TDAIO-TPH-ON-CCCV-300W-RD Design Guide

Battery Charger Power Adapter Description

This design guide of the 75 V 4 A Constant Current (CC) Constant Voltage (CV) universal input line voltage AC-DC battery charger reference board describes a peak (20 minutes) power of 300 W PFC + LLC implementation with peak efficiency of ~ 95%, a power density of 30 W/in^3 using 3 Transphorm GaN TP65H070G4PS (650 V SuperGaN® FET) TO-220 with Transphorm's latest SuperGaN® Gen IV technology with On Semi's NCP1654 CCM PFC controller and NCP1399 LLC controller on primary side. Continuous power is recommended at 250 W. As compared with traditional implementation of a constant voltage AC-DC adaptor plus additional (separate hardware enclosure) battery charging constant current stage architecture, this design attempts with a simpler architecture by modifying the LLC stage to a wide output voltage range and constant current capability, aiming on system cost down and yet maintaining the high-power density and efficiency.

This document contains the battery charger specification, schematic, bill-of-materials, transformer documentation, printed circuit layout, and performance data.

Key Specs	Schematics
Input	90-264 Vac
Output Voltages	40 V ~ 77 V
Max Output Current	4 A
Max Output Power	310 W
Efficiency	~95% Full Power Efficiency@264 V

Features

- Transphorm SuperGaN® TP65H070G4PS TO-220 x 3
- CCM PFC + LLC topology
- Board-end ~92% Peak Efficiency (90 VAC)
- Flat Efficiency Across Universal (90 ~ 264 VAC) Input Voltage and Load
- Tight Switching Frequency Regulation for Improved Input EMI Filter Utilization
- Up to 210 kHz Switching Frequency Operation
- OTP, UVLO, OCP, OSC and Output Reverse Polarity Protections
- < 1 W No Load Power Consumption
- Up to 310 W Output Power

Applications

- High-Power-Density AC/DC Battery Chargers (CCCV)
- High-Power-Density AC/DC CV Power Supplies
- High-Power-Density AC/DC LED Dimmable Drivers
- Gaming Devices
- Fast charging
- Laptops and IoT devices

Warning

The DC bus voltage on DC link bulk cap C1 is NOT discharged after powering off. It stays at high voltage for a long time. For safe handling, please discharge this DC bus voltage after powering down.

Disclaimers:

1. **Caution – High Voltage Operation: Lethal high voltages are present when this evaluation board is powered from AC mains. Improper contact with high voltages could lead to electrical shock, burn and/or fire hazards, risking property damage, personal injury, and death**.
2. **Evaluation Purpose Only: This evaluation board is intended for evaluation purposes only and not for commercial use. Care must be taken when testing the board, and an isolation transformer should be utilized.**
3. **Patents: The evaluation board design, along with circuits shown in this test report, may be covered by one or more U.S. and foreign existing/pending patents.**

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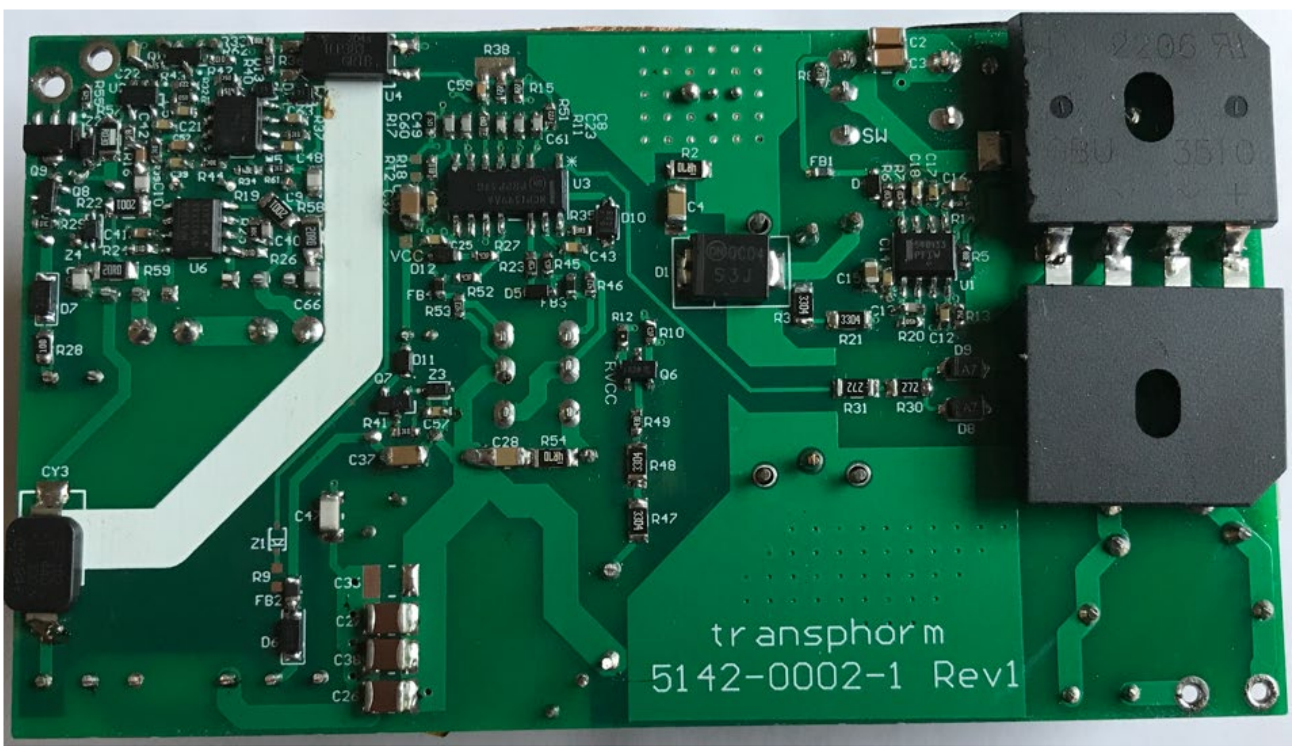
Battery Charger Board Pictures

Top Side of the EVB

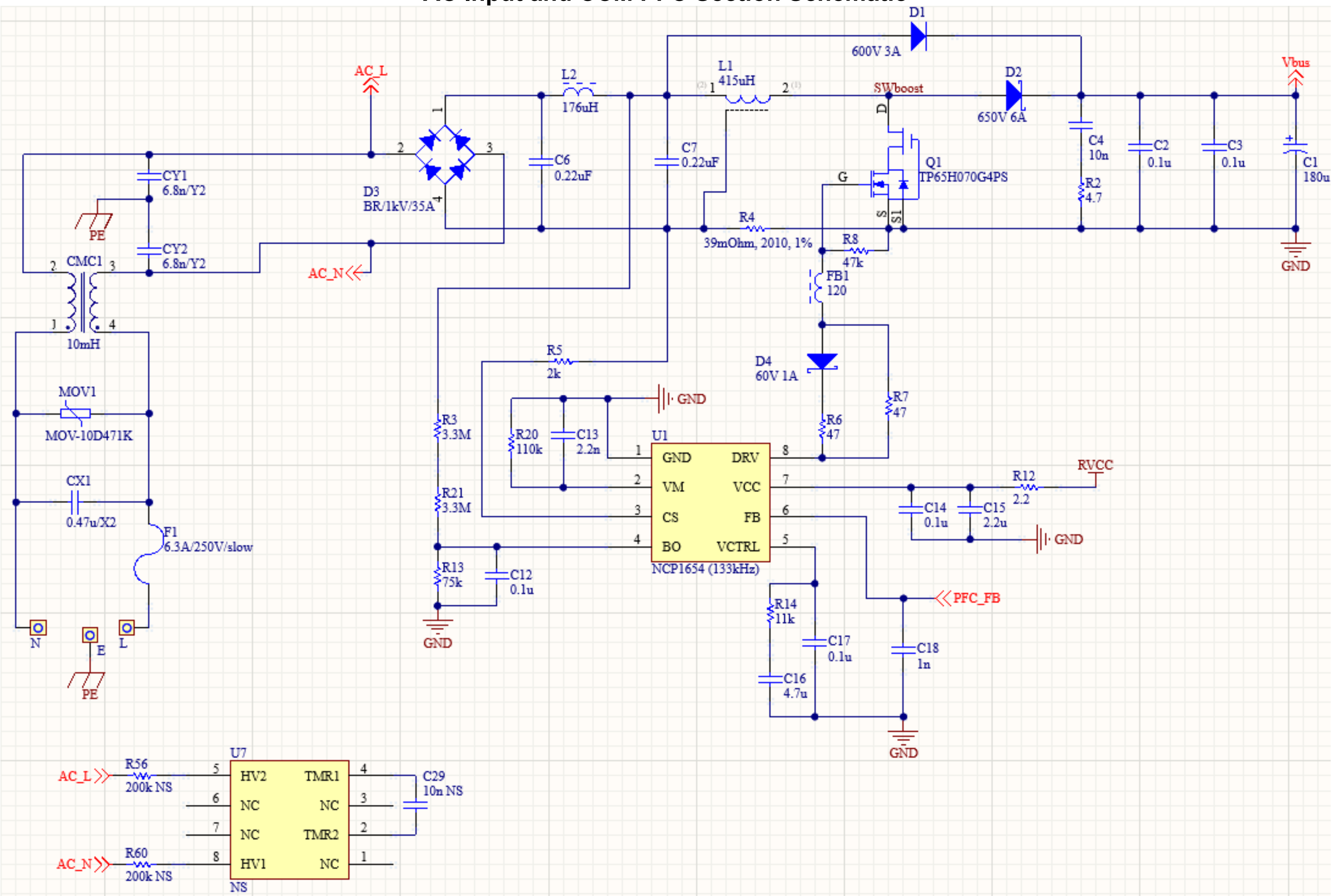


Bottom Side of the EVB

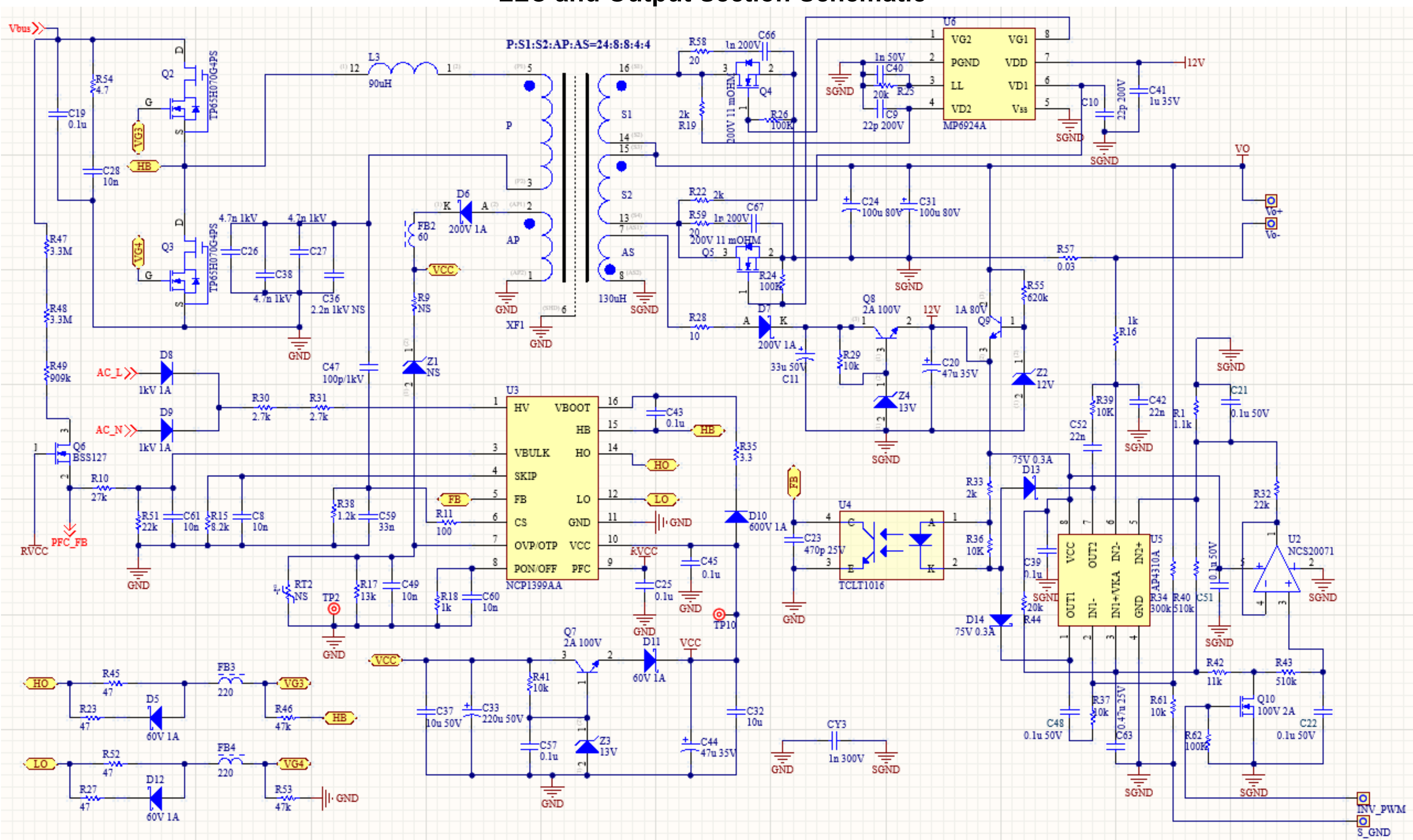
Dimensions of PCB board: 107 mm x 60 mm x 26 mm, power density of 30 W/in^3.

Schematic

AC Input and CCM PFC Section Schematic



LLC and Output Section Schematic



Circuit Description

Input Protection

The design incorporates a slow-acting input fuse (F1) as a form of protection in case of destructive failure of any of the downstream components.

EMI Filtering

To meet the target EN55022 conducted EMI specification with the least number of components and the highest power processing efficiency, the design utilizes an input filter consisting of an X-capacitor (CX1) and a single common- mode choke (CMC1).

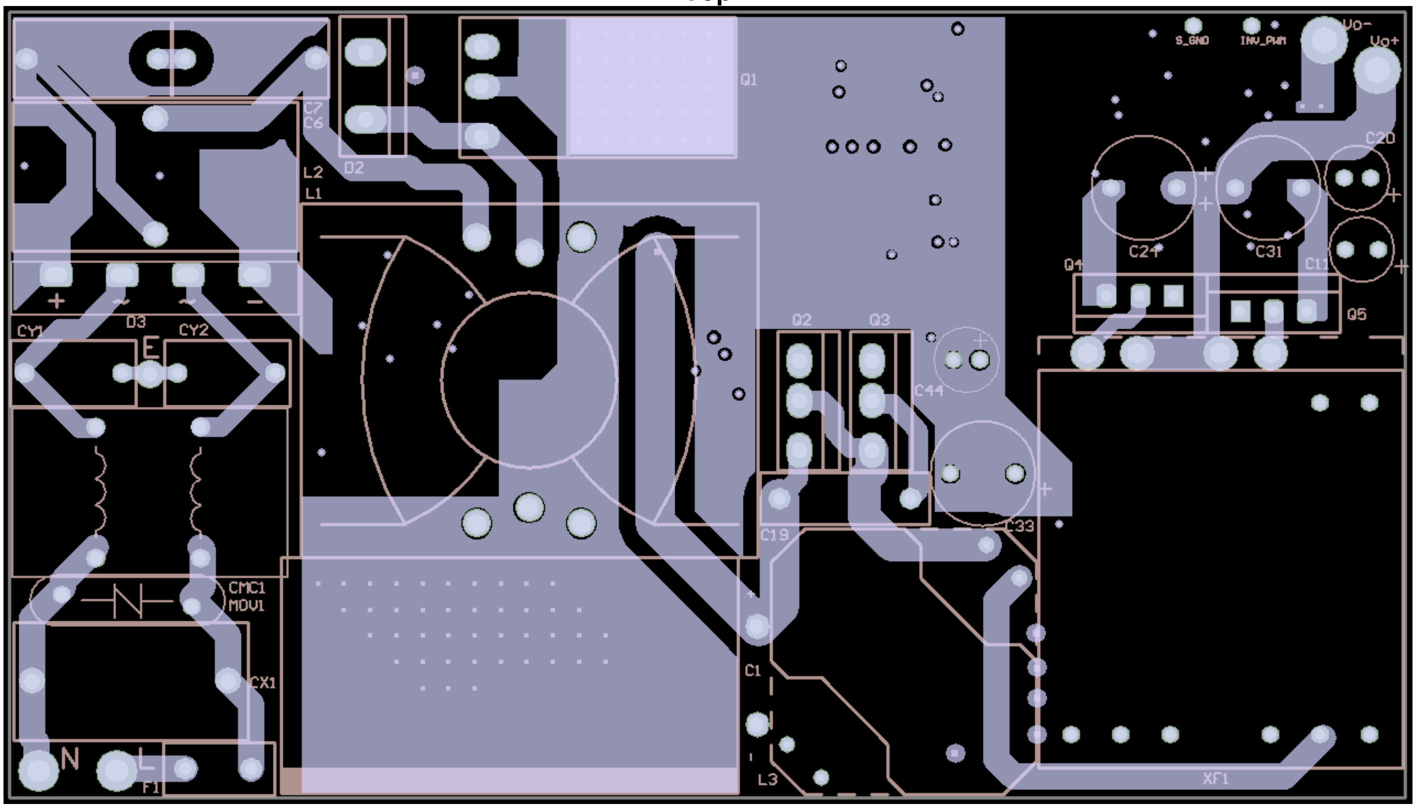
Fault Protections

Table 1: Recovery Behavior

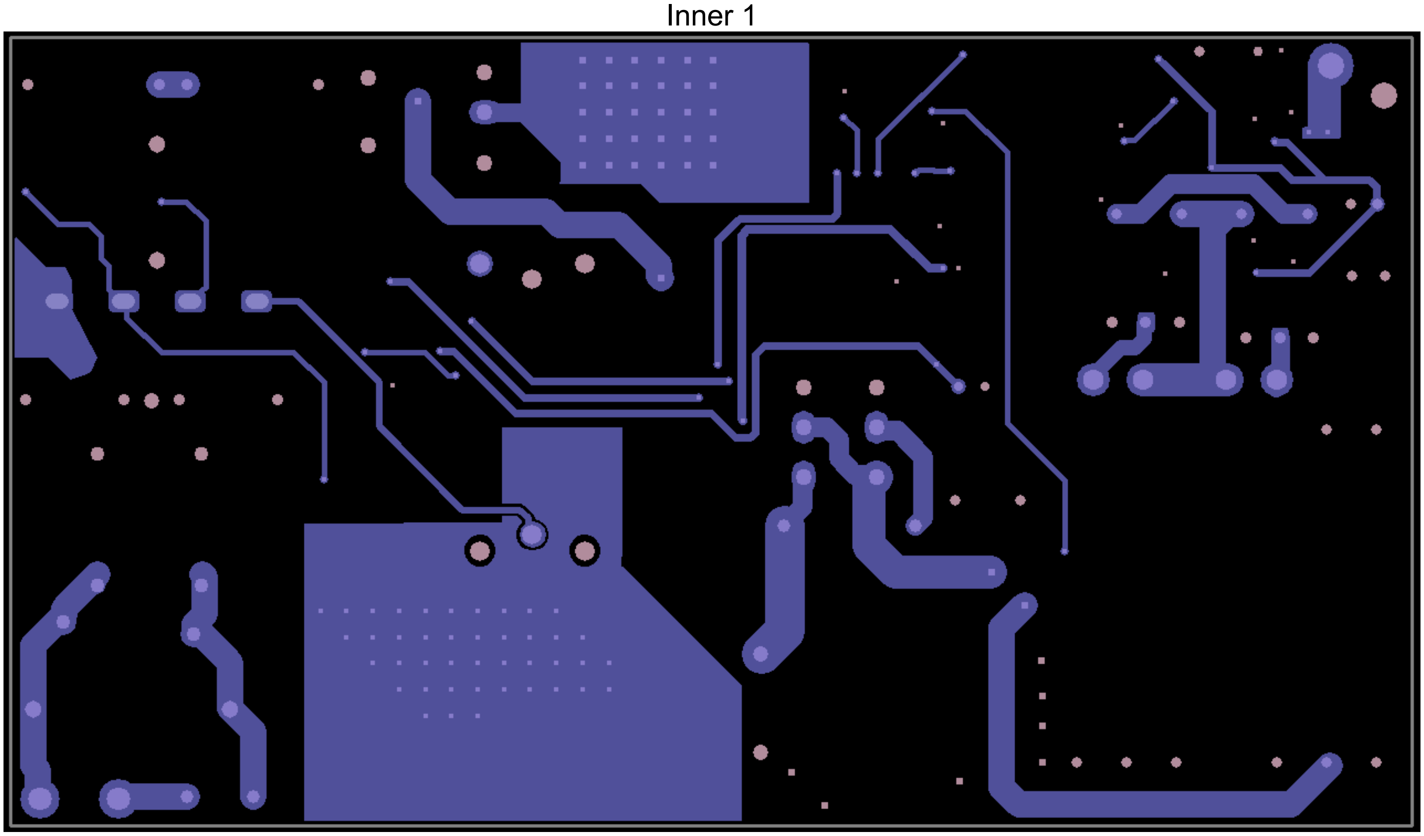
Fault Protection	Reaction
Input Under Voltage Lockout (UVLO)/ Brown-Out	Auto-Recovery
Input Surge Protection	Not Populated on PCB
Over-Current Protection (OCP)	Self-clamping
Output Short Circuit (OSC)	Auto-Recovery
Output Over Voltage (OVP)	Not Populated on PCB
Output Load Polarity Reversed	Auto-Recovery

PCB Layout

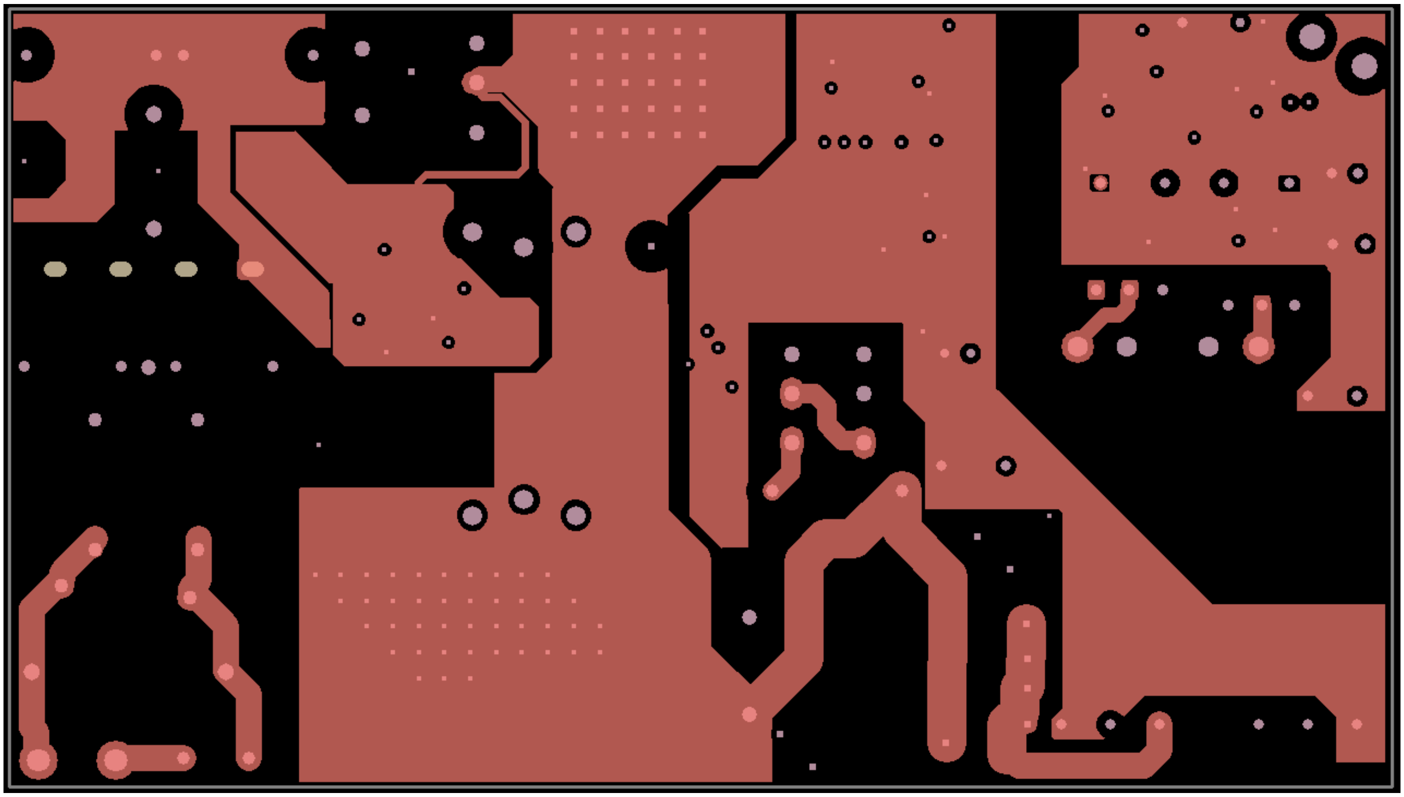
Top



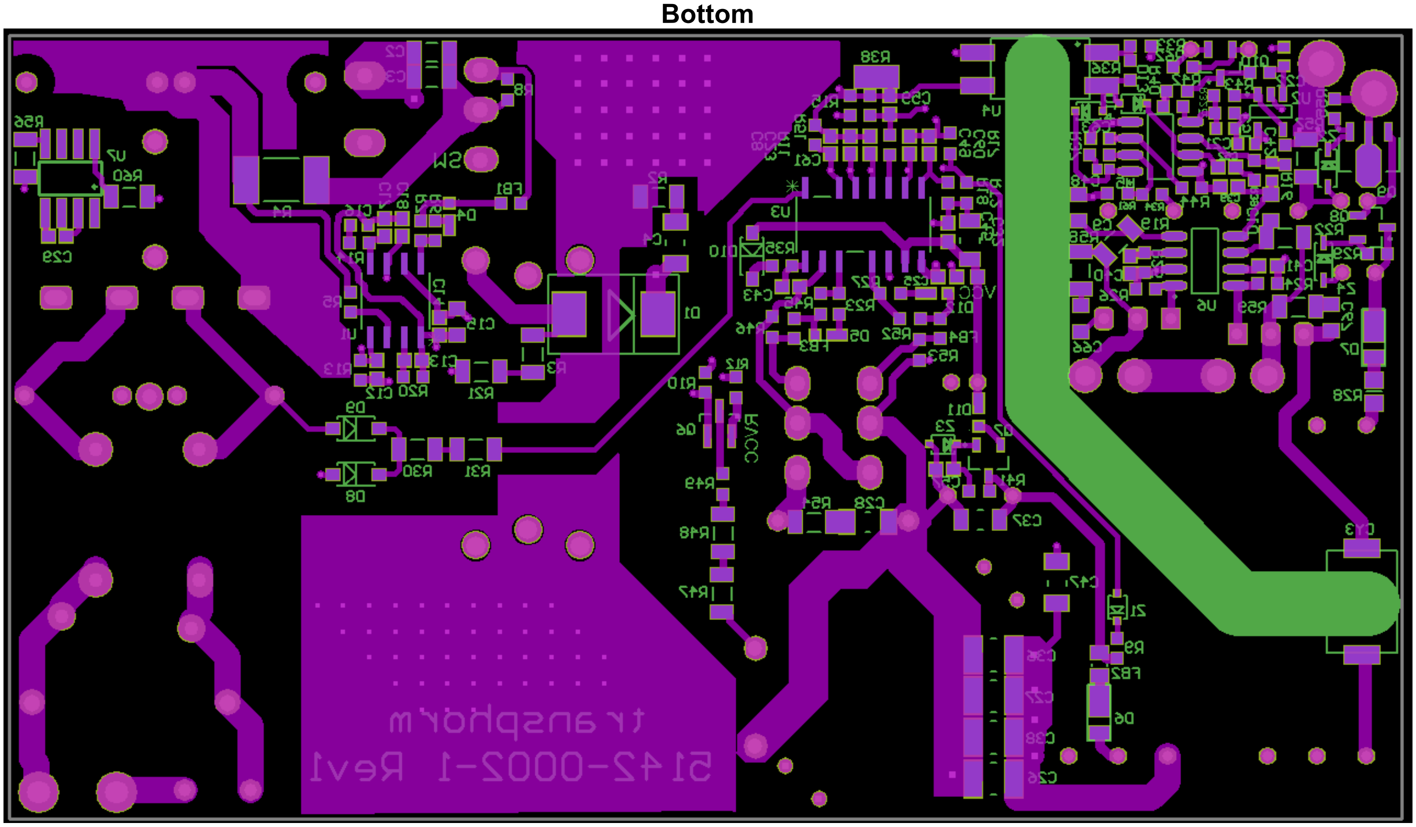
Inner 1



Inner2



Bottom



Transphorm SuperGaN FET SPEC

transphorm SuperGaN

TP65H070G4PS

650V SuperGaN® GaN FET in PQFN (source tab)

Description

The TP65H070G4PS 650V, 72mΩ Gallium Nitride (GaN) FET is a normally-off device. It combines state-of-the-art high voltage GaN HEMT and low voltage silicon MOSFET technologies—offering superior reliability and performance.

The Gen IV SuperGaN® platform uses advanced epi and patented design technologies to simplify manufacturability while improving efficiency over silicon via lower gate charge, output capacitance, crossover loss, and reverse recovery charge

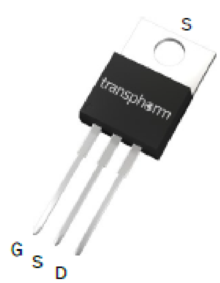
Related Literature

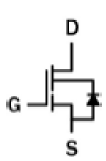
- AN0009: Recommended External Circuitry for GaN FETs
- AN0003: Printed Circuit Board Layout and Probing
- AN0010: Paralleling GaN FETs
- AN0014: Low cost driver solution

Ordering Information

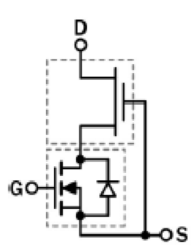
Part Number	Package	Package Configuration
TP65H070G4PS	3 lead TO-220	Source

TP65H070G4PS
TO-220
(top view)





Cascode Schematic Symbol



Cascode Device Structure

Features

- Gen IV technology
- JEDEC-qualified GaN technology
- Dynamic $R_{DS(on)eff}$ production tested
- Robust design, defined by
  - Wide gate safety margin
  - Transient over-voltage capability
- Very low Q_{RR}
- Reduced crossover loss
- RoHS compliant and Halogen-free packaging

Benefits

- Achieves increased efficiency in both hard- and soft-switched circuits
  - Increased power density
  - Reduced system size and weight
  - Overall lower system cost
- Easy to drive with commonly-used gate drivers
- GSD pin layout improves high speed design

Applications

- Datacom
- Broad industrial
- PV inverter
- Servo motor
- Computing
- Consumer

Key Specifications	
V_{DSS} (V)	650
$V_{DSS(TR)}$ (V)	800
$R_{DS(on)eff}$ (mΩ) max*	85
Q_{oss} (nC) typ	78
Q_G (nC) typ	9

* Dynamic on-resistance; see Figures 18 and 19

August 23, 2023
tp65h070g4ps.1v2

1

Bill of Materials (BOM)

Quantity	Designator	Comment	Description	Manufacturer	Part Number
1	C1	180u	420CXW180MEFR18X40 Aluminum Electrolytic Capacitors - Radial Leaded 180uF 420V 18mm Diameter 40mm length 7.5mm SP	Rubycon	420CXW180MEFR18X40
2	C2, C3	0.1u	CGA5L4X7T2W104K160AE 0.1 µF ±10% 450V Ceramic Capacitor X7T 1206 (3216 Metric)	TDK Corporation	CGA5L4X7T2W104K160AE
2	C4, C28	10n	CL31B103KHFNNNE 10000 pF ±10% 630V Ceramic Capacitor X7R 1206 (3216 Metric), CL31B103KHFNNNE CAP CER 10000PF 630V X7R 1206	Samsung Electro-Mechanics	CL31B103KHFNNNE
2	C6, C7	0.22uF	0.22 µF Film Capacitor 160V 450V Polypropylene (PP), Metallized Radial	KEMET	R71XF322050H0K
4	C8, C49, C60, C61	10n	CAP CER 10000PF 25V C0G/NP0 0603	Murata Electronics	GRT1885C1E103JA02D
2	C9, C10	22p 200V	CAP CER 22PF 200V C0G/NPO 0805	YAGEO	CC0805JRNPOABN220
1	C11	33u 50V	CAP ALUM 33UF 20% 50V RADIAL	Panasonic	ECA-1HHG330I
8	C12, C14, C17, C25, C39, C43, C45, C57	0.1u	0.1 µF ±20% 50V Ceramic Capacitor X7R 0603 (1608 Metric), CAP CER 0.1UF 50V X7R 0603	KEMET	C0603C104M5RAC7867
1	C13	2.2n	C1608C0G1H222J080AA CAP CER 2200PF 50V C0G 0603	TDK Corporation	C1608C0G1H222J080AA
1	C15	2.2u	CL21B225KAFNFNE CAP CER 2.2UF 25V X7R 0805	Samsung Electro-Mechanics	CL21B225KAFNFNE
1	C16	4.7u	CAP CER 4.7UF 16V X7R 0603	Murata Electronics	GRM188Z71C475KE21J
1	C18	1n	CAP CER 1000PF 25V C0G/NP0 0603	KYOCERA AVX	06033A102JAT2A
1	C19	0.1u	B32671P4104K000 CAP FILM 0.1UF 10% 450VDC RADIAL	EPCOS - TDK Electronics	B32671P4104K000
1	C20	47u 35V	860010572005 CAP ALUM 47UF 20% 35V RADIAL	Würth Elektronik	860010572005
3	C21, C22, C51	0.1u 50V	CAP CER 0.1UF 50V X7R 0603	KEMET	C0603C104M5RAC7867
1	C23	470p 25V	CAP CER 470PF 25V C0G/NP0 0603	Würth Elektronik	885012006042
2	C24, C31	100u 80V	CAP ALUM 100UF 20% 80V RADIAL	Panasonic Electronic Components	EEU-FS1K101LB
3	C26, C27, C38	4.7n 1kV	CAP MLCC 4700PF 1KV C0G 1210	Murata Electronics	GCM32D5C3A472JX01K
1	C29	10n NS	CAP CER 10000PF 25V X7R 0603 DNP	YAGEO	CC0603KRX7R8BB103
1	C32	10u	CL31B106KLHNFNE CAP CER 10UF 35V X7R 1206	Samsung Electro-Mechanics	CL31B106KLHNFNE
1	C33	220u 50V	Aluminum Electrolytic Capacitors - Radial Leaded 50VDC 220uF 9000H 8x20mm	Panasonic	EEU-FS1H221LB
1	C36	2.2n 1kV NS	CAP CER 2200PF 1000V C0GNP0 1210	KEMET	C1210C222MDGAC7800
1	C37	10u 50V	CAP CER 10UF 50V X7R 1206	Samsung Electro-Mechanics	CL31B106KBHNNNE
1	C40	1n 50V	CAP CER 1000PF 50V X7R 0603	YAGEO	CC0603JRX7R9BB102
1	C41	1u 35V	GMK107AB7105KAHT CAP CER 1UF 35V X7R 0603	Taiyo Yuden	GMK107AB7105KAHT
1	C42	22n	CAP CER 0.022UF 50V X7R 0603	TDK Corporation	C1608X7R1H223K080AA
1	C44	47u 35V	860010572005 CAP ALUM 47UF 20% 35V RADIAL	Würth Elektronik	860010572005
1	C47	100p/1kV	CL31C101JIFNFNE CAP CER 100PF 1KV C0G/NP0 1206	Samsung Electro-Mechanics	CL31C101JIFNFNE
1	C48	0.1u 50V	CAP CER 0.1UF 50V X7R 0603	KEMET	C0603C104M5RAC7867
1	C52	22n	CAP CER 0.022UF 50V X7R 0603	TDK Corporation	C1608X7R1H223K080AA
1	C59	33n	CAP CER 0.033UF 50V X7R 0603	KEMET	C0603C333M5RAC7867
1	C63	0.47u 25V	CAP CER 0.47UF 25V X7R 0603	YAGEO	CC0603KRX7R8BB474
2	C66, C67	1n 200V	CAP CER 1000PF 200V C0G/NP0 0805	Würth Elektronik	885342007003
1	CMC1	10mH	MPS P5334 Common Mode Choke 10mH 38mOHM Max	MPS Industries	P5334_1
1	CX1	0.47u/X2	B32922C3474K000 CAP FILM 0.47UF 10% 630VDC RAD	EPCOS - TDK Electronics	B32922C3474K000
2	CY1, CY2	6.8n/Y2	VY2682M47Y5VS63V7 CAP CER 6800PF 300VAC Y5V RADIAL X1/Y2	Vishay Beyschlag/Draloric/BC Components	VY2682M47Y5VS63V7
1	CY3	1n 300V	CAP CER 1000PF 300V NONSTND SMD	Murata Electronics	DK1E3EA102M86RBH01
1	D1	600V 3A	DIODE GEN PURP 600V 3A SMC	ON SEmi	S3J
1	D2	650V 6A	DIODE SIL CARB 650V 6A TO220AC	SMC Diode Solutions	S3D06065A
3	D3	BR/1kV/35A	GBU3510_T0_00601 GBU PACKAGE, 35A/1000V STANDARD	Panjit International Inc.	GBU3510_T0_00601
4	D4, D5, D11, D12	60V 1A	DIODE SCHOTTKY 60V 1A PWRDI323	Diodes Incorporated	PD3S160Q-7
2	D6, D7	200V 1A	DIODE SBR 200V 1A POWERDI123	Diodes Incorporated	SBR1U200P1-7
2	D8, D9	1kV 1A	DIODE GP 1KV 1A MINI SMA/SOD123	Comchip Technology	CGRM4007-G
1	D10	600V 1A	DIODE GEN PURP 600V 1A SOD123F	Taiwan Semiconductor Corporation	ES1JFL
2	D13, D14	75V 0.3A	DIODE GEN PURP 75V 300MA SOD323	SMC Diode Solutions	1N4148WS
1	F1	6.3A/250V/slow	39216300000 Fuses with Leads - Through Hole 250V 6.3A IEC TL TE5	Littelfuse	39216300000
1	FB1	120	0603 ferrite bead 120ohm@100MHz	TDK Corporation	MPZ1608S121ATDH5
1	FB2	60	60 Ohms @ 100 MHz 1 Power Line Ferrite Bead 0805 (2012 Metric) 1.9A 20mOhm	Murata Electronics	BLM21PG600BH1D
2	FB3, FB4	220	0603 ferrite bead 220ohm@100MHz	Murata Electronics	BLM18AG221SN1D
1	L1	415uH	P19118	MPS Industries	P19118_2
1	L2	176uH	MPS P11062	MPS Industries	P11062_2
1	L3	90uH	Custom RM8 inductor, wind with as big Litz wire as possible.		
1	MOV1	MOV-10D471K	VARISTOR 470V 2.5KA DISC 10MM	Bourns Inc.	MOV-10D471K

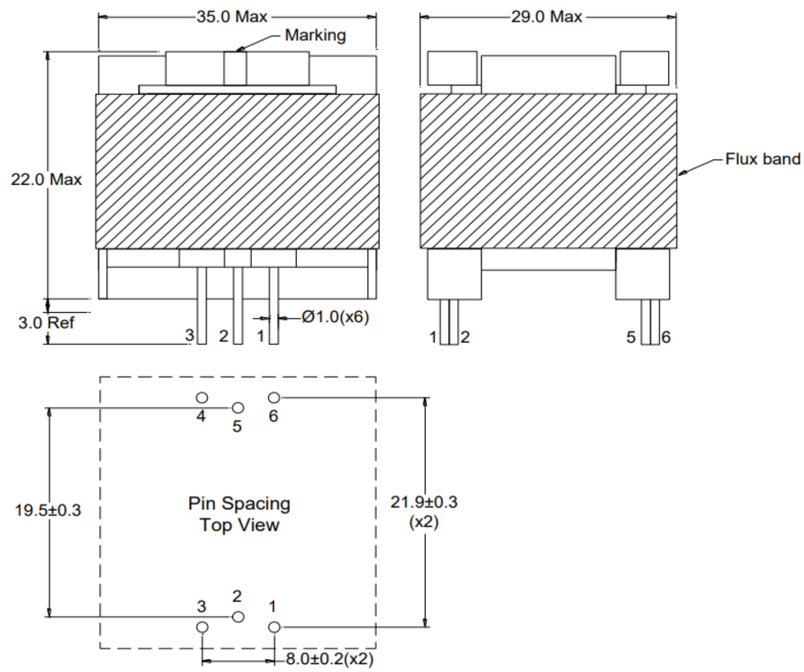
Quantity	Designator	Comment	Description	Manufacturer	Part Number
1	Q1	TP65H070G4PS	GAN FET N-CH 650V TO-220	Transphorm	TP65H070G4PS
2	Q2, Q3	TP65H070G4PS	GAN FET N-CH 650V TO-220	Transphorm	TP65H070G4PS
1	Q4	200V 11mOHM	MOSFET N-CH 200V 88A TO220-3	Infineon Technologies	IPP110N20NAAKSA1
1	Q5	200V 11 mOHM	MOSFET N-CH 200V 88A TO220-3	Infineon Technologies	IPP110N20NAAKSA1
1	Q6	BSS127	MOSFET 600V 50mA NMOS SOT-23	Diodes Incorporated	BSS127SSN-7
1	Q7	2A 100V	TRANS NPN 100V 2A SOT-23	ON Semiconductor	NSS1C201LT1G
1	Q8	2A 100V	TRANS NPN 100V 2A SOT-23	ON Semiconductor	NSS1C201LT1G
1	Q9	1A 80V	TRANS NPN 80V 1A SOT89-3	Diodes Incorporated	BCX5616QTA
1	Q10	100V 2A	MOSFET N-CH 100V 2A SOT23	Micro Commercial Co	SI2324A-TP
1	R1	1.1k	RES 1.1K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT1K10
2	R2, R54	4.7	RESA-AS 1206 4R7 1% 250MW TC400	Bourns Inc.	CR1206AF/-4R70EAS
4	R3, R21, R47, R48	3.3M	RES 3.3M OHM 1% 1/4W 1206	Stackpole Electronics Inc	RMCF1206FT3M30
1	R4	39mOhm, 2010, 1%	RES 0.039 OHM 1% 1W 2010	Vishay Dale	WSLT2010R0390FEB18
1	R5	2k	RC0603FR-072KL RES 2K OHM 1% 1/10W 0603	YAGEO	RC0603FR-072KL
6	R6, R7, R23, R27, R45, R52	47	47 Ohms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film, RES 47 OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT47R0
3	R8, R46, R53	47k	CRGCQ0603F47K RES 47K OHM 1% 1/10W 0603	TE Connectivity Passive Product	CRGCQ0603F47K
1	R9	NS			
1	R10	27k	RES 27K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT27K0
1	R11	100	RES SMD 100 OHM 1% 1/10W 0603	YAGEO	RC0603FR-07100RP
1	R12	2.2	ESR03EZPJ2R2 RES SMD 2.2 OHM 5% 1/4W 0603	Rohm Semiconductor	ESR03EZPJ2R2
1	R13	75k	RES 75K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT75K0
1	R14	11k	RES 11K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT11K0
1	R15	8.2k	RES 8.2K OHM 1% 1/10W 0603	YAGEO	RC0603FR-138K2L
1	R16	1k	RES 1K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FG1K00
1	R17	13k	RES 13K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT13K0
1	R18	1k	RES 1K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FG1K00
2	R19, R22	2k	RES 2K OHM 1% 1/4W 1206	Stackpole Electronics Inc	RMCF1206FT2K00
1	R20	110k	RES 110K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT110K
2	R24, R26	100K	RES 100K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FG100K
2	R25, R44	20k	RES 20K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT20K0
1	R28	10	RES 10 OHM 5% 1/8W 0805	Stackpole Electronics Inc	RMCF0805JT10R0
2	R29, R61	10k	RES 10K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT10K0
2	R30, R31	2.7k	RES 2.7K OHM 5% 1/4W 1206	YAGEO	RC1206JR-072K7L
2	R32, R51	22k	RES 22K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT22K0
1	R33	2k	RES 2K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT2K00
1	R34	300k	RES 300K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT300K
1	R35	3.3	RES 3.3 OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT3R30
3	R36, R37, R39	10K	RES 10K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT10K0
1	R38	1.2k	RES 1.2K OHM 1% 1/10W 0603	YAGEO	RC0603FR-071K2L
2	R40, R43	510k	RES 510K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT510K
1	R41	10k	RES 10K OHM 1% 1/8W 0603	Stackpole Electronics Inc	RNCP0603FTD10K0
1	R42	11k	RES 11K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT11K0
1	R49	909k	RES 909K OHM 1% 1/10W 0603	YAGEO	RC0603FR-07909KL
1	R55	620k	RES 620K OHM 1% 1/10W 0603	YAGEO	RC0603FR-07620KL
2	R56, R60	200k NS	RES 200K OHM 5% 1/4W 1206 DNP	Stackpole Electronics Inc	RMCF1206JT200K
1	R57	0.03	RES 0.03 50PPM 1% 1W 1206	YAGEO	PE1206FRE470R03L
2	R58, R59	20	RES 20 OHM 1% 1/2W 1206	Stackpole Electronics Inc	RNCP1206FTD20R0
1	R62	100K	RES 100K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FG100K
1	RT2	NS	NTC resistor		
1	U1	NCP1654 (133kHz)	NCP1654BD133R2G IC PFC CTRLR CCM 146KHZ 8SOIC	onsemi	NCP1654BD133R2G
1	U2	NCS20071	FET Operational Amplifier	onsemi	NCS20071SN2T1G
1	U3	NCP1399AA	LLC Controller IC OFFLINE SW HALF-BRDG 16SOIC	onsemi	NCP1399AADR2G
1	U4	TCLT1016	OPTOISOLATOR 5KV TRANS SOP-6L4	Vishay Semiconductor Opto Division	TCLT1016
1	U5	AP4310A	IC OPAMP GP 2 CIRCUIT 8SO	Diodes Incorporated	AP4310AMTR-G1
1	U6	MP6924A	Power Supply Controller Secondary-Side Controller, Synchronous Rectifier 8-SOIC	Monolithic Power Systems Inc.	MP6924AGS
1	U7	NS	X-cap discharger IC AUTOMATIC DISCHARGE 8SO	NXP USA Inc.	TEA1708T/1J
1	XF1	130uH	PQ2620 P:S1:S2:AP:AS=24:8:8:4:4		
1	Z1	NS			
1	Z2	12V	DIODE ZENER 12V 300MW SOD323	onsemi	MM3Z12VST1G
2	Z3, Z4	13V	DIODE ZENER 13V 300MW SOD323	onsemi	MM3Z13VT1G

PFC Power Inductor Specification (L1) (PQ3220)

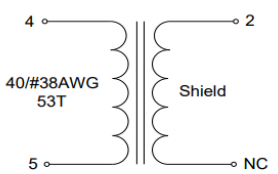
ELECTRICAL SPECIFICATIONS @ 25°C

OCL (4-5):	415µH ±10% @ 10KHz, 0.1V_{RMS} ΔL≤10% @ 4.5Adc
DCR (4-5):	200mΩ Max
Hipot:	1.5KVrms, 1mA Max, 10S (wdgs to core)
RoHS Compliant:	Yes
Operating Temp:	-40°C to +100°C

DIMENSIONS



SCHEMATIC



MARKING

MPS
P19118_Rev
Date Code
Dot at pin 1

WINDING SEQUENCE

	A	B
TURNS WIRE SIZE WIND METHOD	53T 40/#38S layers	1.25T 2mil copper foil Wrap on epoxied part
TAPS		
Mylar TAPE INSULATION	2L	2L
TERM. IDENT. (S - F) TERM. TYPE LEAD OUT	4-5 PINS	2-NC PIN 2
SLEEVING # CREEPAGE		#23PTFE

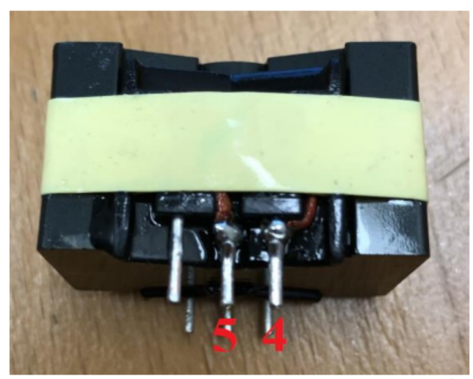


Fig.1 Lead out with proper wire routing and sufficient clearance b/t pin 4 and pin 5

NOTE

The wire to pin 4 should go through the slot on the right-hand side(see Fig.1 for proper lead routing)
Wrap 1.25 layer of copper foil band on finished inductor. Then secure with 2L mylar tape
Varnish in BC-359 or equiv

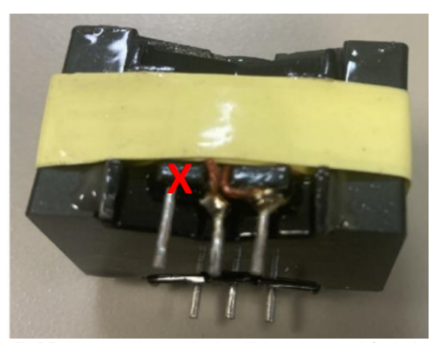


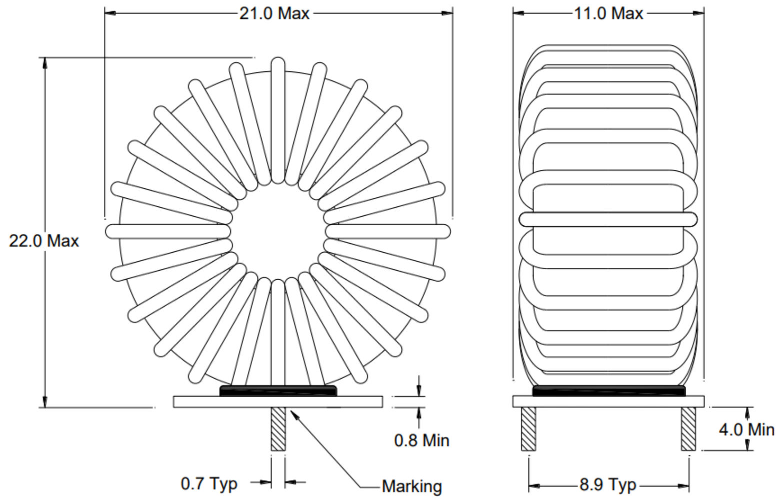
Fig.2 Bad wire routing causing insufficient clearance b/t pin 4 and pin 5

L2 spec

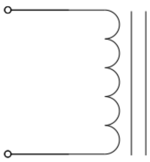
ELECTRICAL SPECIFICATIONS @ 25°C

OCL:	176µH±15% @ 10kHz, 1Vrms ΔL≤15%@3.5Arms, 60Hz
DCR:	115mΩ Max
Operating Temp:	-40°C to +105°C
Insulation Class:	Class F, 155°C Min
RoHS Compliant:	Yes

DIMENSIONS



SCHEMATIC



MARKING

WINDING SEQUENCE

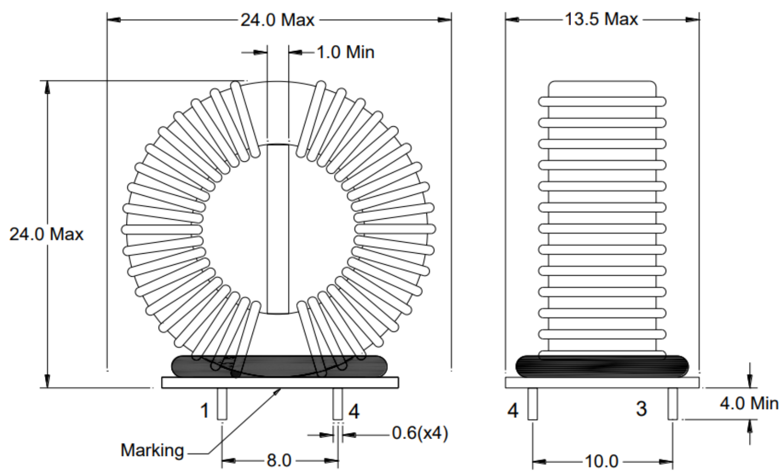
	A	B
TURNS	64T	
WIRE SIZE	#22H	
WIND METHOD	2L Dist.	
TAPS		
FIBERGLASS CLOTH INSULATION		
TERM. IDENT. (S - F)	S-F	
TERM. TYPE	SELF	
LEAD OUT	4mm	
SLEEVING #		
CREEPAGE		

Common-Mode Choke Specification (CMC1)

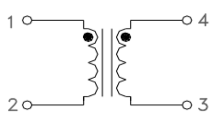
ELECTRICAL SPECIFICATIONS @ 25°C

Inductance(1-2, 4-3):	10mH Min@ 10kHz, 0.1V_{RMS}
DCR(1-2, 4-3):	38mΩ Max
Rated Current:	3.5Arms
Turns Ratio(1-2 to 4-3):	1:1±2%
Polarity:	1 and 4 are in phase
Hipot(1-2 to 4-3):	1.0KVdc, 1 mA, 5 sec
RoHS Comp:	Yes

DIMENSIONS



SCHEMATIC

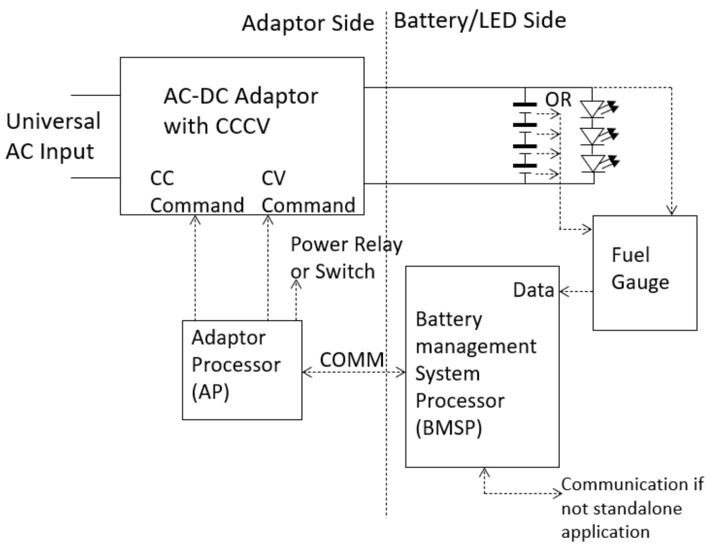


WINDING SEQUENCE

	A	B
TURNS	21	21
WIRE SIZE	#22 HPN	#22 HPN
WIND METHOD	half core	half core
TAPS		
INSULATION		
INSULATION		
TERM. IDENT. (S - F)	1 - 2	4 - 3
TERM. TYPE	Self	Self
LEAD OUT	4mm	4mm
SLEEVING #		
CREEPAGE		

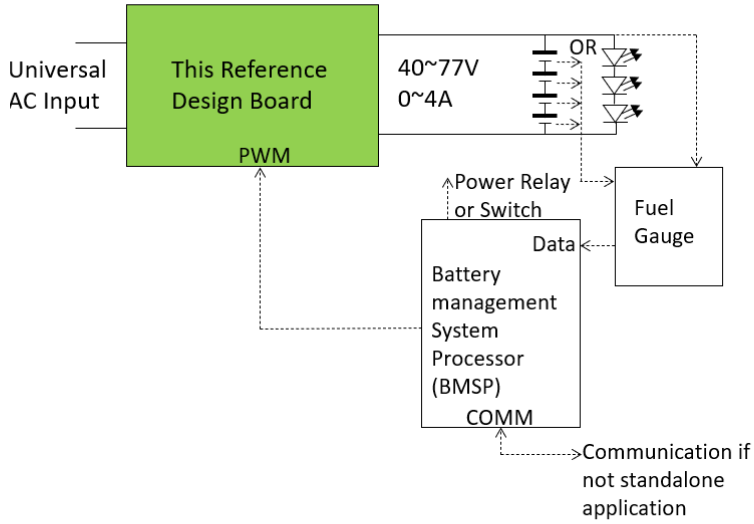
Application Description

A traditional battery charging system is depicted in the block diagram below. The fuel gauge circuit (maybe dedicated ICs) collects battery charge and health information for a battery management microprocessor (BMSP) for control, display, and warning purposes. In the event when the battery needs charging, the BMSP sends commands to a processor on the AC-DC Adaptor side. The adaptor processor (AP) interprets the commands and translates them into appropriate command format (mostly analog) for the CCCV loop in the adaptor. The adaptor is built with CCCV capability.



Although the adaptor processor (AP) circuit and programming are simpler as compared with the BMSP implementation, requiring a processor on the adaptor side burdens system cost and size. For smaller systems, the battery may sit relatively close to the charging adaptor, the BMSP may be able to issue commands directly to the adaptor control loop.

This reference design implements the power section of a battery charger or a dimmable LED driver with above compact system architecture requirement by providing only one command input in PWM format, which can be issued directly by any microprocessor including a BMSP. Typical application scenarios can be illustrated by the block diagram below. This reference design, the green block, takes universal input line voltages from 90Vac to 264Vac. Its output ranges from 40 V ~ 77 V and 0 A ~ 4 A DC. At no load its output voltage is set to 77 V. Its output current is limited to 4 A. The reference design has a PWM input port converting a PWM input signal to an internal current command, suitable for battery charging or dimmable LED driver applications. Only the green block in the block diagram is implemented as the reference design board.

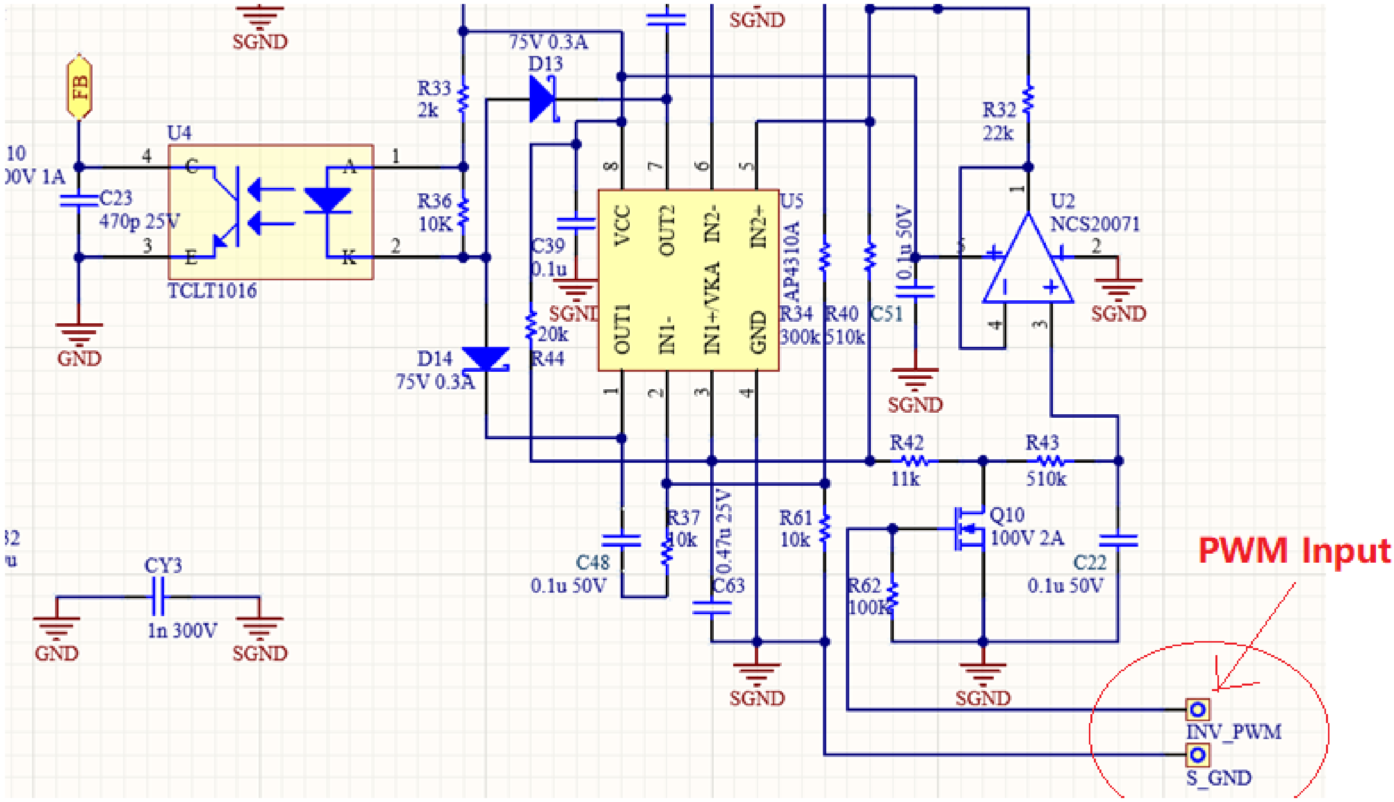


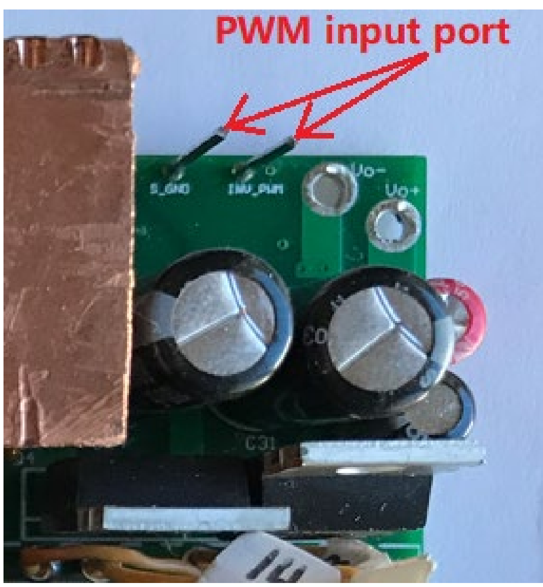
For a battery charger application, a charging profile specific to the battery chemistry is stored and managed by the battery management system microprocessor (BMSP). The microprocessor collects fuel gauge information such as the battery terminal voltage, charge, health and determines an appropriate current level to charge. The current level is represented by the PWM duty cycle output from the microprocessor to the green reference design board. Duty cycle of 100% will have the reference design board outputting 4 A full current. A duty cycle of 0% will reduce output current to its minimum. Additionally, the microprocessor can manage a power relay or switch to disconnect the battery from this reference design board if desired. If this is a part of a bigger system, like in an electric vehicle (EV), the microprocessor can accept commands from other parts of the system as well. This system is simpler, smaller in size, and lower in cost system as compared with traditional charging system while maintaining high system efficiency.

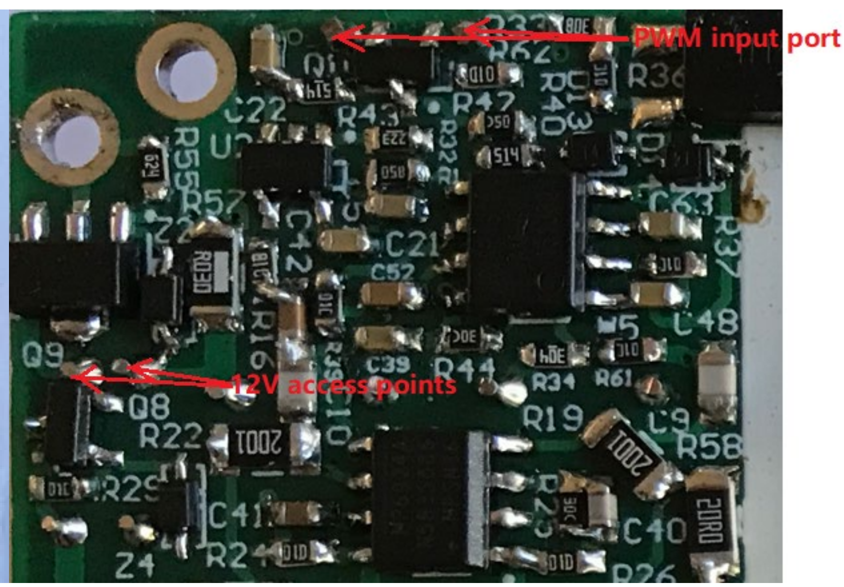
For a LED driver application, the PWM input is the dimming command. A microprocessor may not be required. A 0 V ~ 10 V to PWM circuit is sufficient. LED current under dimming has significant ripple < 1 kHz. A bigger output bulk capacitor may be required to reduce this ripple content.

PWM input for Battery Current Regulation

This reference design incorporates a PWM input as shown in the schematic (part of output circuit) and PCB pictures below.

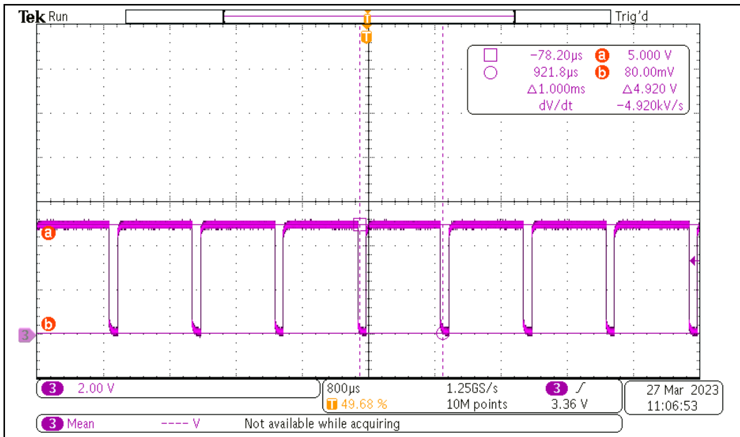




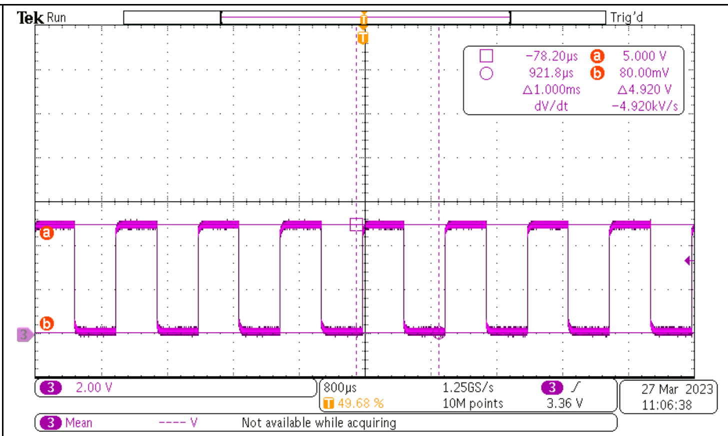


The PWM signal can come from a microprocessor or a function generator. Test data in this report are collected with a function generator. If the microprocessor needs power, it can access a 12 V power supply from this reference design board as pointed in above PCB picture.

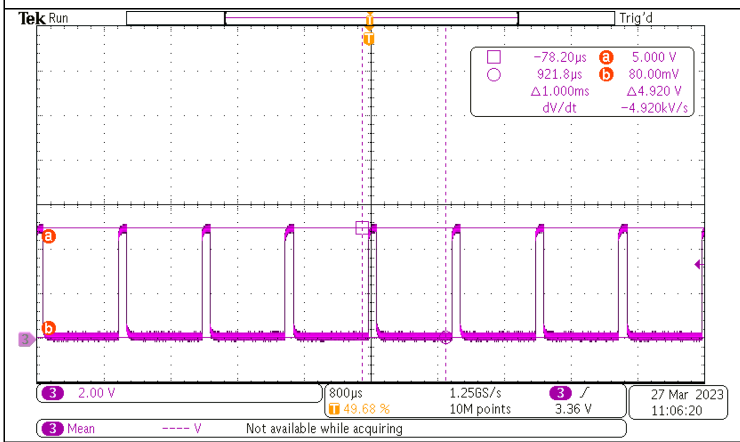
As indicated by the schematic, an inverter circuit by Q10 is used to convert the PWM signal to internal current regulation signal. Because of this Q10 inverter circuit, the PWM signal input needs to be in inverted polarity. PWM frequency of 1 kHz is used for the tests. Below are scope plots showing PWM signal waveforms vs duty cycles, clearly indicating the inverted polarity requirement.



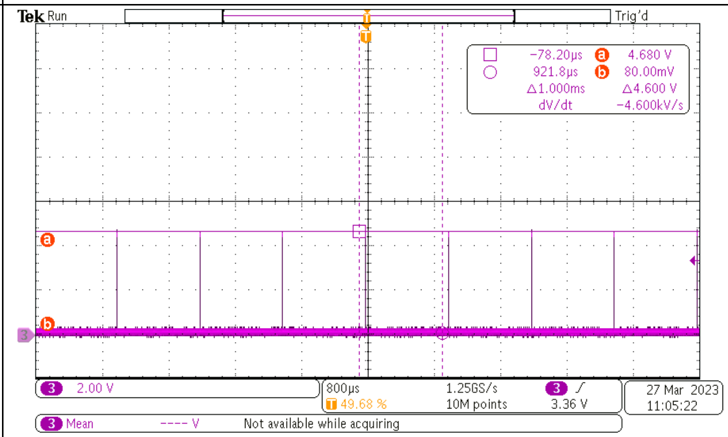
10% duty cycle



50% duty cycle



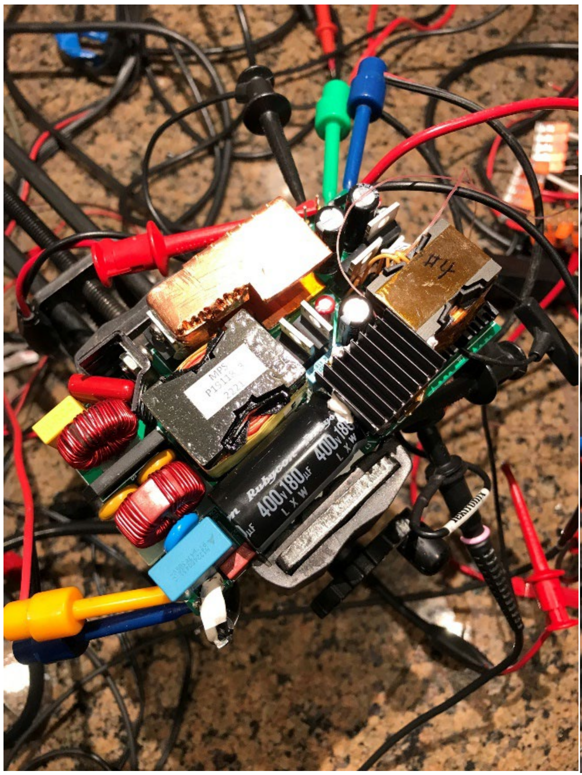
90% duty cycle

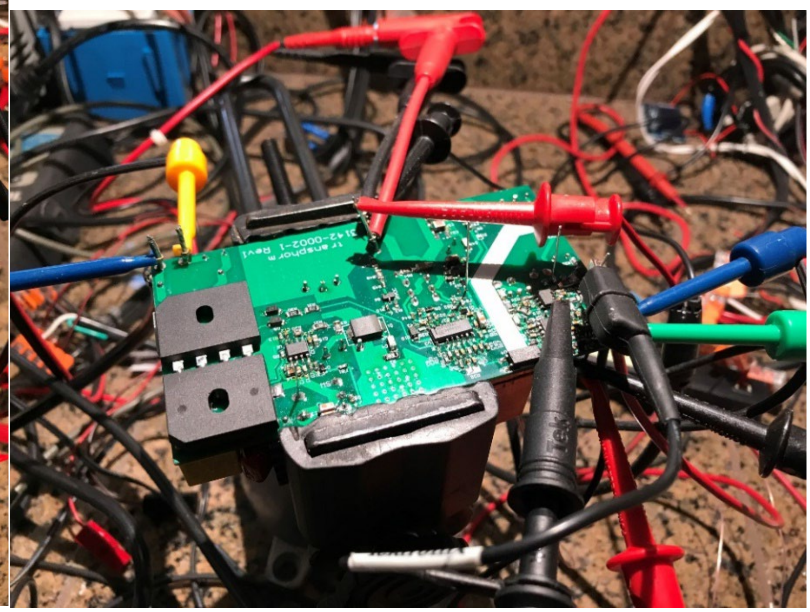


99.995% duty cycle

Test Setup

Below pictures show the test setup with input and output wire connections. There are also scope probes and thermal couple wires connected during the tests. It is important to bring power meter voltage sense wires to adaptor PCB terminals for accurate efficiency reading.





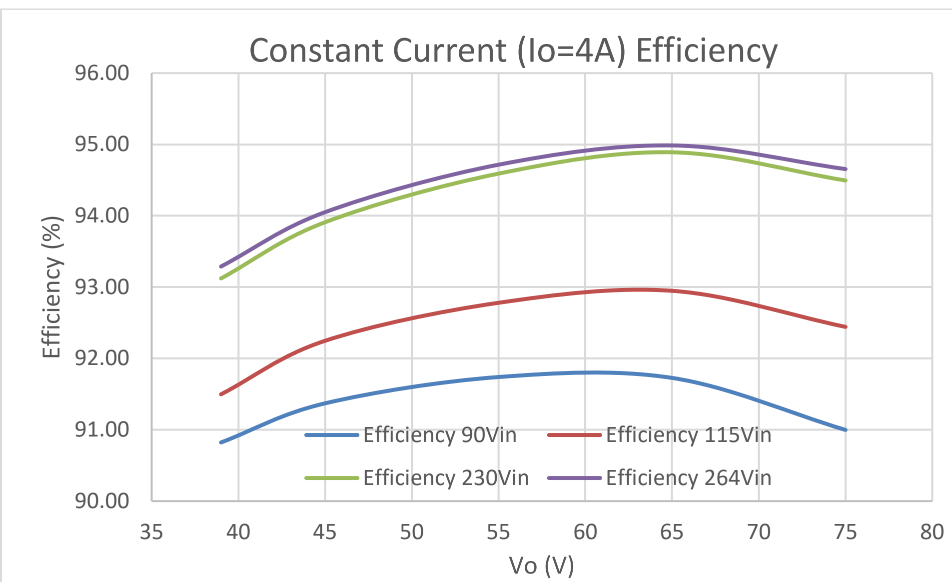
Performance Data

No-Load Input Power

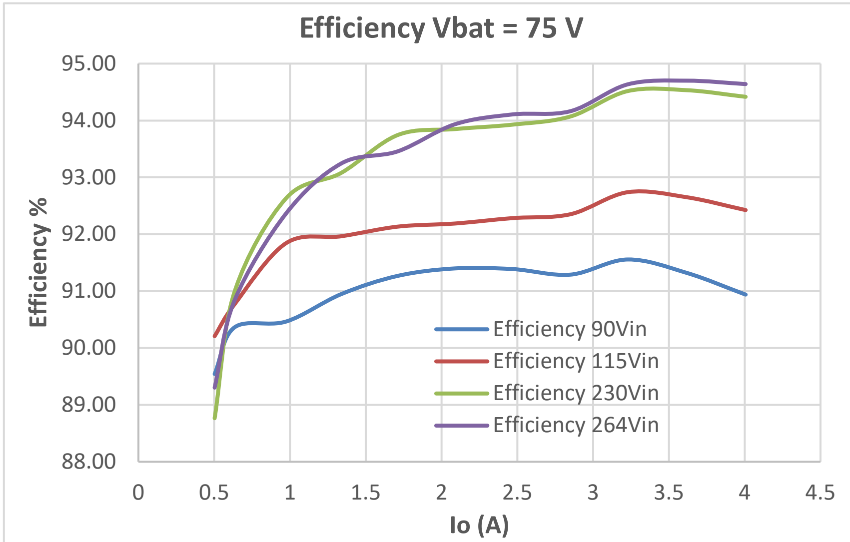
Input Voltage Vin(ac)	Frequency	No-Load Pin (W)
90	60	0.60
115	60	0.56
230	50	0.40
264	50	0.55

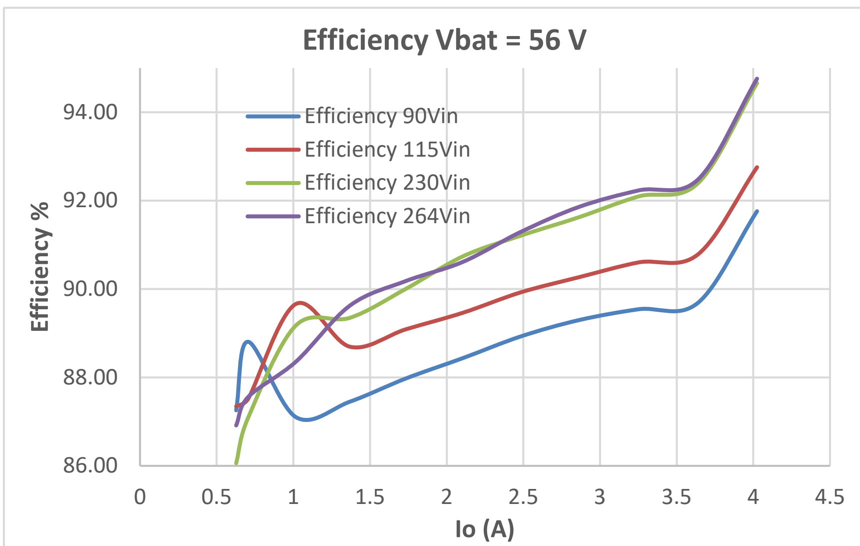
Full Load Efficiency

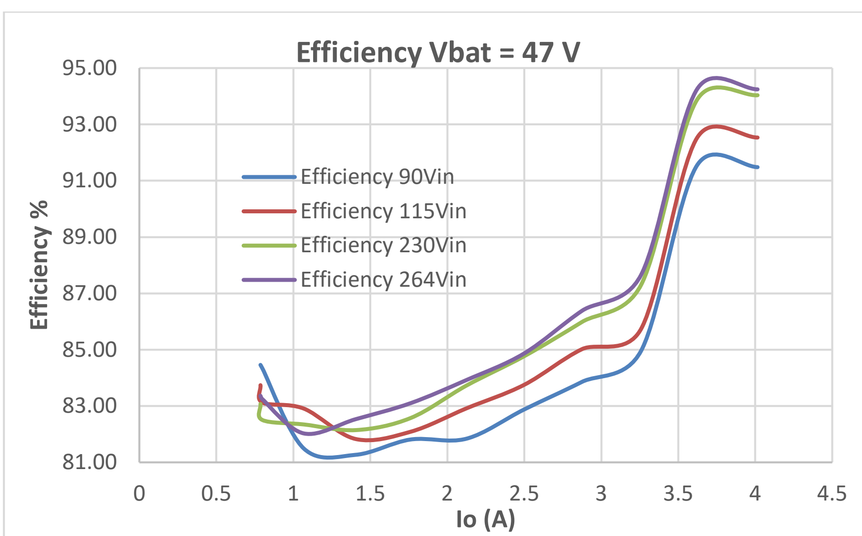
Vbat	Efficiency 90Vin	Efficiency 115Vin	Efficiency 230Vin	Efficiency 264Vin
75	91.00	92.44	94.49	94.65
65	91.73	92.95	94.89	94.99
55	91.74	92.78	94.59	94.72
45	91.37	92.25	93.91	94.05
39	90.82	91.50	93.12	93.29



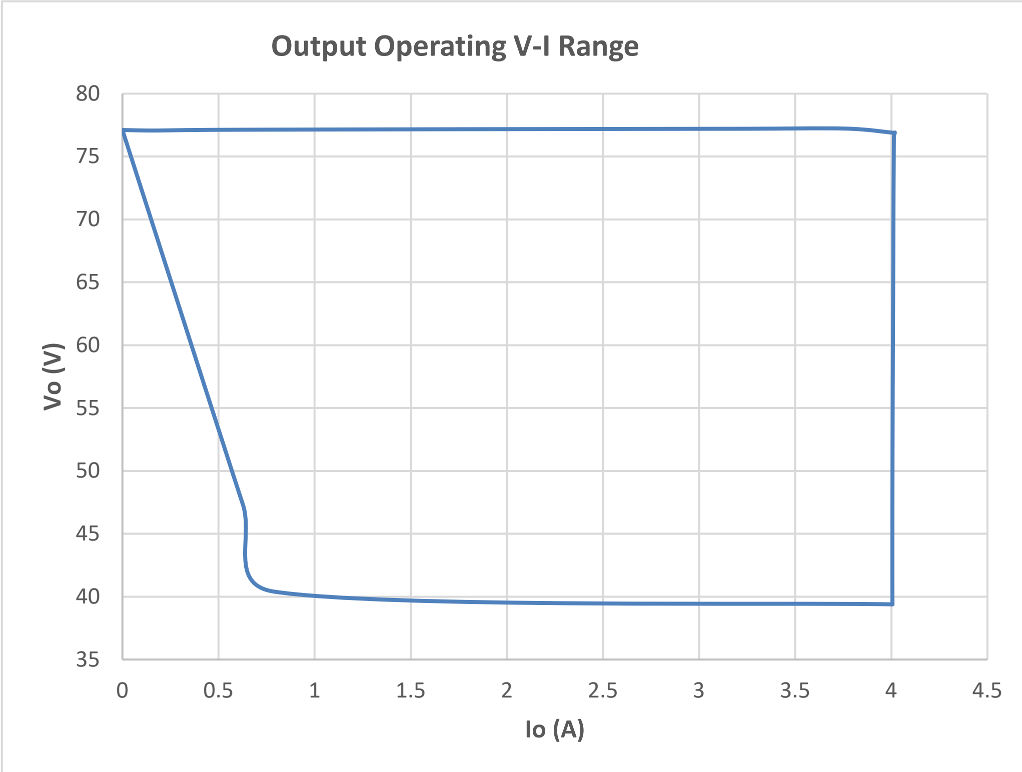
Efficiency at Various Battery Voltages with Various Load Current Levels



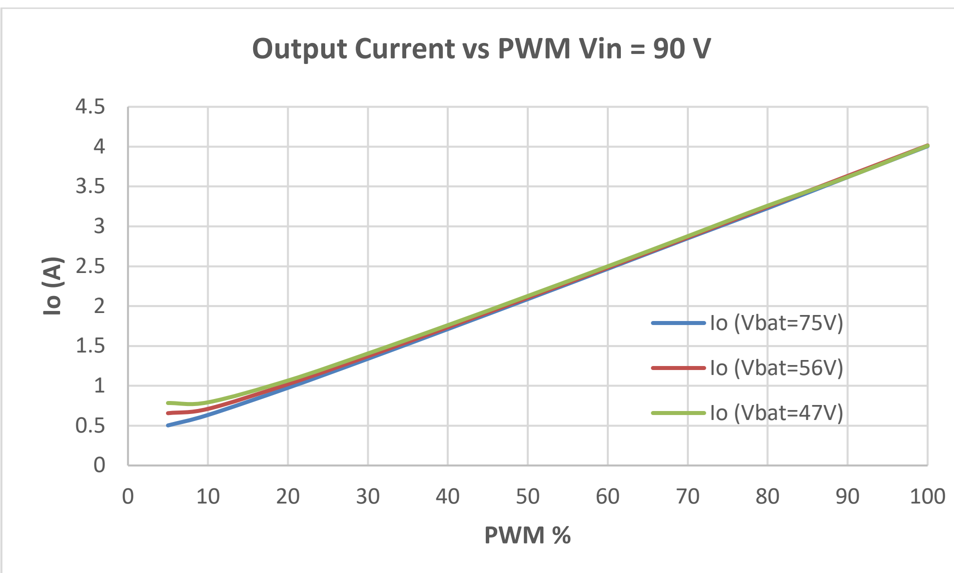


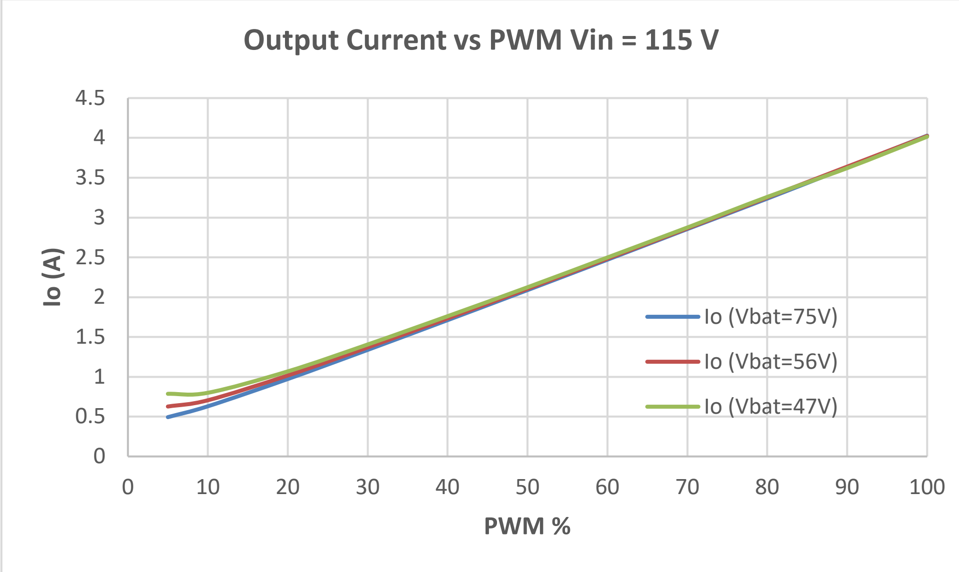


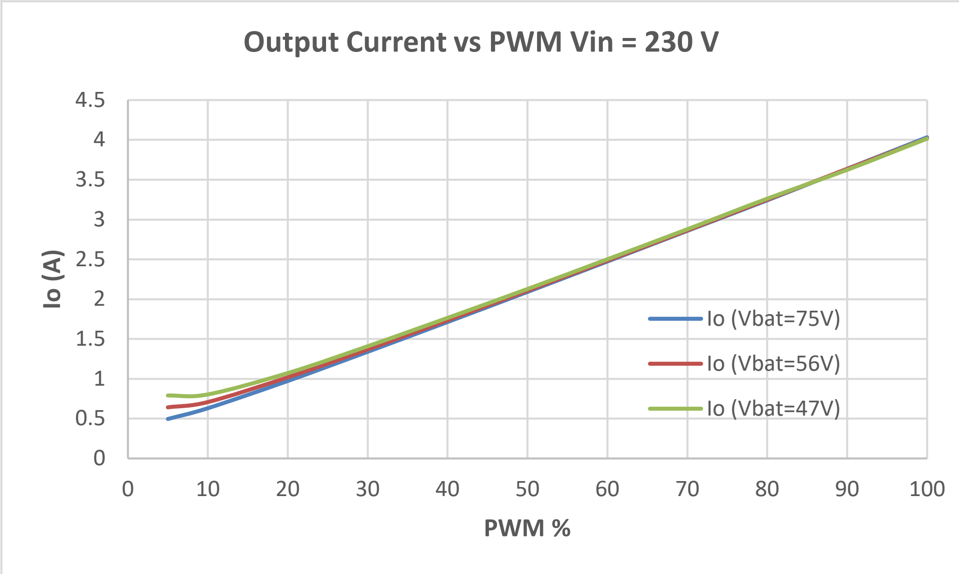
Output Voltage and Current Operation Range

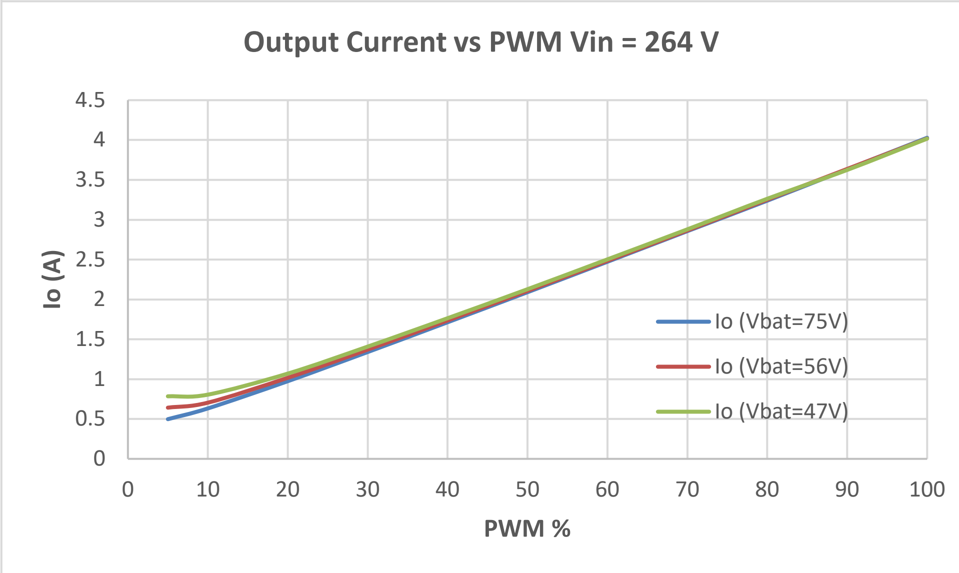


Output Current Level vs PWM Duty Cycle % Plots

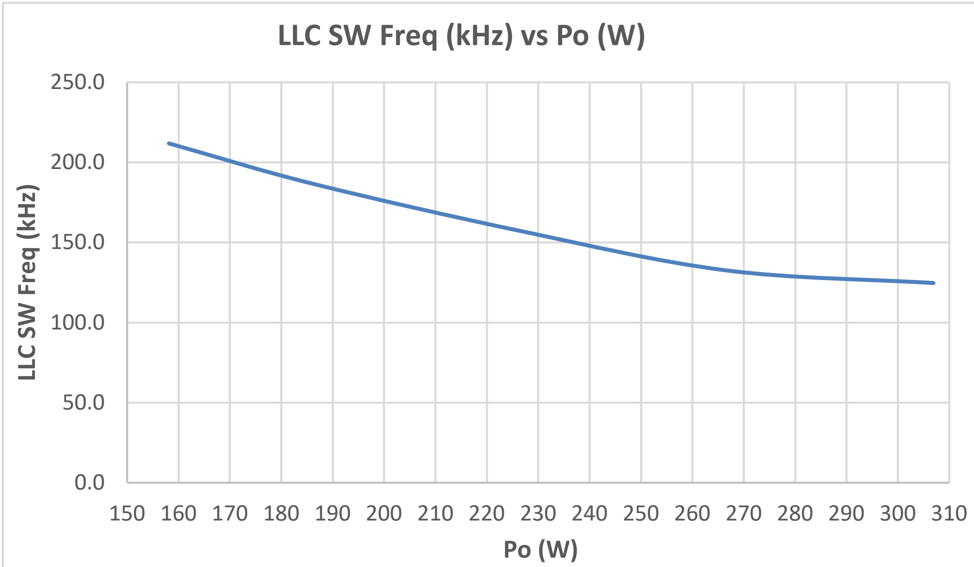


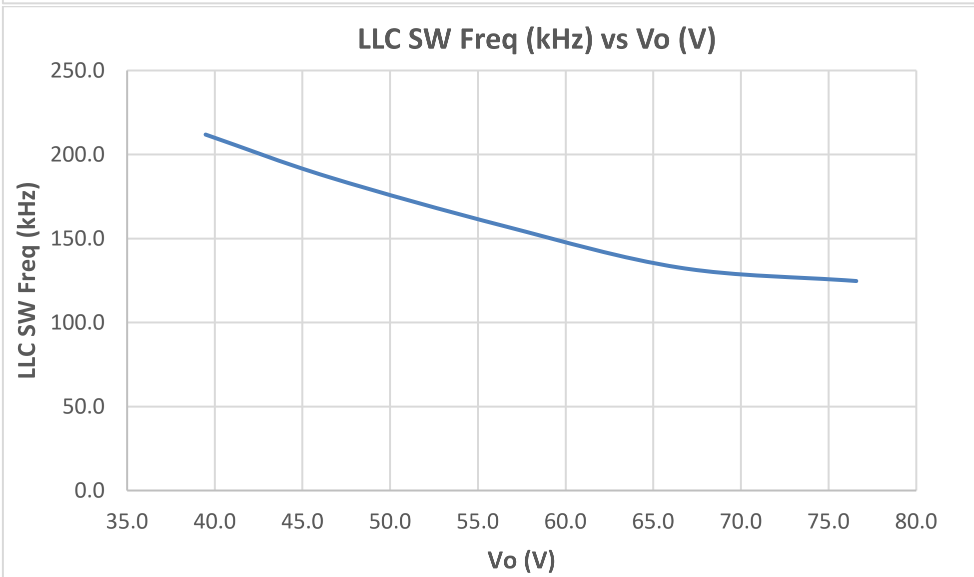

Output Current vs PWM Vin = 115 V
Io (A)
PWM %
Io (Vbat=75V)
Io (Vbat=56V)
Io (Vbat=47V)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
10
20
30
40
50
60
70
80
90
100


Output Current vs PWM Vin = 230 V
Io (A)
PWM %
Io (Vbat=75V)
Io (Vbat=56V)
Io (Vbat=47V)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
10
20
30
40
50
60
70
80
90
100


Output Current vs PWM Vin = 264 V
Io (A)
PWM %
Io (Vbat=75V)
Io (Vbat=56V)
Io (Vbat=47V)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
10
20
30
40
50
60
70
80
90
100

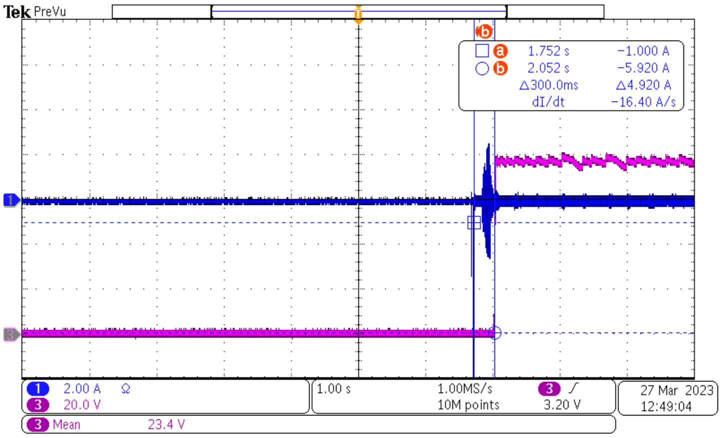
LLC Switching Frequency Plots



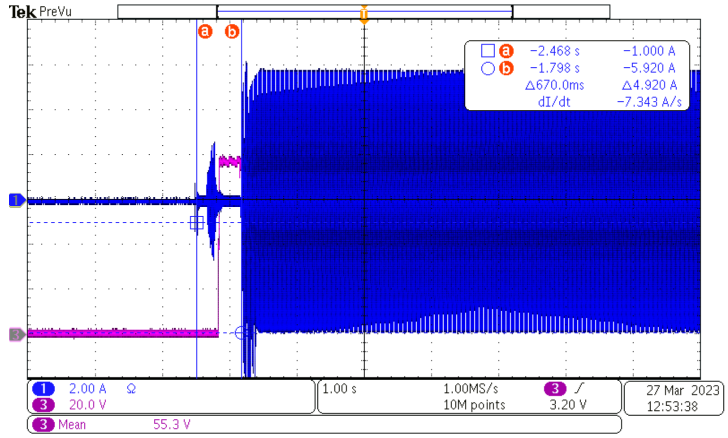


Startup

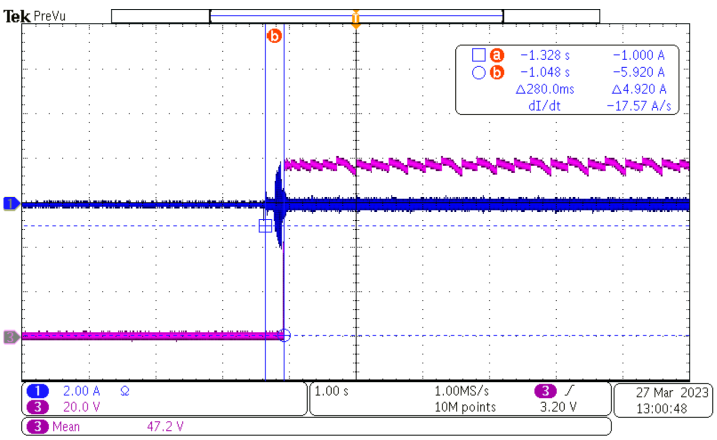
Vin (Vac)	Iout (A)	Startup Time (second)	Note
90	0	0.30	Vo = 77 V
90	4	0.67	Vo = 77 V
115	0	0.28	Vo = 77 V
115	4	0.57	Vo = 77 V
230	0	0.20	Vo = 77 V
230	4	0.53	Vo = 77 V
264	0	0.20	Vo = 77 V
264	4	0.53	Vo = 77 V



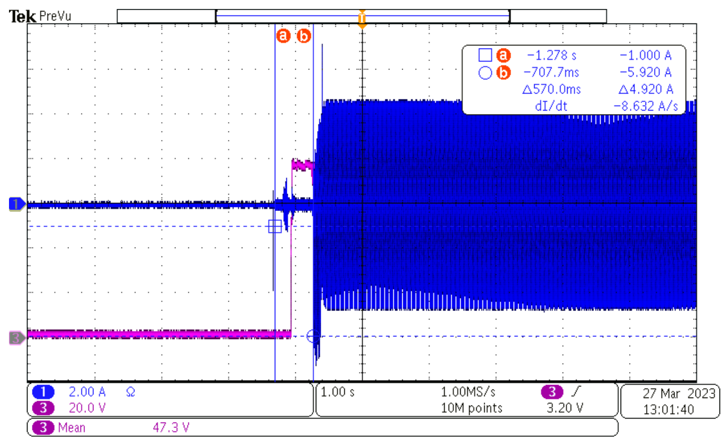
Vin = 90 Vac, 60 Hz; Vout = 77 V; Iout = 0 A



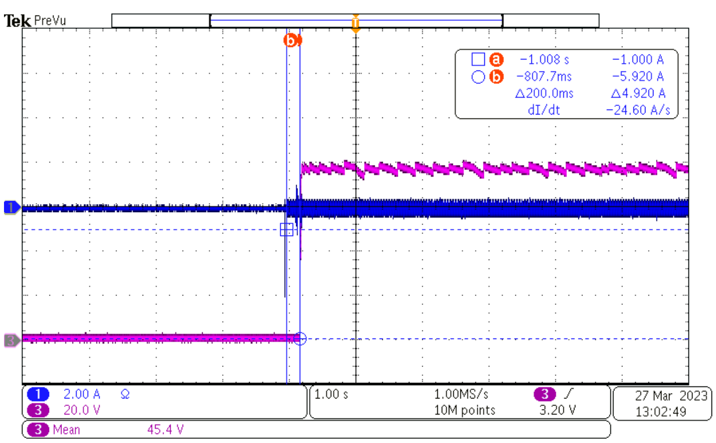
Vin = 90 Vac, 60 Hz; Vout = 77 V; Iout = 4 A



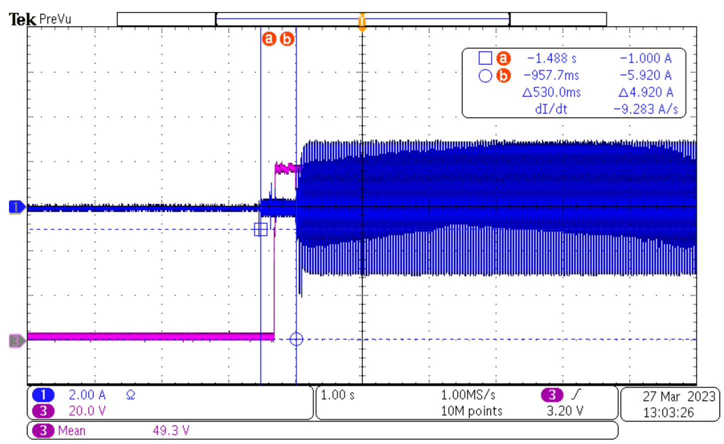
Vin = 115 Vac, 60 Hz; Vout = 77 V; Iout = 0 A



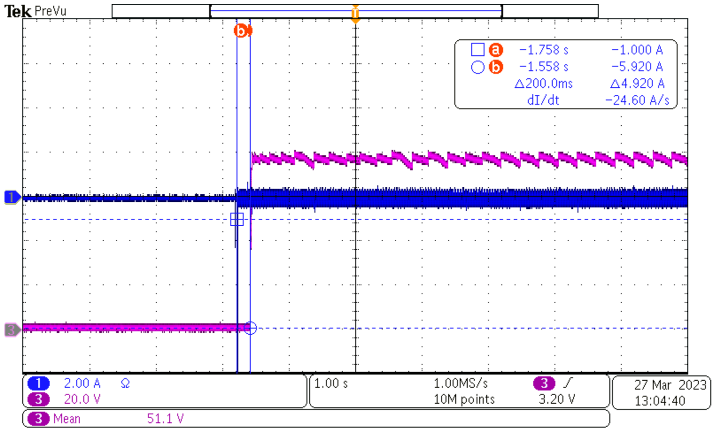
Vin = 115 Vac, 60 Hz; Vout = 77 V; Iout = 4 A



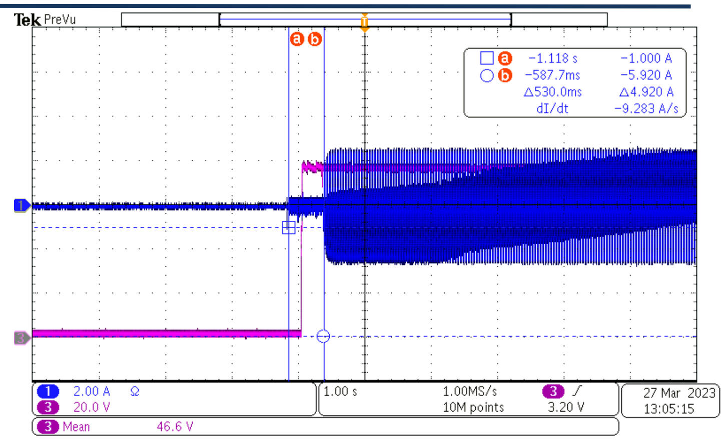
Vin = 230 Vac, 50 Hz; Vout = 77 V; Iout = 0 A



Vin = 230 Vac, 50 Hz; Vout = 77 V; Iout = 4 A



Vin = 264 Vac, 50 Hz; Vout = 77 V; Iout = 0 A

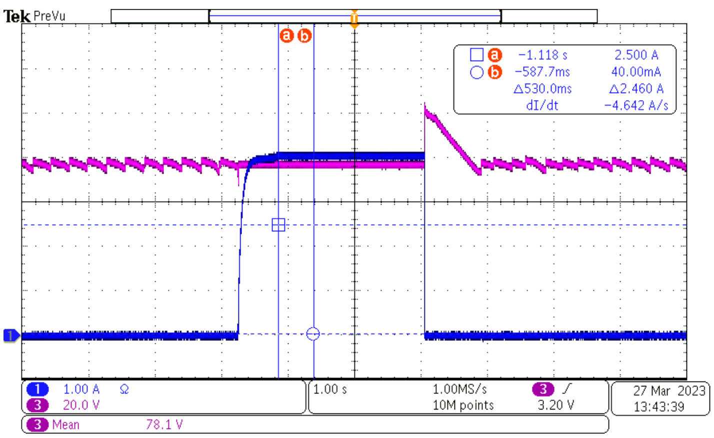


Vin = 264 Vac, 50 Hz; Vout = 77 V; Iout = 4 A

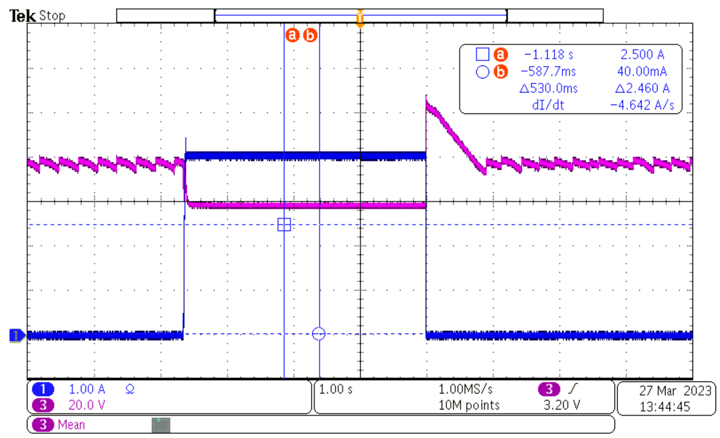
Note: Ch1 (Blue): Iin. Ch3 (Purple): Vout.

Load Transitions

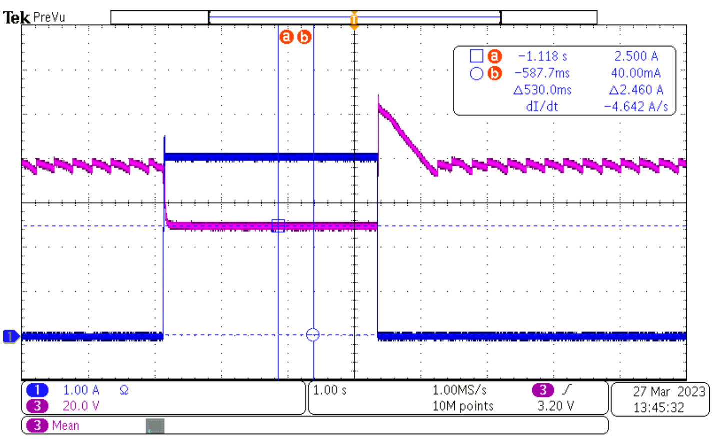
We do not vary input line voltages for this test. Load transients are more related to the LLC and output section. Input line voltage is set to 230 V 50 Hz only. LED load profile from the electronic load ET5411 is used with Coeff=0.186.



Vbat = 75 V; Iout = 0 A to 4 A to 0 A Transitions, LED Load



Vbat = 56 V; Iout = 0 A to 4 A to 0 A Transitions, LED Load



Vbat = 47 V; Iout = 0 A to 4 A to 0 A Transitions, LED Load

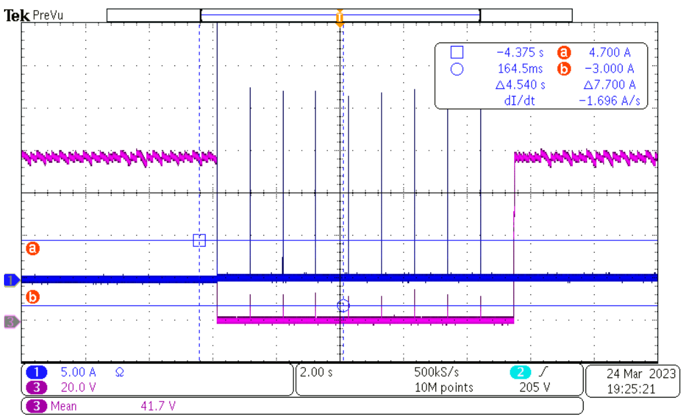
Note: Ch1 (Blue): Iout. Ch3 (Purple): Vout.

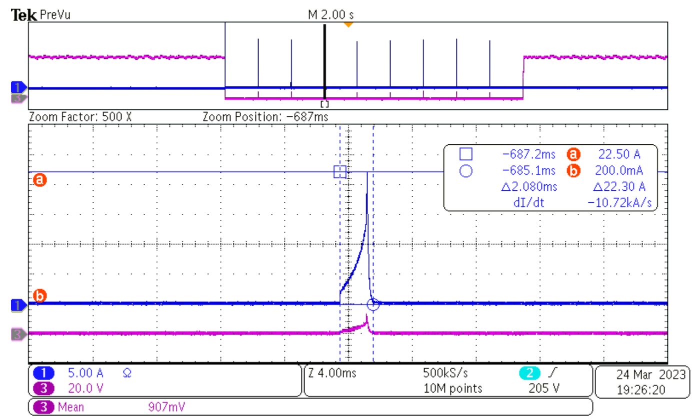
Output Overcurrent Protection (OCP)

This reference design board can achieve constant current operation. Overcurrent protection (OCP) should not be entered.

Output Short Circuit Protection

The output short test is performed with the electronic load ET5411. The reference board is able to recover after a short circuit fault is removed.



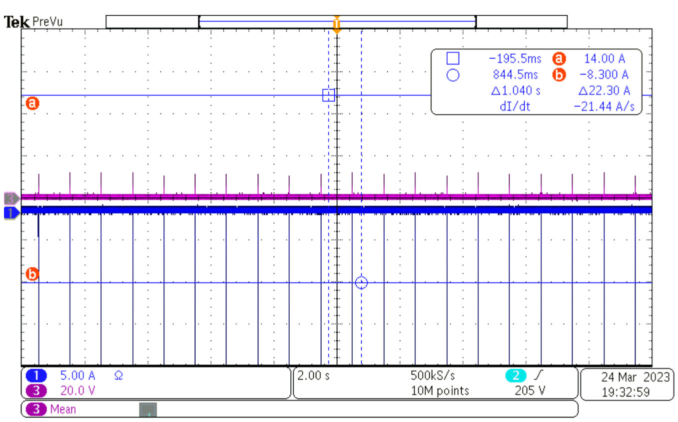


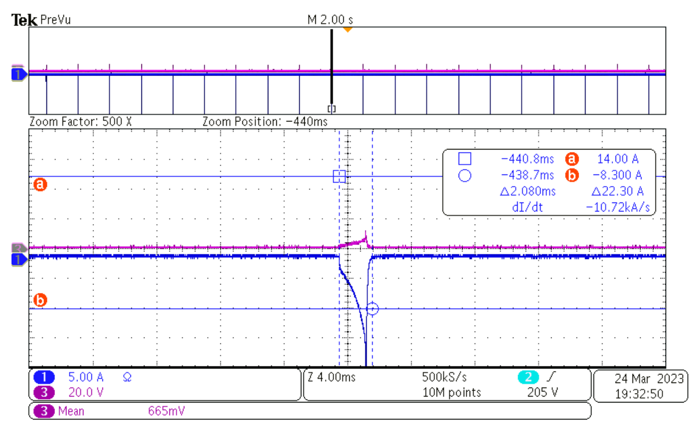
Output No Load-Shorted-No Load Transitions **Zoom at short circuit**

Note: Ch1 (Blue): Iout. Ch3 (Purple): Vout.

Output Reverse Polarity Protection

The output reverse polarity test is performed with the electronic load ET5411. The reference board can recover after a reverse fault is removed.





Output Reverse Polarity **Zoom at Current Pulse**

Note: Ch1 (blue): Iout. Ch3 (Purple): Vout.

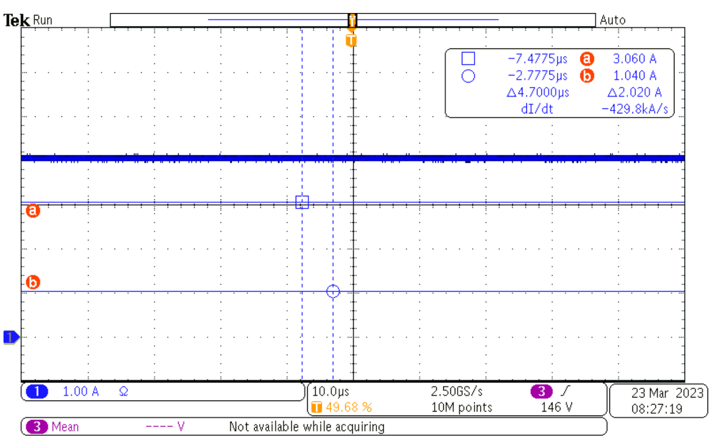
Output Current Ripple

LLC controller IC NCP1399AA is built as a constant voltage adaptor controller. When the load is light enough, it uses pulse mode to preserve the LLC resonant frequency and to maintain high enough efficiency. This pulse mode can have pulse frequency from 200 Hz to 1 kHz, creating large output ripple current.

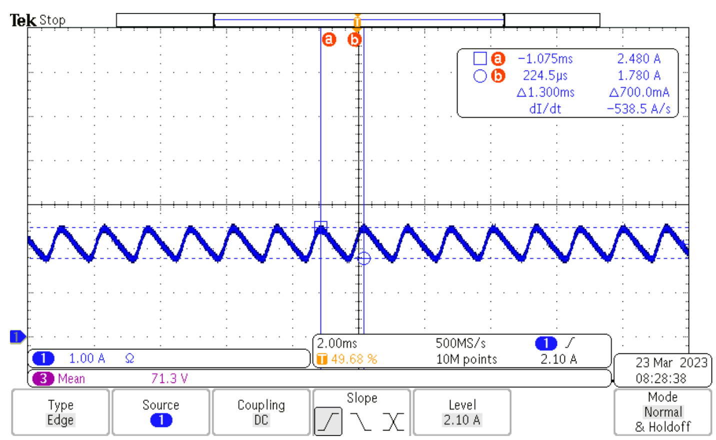
Output Voltage Ripple Summary

Vbat (V)	Iout (avg A)	Iout_Rippe (pk_pk A)
75	4	0
75	2	0.7
75	1	0.9
56	4	0
56	2	1.04
56	1	1.24
47	4	0
47	2	1.34
47	1	1.54

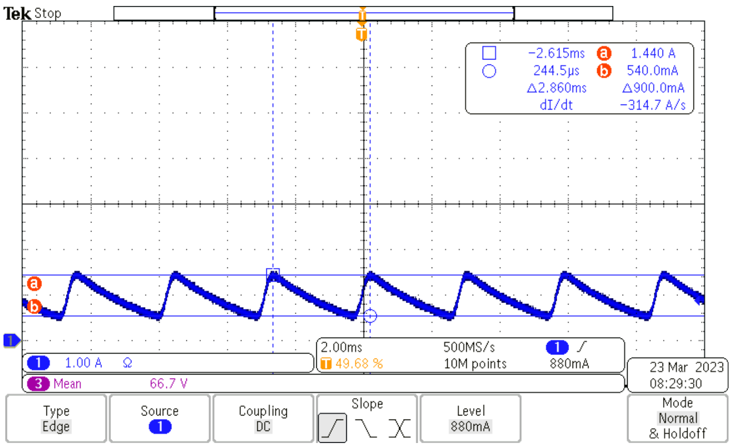
Output Current Plots



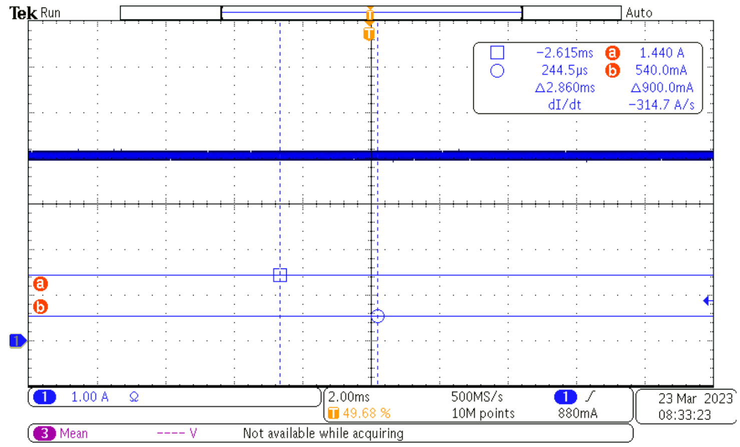
Vbat = 75 V; Iout = 4 A



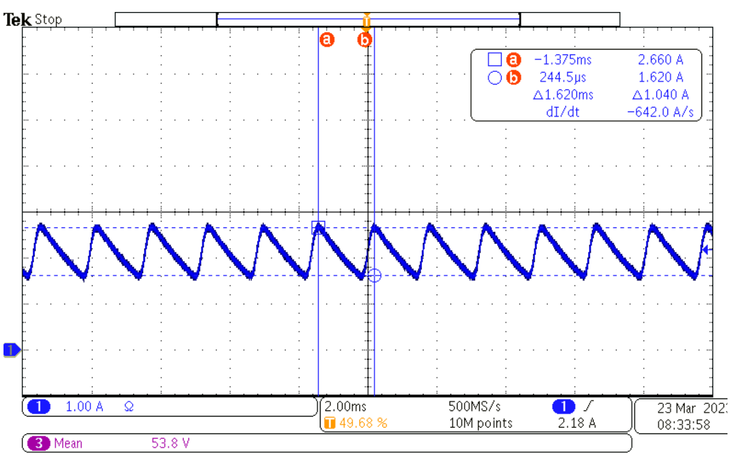
Vbat = 75 V; Iout = 2 A



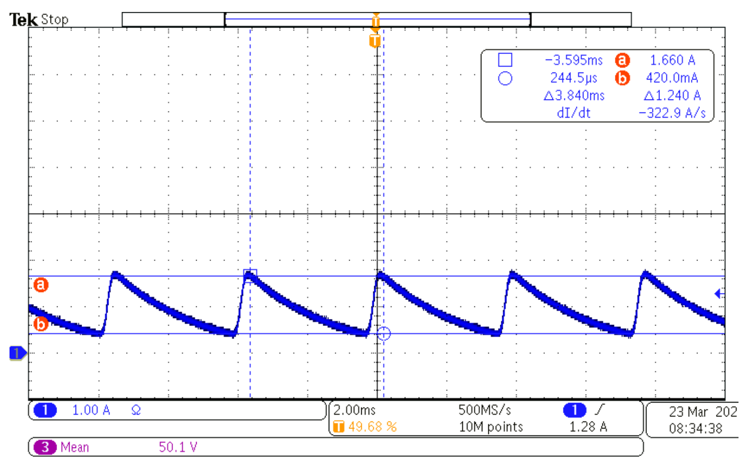
Vbat = 75 V; Iout = 1 A



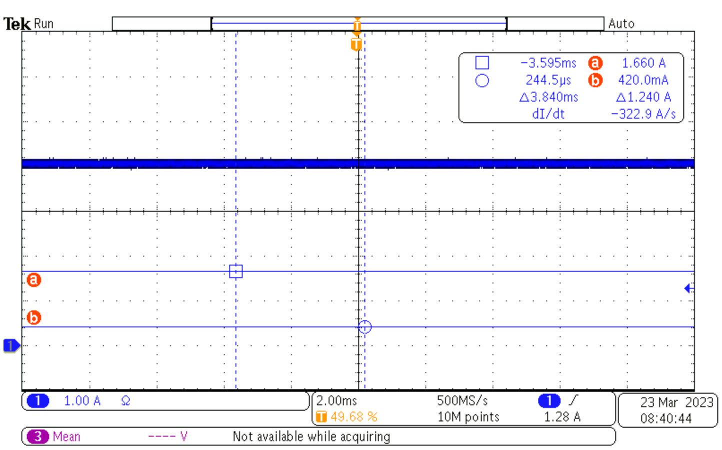
Vbat = 56 V; Iout = 4 A



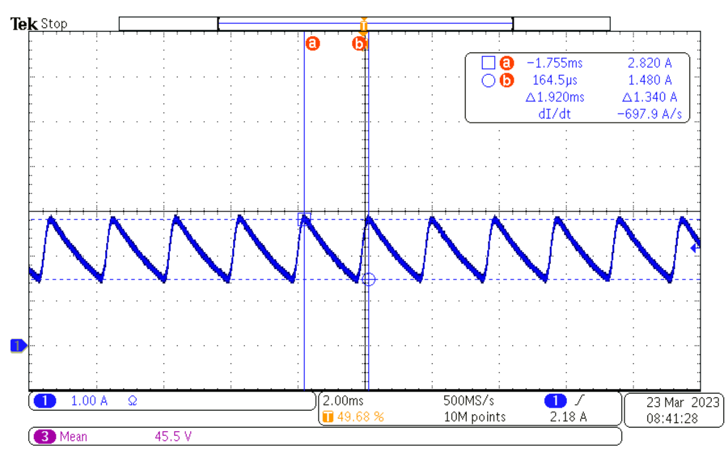
Vbat = 24 V; Iout = 2 A



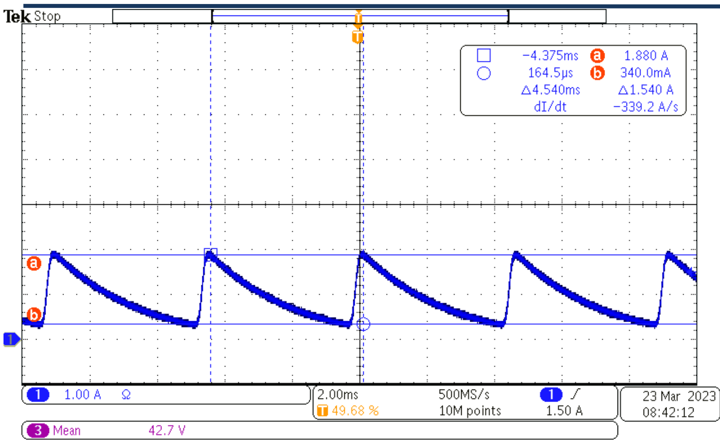
Vbat = 56 V; Iout = 1 A



Vbat = 47 V; Iout = 4 A



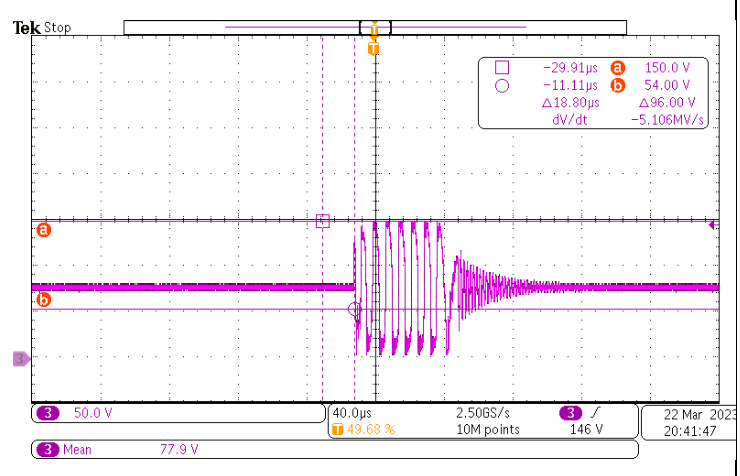
Vbat = 47 V; Iout = 2 A



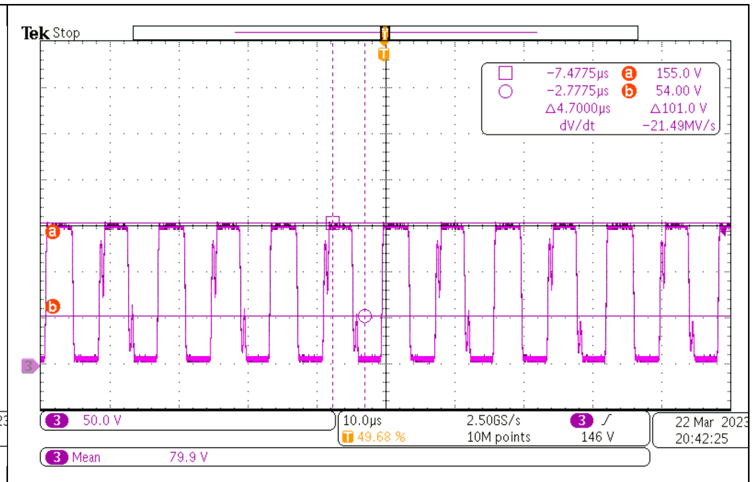
Vbat = 47 V; Iout = 1 A

Key Waveforms

Primary side FETs on both PFC and LLC see Vbus (~400 V) as their maximum voltage. There is enough margin for the 3 Transphorm FETs TP65H070G4PS. The key waveforms for the worst-case voltage conditions as seen by the secondary side MOSFETs are shown below. The secondary side MOSFET voltage is rated at 200 V, also having sufficient margin.

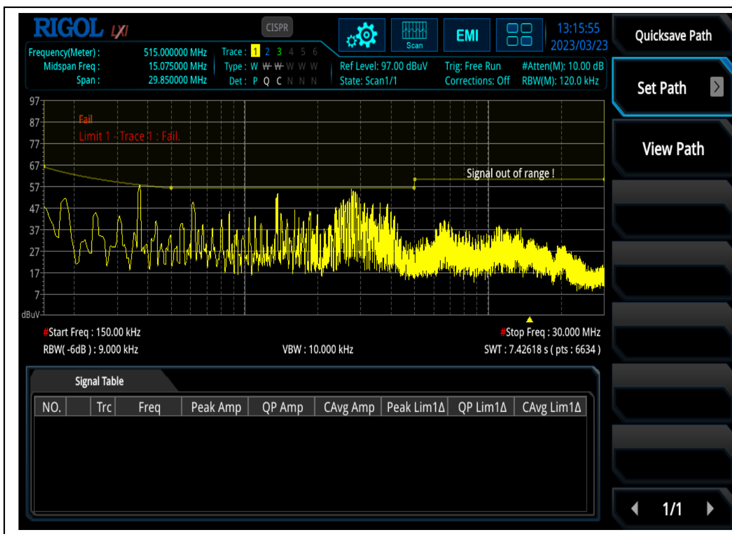


Vout = 77 V, Iout = 0 A, Vds_sec (max) = 150 V

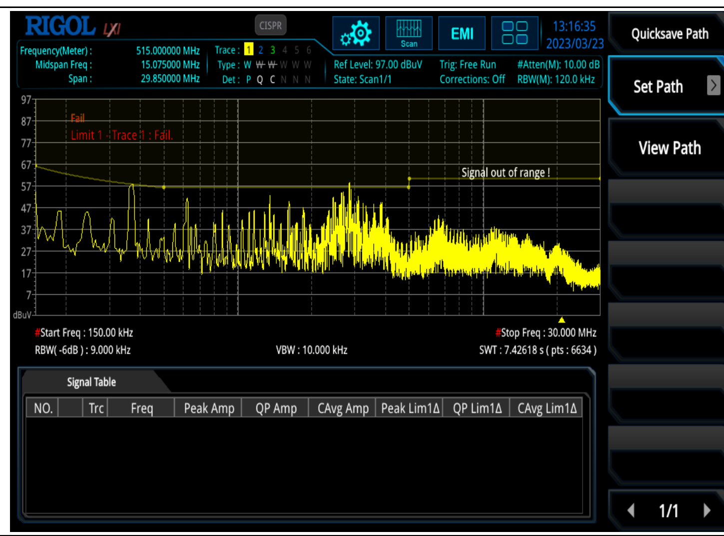


Vout = 77 V, Iout = 4 A, Vds_sec (max) = 155 V

Conducted EMI Scans



Input: AC 115 V 60 Hz, Output: DC 77 V 4 A



Input: AC 230 V 50 Hz, Output: DC 77 V 4 A

Thermal Measurements

Open Air Thermal Tests

The key component temperatures with the adaptor running at 250W are shown for operating conditions below after 60min bake time. PCBA does not have any enclosure and is tested open air on bench, like the left picture under the test setup section.

Vin (V)	Iout (A)	Po (W)	T_D3	T_Q1	T_D2	T_Q2	T_XF	T_Q4	T_L3	T_L1	T_L2	T_amb
90	3.270	252.59	117.0	97.0	99.4	105	103.8	102.7	97.1	107.8	120.8	21.4
100	3.272	252.72	107.3	89.1	94.7	106.5	104.2	101.3	98.7	93.3	107.1	21.4
115	3.272	252.73	98.9	83.4	88.0	99.7	104.6	95.7	96.3	90.3	94.1	21.2
230	3.244	250.55	78.0	80.5	76.0	97.8	104.3	100.3	97.7	83.7	70.6	21.2
264	3.242	250.41	66.7	67.0	71.0	96.2	105.2	100.8	98.0	72.8	61.0	21.2

Data of 10- and 20-minute thermal runs are collected for 300 W with Vin = 115 V typical line voltage below. PCBA does not have any enclosure and is tested open air on bench, like the left picture under the test setup section. With a high line of 230 V, components in PFC section should run cooler while components from LLC section should stay the same.

Vin (V)	Iout (A)	Po (W)	T_D3	T_Q1	T_D2	T_Q2	T_XF	T_Q4	T_L3	T_L1	T_L2	T_amb	Time (minutes)
115	3.987	305.0	90.0	68.0	78.6	76.4	78.0	79.1	72.5	61.9	90.3	21.1	10
115	3.976	304.1	103.3	83.7	94.2	96.8	94.5	96.3	93.1	81.1	92.9	21.1	20

Thermal Tests within an Enclosure

Below picture shows the adaptor enclosed by a plastic box. Input, output, and thermal couple wires are routed outside the box. Both input and output holes of the plastic box are then sealed by electrical tape. Inside the box, thermal gap filler material is placed between the adaptor and the plastic box to bridge the heat from adaptor components to surface of the box. Below is test data under high line 230 V 50 Hz.

Vin (V)	Iout (A)	Pout (W)	T_D3	T_Q1	T_L1	T_Q2	T_XF	T_Q4	T_L3	T_box	T_amb	Time (Hour)
230	3.293	253.5	69.4	74.0	75.9	94.2	94.0	94.8	95.0	58.6	18.6	1.0
230	3.963	301.4	80.7	84.9	88.4	110.3	111.1	110.4	111.7	68.4	18.9	1.5

Below is the picture of the thermal test setup for the box.

Please note that we attempt to collect the above thermal data both in open air and within enclosure at worst adaptor working conditions. Battery charger and LED driver application scenarios may not fall into all such worst scenarios. For example, PFC components work harder at low line. There are applications that are high line only. Battery charging may only demand high current at low battery voltage and start to reduce charging current when battery voltage is high enough. In such a scenario, total power requirement can be much lower than 300 W.

The above thermal data indicates that PFC components at low line and LLC magnetic components at high power are at their limitations. With re-designing of magnetic components and further debugging effort, we can improve the situation.

Revision History Revision

Hardware Info

Info	Value
Timestamp	March 27, 2023
Primary Side IC	NCP1654, NCP1399
Key FETs	Transphorm 650 V SuperGaN™ FET (TP65H070G4PS)
Secondary Side IC	MP6924A, AP4310A, NCS20071
AC Supply	Chroma Programable AC Source, 61601
Input Meter	Chroma digital power meter 66202
Output Meter	Chroma digital power meter 66202
Oscilloscope	Tektronix MDO3014
No-load bake time	30
Input voltages	[(90, 60), (115, 60), (230, 50), (264, 50)]
Output voltages	[40~77]
Electronic Load	ET5411