

Demonstration Board EPC9171 Quick Start Guide

*90–265 V_{RMS} Universal AC Input to 15 V–48 V_{DC},
5 A Output USB PD3.1 Evaluation Board*

Revision 1.0



DESCRIPTION

The EPC9171 demonstration board is an universal AC input voltage range and frequency isolated power supply, designed for USB PD3.1 systems and supports operation in Extended Power Range (EPR) Mode. It is capable of supplying 240 W maximum output power at 48 V output voltage and 5A load current. A power density of about 1.1 W/cm³ is achieved by employing, GaN power switches operated at high switching frequencies in both the primary and secondary circuits.

The output voltage is variable over the whole Adjustable Voltage Supply (AVS) range of 15 V through 48 V as specified by the corresponding USB PD3.1 standard, when operating in constant voltage (CV) mode. A constant current (CC) mode with precise current control ensures that the output current never exceeds the selected current limit (5 A max.). This power supply topology building blocks consists of a two-phase interleaving boost converter PFC stage and an isolated LCC resonant power stage. This solution provides a higher power density than a conventional, three stage design typically consisting of active PFC, LLC and buck power stages.

The interleaving PFC stage ensures high power factor and low AC line current harmonics to meet the harmonics requirements of the EMC standards such as IEC 61000-3-2 / Class A. It supports full-power operation over a wide input voltage range of 90–265 VAC_{RMS}, while optimizing the light load efficiency by means of load dependent PFC phase control. The Critical Conduction Mode (CrCM) operation of the PFC stage in combination with 650 V GaN power switches enable high frequency operation well above 200 kHz. The power density advantage is gained by the elevated switching frequency that requires small physical dimension PFC inductors.

The LCC resonant power stage, operated from the pre-regulated PFC bus voltage, provides both the galvanic isolation and the output voltage/current regulation. Unlike the well-known LLC resonant power stages, which suffers from limited output voltage range, the LCC resonant converters are ideal for wide output voltage range applications with limited switching frequency variation, that also features superior constant-current characteristics. The LCC resonant converter also utilizes 650V GaN switches in primary high voltage circuit in this design and operates in the frequency range of 350 to 580 kHz, which helps to reduce the size of the power transformer as well as that of the other passive components in the resonant circuit.

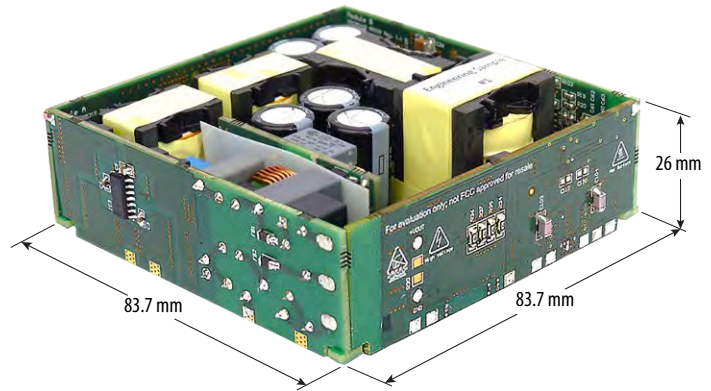
A synchronous rectifier stage employs a pair of 100 V rated, 3.2 mΩ, EPC2218 GaN switches on the secondary side of the LCC stage. The GaN switches are driven by fast synchronous rectifier controllers to minimize the losses over the whole output voltage and current range and allow a simple yet effective thermal design.

PRECAUTIONS

Attention and Warnings:



- Only personnel with technical background should handle the EPC9171 at the stage of “**Engineering sample**”. Failure to comply may result in personal injury and/or equipment damage.
- The EPC9171 “Engineering sample” provides a **functional insulation only**, therefore it shall always be operated from a proper isolation transformer. It does not provide a safety insulation as the insulation of the used components has not been tested and specific electrical creepage and clearance requirements for electrical safety may not be met.
- The EPC9171 “Engineering sample” **does not have any overtemperature protection**. Component temperatures must be carefully monitored during operation to avoid any potential damage caused by overheating.
- The EPC9171 system contains parts and assembly’s sensitive to Electrostatic Discharge (ESD). Electrostatic control precautions are required when testing, servicing, or repairing this assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to applicable ESD protection handbooks and guidelines.
- The EPC9171 system, incorrectly applied or installed, can result in component damage or reduction in product lifetime. Wiring or application errors such as under- or oversizing the load, operation with not authorized loads, supplying an incorrect or inadequate mains supply or excessive ambient temperatures may result in system malfunction or damage. This can result in personal injury and/or equipment damage.
- The EPC9171 system might be shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials which are unnecessary for system installation may result in overheating or abnormal operating condition.



EPC9171 fully assembled demonstration board

REGULATORY INFORMATION

This power module is for evaluation purposes only. It is not a full-featured power module and cannot be used in final products. No EMI test was conducted, and it is not FCC approved.

QUICK START PROCEDURE

The demonstration board EPC9171 is easy to set up to evaluate the performance of the EPC2218 eGaN FETs in this USB PD 3.1 adapter. The main connection diagram is illustrated in Figure 1. The output voltage and output current limit can be set by adjusting the potentiometers R301 and R302 shown in Figure 2.

Power up procedure:

- 1) With power off, connect the EPC9171 to an appropriate AC source.
- 2) With power off, connect the EPC9171 to an appropriate DC load
- 3) Turn on the AC source.
- 4) Adjust the output voltage and current as needed using a non-conductive screw driver. **Observe caution as high voltage is present.**
- 5) When testing is complete, turn off the AC source.

Table 1: Electrical Characteristics (T_A = 25°C) EPC9171

Symbol	Parameter	Min	Typ	Max	Units
V _{IN}	Input voltage	90		265	V _{AC,RMS}
V _{OUT}	Output voltage ⁽¹⁾	15		48	V _{DC}
ΔV _{OUT}	Output voltage ripple		100		mV
I _{OUT}	Output current ⁽¹⁾			5	A
f _S	Switching frequency	350		580	kHz
PF	Power Factor (120 VAC/60 Hz)		0.991		
THD	THD[%] (120 VAC/ 60 Hz)		12.7		%

(1) Variable adjustable

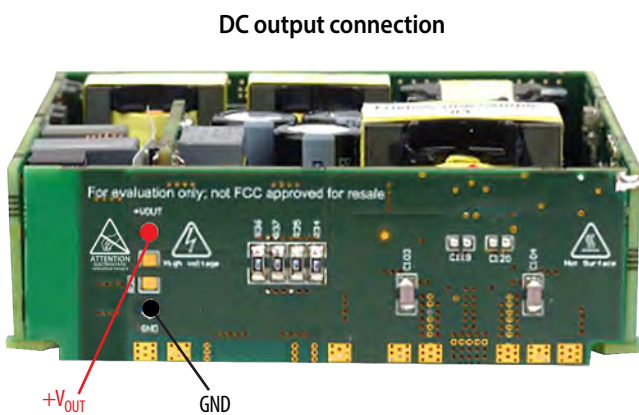
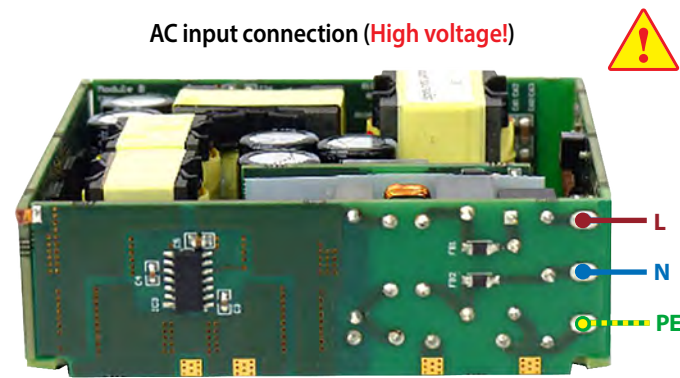


Figure 1: Input and output connections

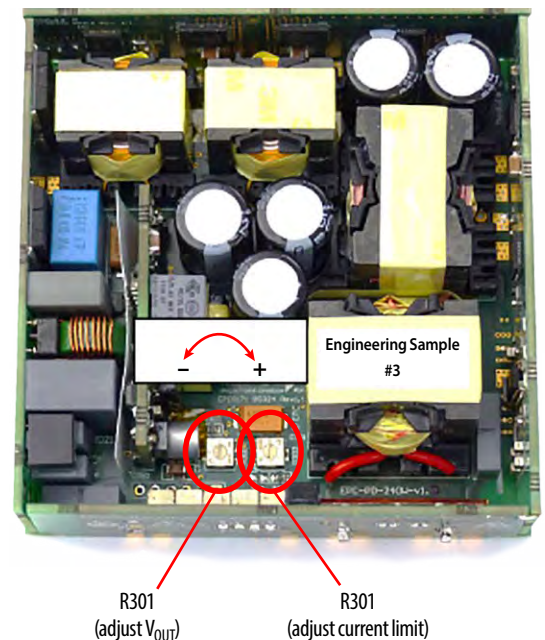
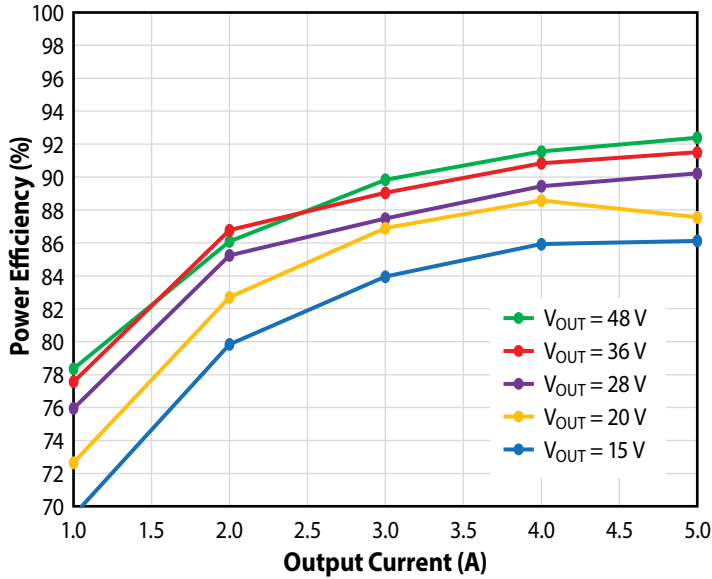


Figure 2: Output voltage adjustable by R301 and output current limit adjustable by R302

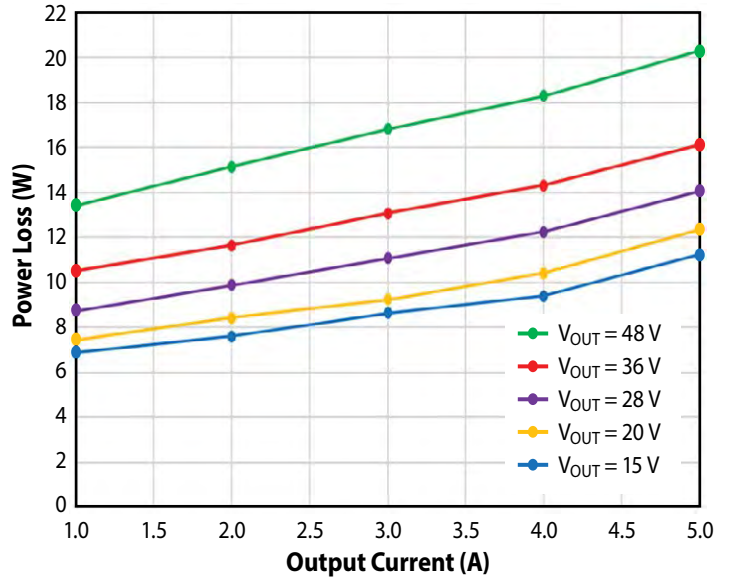
EXPERIMENTAL RESULTS

Typical efficiency and power losses

Power efficiency was measured over a output current range of 1-5 A at 15 V, 20 V, 28 V, 36 V and 48 V output voltages, and at 120 VAC_{RMS} and 230 VAC_{RMS} input voltages, respectively. The input power was measured by an AC power analyzer, while DC output parameters were recorded by precision digital multimeters.

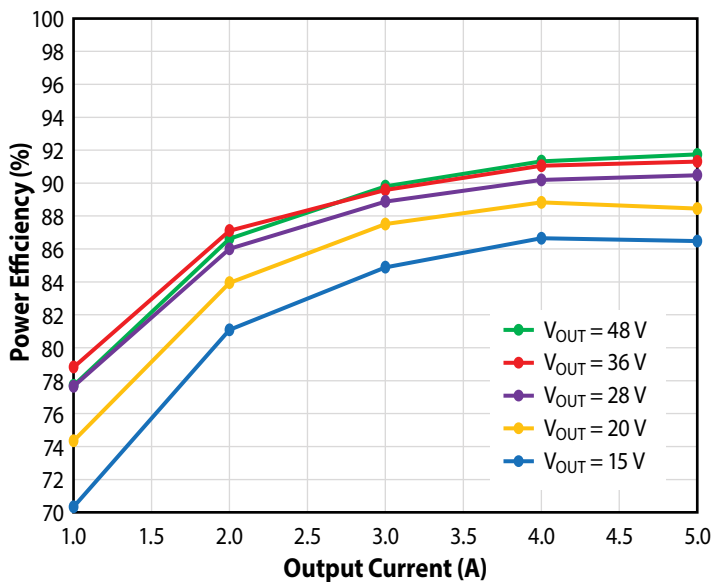


(a)
Power efficiency @ V_{IN} = 120 VAC_{RMS}

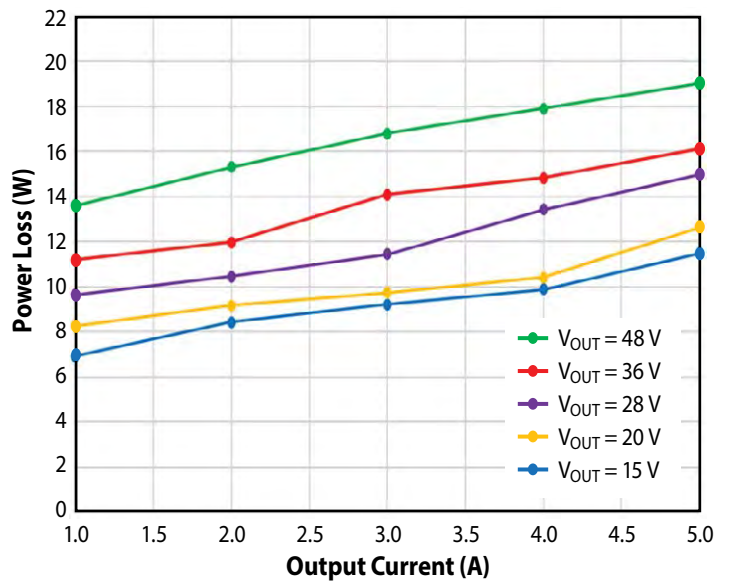


(b)
Power losses @ V_{IN} = 120 VAC_{RMS}

Figure 3: Typical efficiency (a) and power losses (b) for various output voltages with V_{IN} = 120 VAC_{RMS}



(a)
Power efficiency @ V_{IN} = 230 VAC_{RMS}

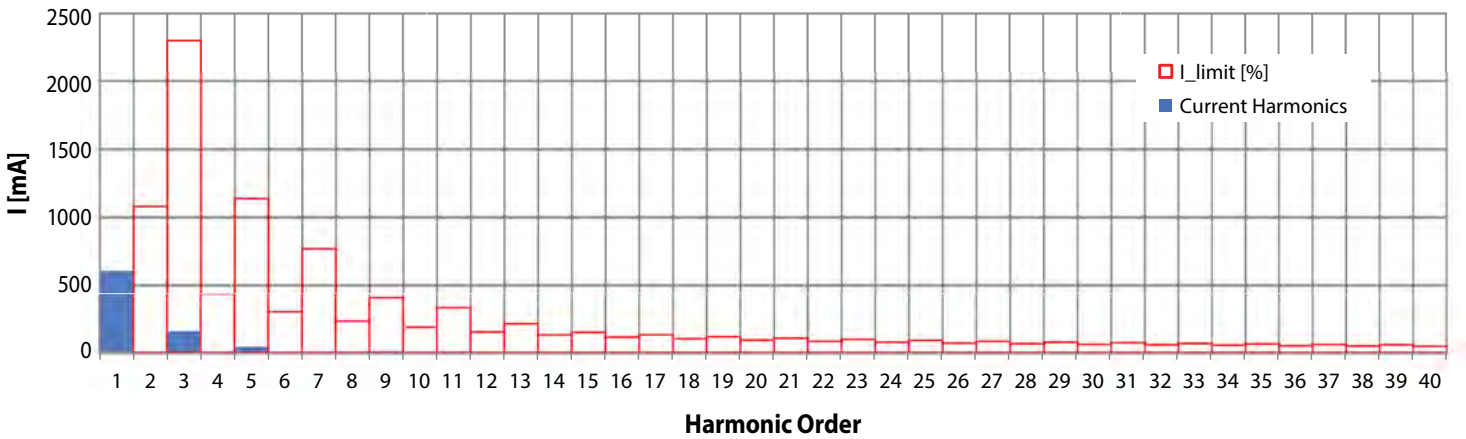


(b)
Power losses @ V_{IN} = 230 VAC_{RMS}

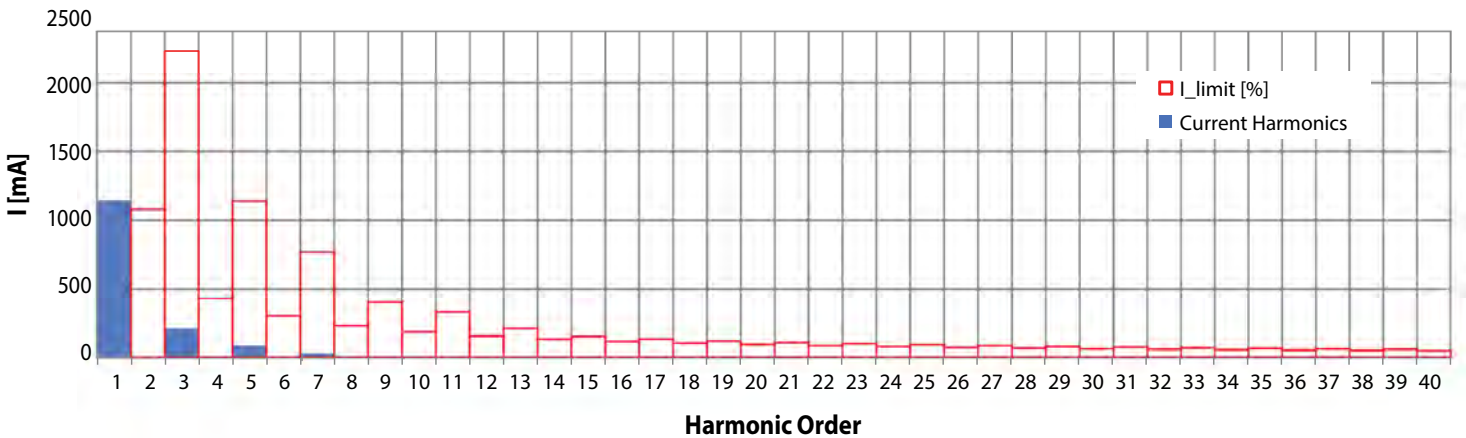
Figure 4: Typical efficiency (a) and power losses (b) for various output voltages with V_{IN} = 230 VAC_{RMS}

AC performance

AC line parameters were measured with an AC power analyzer at 48 V / 5A and 48 V / 2.5 A load, and at 120 V_{RMS} and 230 V_{RMS} input voltages, respectively. Line harmonics were evaluated and compared with the IEC 61000-3-2 / CLASS A line harmonic current limits. (only full-load curves are shown here)



(a)
Current harmonics @ V_{IN} = 120 V_{AC_RMS} / 60 Hz / P_{OUT} = 240 W,
48 V/5000 mA



(b)
Current harmonics @ V_{IN} = 230 V_{AC_RMS} / 50 Hz / P_{OUT} = 240 W,
48 V/5000 mA

Figure 5: (a) Measured current harmonics, V_{IN} = 120 V_{AC_RMS} / 60 Hz,
(b) Measured current harmonics, V_{IN} = 230 V_{AC_RMS} / 50 Hz

Typical load regulation

The output voltage regulation characteristic was measured at voltage settings $V_{OUT} = 48\text{ V}, 36\text{ V}, 28\text{ V}, 20\text{ V}$ and 15 V , respectively (CV aka. Constant voltage mode). The current limit was set to 5 A .

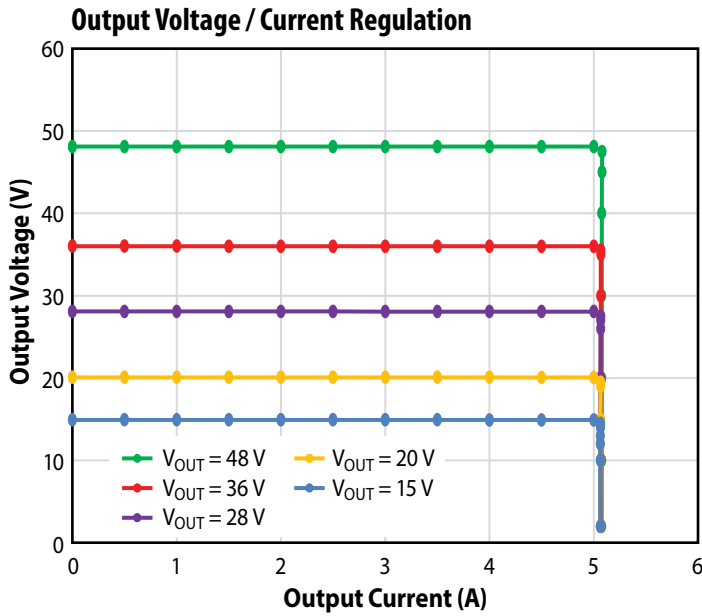


Figure 6: Typical load regulation for output voltages from 15 V – 48 V , $V_{IN} = 120\text{ VAC}_{RMS} / 60\text{ Hz}$

Typical output voltage ripple

Output ripple voltage measured with 20 MHz bandwidth

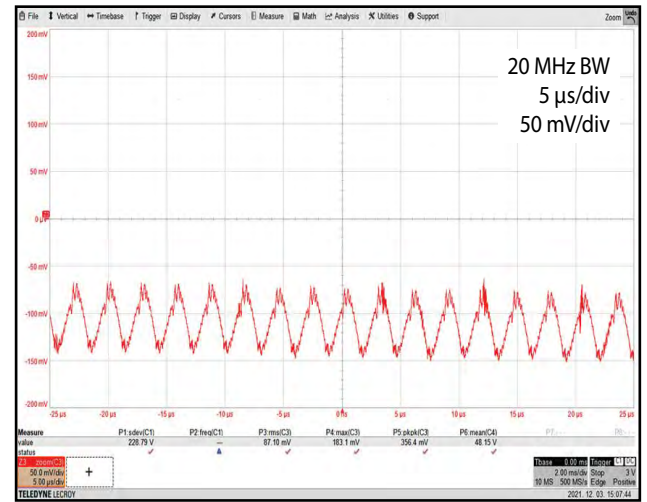


Figure 7: Typical output ripple $V_{IN} = 120\text{ VAC}_{RMS} / 60\text{ Hz}$

Typical load transient waveforms

Measured load step waveform from 0% to 100% and vice versa

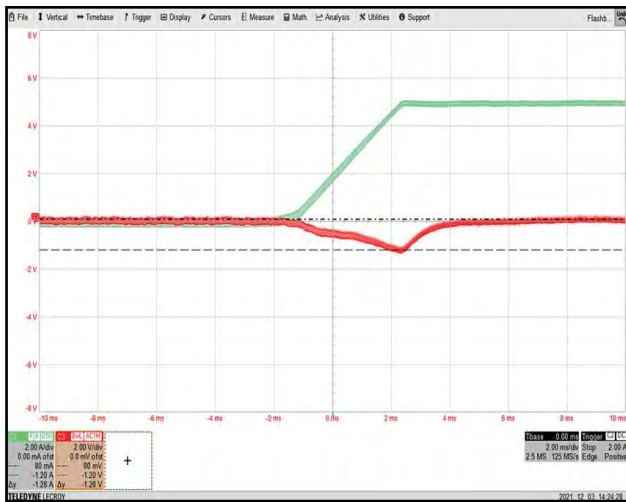


Figure 8: Typical load transient waveforms: $V_{OUT} = 48\text{ V}$, output 0% (0 A) to 100% (5 A), $V_{IN} = 120\text{ VAC}_{RMS} / 60\text{ Hz}$.

Typical output voltage ripple

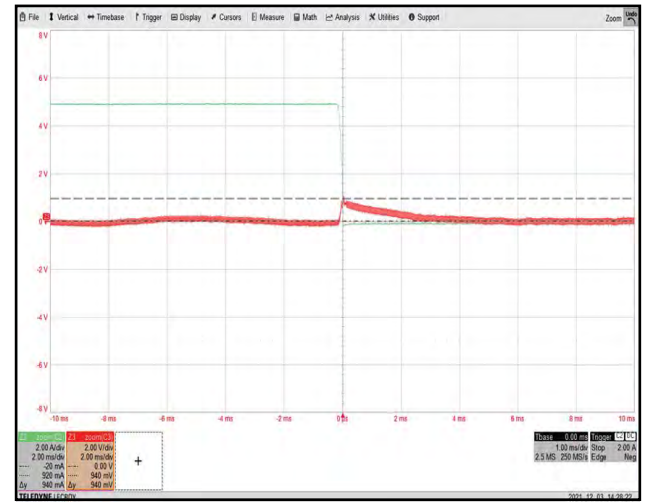
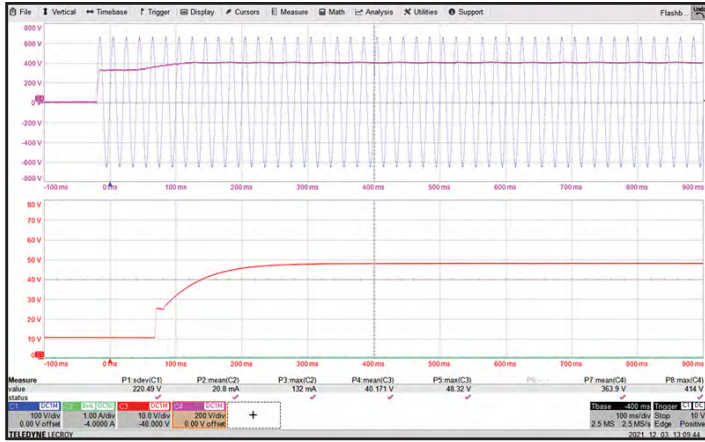
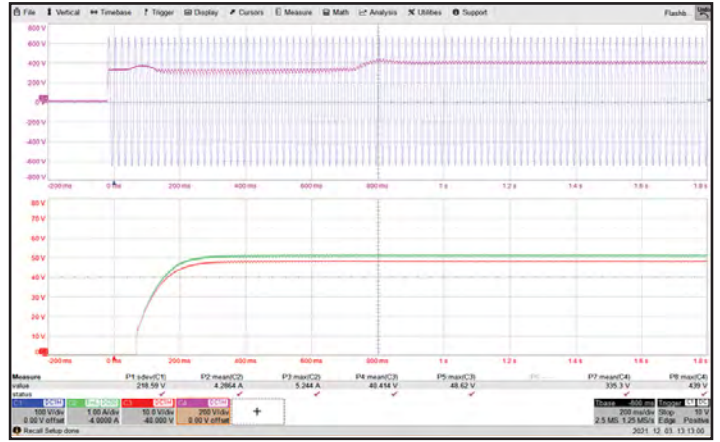


Figure 9: Typical load transient waveforms: $V_{OUT} = 48\text{ V}$, output 100% (5 A) to 0% (0 A), $V_{IN} = 120\text{ VAC}_{RMS} / 60\text{ Hz}$.

Startup waveform

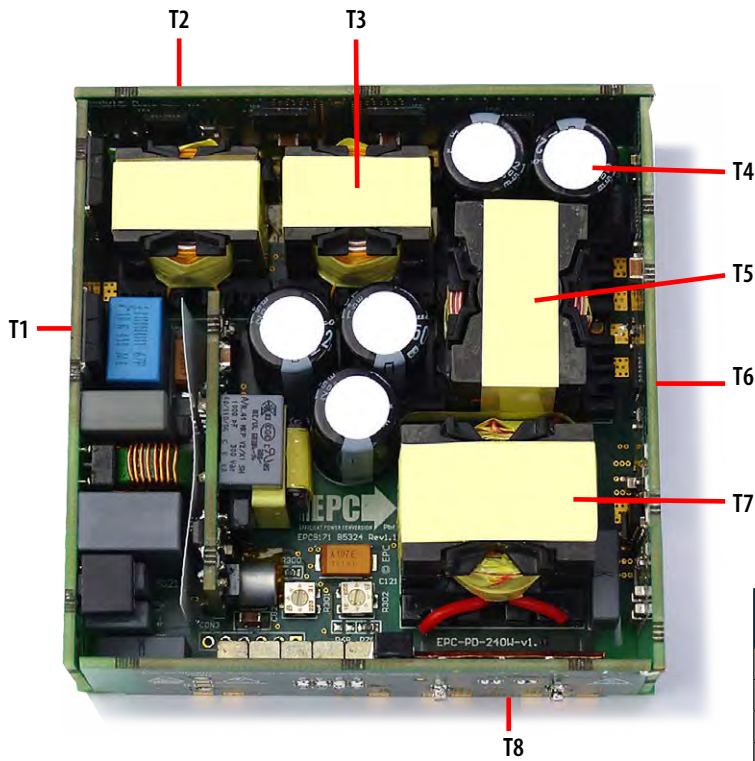


(a)



(b)

Figure 10: Startup waveform at (a) $V_{IN}=120\text{ VAC}_{RMS}/50\text{ Hz}$, $I_{OUT}=5\text{ A}$
 (b) Startup waveform at $V_{IN}=230\text{ VAC}_{RMS}/50\text{ Hz}$, $V_{OUT}=48\text{ V}$, $I_{OUT}=5\text{ A}$



Input: 230 VAC/50 Hz or 120 VAC/60 Hz

Output: 48 V/5 A

Test interval: 10 min

Tamb: 21°C

Notes: DUT placed on 20 mm distance holders to ensure some airflow underneath

Location	Description	Max. temperature 120 VAC/60 Hz	Max. temperature 230 VAC/50 Hz
T1	Input active rectifier	68°C	51°C
T2	PFC switch (IC1)	75°C	77°C
T3	PFC inductor (L5)	81°C	65°C
T4	PFC bus capacitor (C99)	73°C	72°C
T5	LCC resonant inductor (L2)	94°C	95°C
T6	LCC switch (IC6)	93°C	94°C
T7	Transformer (T1)	97°C	96°C
T8	Output sync. rectifier (Q5/Q6)	89°C	90°C

Figure 11: Thermal performance when operating from 120 VAC_{RMS} and 230 VAC_{RMS} input and delivering 5 A into 48 V in an ambient of 21°C.

Table 3: Bill of Materials

Item	Qty	Reference	Part Description	Manufacturer	Part #
1	1	C1	Capacitor		R46L1333000NOK
2	1	C2	Capacitor		JFV-220n/275-P15
3	2	C3, C4	Capacitor		
4	4	C5, C41, C42, C299	Capacitor		
5	1	C6	Capacitor		B32671P4105
6	4	C7, C16, C17, C26	Capacitor		C3225X7T2W224
7	3	C8, C105, C106	Capacitor		B32021A3222/R413F12204000M
8	4	C9, C43, C102, C202	Capacitor		B32021A3102/R413F11004000M, B32021A3222/R413F12204000M
9	27	C10, C11, C24, C25, C33, C34, C47, C53, C64, C65, C73, C74, C75, C76, C78, C85, C90, C93, C97, C98, C123, C223, C290, C293, C297, C298, C301	Capacitor		
10	5	C12, C13, C20, C21, C83	Capacitor		
11	4	C14, C15, C22, C23	Capacitor		
12	5	C18, C19, C99, C100, C101	Polarized Capacitor (Radial)		450BXW22MEFR12
13	4	C27, C28, C87, C287	Capacitor		C3225C0G2J223K230AA / C1210C223JBGACAUTO
14	4	C29, C30, C39, C40	Capacitor		C3216C0G2J682J115AA
15	2	C31, C113	Capacitor		CC1206JKNPOCBN101
16	2	C32, C114	Capacitor		CC1206JKNPOCBN100
17	4	C35, C36, C112, C212	Capacitor		-
18	2	C37, C38	Capacitor		22201C475KAT4A
19	11	C44, C45, C46, C49, C57, C58, C59, C79, C80, C124, C224	Capacitor		
20	1	C48	Capacitor		
21	2	C50, C56	Capacitor		
22	2	C51, C84	Capacitor		
23	1	C52	Capacitor		
24	2	C54, C55	Capacitor		
25	13	C60, C61, C62, C63, C81, C91, C94, C95, C291, C294, C295, C300, C302	Capacitor		
26	1	C66	Capacitor		
27	2	C67, C77	Capacitor		
28	1	C68	Capacitor		
29	1	C69	Capacitor		
30	5	C70, C92, C119, C120, C292	Capacitor		
31	1	C71	Capacitor		
32	1	C72	Capacitor		
33	1	C82	Capacitor		C3216X7T2E224K160AA / C3216X7R2A224M115AA
34	2	C88, C288	Capacitor		C3216C0G2J102J085AA
35	2	C89, C121	Polarized Capacitor (Radial)		TCJE107M025R0080 / TCJD107M025R0070
36	2	C96, C296	Polarized Capacitor (Radial)		865080545012
37	2	C103, C104	Capacitor		CGA5L3C0G2E223J160AA / C3216C0G2A223K160AA / TDK GRM3195C2A223JA01D /
38	5	C107, C108, C109, C110, C111	Polarized Capacitor (Radial)		T521X226M063ATE075 / T59EE226M063C0100
39	2	C115, C116	Capacitor		C3216C0G2J332J160AA
40	1	C117, C118	Capacitor		-
41	2	CON3			
42	5	CON11, CON12, L, N, PE	Testpoint		
43	4	D1, D2, D5, D6	Zener Diode		BZT52B6V25
44	2	D3, D4	5th Generation thinQ! 650 V SiC Schottky Diode, IF 4 A		IDL04G65C5/IDL06G65C5/ FFSM0665B
45	1	D7			
46	8	D8, D10, D13, D14, D15, D22, D221, D222	Fast Switching Diode 100 V/250 mA SOD-323		
47	3	D9, D17, D217			
48	8	D11, D12, D223	Fast Switching Diode 250 V/250 mA, Zener Diode		
49	3	D16, D20, D220	Zener Diode		BZT52C24V
50	4	D18, D19, D218, D219	Fast Switching Diode 250 V/250 mA		BAV21W

Table 3: Bill of Materials (continued)

Item	Qty	Reference	Part Description	Manufacturer	Part #
51	1	D21	Zener Diode		BZT52C13V
52	1	D23	Zener Diode		BZT52C18V
53	1	F1			
54	2	FB1, FB2	WE-CBF SMT EMI Suppression Ferrite Bead, size 1206, 80 Ω, 4 A		
55	4	IC1, IC2, IC6, IC7	Navitas GaN		
56	1	IC3	Active bridge rectifier controller		
57	1	IC4	Natural Interleaving Transition Mode PFC Controller with Improved Light Load Efficiency, D0016A (SOIC-16)		
58	1	IC5	UCC25640x LCC Resonant Controller with Ultra-Low Audible Noise and Standby Power		
59	2	IC8, IC9	NCP4308 Synchronous Rectifier Controller		NCP43080ADR2G
60	1	IC10	TCLT1003 / TLP383 4-Pin Phototransistor Optocoupler		
61	2	IC11, IC211	Vsense/Isense with reference		
62	2	IC12, IC13	Low Power Dual Operational Amplifier		
63	1	IC14	Precision Shunt Regulator, normal pinout		
64	1	IC212	Positive Voltage Regulator		LM2937IMP-12
65	1	IC213	Low-power Switching Voltage Regulator		
66	1	L1	WE-CMB Common Mode Power Line Choke, Type XS, 39 mH, 0.3 A, 250 V		744841330
67	1	L2	Ferrite core single inductor		
68	1	L2b	Ferrite core single inductor		
69	1	L3	Ferrite core single inductor		AIAP-02-220K
70	2	L4, L5	Ferrite core coupled inductor		
71	1	L6	WE-HCI SMT Flat Wire High Current Inductor, size 5040, 0.33 μH, 18.5 A		744316033
72	1	L7	WE-TPC SMT Tiny Power Inductor, size 4828, 3.3 μH, 2.15 A		744043003
73	4	Q1, Q2, Q3, Q4	Infineon CoolMOS G7 SJ MOSFET		IPT60R050G7 / IPT60R040S7
74	2	Q5, Q6	100 V 60 A 3.2 mΩ		EPC2218
75	1	Q7	NPN 100 V/1 A Low CEsat Transistor		
76	1	Q8	NPN General-purpose Transistor		
77	2	Q21, Q22	N-channel Enhancement Mode Vertical D-MOSFET		
78	4	R1, R2, R3, R4	Resistor		
79	7	R5, R7, R11, R12, R13, R14, R92	Resistor		
80	6	R6, R8, R90, R91, R110, R111	Resistor		
81	6	R9, R10, R114, R115, R214, R215	Resistor		
82	4	R15, R16, R17, R18	Resistor		
88	2	R19, R107	Resistor		
84	1	R20	Resistor		
85	2	R21, R22	Resistor		
86	6	R23, R24, R25, R46, R68, R83	Resistor		-
87	4	R26, R27, R28, R29	Resistor		
88	1	R30	Resistor		
89	2	R32, R33	Resistor		
90	4	R34, R35, R36, R37	Resistor		
91	2	R42, R43	Resistor		
92	7	R44, R51, R60, R66, R122, R222, R225	Resistor		
93	2	R45, R120	Resistor		
99	2	R47, R53	Resistor		
95	7	R48, R62, R63, R64, R65, R220, R224	Resistor		
96	3	R49, R57, R85	Resistor		
97	3	R50, R59, R82	Resistor		
98	3	R52, R70, R300	Resistor		
99	1	R55	Resistor		
100	1	R58	Resistor		

Table 3: Bill of Materials *(continued)*

Item	Qty	Reference	Part Description	Manufacturer	Part #
101	1	R61	Resistor		
102	2	R67, R96	Resistor		
103	2	R69, R93	Resistor		
104	3	R71, R72, R73	Resistor		
105	9	R74, R75, R76, R77, R78, R79, R101, R102, R103	Resistor		
106	1	R80	Resistor		
107	1	R81	Resistor		
108	1	R84	Resistor		
109	1	R86	Resistor		
110	1	R87	Resistor		
111	1	R88	Resistor		
112	1	R89	Resistor		
113	1	R94	Resistor		
114	2	R95, R109	Resistor		
115	2	R97, R127	Resistor		
116	1	R98	Resistor		
117	2	R99, R100	Resistor		
118	1	R104	Resistor		
119	1	R105	Resistor		
120	1	R106	Resistor		-
121	1	R108	Resistor		
122	1	R112	Resistor		
123	2	R113, R213	Resistor		
124	2	R116, R216	Resistor		
125	2	R117, R221	Resistor		
126	2	R118, R218	Resistor		
127	2	R119, R219	Resistor		
128	1	R121	Resistor		
129	2	R123, R223	Resistor		
130	3	R124, R125, R126	Resistor		
131	1	R217	Resistor		
132	2	R301, R302	Potentiometer		3314J-1-503E
133	1	T1	Transformer with Multiple Windings		
134	2	T2, T202	Transformer with Multiple Windings		

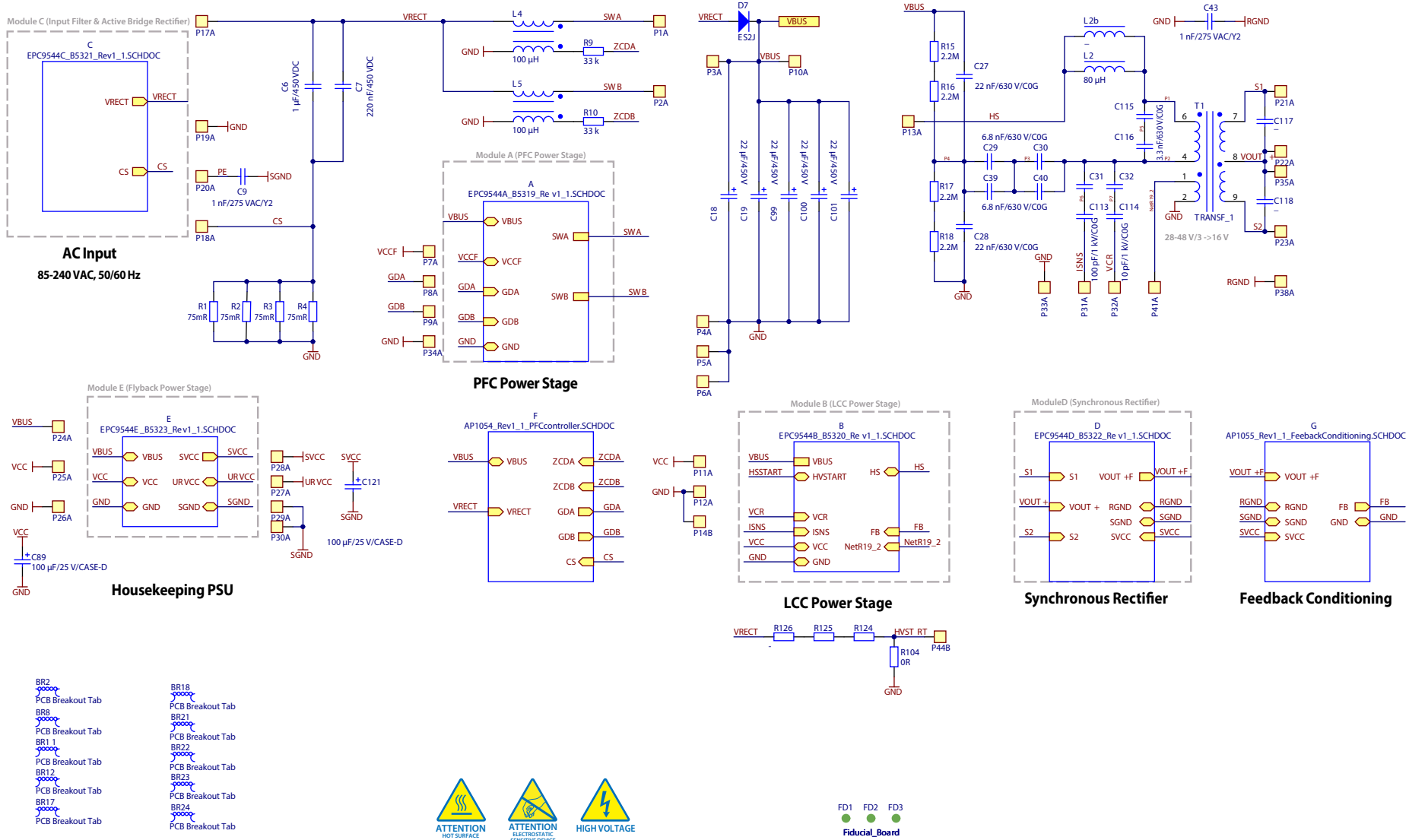


Figure 12: EPC9171 Universal Input USB-C power adapter schematic

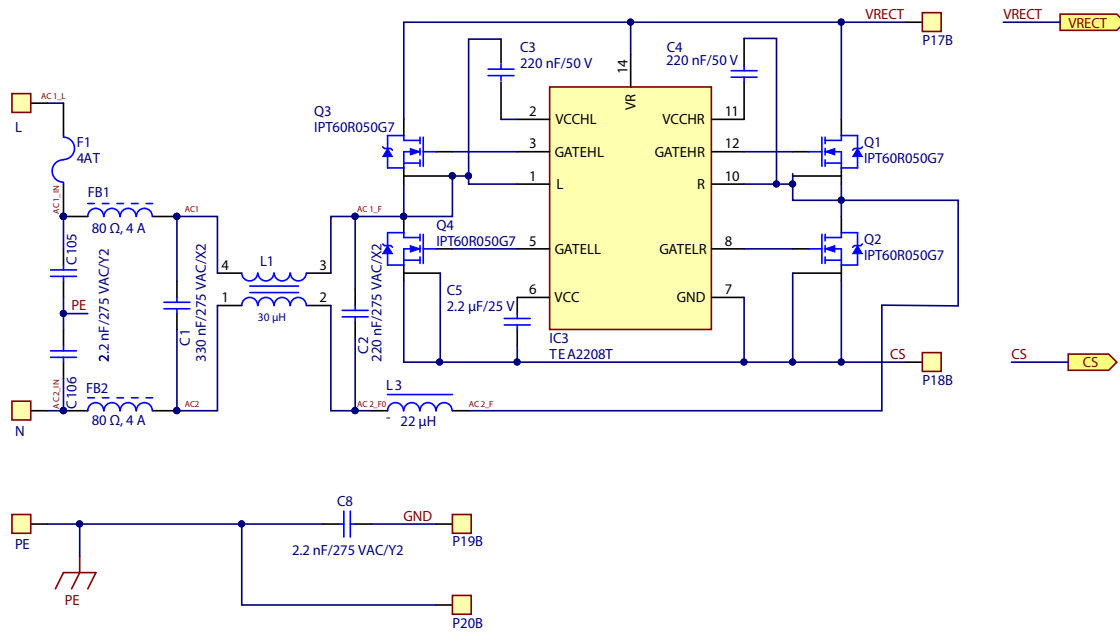


Figure 13: Input Filter & Active Bridge Rectifier schematic

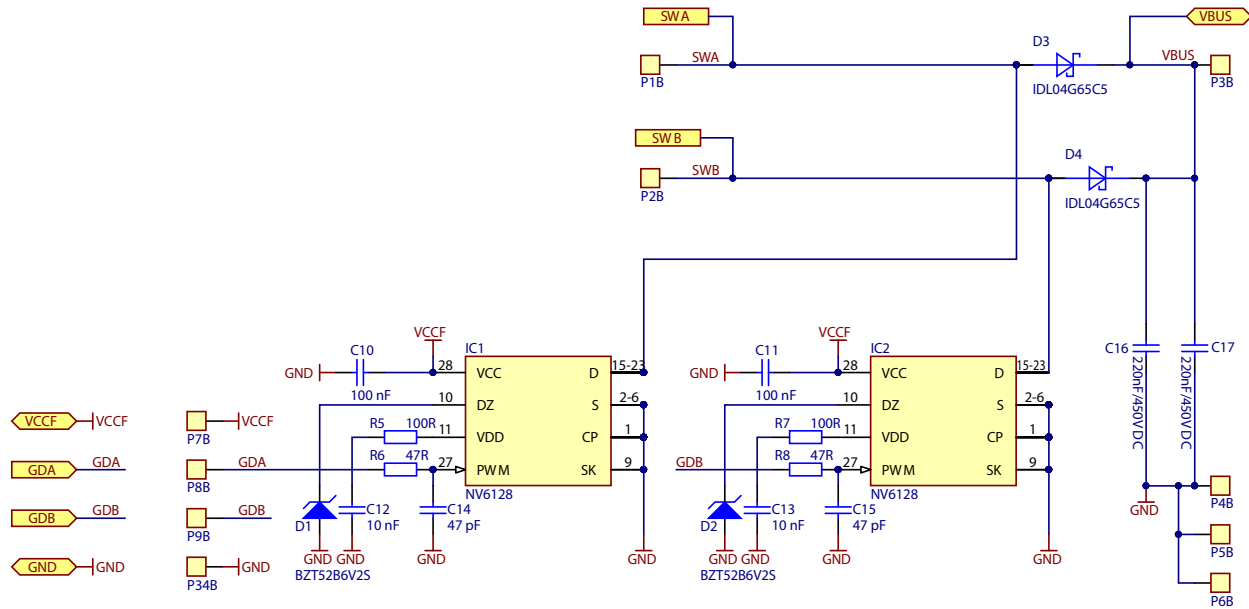


Figure 14: PFC Power Stage schematic

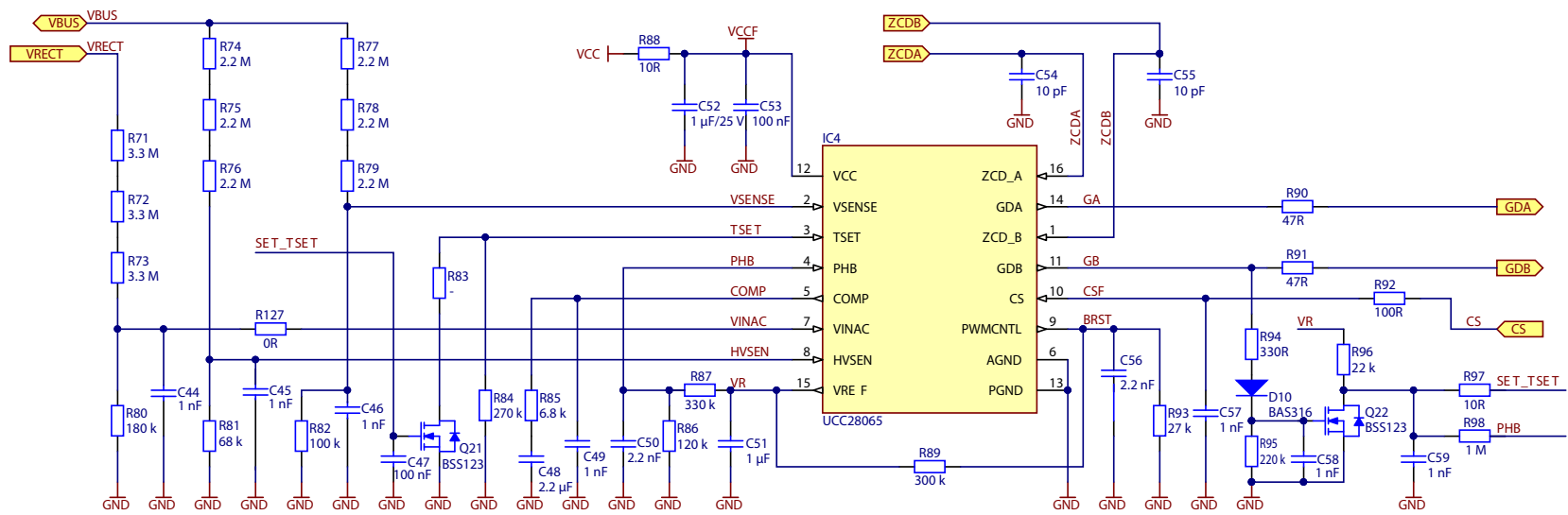


Figure 15: Interleaved PFC Boost Controller schematic

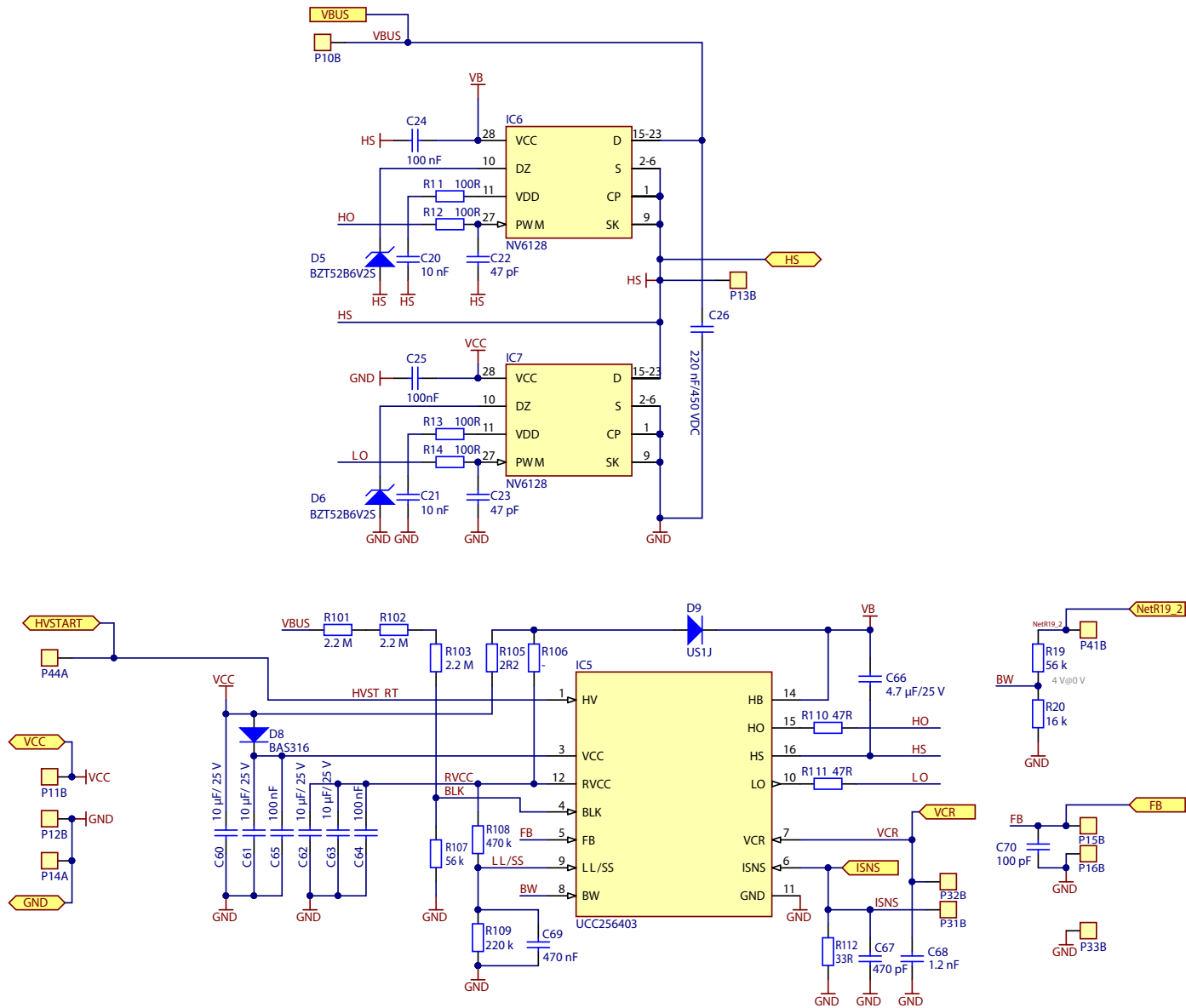


Figure 16: LCC Power Stage schematic

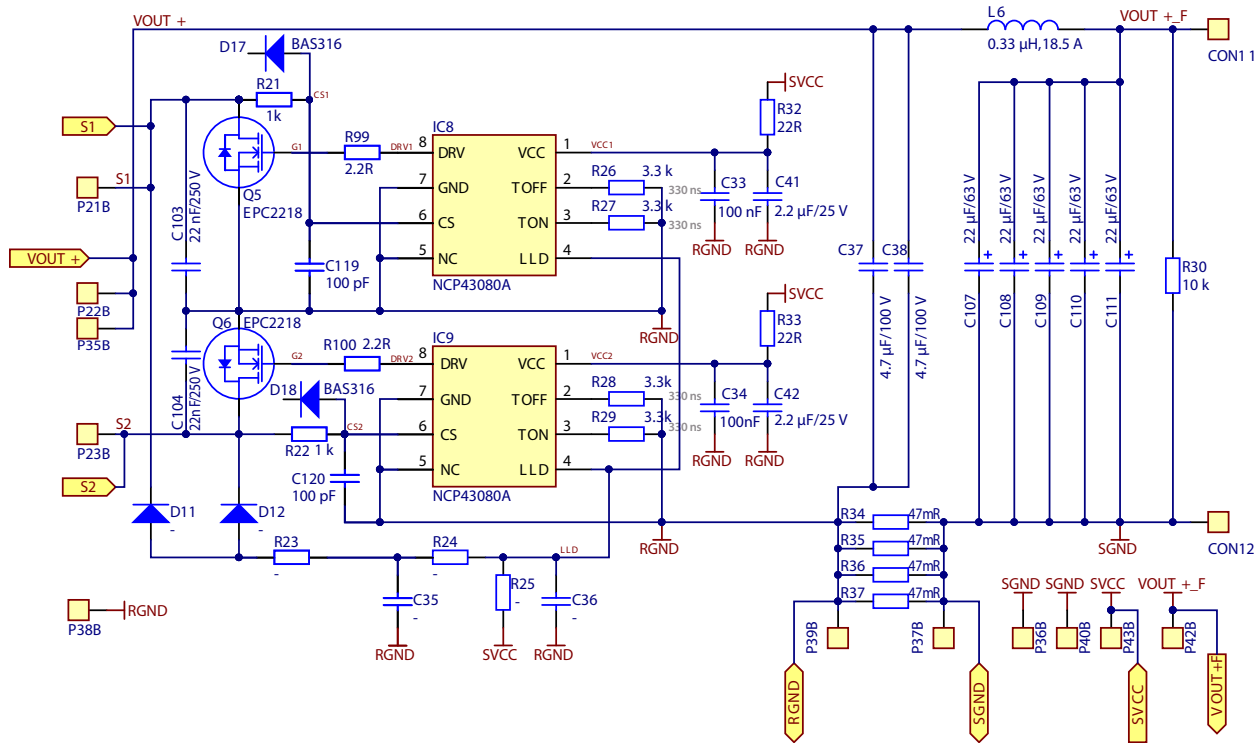


Figure 17: Synchronous Rectifier schematic

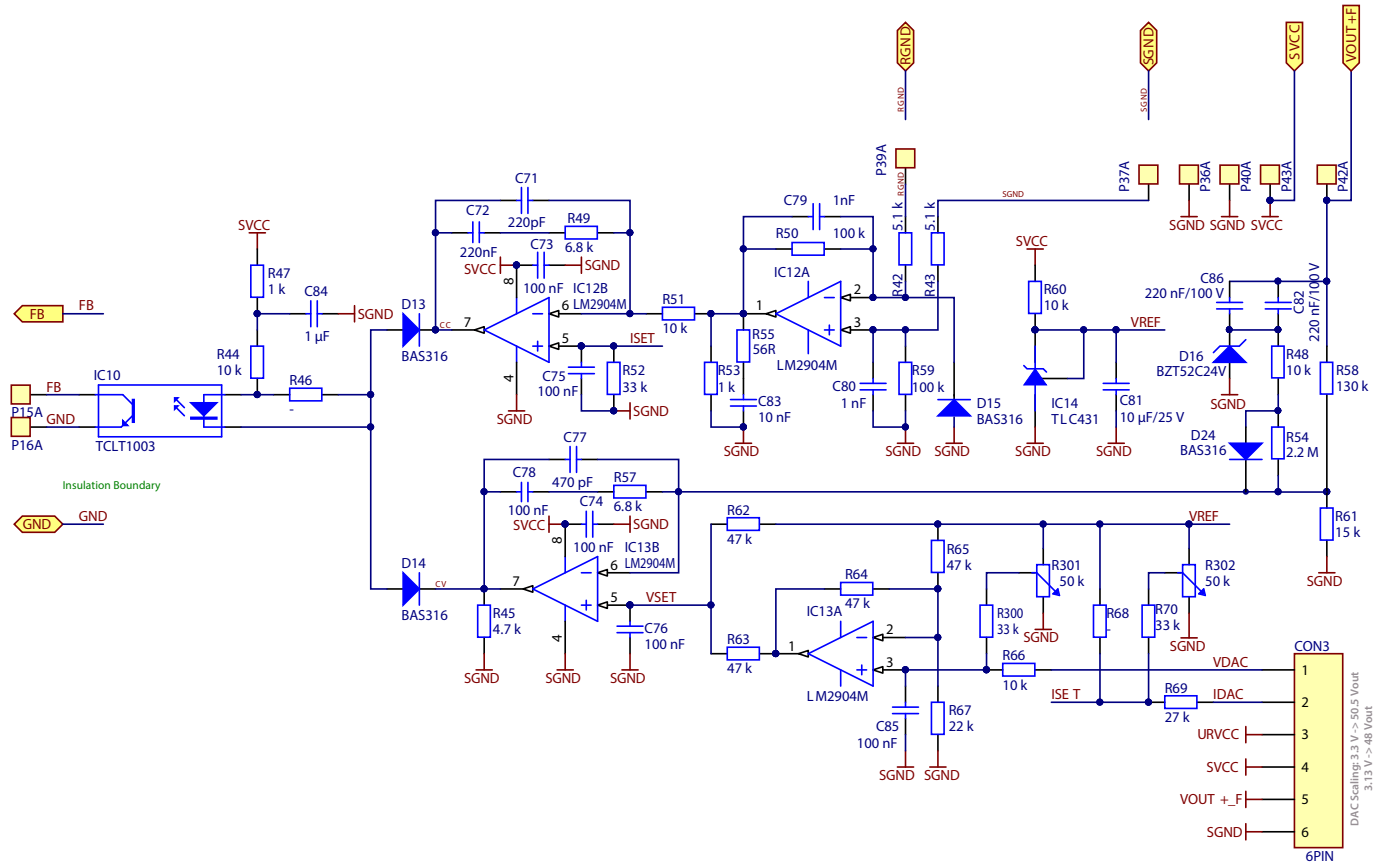


Figure 18: Feedback Conditioning schematic

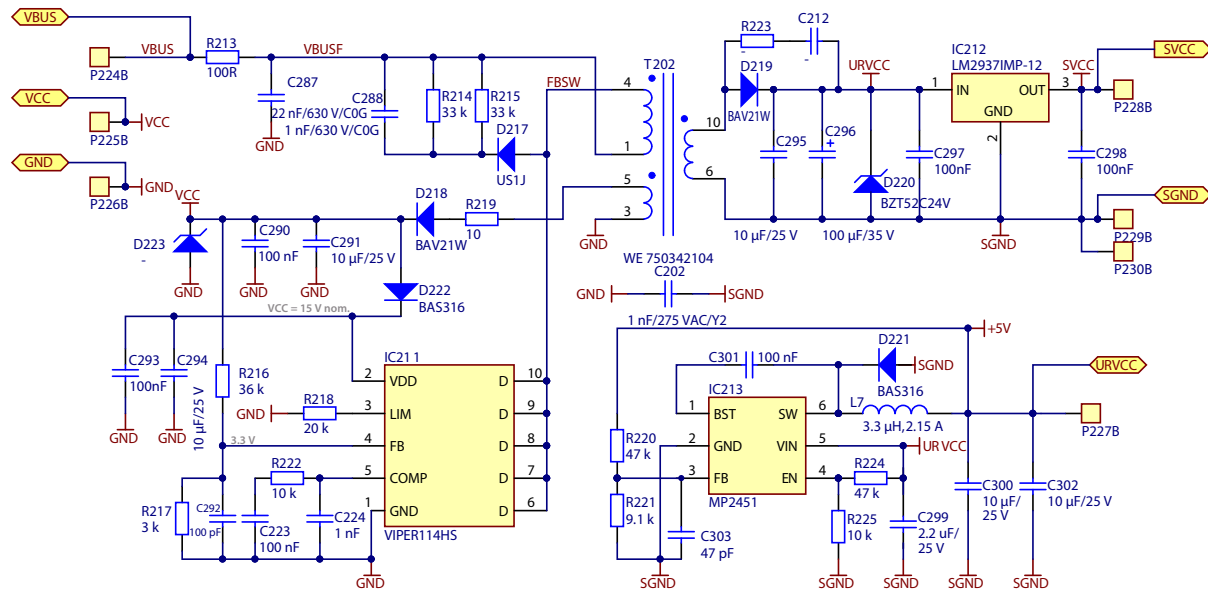


Figure 19: Bi-directional current sense amplifier schematic



EPC would like to acknowledge ONgineer GmbH (<https://www.ongineer.de/en/home/>) for their support of this project.

ONgineer is an innovative and experienced development company – focused on the most promising segments of the growing global power electronics market.

Core products include:

- Switching power supplies for industry, mobility applications and the consumer market
- Power supplies with high power density (HF power (MHz) & GaN-on-Si applications)
- Charging and battery management systems
- Wireless power supply

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