivering both small size and high efficiency not possible with existing silicon solutions. With a universal AC input, the all-in-one power supply evaluation board can deliver up to 20A from the 12V output with a peak efficiency of 95.4% from a 230V$_{AC}$ line.

The TDAIO250P200-KIT is for evaluation purposes only.

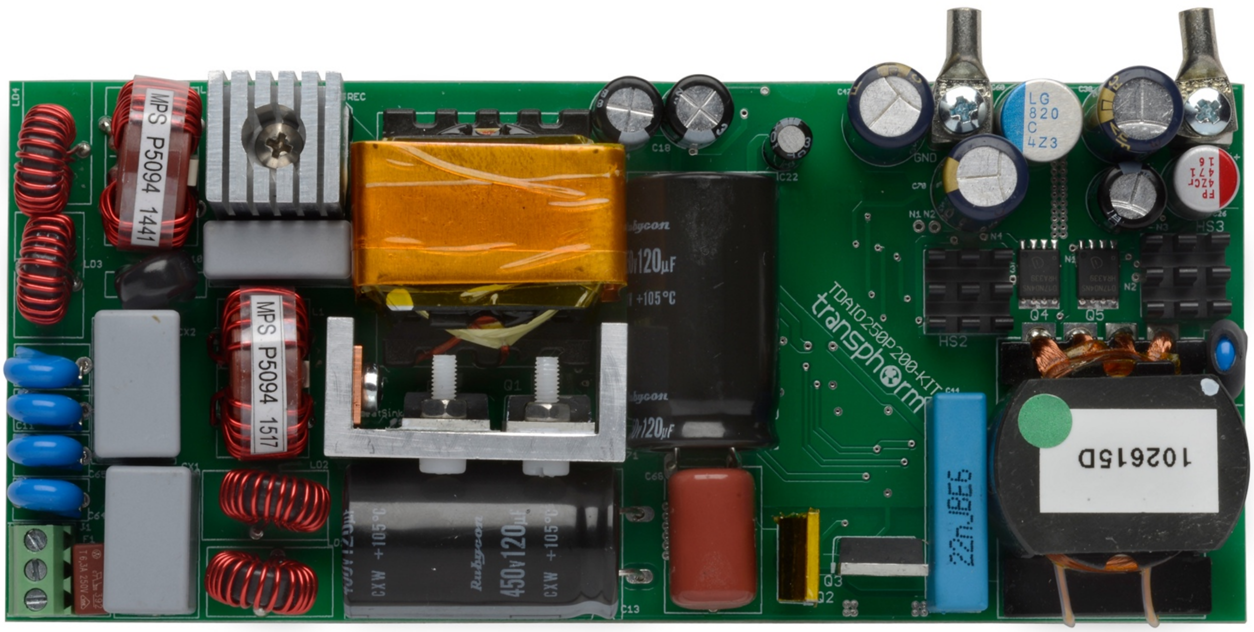


Figure 1. TDAIO250P200 all-in-one PFC + LLC evaluation board

TDAIO250P200 input/output specifications

Universal AC input: 90 V_{AC} to 265V_{AC}

Output: 12V_{DC} at 20A

PFC PWM frequency: 200kHz

LLC switching frequency: 170kHz to 250kHz

Circuit description

Figure 2 illustrates the topology of the power supply. Three basic functions are shown: an input EMI filter, a boost-mode PFC circuit, and an LLC DC-DC converter. Not shown is a 12V DC regulator which provides power to the PFC and LLC controllers. The link between the PFC and LLC is a 390V DC voltage, identifiable in the schematic as the voltage across capacitor C1. The detailed schematic and bill of materials (see Table 1) are included in the design files at transphormusa.com/aio25kit.

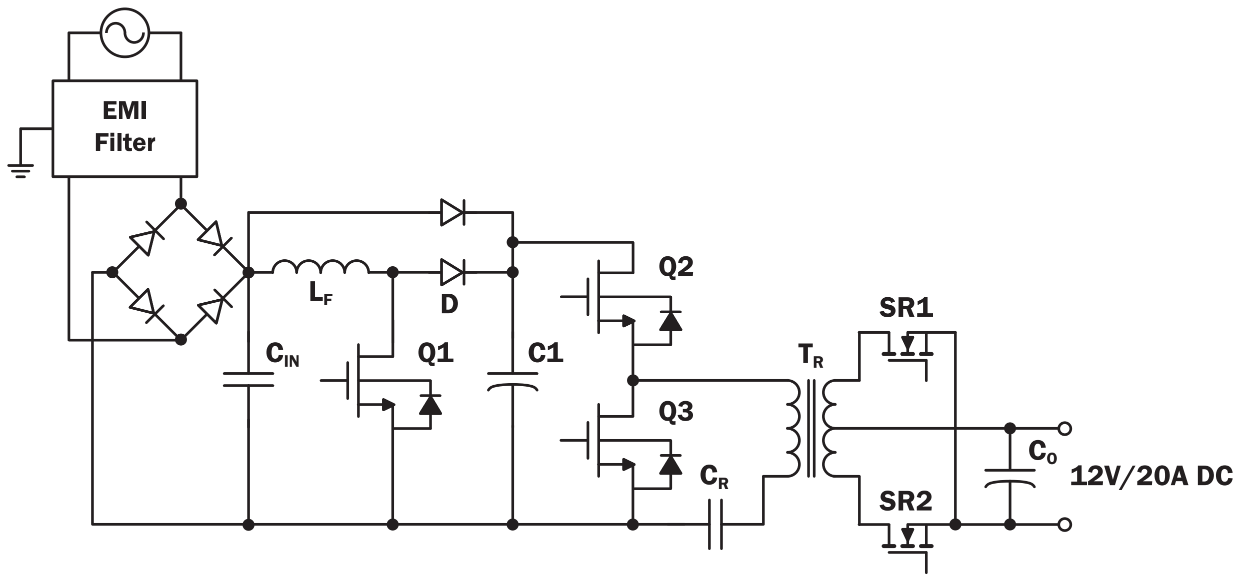
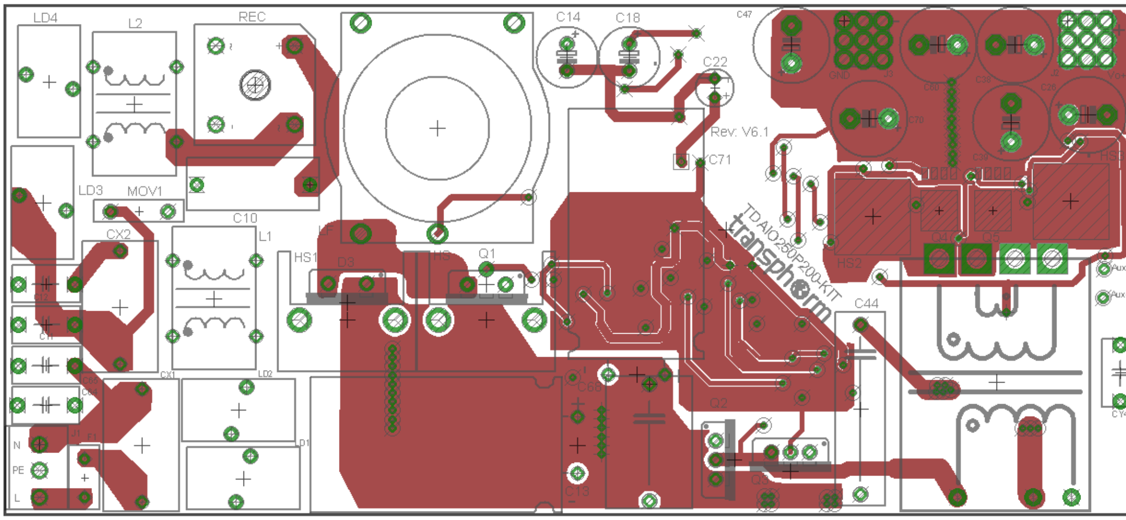
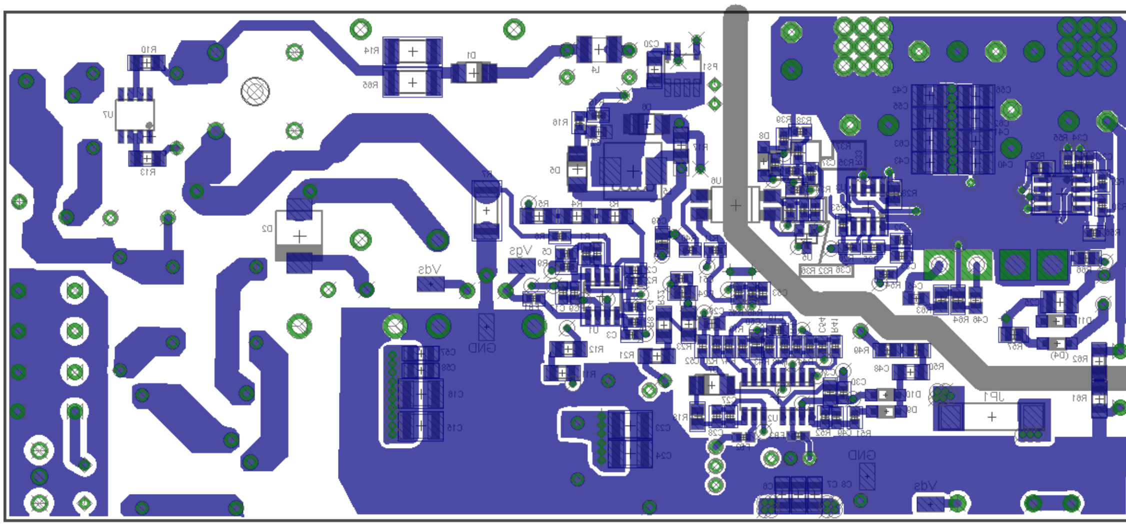


Figure 2. Simplified schematic for the complete power supply

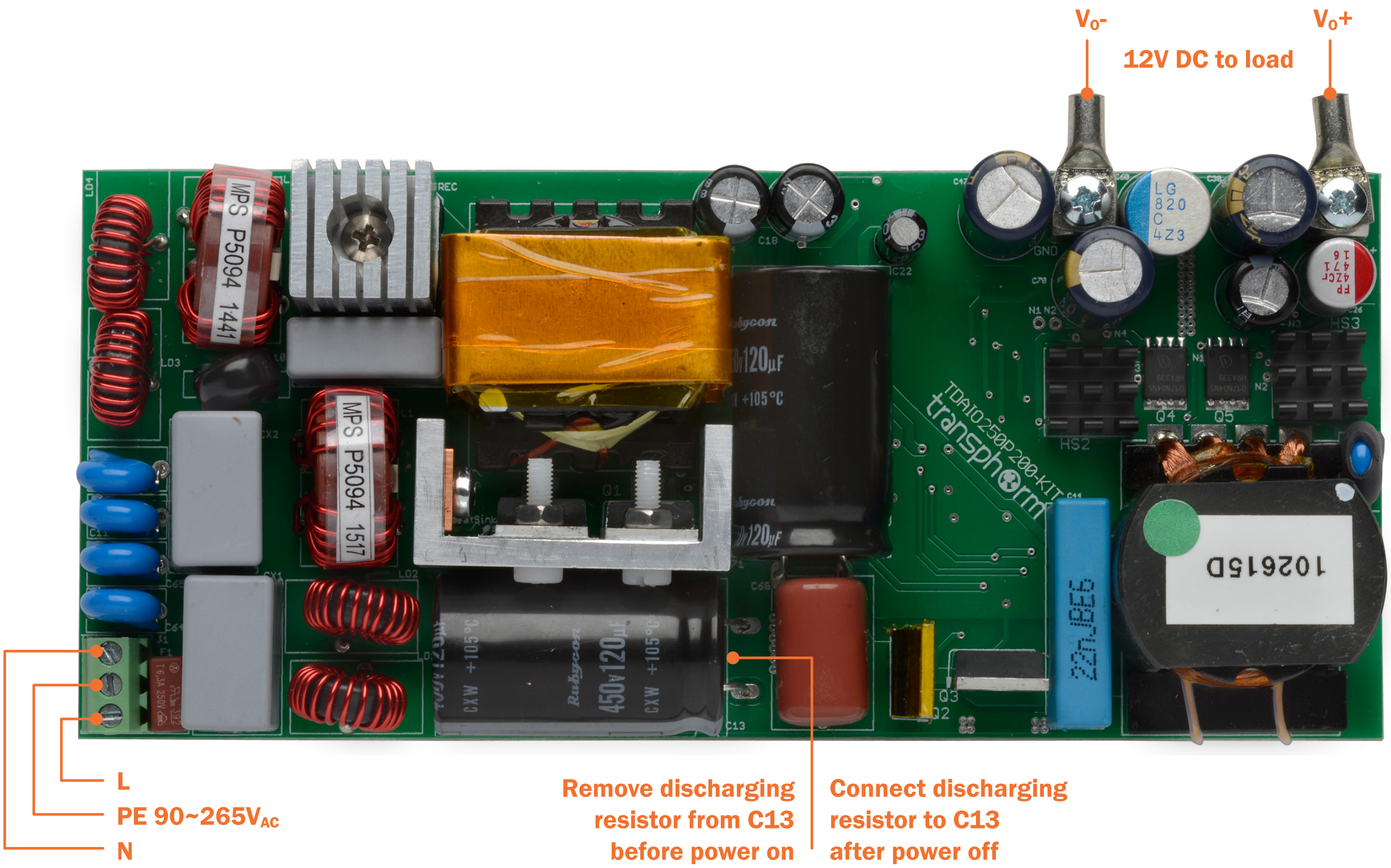
While a typical silicon (Si) MOSFET has a maximum dv/dt rating of 50V/ns, the Transphorm GaN FET will switch at dv/dt of 100V/ns or higher. At this level of operation, even the layout becomes a significant contributor to performance. Figure 3 shows the layout of the layers in the evaluation board. The recommended layout minimizes the gate drive loop for each GaN FET. In addition, it keeps the traces between the switching nodes very short, with the shortest practical return trace to power ground, as the power ground plane provides a large cross sectional area to achieve an even ground potential throughout the circuit. Note that Transphorm GaN FETs in TO-220 packages have a pin configuration of G-S-D, as opposed to the traditional MOSFET configuration of G-D-S. Placement of the source pin in the center reduces coupling between the input and output loops.



(a) Top layer



(b) Bottom layer



(c) Connections

Figure 3. PCB layers—size: 5.88in x 2.66in/149mm x 67.5mm

Table 1. TDAIO250P200 evaluation board bill of materials (BOM)

Designator	Qty	Value	Description	Part Number	Manufacturer
C1, C53	2	2.2nF	CAP., X7R, 16V, 10%, 0603	0603YC222KAT2A	AVX
C2, C9, C28, C32, C34, C52	6	1µF	CAP., X7R, 16V, 10%, 0603	EMK107B7105KA-T	Taiyo Yuden
C3	1	1.5nF	CAP., X7R, 16V, 10%, 0603	C0603C152K4RACTU	Kemet
C4	1	2.2µF	CAP., X5R, 16V, 10%, 0603	C1608X5R1C225K080AB	TDK
C5	1	100pF	CAP., NPO, 50V, 5%, 0603	C1608C0G1H101J080AA	AVX
C6, C7, C8	3	4.7nF	CAP., NPO, 630V, 5%, 1206	C3216C0G2J472J085AA	TDK
C10	1	0.22µF	CAP., Film, 630V, 20%, 7x15x17.5(mm)	BFC233820224	Vishay
C11, C12, C64, C65, CY4	5	4.7nF	CAP., X1Y2, 250VAC, 20%, Rad.	C947U472MYVDBA7317	Kemet
C13, C71	2	120µF	CAP., Alum., 450V, 20%, Rad. 18x33.5(mm)	450QXW120MEFC18X31.5	Rubycon
C14, C18	2	3.3µF	CAP., Alum., 400V, 20%, E3.5-8	400LLE3R3MEFC8X11R5	Rubycon
C17, C19, C27, C37, C35	5	0.1µF	CAP., X7R, 16V, 10%, 0603	GRM188R71C104KA01D	Murata

Designator	Qty	Value	Description	Part Number	Manufacturer
C15, C16, C23, C24	4	0.1µF	CAP., X7R, 630V, 10%, 1812	C4532X7R2J104K230KA	TDK
C20	1	0.1µF	CAP., X7R, 25V, 10%, 1206	C1206F104K3RACTU	Kemet
C21, C29	2	10µF	CAP., X5R, 16V, 20%, 0805	C0805C106M4PACTU	Kemet
C22	1	100µF	CAP., Alum., 16V, 20%, Rad. 5x2(mm)	16PX100MEFCTA5X11	Rubycon
C26	1	470µF	CAP., Poly. Alum., 16V, 20%, E3.5-8	RNE1C471MDN1PX	Nichicon
C31, C50, C59	3	4.7µF	CAP., X5R, 16V, 10%, 0805	C0805C475K4PACTU	Kemet
C36	1	68nF	CAP., X7R, 16V, 10%, 0603	CC0603KRX7R7BB683	Yageo
C38, C47, C70	3	820µF	CAP., Alum., 16V, 20%, E5-10.5	EEU-FC1C821	Panasonic
C39	1	680µF	CAP., Alum., 16V, 20%, E3.5-8	EEU-FC1C681L	Panasonic
C40, C41, C42, C43, C55, C56, C62, C63	8	100µF	CAP., X5R, 16V, 20%, 1210	EMK325ABJ107MM-T	Taiyo Yuden
C44	1	22nF	CAP., Film, 1kV, 5%, 26x6.5(mm)	PHE450PD5220JR06L2	Kemet
C45, C46	2	330pF	CAP., NP0, 50V, 5%, 0805	C0805C331J5GACTU	Kemet
C51	1	10nF	CAP., X7R, 16V, 10%, 0603	CGJ3E2X7R1C103K080AA	TDK
C54	1	1nF	CAP., X7R, 16V, 5%, 0603	C0603C102J4RACTU	Kemet
C57, C58	2	8.2nF	CAP., NP0, 630V, 5%, 1206	C3216C0G2J822J160AA	TDK
C60	1	820µF	CAP., Poly. Alum., 16V, 20%, E5-10.5	PLG1C821MDO1	Nichicon
C68	1	2.2µF	CAP., Film, 450V, 5%, 18.8x12.8(mm)	ECW-F2W225JA	Panasonic
CX1, CX2	2	470nF	CAP., Film, 630V, X2	BFC233920474	Vishay
R1	1	110kΩ	RES., 0.1W, 1%, 0603	CRCW0603110KFKEA	Vishay
R2	1	75kΩ	RES., 0.1W, 5%, 0603	CRCW060375K0JNEA	Vishay
R3, R4, R5	3	2.37MΩ	RES., 1/8W, 1%, 0805	RC0805FR-072M37L	Yageo
R6	1	3.3kΩ	RES., 0.1W, 1%, 0603	RMCF0603FT3K30	Stackpole
R7	1	60mΩ	RES., 1W, 1%, 2512	WSL2512R0600FEA	Vishay
R8, R34	2	11kΩ	RES., 0.1W, 1%, 0603	ERJ-3EKF1102V	Panasonic
R9, R38	2	23.2kΩ	RES., 0.1W, 1%, 0603	ERA-3AEB2322V	Panasonic
R10, R13	2	220kΩ	RES., 1/4W, 1%, 1206	RC1206FR-07220KL	Yageo
R12	1	1.8MΩ	RES., 1/8W, 1%, 0805	KTR10EZPF1804	ROHM
R11	1	1.78MΩ	RES., 1/8W, 1%, 0805	CRCW08051M78FKEA	Vishay
R14	1	10Ω	RES., 2W, 2%, 2512	RCL122510R0FKEG	Vishay
R15	1	2.05kΩ	RES., 0.1W, 1%, 0603	RC0603FR-072K05L	Yageo
R16	1	13kΩ	RES., 0.1W, 1%, 0603	RC0603FR-0713KL	Yageo
R17	1	13kΩ	RES., 1/4W, 5%, 1206	ERJ-8GEYJ133V	Panasonic
R18	1	4.7Ω	RES., 1/8W, 1%, 0805	KTR10EZPF4R70	ROHM
R19	1	4.32kΩ	RES., 0.1W, 1%, 0603	ERJ-3EKF4321V	Panasonic
R20	1	4.7kΩ	RES., 0.1W, 1%, 0603	RC0603FR-074K7L	Yageo
R21, R22, R23	3	953kΩ	RES., 1/8W, 1%, 0603	ERJ-6ENF9533V	Panasonic
R24	1	10kΩ	RES., 1/8W, 1%, 0805	ERJ-6ENF1002V	Panasonic
R25, R27	2	20kΩ	RES., 0.1W, 1%, 0603	MCR03ERTF2002	ROHM
R26, R30	2	5.9kΩ	RES., 0.1W, 1%, 0603	RC0603FR-075K9L	Yageo
R28, R29	2	0.56Ω	RES., 1/8W, 1%, 0805	RL0805FR-070R56L	Yageo
R31	1	2.2kΩ	RES., 0.1w, 1%, 0603	RC0603FR-072K2L	Yageo

Designator	Qty	Value	Description	Part Number	Manufacturer
R32, R40	2	1kΩ	RES., 0.1W, 1%, 0603	RC0603FR-071KL	Yageo
R33	1	14.7kΩ	RES., 0.1W, 1%, 0603	ERJ-3EKF1472V	Panasonic
R35	1	13.7kΩ	RES., 0.1W, 1%, 0603	ERJ-3EKF1372V	Panasonic
R36	1	750Ω	RES., 0.1W, 1%, 0603	RC0603FR-07750RL	Yageo
R37	1	249Ω	RES., 0.1W, 1%, 0603	MCR03ERTF2490	Vishay
R39	1	100Ω	RES., 0.1W, 1%, 0603	RC0603FR-07100RL	Yageo
R41	1	7.5kΩ	RES., 0.1W, 1%, 0603	MCR03ERTF7501	Yageo
R42, R46	2	2kΩ	RES., 0.1W, 1%, 0603	ERJ-3EKF2001V	Panasonic
R43	1	150kΩ	RES., 0.1W, 1%, 0603	RC0603FR-07150KL	Yageo
R44	1	12.4kΩ	RES, 0.1W, 1%, 0603	RC0603FR-0712K4L	Yageo
R47, R48, R57, R58, R59, R60, R51	6		RES., N/A, 0603		N/A
R45	1	6.8kΩ	RES, 0.1W, 1%, 0603	RC0603FR-076K8L	Yageo
R53, R56,	3	0Ω	RES., 0.1W, 0603	RC0603JR-070RL	Yageo
R49, R50	2	24kΩ	RES., 1/8W, 5%, 0805	RC0805JR-0724KL	Yageo
R54, R55	2	4.7Ω	RES., 0.1W, 1%, 0603	P4.7AJCT-ND	Panasonic
R61, R62	2	2.2MΩ	RES., 1/4W, 5%, 1206	RC1206JR-072M2L	Yageo
R63, R64	2	10Ω	RES., 1/4W, 5%, 0805	RPC0805JT10R0	Stackpole
D1	1	1000V	Diode, 1A, DO-214AC	S1M-13-F	Diodes Inc.
R44	1	12.4kΩ	RES, 0.1W, 1%, 0603	RC0603FR-0712K4L	Yageo
D2	1	600V	Diode, 3A, DO-214AB	S3J	Fairchild
D3	1	600V	Diode, SiC, 2A, TO220-2	C3D02060A	Cree
D5	1	600V	Diode, 1A, DO-214AC	S1J-13-F	Diodes Inc.
D6, D7	1	600V	Diode, Ultra Fast, 1A, DO-214AC	ES1J-LTP	Diodes Inc.
D8	1	11V	Diode, Zener, 0.5W, SOD123	MMSZ5241BT1G	ON Semiconductor
D9, D10	2	75V	Diode, 0.15A, SOD323F	1N4148WS	Fairchild
Q1, Q2, Q3	3	600V	GaN FET, 9A, TO-220	TPH3202PS	Transphorm
Ld1, Ld2, Ld3, Ld4	4	26µH	IND., DCR < 40mΩ	P1131	MPS Inc.
L1, L2	2	9mH	Common Mode Chk, 1.9A, 22x15(mm)	P5094	MPS Inc.
L4	1	1mH	IND., 70mA, 1210	744045102	Wurth Elek.
L5	1	1mH	IND., 0.235A, 7.6x7.6(mm)	DRA73-102-R	Cooper Buss.
LF	1	480µH	IND., 200kHz, CC30/19	019-8202-00R	Precision
J1	1	300V	CONN., 10A, 3Pin_3.5mm	6.91214E+11	Wurth Elek.
J2, J3	2		BUSH, 54A	7461093	Wurth Elek.
HS2, HS3	2		HEATSINK, 10x10(mm)	V2017B	Assmann WSW Comp.
PS1	1	12V	PowerChip, Offline, 1.44W, SO-8C	LNK304DG-TL	Power Integrations
MOV1	1	504V	MOV, 3.5kA, Disc 10.5mm	ERZ-E08A561	Panasonic
U2	1		LLC Controller, 16-SOIC	NCP1397BDR2G	ON Semiconductor
U1	1		PFC Controller, CCM, 200kHz, SO-08	NCP1654BD200R2G	ON Semiconductor
U3, U4	2		Synchronous Rectifier Driver, SO-08	NCP4304BDR2G	ON Semiconductor
U5	1		Voltage Reference, SOT23	NCP432BCSNT1G	ON Semiconductor
U6	1	5kV	Optoisolator, 4-SMD	HCPL-817-50AE	Broadcom
U7	1		X2 CAP. DIS., SOIC-8	NCP4810DR2G	ON Semiconductor
F1	1	250V	FUSE, SLOW, 6.3A	39216300000	Littlefuse Inc.
Q4, Q5	2	40V	MOSFET, N-CH, 100A, PG-	BSC017N04NS G	Infineon

Designator	Qty	Value	Description	Part Number	Manufacturer
			TDSON-8		
Transformer	1	240W	Transformer, LLC, 170kHz – 200kHz	019-7896-00R	Precision
FB1, FB2, FB3	3	60Ω	Ferrite Bead, 60Ω@100MHz, 500mA, 0603	MMZ1608Y600B	TDK
REC	1	600V	Rectifier Bridge, 8A, D-72	VS-KBPC806PBF	Vishay
	1		Thermal Pad, 0.9W/m-K, 18.42x13.21(mm)	53-77-9G	Aavid Thermalloy
	1	47Ω	Ferrite Core, 47Ω@100MHz, 4.2mm OD	74270012	Wurth Elek.

Circuit description for the PFC AC-DC converter

Please refer to the NCP1654 datasheet and AND8324-D application note from ON Semiconductor. A generic NCP1654 application schematic (Figure 4) and parameters of the PFC controller (Table 2) and the inductor (Table 3) follow.

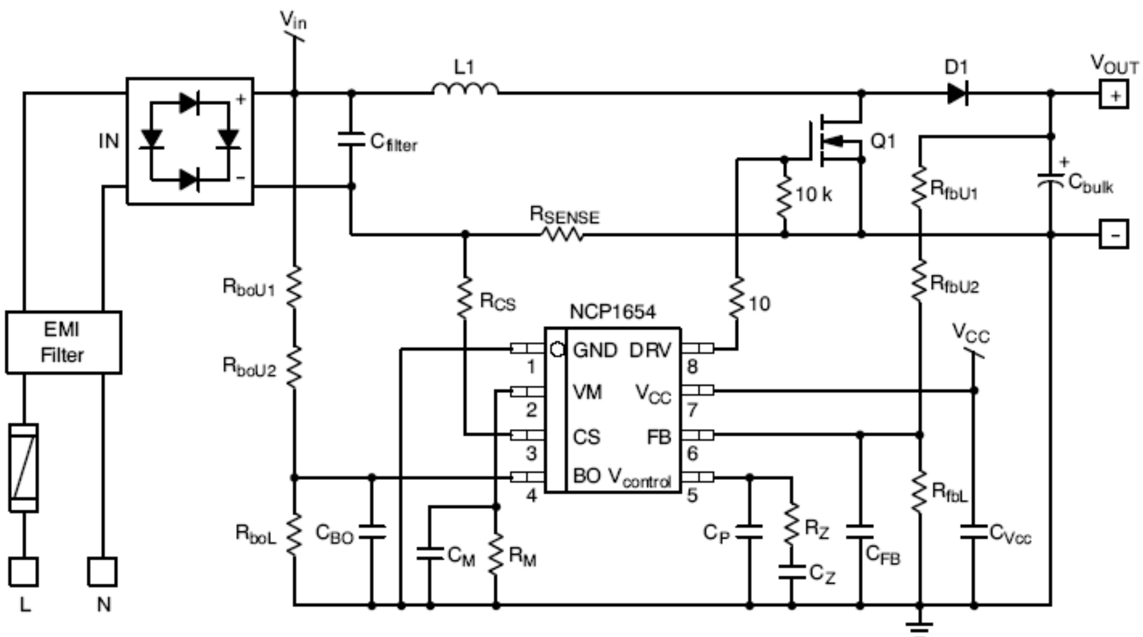


Figure 4. Generic NCP1654 application schematic

Table 2. NCP1654 PFC controller parameters

Parameter	Unit	Value	Description
f_{ac}	Hz	60	Ac line frequency
V_{acLL}	V	90	Ac line rms lowest level (generally 85V or 90V in wide mains applications)
V_{acHL}	V	265	Ac line rms highest level (generally 265V in wide or European mains applications)
$V_{ac,on}$	V	75	Ac line rms voltage to start up (generally 75Vac in wide mains applications)
V_{out}	V	385	Wished regulation level for the output voltage (generally 390V or 400V in wide mains applications)
V_{outLL}	V	385	Minimum output voltage you can accept in normal operation – use

Parameter	Unit	Value	Description
			V_{outLL} = V_{out} as a default value if you don't know
eff	%	95	Expected efficiency at low line, full load
P_{out}	W	216	Maximum output power
ΔI_{pk-pk}	%	30	Targeted peak to peak ripple of the coil current at low line and full load
R_{dsON}	Ω	0.29	MOSFET on-time resistance @ 25°C
$T_{hold-up}$	ms	20	Hold-up time – put 0 if no hold-up time is specified or if you don't know
(V_{out})min	V	310	Minimum output voltage you can accept at the end of the hold-up time
$\%DV_{pk-pk}$	%	3	Peak to peak low frequency ripple that is acceptable across the bulk capacitor as a percentage of the regulation output voltage ("V_{out}")
Bulk capacitor and coil specifications			
C_{bulk} cal.	µF	166	Minimum C_{bulk} capacitance meeting the low frequency ripple and hold-up time constraints*
C_{bulk} selected	µF	240	Choose higher standard value
ESR of C_{bulk}	mΩ	150	The ESR of C_{bulk}
L_{calc}	µH	397	Proposed coil inductance
L selected	µH	480	Your inductance choice
(I_{coil})max	A	4.02	Max peak coil current resulting from your inductance choice
(I_{coil})rms	A	2.53	Maximum rms coil current
Conduction losses			
Input bridge	W	4.5	Assuming the forward voltage of each diode is 1V
MOSFET	W	2.9	Assuming R_{dsON} doubles at the highest junction temperature of your application
Diode	W	0.6	Assuming R_{dsON} doubles at the highest junction temperature of your application and assuming the diode forward voltage is 1V
Feedback arrangement			
R_{fbL}	kΩ	23.2	Choose a standard value
R_{fbU1} + R_{fbU2}	kΩ	3,550	(R_{fbU1} + R_{fbU2}) calculated based on R_{fbL} and V_{out}
C_{fb}	pF	100	
Input voltage sensing - choose high accuracy resistors for R_{boU1}, R_{boU2} and R_{boL}			
R_{boL}	kΩ	24.7	Choose a standard value < 140kΩ
R_{boU1} + R_{boU2}	kΩ	2,007	(R_{boU1} + R_{boU2}) calculated based on R_{boL} and $V_{ac,on}$
C_{bo} cal.	µF	1.69	C_{bo} calculated based on R_{boL} and line frequency
C_{bo} selected	µF	2.20	Choose the closest standard value
Current sense network			
R_{sense} cal.	Ω	0.17	Value that makes the R_{sense} dissipation = (0.5% * P_{out})
R_{sense} selected	Ω	0.06	Your " R_{sense} " choice
P_{Rsense}	Ω	0.4	Losses resulting from your R_{sense} choice
R_{cs} cal.	kΩ	1.3	Value resulting from your R_{sense} choice
R_{cs} selected	kΩ	3.3	Choose higher standard value
R_m	kΩ	110	Value resulting from your R_{sense} choice
C_m	nF	2.2	Value resulting from your R_m choice
Compensation arrangement			
F_c	Hz	20	The desired crossover frequency at high line
C_z cal.	µF	2.0	The calculated C_z based on (G0)dB and fc
C_z	µF	2.2	Choose closest standard value
R_z cal.	(kΩ	25	The calculated R_z based on fz1
R_z	kΩ	11	Choose closest standard value
C_p cal.	nF	1.5	The calculated C_p based on fp1

* Do not forget to check that the ESR is low enough to avoid any over-heating of the bulk capacitor. You can use 1.8A as a starting value for the bulk capacitor rms current (rough estimation based on the figures you entered). Double check on the bench that the bulk capacitor heating is not excessive.

Table 3. PFC inductor parameters

Item	Value	Comments
Inductance	480µH	~25% ΔI_{pk_pk}
Core type	CC30/19	Height < 20mm
Core material	A-core JPP-95	Similar to 3C95
Wire	40/38 Litz wire	~0.11Ω DCR
Winding turns	38	< 10pF winding capacitance
Air gap	~0.42mm	

Circuit description for the LLC DC-DC converter

Figure 5 illustrates the topology of the LLC DC-DC converter portion of the evaluation board, which is based on the NCP1397 and NCP4304 controllers. The series capacitor forms the series-parallel resonant tank with leakage and magnetizing inductances in the primary side of the transformer. From this configuration, the resonant tank and the load on the secondary side act as a voltage divider. By changing the frequency of input voltage, the impedance of resonant tank will change; this impedance will divide the input voltage with load. The primary-side switches, Q1 and Q2, are the GaN FETs. Transistors SD1 and SD2 on the secondary side are synchronous rectifiers to improve the performance and efficiency. As can be seen in Figure 5, there is no need for special gate drivers for the GaN FETs. For further reading: information and discussion on the fundamental circuit schematics and the characteristics of LLC DC-DC converters [1], [2], [3].

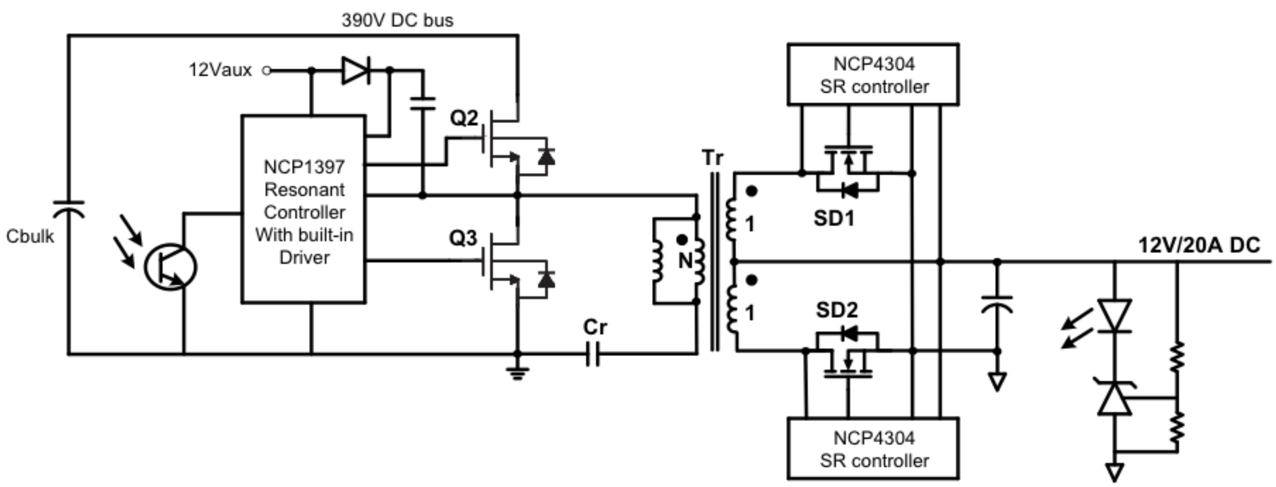


Figure 5. Circuit topology for LLC DC-DC converter using Si MOSFETs for line rectification

Although the LLC is a resonant topology, characterized by soft switching, hard switching does nevertheless occur during start-up. During this phase, the large reverse recovery charge (Q_{rr}) of typical Si MOSFETs causes problematic overshoot, ringing, and loss. Transphorm's TPH3202PS GaN power devices show a low on-resistance of 0.29Ω (typical) and are capable of reverse conduction during dead time, with a low Q_{rr} of 29nC, more than 20 times lower than state-of-the-art Si counterpart as seen in Figure 6. These features can remarkably improve the performance and efficiency of hard-switch circuits and are also important for hard starting in resonant circuits such as the LLC topology.

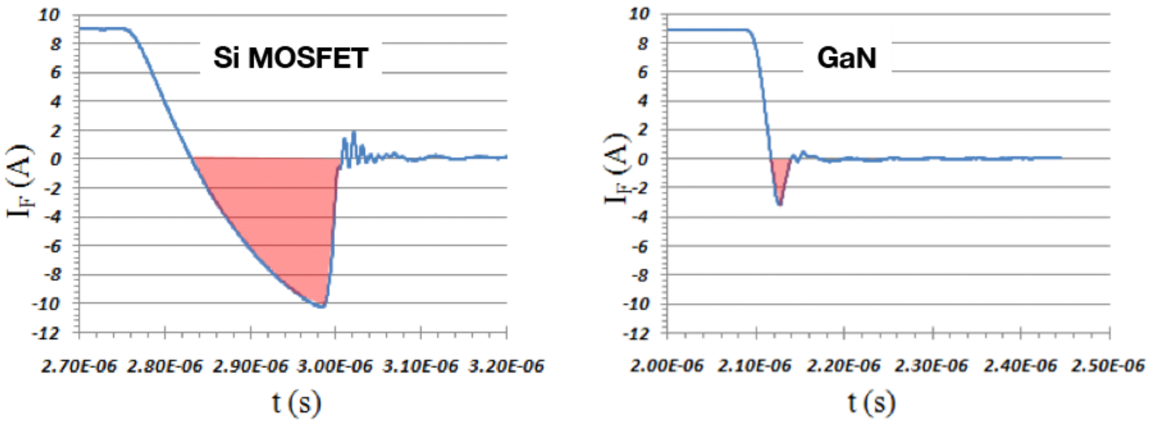


Figure 6. Reverse recovery charge test result for a Si MOSFET and a GaN FET: Similar on-resistance and a 20x reduction of Q_{rr} for GaN

Startup sequence

1. Connect a load – the load should be resistive and maximum of 240W at $12V_{DC}$
2. Connect an AC power source and set to the desired voltage, higher than 90V
3. Place a cooling fan facing the GaN FETs' heat sinks of the PFC and LLC, providing a minimum of 30 CFM air flow
4. Turn on the cooling fan if output power is higher than 200W

Probing

To minimize additional inductance during measurement, the tip and the ground of the probe should be directly attached to the sensing points to minimize the sensing loop, while the typical long ground lead should be avoided since it will form a sensing loop and could pick up the noise. An example of low inductance probing is shown in Figure 7. Differential probes are not required.

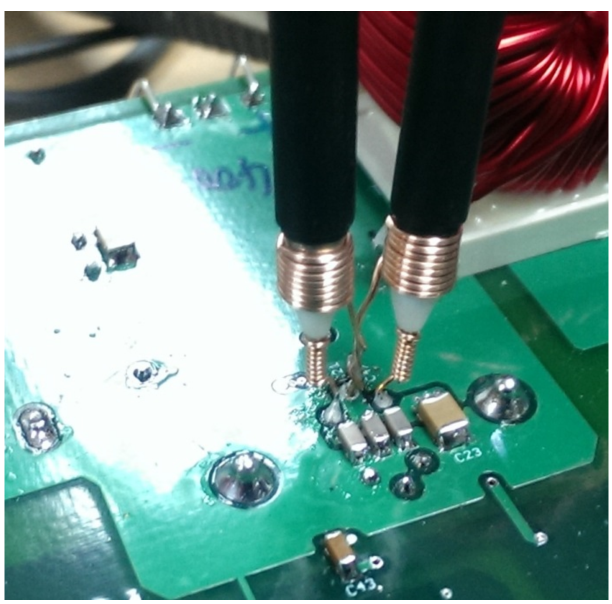
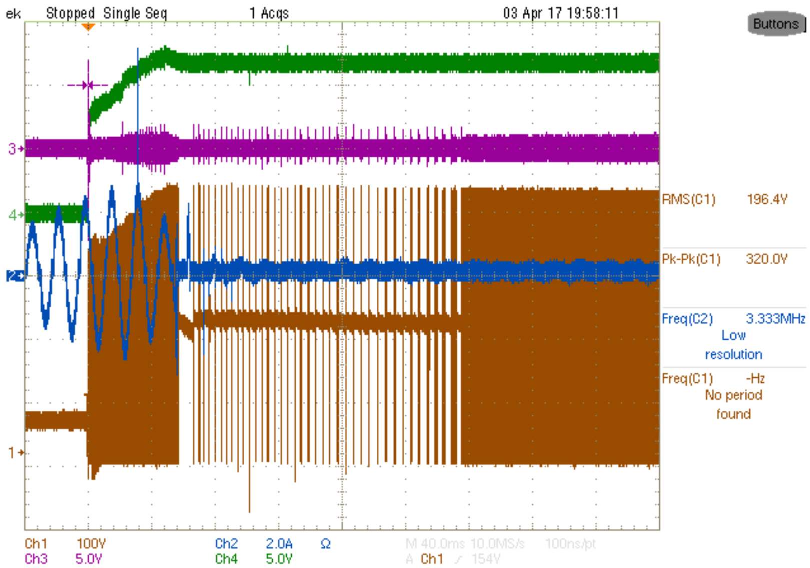


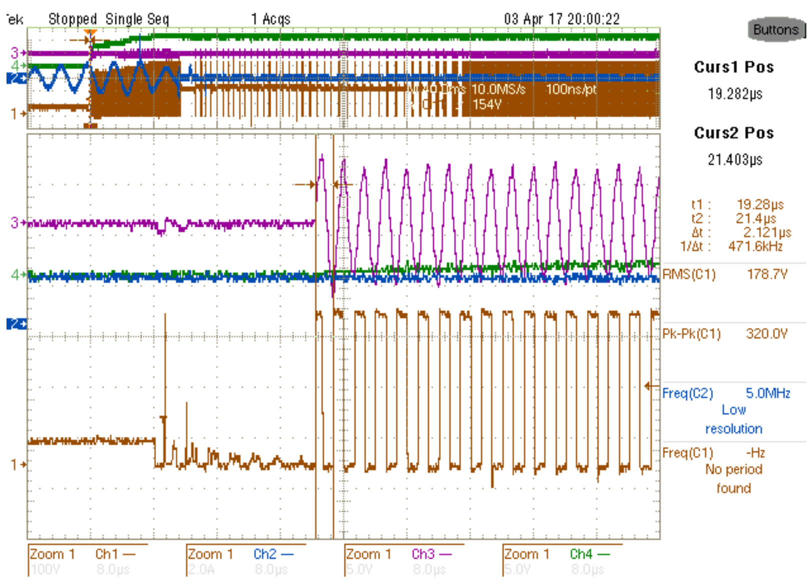
Figure 7. Low inductance probing of fast, high-voltage signals

Power-up waveforms

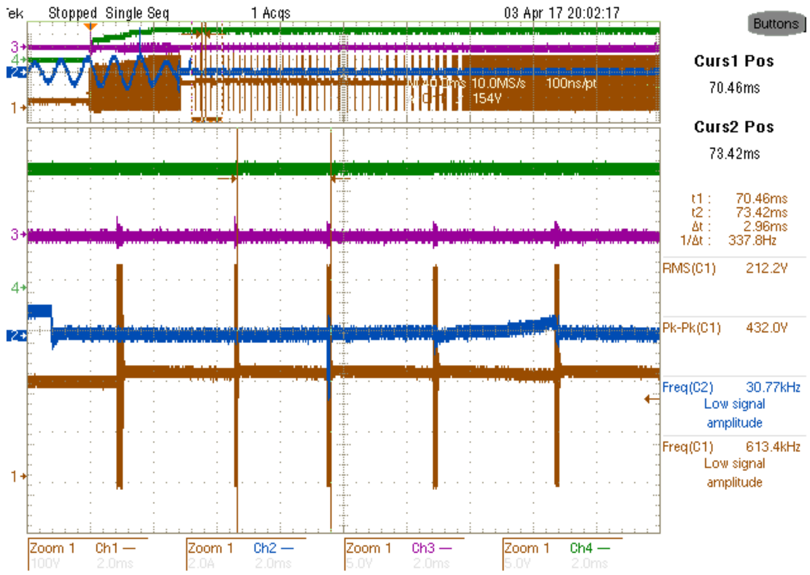
The power-up waveforms were measured in different conditions. Figure 8 shows the no-load LLC power-up at 115V input. As shown in Figure 8(a), the DC bus voltage increases to 360V, the LLC converter starts to operate, and the output voltage (CH4) gradually increases to 12V. In Figure 8(b), when the LLC half-bridge starts switching, the initial switching frequency is 471kHz in the beginning and the peak transformer current is around 7.5A. Figure 9 shows the full-load LLC power-up. In the current waveforms, the peak current appeared after 3-4 line cycles in both no-load and full-load conditions. This is because, when the output voltage increases to around 10V, the SR driver is engaged and the MOSFET will run in synchronized rectified mode and the voltage drop on body diode will be eliminated.



(a)

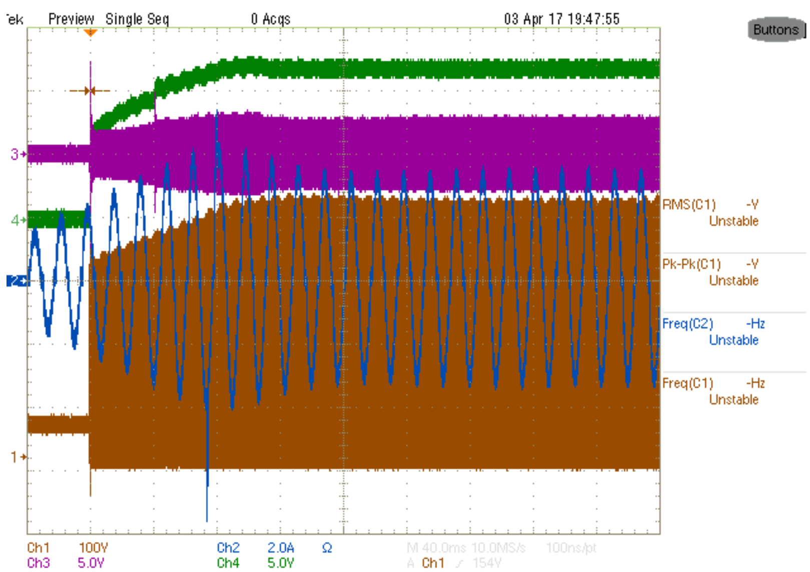


(b)

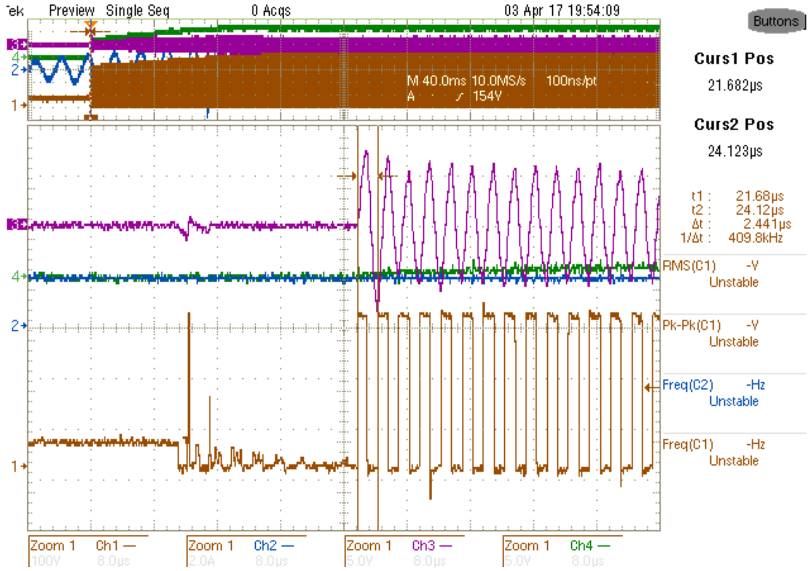


(c)

Figure 8. Power-up at no-load condition at 115V input
(a) LLC power-up waveforms: CH1 – V_{DS} voltage of LLC, CH2 – input current, CH3 – LLC primary side transformer, CH4 – output voltage
(b) LLC start-up frequency – f_{sw}=471.6kHz, I_{L_pk}=7.5A
(c) Burst mode at startup with no load



(a)



(b)

Figure 9. Power-up at 240W condition at 115V input
(a) LLC power-up waveforms: CH1 – V_{DS} voltage of LLC, CH2 – input current,
CH3 – LLC primary side transformer current, CH4 – output voltage
(b) LLC startup frequency – f_{sw}=409.8kHz, I_{L_pk}=8.65A

Performance

Efficiency and power factor were measured at low line (115V_{AC}) and high line (230V_{AC}) input for a range of loads on the 12V_{DC} output using the Yokogawa WT1800 precision power analyzer. The results are shown in Figures 10-12 for the complete power supply and for the individual LLC circuits. The mid-load efficiency is more than 94% at low line and about 95.4% at high line, which is noticeably better than commercial boards with Si switches.

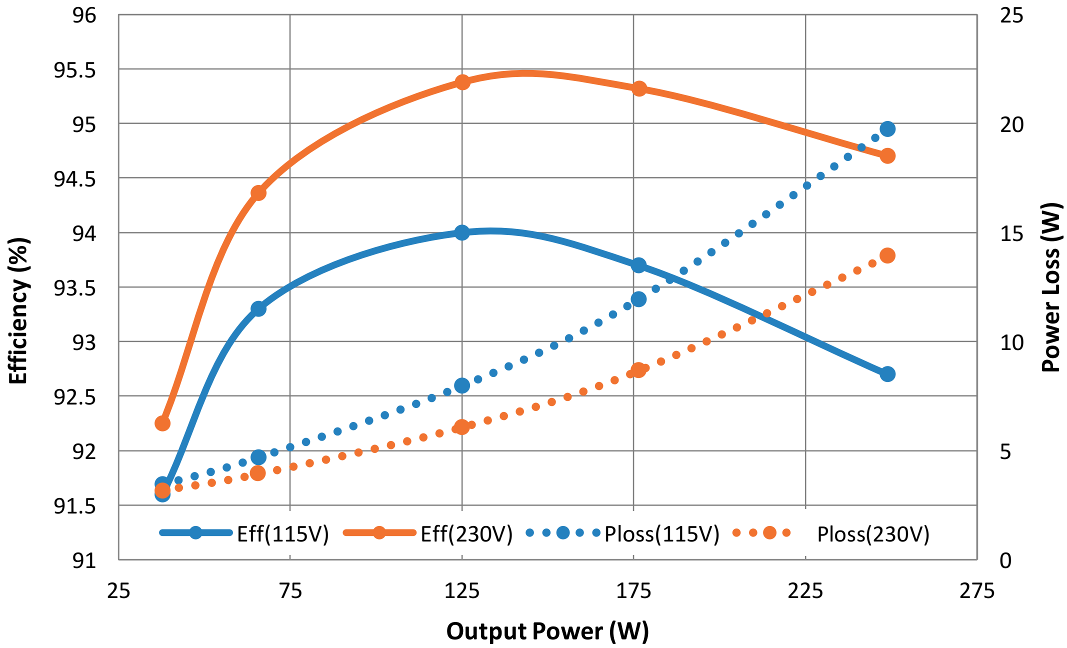


Figure 10. Efficiency for the power supply at 115V and 230V input

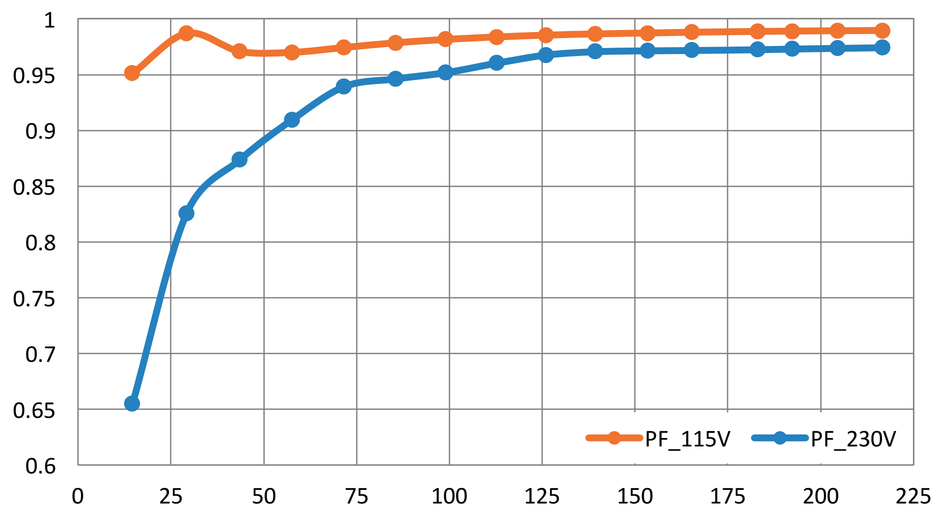


Figure 11. Power factor vs. output power at 115V and 230V input

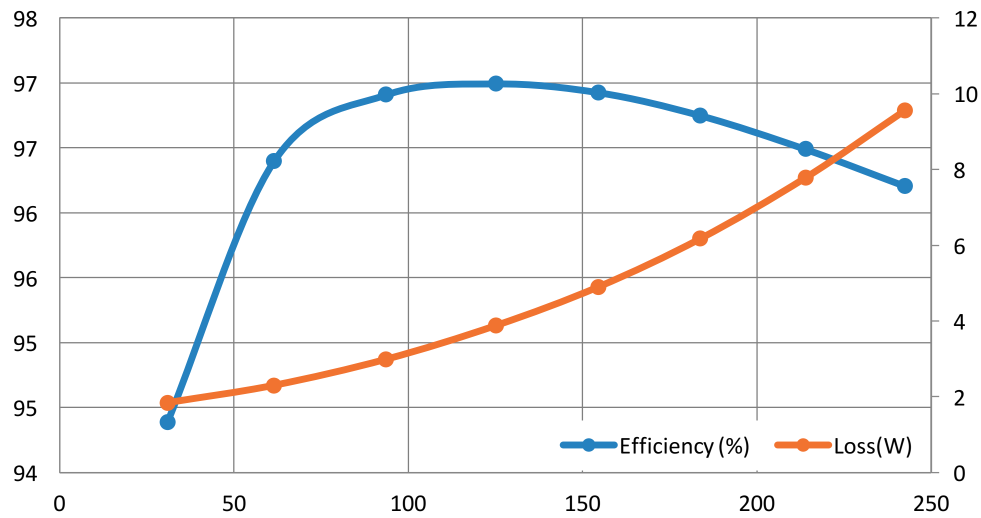


Figure 12. Efficiency results for the LLC DC-DC converter circuit at 390V_{DC} input to 12V_{DC} output

Conducted emissions have also been measured for the TDAIO250P200 board, using an LIN-115A LISN by Com-Power, and the results compared to EN55022B limits (Figure 13.)

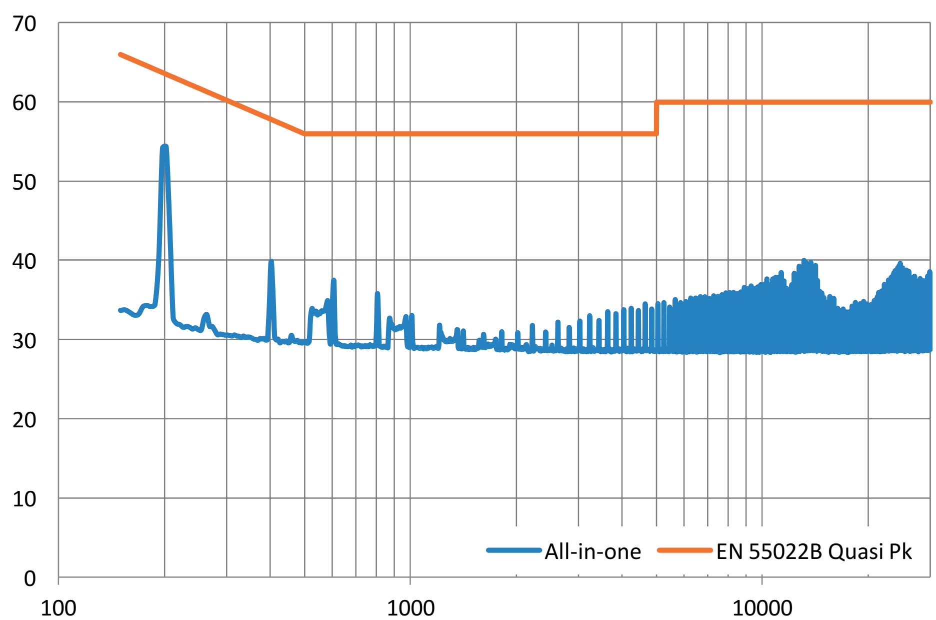
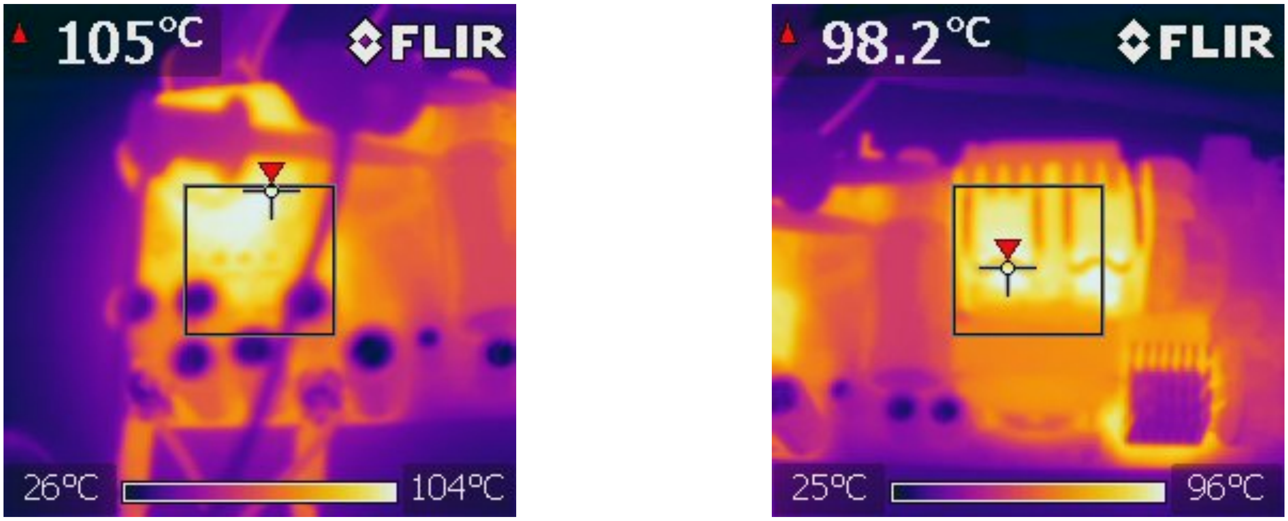


Figure 13. Conducted emissions at 115V_{AC} and 240W load

In this design, standby power consumption is not optimized to show the superior performance over Si-based devices. Current Controlled Frequency Foldback (CCFF) and burst mode methods can be applied for very low power loss requirement at zero and light load using corresponding controllers and circuits.

The temperature rise was measured with natural air convection at 23°C ambient temperature. At 240W load and 115V input, the transformer temperature went to 105°C (a) and the TPH3202PS (Q1) went to 98.2°C (b) in one hour (Figure 14.) It is suggested to add a moderate air flow when the load is over 200W.



(a) (b)

Figure 14. Temperature measurement at full load, 115V input T_A=23°C

Warnings

300V high voltage in DC capacitors. Do not touch the board after turning the power off. Connect a discharge resistor to C13, or wait 15 minutes, to make sure the voltage decreases to a safe level.

There is no specific current or voltage protection on this board. Users should carefully follow the test procedure and operation limits. The TDAIO250P200 board is for evaluation purposes only.

Further reading

[1] B. Lu, W. Liu, Y. Liang, F. Lee and J. VanWyk, "Optimal design methodology for LLC resonant converter," *Proc. IEEE APEC '06,* pp. 19-23, 2006.

[2] R. Steigerwald, "A comparison of half-bridge resonant converter topologies," *IEEE Transactions on Power Electronics,* vol. 3, no. 2, pp. 174-182, 1988.

[3] B. Yang, F. Lee, A. Zhang and H. Guisong, "LLC resonant converter for front end DC/DC conversion," *Proc. IEEE APEC '02,* pp. 1108-1112, 2002.