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TDAIO-TPH-MPS-CCCV-600W-RD Design Guide

Battery Charger Power Adapter Description

This design guide of the 58 V 11.4 A Constant Current (CC) Constant Voltage (CV) universal input line voltage AC-DC battery charger reference board describes a 600 W PFC+LLC implementation with peak efficiency of ~94%, using 3 Transphorm GaN TP65H070G4PS and TP65H150G4PS (650 V SuperGaN FET) TO-220 with Transphorm's latest SuperGaN® Gen IV technology, and Monolithic Power Systems (MPS) HR1211 PFC+LLC combo controller. 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 good 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	34 V ~ 58 V
Max Output Current	11.4 A
Max Output Power	660 W
Efficiency	~94.4% Full Power Efficiency @ 264 V

Features

- Transphorm SuperGaN® TP65H070G4PS TO-220 x 1 and TP65H150G4PS TO-220 x 2
- DCM/CCM PFC + LLC topology
- Board-end ~92.5% Peak Efficiency (115 Vac)
- Flat Efficiency Across Universal (90-264 Vac)Input Voltage and Load
- Tight Switching Frequency Regulation forImproved Input EMI Filter Utilization
- Up to 120 kHz Switching Frequency Operation
- OTP, UVLO, OCP, OSC, and Output Reverse Polarity Protections
- Up to 600 W Output Power

Applications

- 2-Wheeler or 3-Wheeler Battery Charger
- High-Power-Density AC/DC Battery Chargers (CCCV)
- High-Power-Density AC/DC CV PowerSupplies
- High-Power-Density AC/DC LED Dimmable Drivers
- Gaming Devices
- Fast charging
- Laptops and IoT devices

Warning

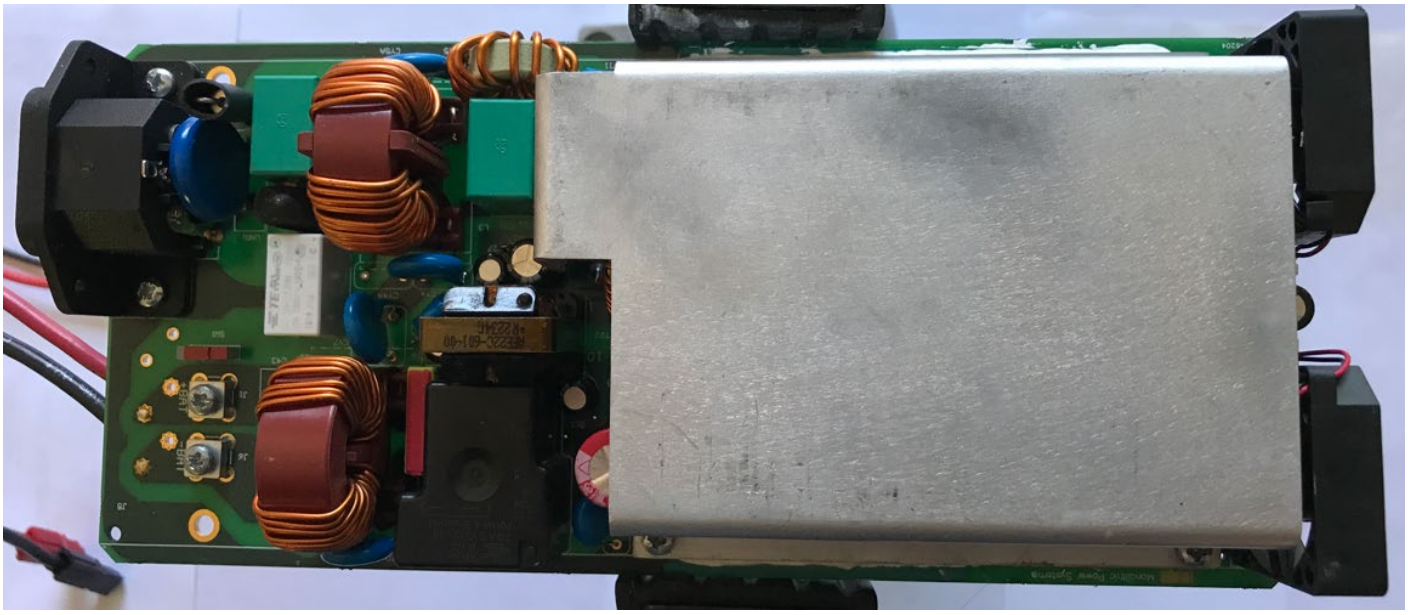
The DC bus voltage on DC link bulk cap is NOT discharged after powering off. It stays at high voltage for a long time. For safe handling, please discharge this DC bus voltage after powering down.

Disclaimers:

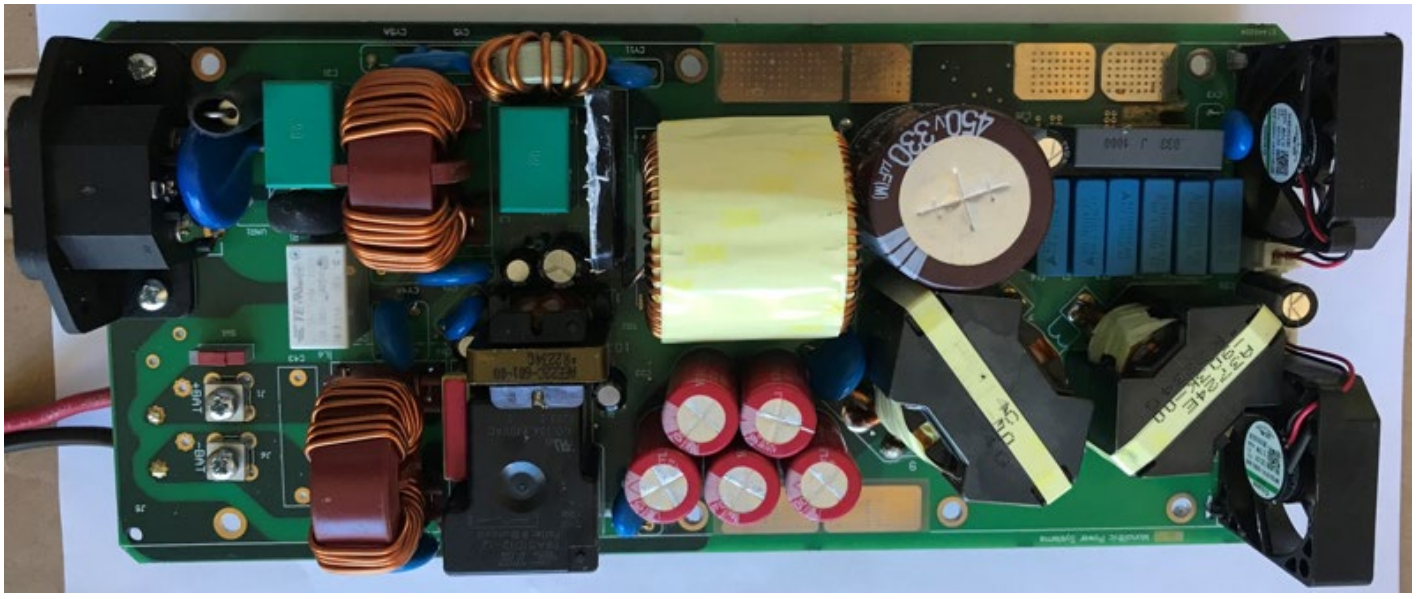
1. **Caution – High Voltage Operation: Lethal high voltages are present when this evaluation board ispowered from AC mains. Improper contact with high voltages could lead to electrical shock, burn and/or fire hazards, risking property damage, personal injury, and death.**
2. **Evaluation Purpose Only: 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 byone or more U.S. and foreign existing/pending patents.**

Table of Contents

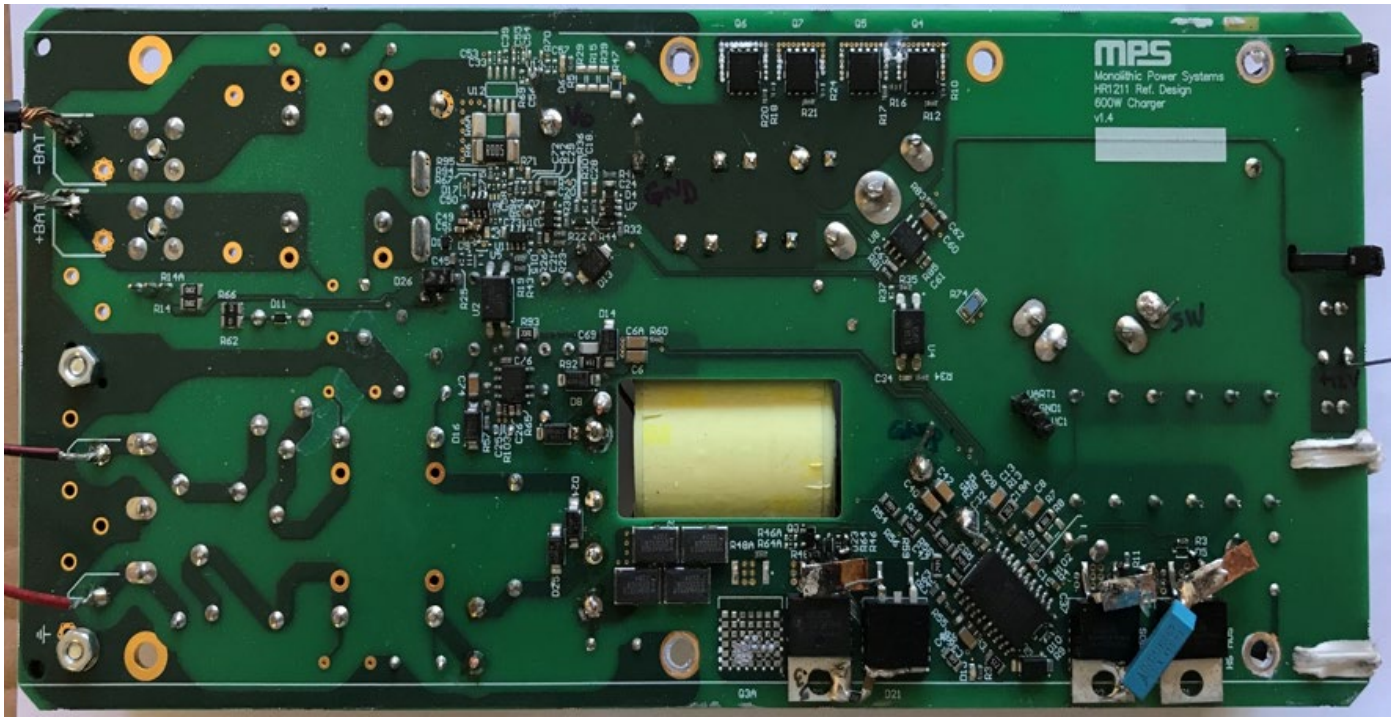
Battery Charger Board Pictures



Top Side of the EVB with Heatsink



Top Side of the EVB without Heatsink

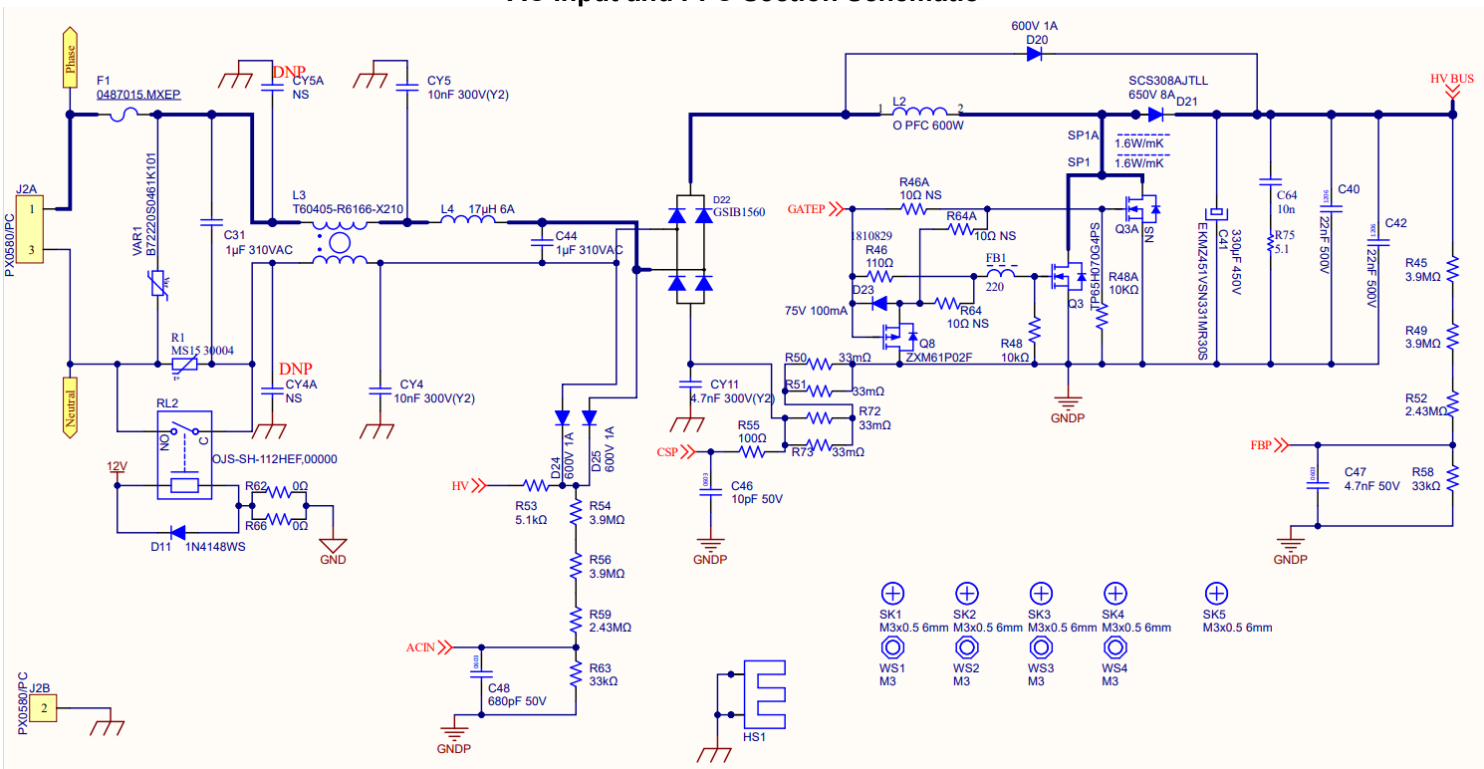


Bottom Side of the EVB

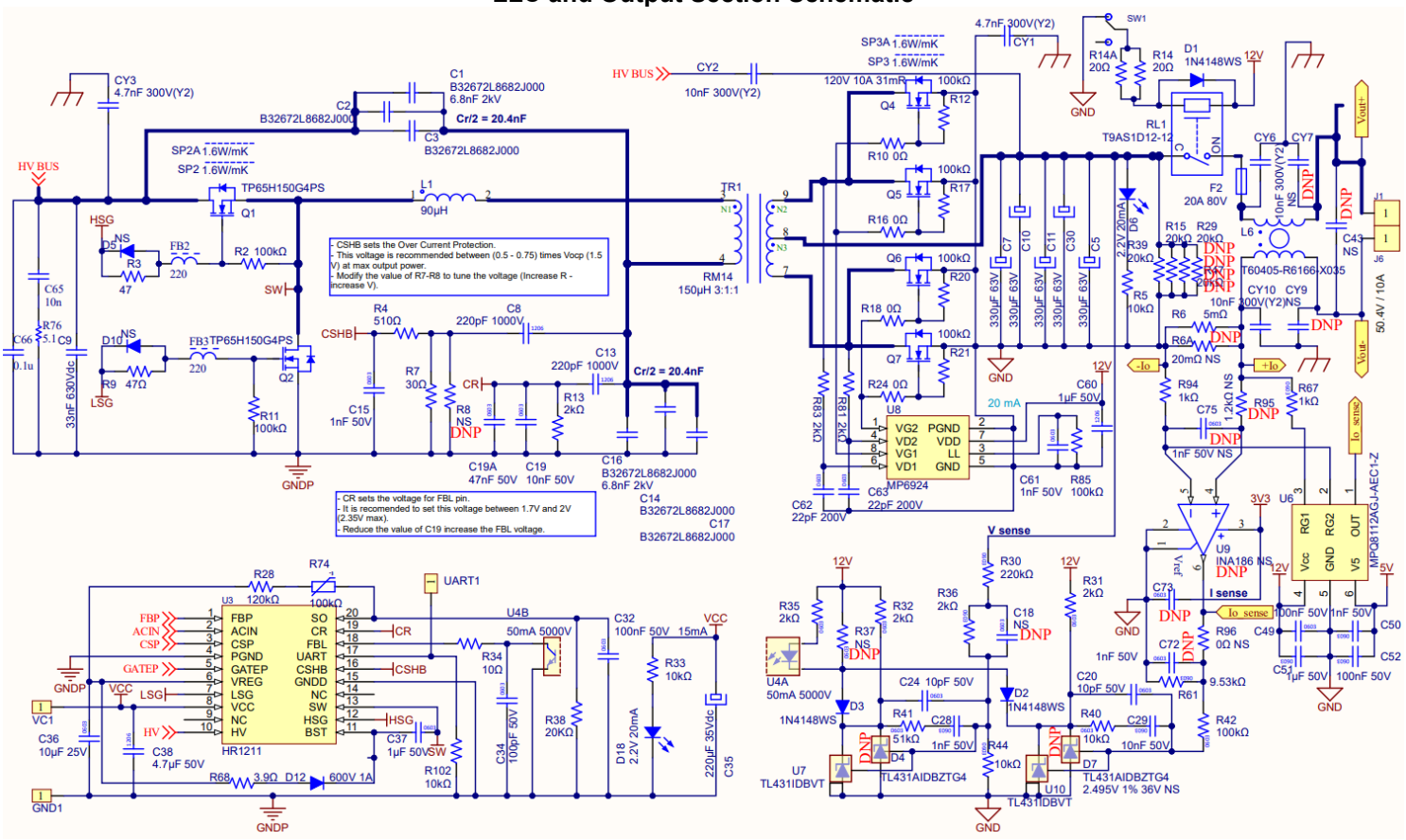
Dimensions of PCB board: 220 mm x 100 mm x 40 mm.

Schematic

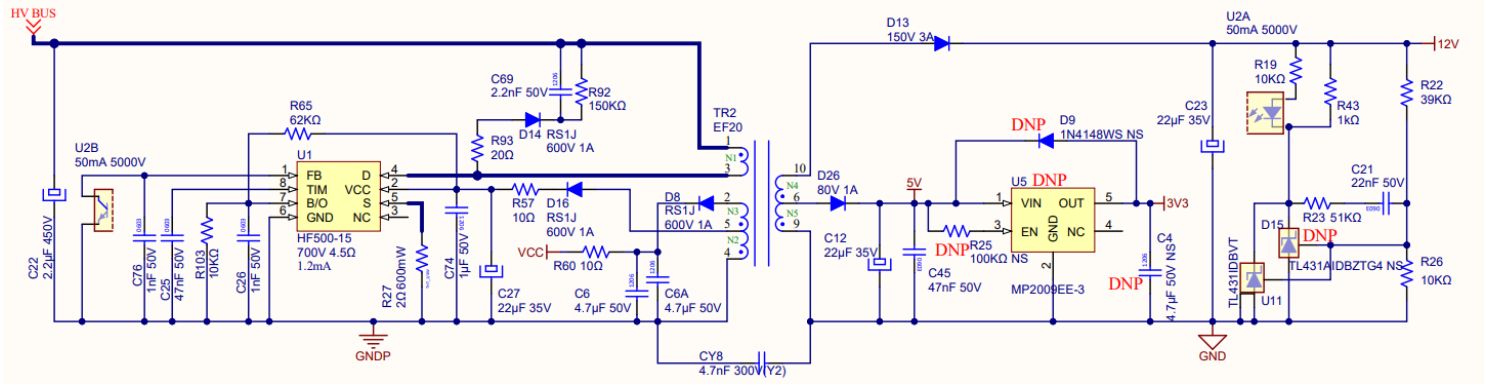
AC Input and PFC Section Schematic



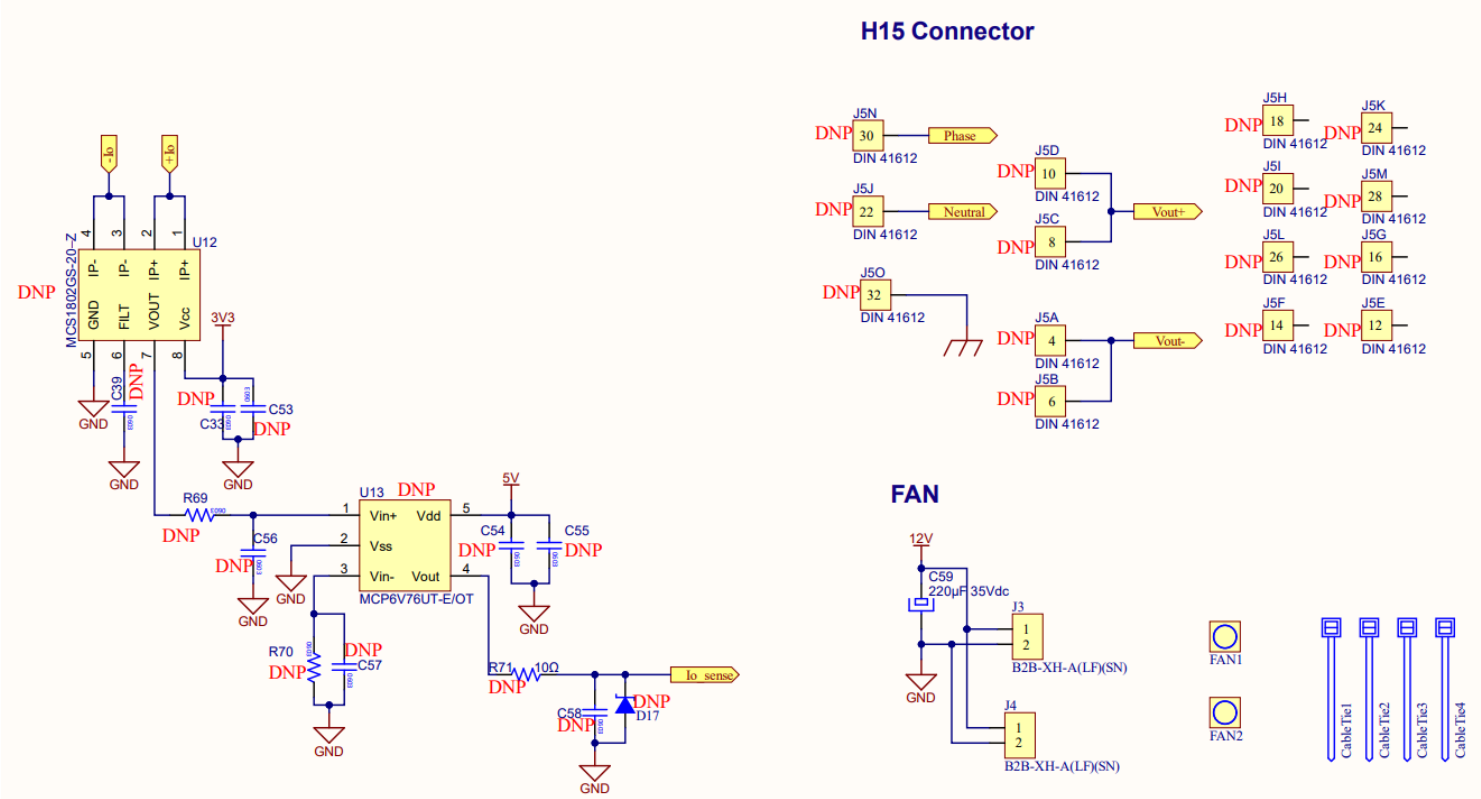
LLC and Output Section Schematic



Flyback Auxiliary Power Supply Section Schematic



Fan 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.

Inrush Protection

The design has NTC thermistor R1 and a relay RL2 for inrush current control at cold start.

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 two X-capacitors (C31 and C44) and one common-mode choke (L3) and one inductor L4.

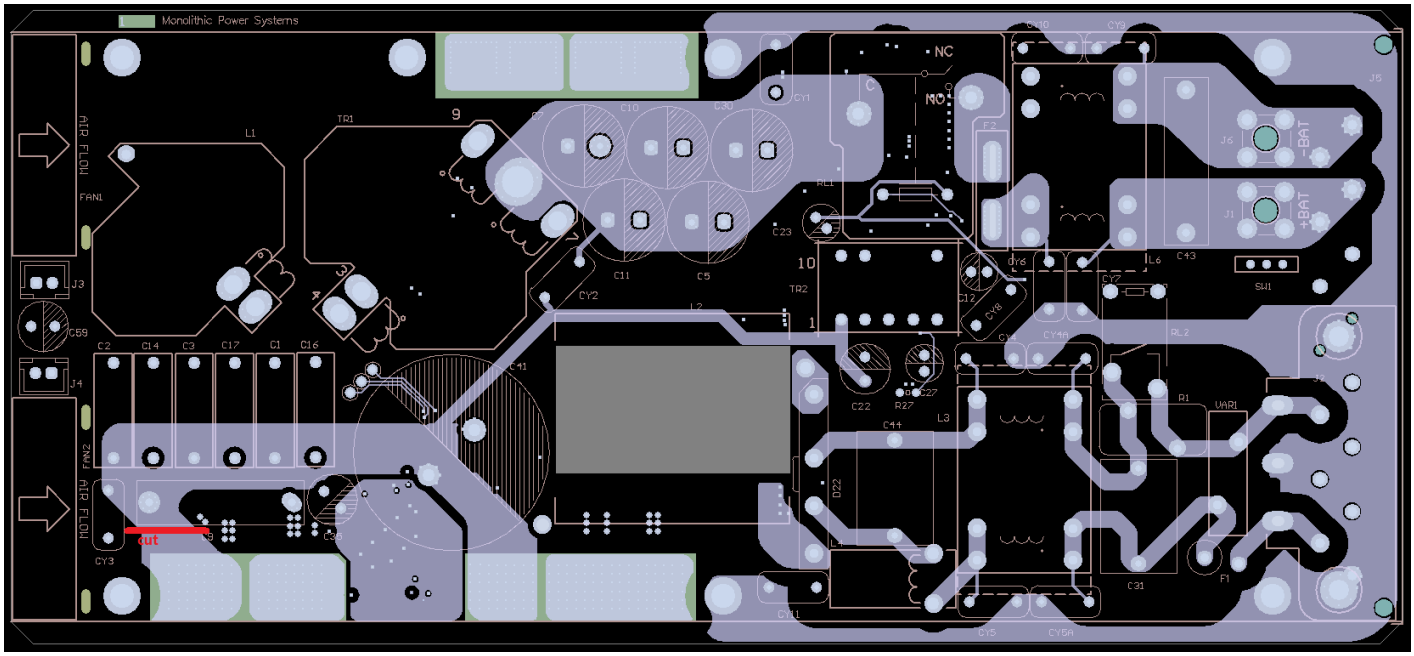
Fault Protections

Table 1: Recovery Behavior

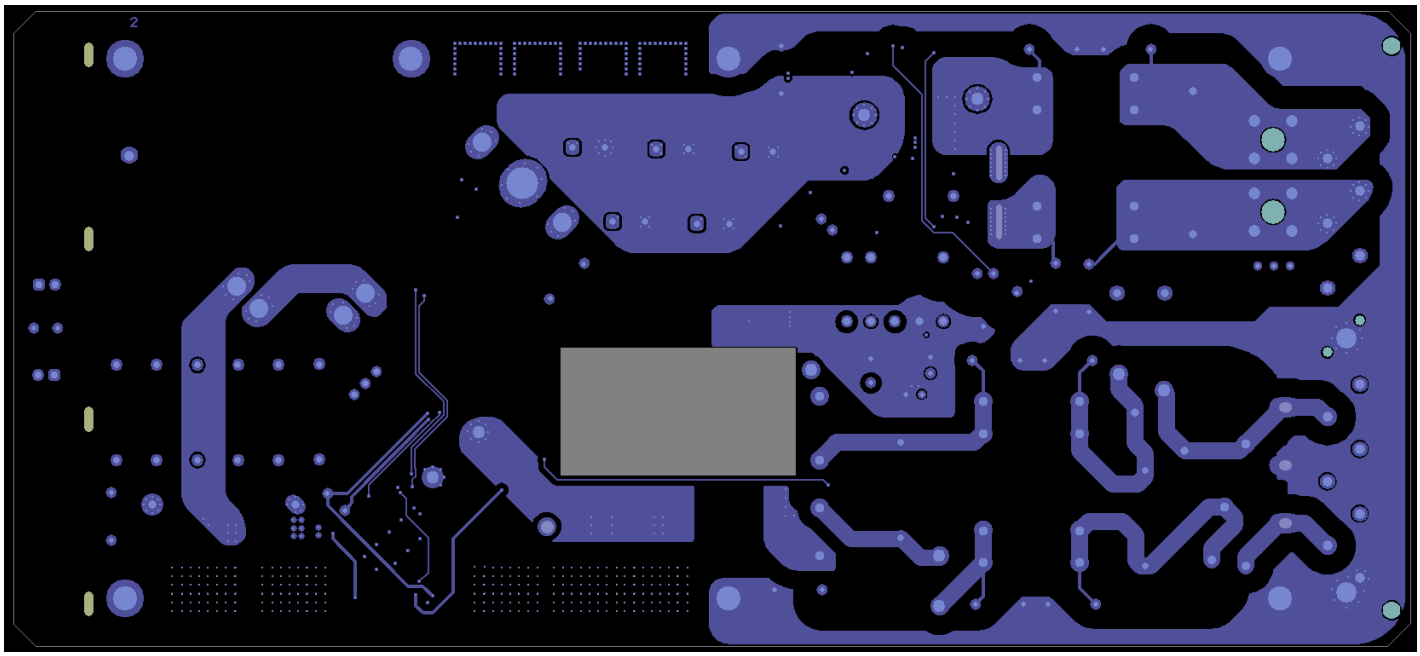
Fault Protection	Response
Input Under Voltage Lockout (UVLO)/ Brown-Out	Auto-Recovery
Input Surge Protection	VAR1 Populated on PCB
Over-Current Protection (OCP)	Self-clamping
Output Short Circuit (OSC)	Auto-Recovery
Bus Over Voltage (OVP)	Populated on PCB
Output Load Polarity Reversed	Auto-Recovery

PCB Layout

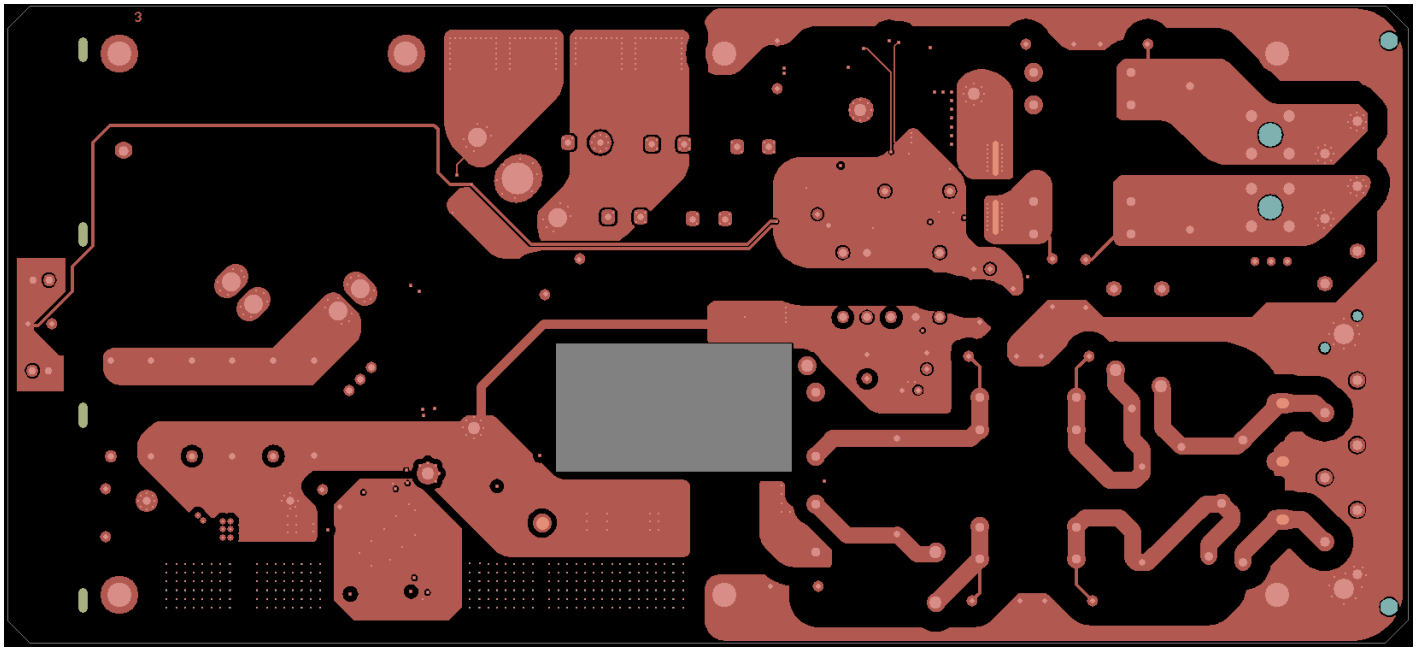
Top (modified with 1 trace cut)



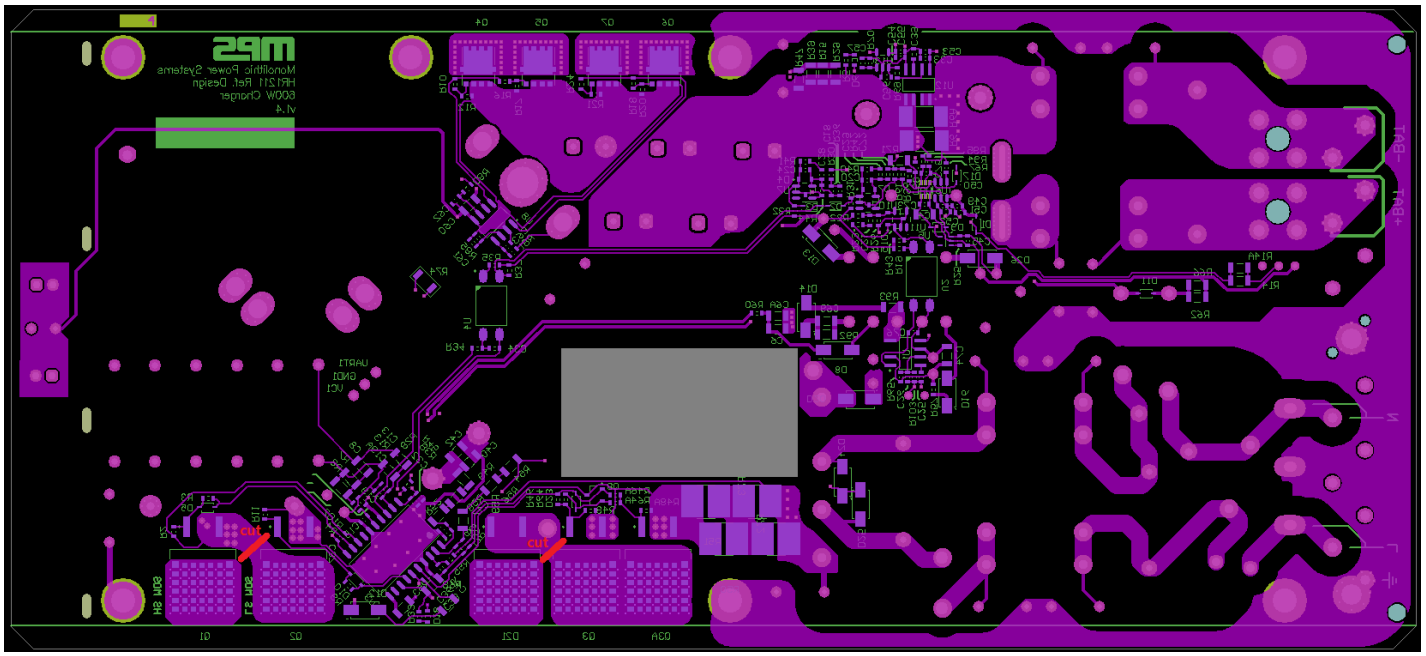
Inner 1



Inner2



Bottom (modified with 2 trace cuts)



Component modifications on bottom layers:

1. Cut 1 thick trace on top layer and 2 thick traces on bottom layer. Cut width > 1 mm.
2. Mount Q1/Q2 (TP65H150G4PS TO-220) and Q3 (TP65H070G4PS TO-220) like TO-252/TO-263 (SMT) on bottom layer.
3. Reconnect Q1 source to Q2 drain with wide (~4 mm) copper strip. Reconnect Q1 drain to C9 HV BUS terminal with wide ~ 4 mm copper strip. Solder snubber R76/C65 and film cap C66 across and on top of Q1/Q2.
4. Remove D5/D10. Change R3/R9 to 47 Ω. Add FB2/FB3 to gates of Q1/Q2

5. Reconnect Q3 drain to D21 anode with wide ~ 4 mm copper strip. Solder snubber R75/C64 across and on top of Q3 and D21.
6. Remove R46A/R64A/R64. Change R46 to 110 Ω and add FB1 between R46 and Q3 gate.

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

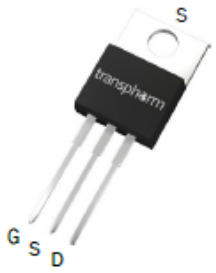
Related Literature

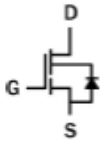
- AN0009: Recommended External Circuitry for GaN FETs
- AN0003: Printed Circuit Board Layout and Probing
- AN0010: Paralleling GaN FETs
- AN0014: Low cost driver solution

Ordering Information

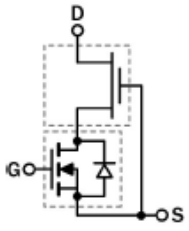
Part Number	Package	Package Configuration
TP65H070G4PS	3 lead TO-220	Source

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

RoHS HALOGEN FREE

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

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TP65H150G4PS

650V SuperGaN® GaN FET in TO-220 (source tab)

Description

The TP65H150G4PS 650V, 150mΩ 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.

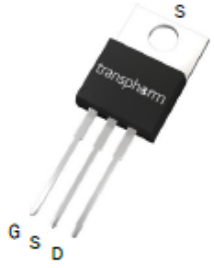
Related Literature

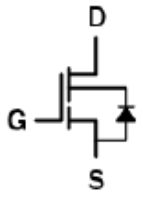
- AN0003: Printed Circuit Board Layout and Probing
- AN0007: Recommendations for Vapor Phase Reflow
- AN0009: Recommended External Circuitry for GaN FETs
- AN0014: Low cost driver solution

Product Series and Ordering Information

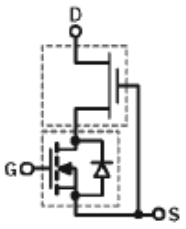
Part Number	Package	Package Configuration
TP65H150G4PS	3 lead TO-220	Source

TP65H150G4PS
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
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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

- Consumer
- Power adapters
- Low power SMPS
- Lighting

Key Specifications	
V_{DS} (V) min	650
$V_{DSS(TR)}$ (V) max	800
$R_{DS(on)}$ (mΩ) max*	180
Q_{oss} (nC) typ	34
Q_G (nC) typ	8

* Dynamic $R_{DS(on)}$; see Figures 18 and 19

Apr. 4, 2023
tp65h150g4PS.2v0

Bill of Materials (BOM)

Quantity	Designator	Value	Description	Package	Manufacturer	Manufacturer PN
6	C1, C2, C3, C14, C16, C17	6.8nF 2kV	6n8 6x11x18 2kV r15	r15 18x6	TDK	B32672L8682J000
1	C4	4.7µF 50V NS	10uF	1206	MURATA	GRM319R61H475KA12D
5	C5, C7, C10, C11, C30	330µF 63V	330uF 63V	r5 d13	WURTH	860080778021
3	C6, C6A, C38	4.7µF 50V	10uF	1206	MURATA	GRM319R61H475KA12D
2	C8, C13	220pF 1000V	220pF	1206	MULTICOMP	MC1206B221K102CT
1	C9	33nF 630Vdc	33nF 630Vdc	r22.5 26.5x16	KEMET	R73QN23304030J
3	C12, C23, C27	22µF 35V	Capacitor 22µF 35V	r2.54 d6.3	UNITED CHEMI CON	EFL-350ELL220MF07D
7	C15, C26, C28, C50, C61, C72, C76	1nF 50V	1nF, 100nF	0603	KEMET	C0603X102K5RAC3316
2	C18, R37	NS		0603	-, [NoValue]	NS
3	C19, C29, C58	10nF 50V	1nF, [NoValue]	0603	AVX	06035C103JAT2A
3	C19A, C25, C45	47nF 50V	1nF	0603	KEMET	C0603C473K5RACTU
3	C20, C24, C46	10pF 50V	10pF	0603	AVX	06035A100JAT2A
1	C21	22nF 50V	1nF	0603	KEMET	C0603C223K5RACAUTO
1	C22	2.2µF 450V	Capacitor 2.2µF 450V	r3.5 d8	UNITED CHEMI CON	ESMQ451ELL2R2MHB5D
2	C31, C44	1µF 310VAC	1uF/310Vac X2-Class	20x18x12mm	Kemet	F861BZ105M310A
8	C32, C33, C49, C52, C55, C56, C57, C73	100nF 50V	100nF, 1nF	0603	KEMET	C0603X104K5RAC3316
1	C34	100pF 50V	10pF	0603	AVX	06035A101JAT2A
2	C35, C59	220µF 35Vdc	Capacitor 220µF 35Vdc	r3.5 d8	RUBYCON	35ZL220MEFC8X16
1	C36	10µF 25V	470nF	0603	TDK	C1608X5R1E106M080AC
3	C37, C51, C53	1µF 50V	470nF	0603	TAYO YUDEN	UMK107BJ105KA-T
1	C39	4.7 nF 50V		0603	YAGEO	CC0603KRX7R9BB472
2	C40, C42	22nF 500V	22nF	1206	KEMET	C1206V223KCRACTU
1	C41	330µF 450V	330uF 450V	r10 d30	UNITED CHEMI CON	EKMZ451VSN331MR30S
1	C43	NS	33nF 1000Vdc	r22.5 26.5x16	KEMET	NS
1	C47	4.7nF 50V	680pF	0603	AVX	06035C472KAT2A
1	C48	680pF 50V	680pF	0603	KEMET	C0603C681J5GACTU
1	C54	1nF 50V	100nF	0603	KEMET	C0603X102K5RACTU
2	C60, C74	1µF 50V	100nF, 1uF	1206	KEMET	C1206C105K5RECTU
2	C62, C63	22pF 200V	1nF	0603	KEMET	C0603C220J2GACTU
2	C64, C65	10nF 630V	CL31B103KHFNNNE 10000 pF ±10% 630V Ceramic Capacitor X7R 1206 (3216 Metric)	1206	Samsung Electro-Mechanics	CL31B103KHFNNNE
1	C66	0.1uF 450V	B32671P4104K000 CAP FILM 0.1UF 10% 450VDC RADIAL	Radial 13mm	EPCOS - TDK Electronics	B32671P4104K000
1	C69	2.2nF 50V	22nF	1206	KEMET	C1206C222K5RACTU
1	C75	1nF 50V NS	1nF	0603	KEMET	C0603X102K5RAC3316
4	CableTie1, CableTie2, CableTie3, CableTie4	Cable tie 100mmx2.5mm	Cable Tie 100x2.5mm Nylon	100mmx2.5mm	RSComponents	233-499
4	CY1, CY3, CY8, CY11	4.7nF 300V(Y2)	4.7nF/300Vac Y-Class	r7.5	KEMET	C947U472MZVDBA7317
5	CY2, CY4, CY5, CY6, CY10	10nF 300V(Y2)	4.7nF/300Vac Y-Class	r7.5	KEMET	C981U103MZVDBA7317
4	CY4A, CY5A, CY7, CY9	NS	4.7nF/300Vac Y-Class	r7.5	KEMET	NS
6	D1, D2, D3, D9, D11, D23	75V 100mA	1N4148 miniMelf Series 500 mW 100 V Max Reverse Voltage 200 mA Small Signal Diode -	SOD-323F	ON SEMICONDUCTOR	1N4148WS
2	D4, D7	2.495V 1% 36V NS	TL43xx Precision Programmable Reference	SOT-23-3	TEXAS INSTRUMENTS	TL431AIDBZR
2	D5, D10	NS	1N4148 miniMelf Series 500 mW 100 V Max Reverse Voltage 200 mA Small Signal Diode -	SOD-323F	ON SEMICONDUCTOR	1N4148WS
2	D6, D18	2.2V 20mA	LED, 0603, Green SMD, 20 mA, 2.2 V, 560 nm	0603	ROHM	SML-D12P8WT86C
7	D8, D12, D14, D16, D20, D24, D25	600V 1A	Fast Rectifier 600 V, 1 A, 1.3 V, 250 ns, 30 A	DO-214AC	ON SEMICONDUCTOR	RS1J

Quantity	Designator	Value	Description	Package	Manufacturer	Manufacturer PN
1	D13	150V 3A	Fast Rectifier 600 V, 1 A, 1.3 V, 250 ns, 30 A	DO-214AC	DIODES INC.	STPS3150U
1	D15	2.495V 1% 36V	TL43xx Precision Programmable Reference	SOT-23-3	TEXAS INSTRUMENTS	TL431AIDBZR
1	D17	5.1V 500mW	D Z 5.1V 500mW			
1	D21	650V 8A	D 650 V, 8 A, 1.35 V	TO-263	ROHM	SCS308AJTLL
1	D22	600V 15A	Diode Bridge	GSIB15	Vishay General Semiconductor	GSIB1560-E3/45
1	D26	80V 1A	Fast Rectifier 600 V, 1 A, 1.3 V, 250 ns, 30 A	DO-214AC	DIODES INC.	B180-13-F
1	F1	15A 450V	Fuse 250Vac/20A	5mmx20mm	LITTLEFUSE	0487015.MXEP
1	F2	20A 80V	Fuse, PCB, 20A, 80Vdc, FKS ATO	FKS ATO	LITTLEFUSE	166.7000.5202
2	FAN1, FAN2	Ventiladores CC Fan	FAN 35x35x10	35mmx35mmx10 mm	Sunon	MF35101V1-1000U-A99
3	FB1, FB2, FB3	220OHM @100MHz	0603 ferrite bead 220ohm@100MHz	RESC1608X06N	Murata Electronics	BLM18AG221SN1D
1	HS1	Custom heatsink	Heatsink 95x93x36mm	95x93x36mm	MPS	MPS600W
2	J1, J6	50A	Connector	M3	WE	74650073R
1	J2	10A	CON 250V 10A IEC 14	AC Power 3 pins connector	Bulgin	PX0580/PC
2	J3, J4	250VAC/DC 3A Connector	Connector 2 poles	Through-hole type shrouded header	JST	B2B-XH-A(LF)(SN)
1	J5	Type D	DIN 41612 Right Angle 15A	H15	HARTING	09 06 115 2932
1	L1	90µH	Custom Inductor 90µH	RM12	MPS	RM12-L1
1	L2	300µH	IND 300uH O 35x25 V 3 núcleos	35x25	MPS	3525-L2
1	L3	2x11.4mH 10A	CM Filter VAC 2x11.7mH@10kHz 12A	37x35x21mm	VAC	T60405-R6166-X210
1	L4	17µH 6A	Custom Inductor 17µH 6A	16,8mmx10mm	Custom	1610-L4
1	L6	2x11.7mH 12A	CM Filter VAC 2x11.7mH@10kHz 12A	38x29.1x21mm	VAC	T60405-R6166-X035
2	Q1, Q2	TP65H150G4PS	TPH GaN 150mOHM	TO-220	Transphorm	TP65H150G4PS
1	Q3	TP65H070G4PS	TPH GaN 70mOHM	TO-220	Transphorm	TP65H070G4PS
1	Q3A	NS	TPH GaN 70mOHM	TO-220	Transphorm	TP65H070G4PS
4	Q4, Q5, Q6, Q7	120V 10A 31mR	NMOS 120V 10A 31mR	PQFN-8	INFINEON	IRFH5015TRPBF
1	Q8	20V 0.9A	PMOS -20V 0.9A 600 mohm	SOT-23-3	DIODES INC.	ZXM61P02F
1	R1	30Ω	NTC	MS15	AMETHERM	MS15 30004
8	R2, R11, R12, R17, R20, R21, R42, R85	100kΩ	Resistor 0603	0603	TE CONNECTIVITY	CRGCQ0603F100K
1	R3	47	Resistor 0603	1206	YAGEO	RC1206JR-070RL
1	R4	510Ω	Resistor 0603	0603	VISHAY	CRCW0603510RFKEA
10	R5, R19, R26, R33, R40, R44, R48, R48A, R102, R103	10kΩ	Resistor 0603	0603	TE CONNECTIVITY	CRGCQ0603J10K
1	R6	5mΩ	Resistor 2512	2512	OHMITE	PCS2512FR0050ET
1	R6A	20mΩ NS	Resistor 2512	2512	OHMITE	PCS2512DR0200ET
1	R7	30Ω	Resistor 1206	1206	MULTICOMP	MCWR12X30R0FTL
1	R8	NS	Resistor 1206	1206	-	NS
1	R9	47Ω	Resistor 0603	1206	YAGEO	RC1206JR-070RL
7	R10, R16, R18, R24, R62, R66, R69	0Ω	Resistor 0603, Resistor 1206, [NoValue]	1206	YAGEO	RC1206JR-070RL
1	R13	2kΩ	Resistor 1206	1206	TT ELECTRONICS	WCR1206-2KFI
3	R14, R14A, R93	20Ω	Resistor 1206	1206	YAGEO	RC1206JR-0720RL
4	R15, R29, R39, R47	20kΩ	Resistor 1206	1206	YAGEO	RC1206JR-0720KL
1	R22	39KΩ	Resistor 0603	0603	TE CONNECTIVITY	CRGCQ0603F39K
2	R23, R41	51KΩ	Resistor 0603	0603	VISHAY	CRCW060351K0FKEA
1	R25	100KΩ NS	Resistor 0603	0603	TE CONNECTIVITY	CRGCQ0603F100K
1	R27	2Ω 600mW	THT 1/4W	MRS25	VISHAY	MRS25000C2008FCT00
1	R28	120kΩ	Resistor 0603	0603	YAGEO	RC0603FR-07120KL
1	R30	220kΩ	Resistor 0603	0603	TE CONNECTIVITY	CRGCQ0603F220K
6	R31, R32, R35, R36, R81, R83	2kΩ	Resistor 0603	0603	VISHAY	CRCW06032K00FKEAHP
3	R34, R57, R60	10Ω	Resistor 0603	0603	VISHAY	CRCW060310R0FKEA
1	R38	20KΩ	Resistor 0603	0603	YAGEO	RC0603FR-0720KL
3	R43, R67, R94	1kΩ	Resistor 0603	0603	YAGEO	RC0603JR-071KL
4	R45, R49, R54, R56	3.9MΩ	Resistor 1206	1206	YAGEO	RC1206FR-073M9L
1	R46	110Ω	Resistor 0603	0603	VISHAY	CRCW060310R0FKEA
3	R46A, R64, R64A	10Ω NS	Resistor 0603	0603	VISHAY	CRCW060310R0FKEA
4	R50, R51, R72, R73	33mΩ	SMD Resistor	2818	VISHAY	WSHM2818R0330FEB
2	R52, R59	2.43MΩ	Resistor 1206	1206	YAGEO	RC1206FR-072M43L
1	R53	5.1kΩ	Resistor 1206	1206	TT ELECTRONICS	WCR1206-5K1FI
1	R55	100Ω	Resistor 0603	0603	VISHAY	CRCW0603100RFKEA
2	R58, R63	33kΩ	Resistor 0603	0603	YAGEO	AC0603FR-0733KL

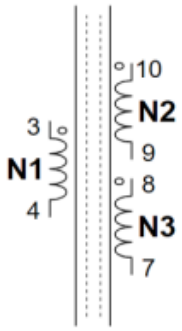
Quantity	Designator	Value	Description	Package	Manufacturer	Manufacturer PN
1	R61	9.53kΩ	Resistor 0603	0603	YAGEO	RC0603FR-079K53L
1	R65	62KΩ	Resistor 0603	0603	VISHAY	CRCW060362K0FKEA
1	R68	3.9Ω	Resistor 1206	1206	VISHAY	CRCW12063R90FKEAHP
1	R70	10.2kΩ		0603	YAGEO	RC0603FR-0710K2L
1	R71	10Ω	Resistor 1206	1206	YAGEO	RC1206JR-0710RL
1	R74	100kΩ	NTC	1206	VISHAY	NTHS1206N17N1003JE
2	R75, R76	5.1 OHM	RES 5.1 OHM 1% 1/4W 1206	1206	Yageo	RC1206FR-075R1L
1	R92	150KΩ	Resistor 1206	1206	TE CONNECTIVITY	CRGCQ1206F150K
1	R95	1.2kΩ NS	Resistor 0603	0603	TE CONNECTIVITY	CRGCQ0603F1K2
1	R96	0Ω NS	Resistor 0603	1206	YAGEO	RC1206JR-070RL
1	RL1	12Vdc 30A	Relay 5VDC 30A	27.9x32.5x27.4mm	TE CONNECTIVITY	T9AS1D12-12
1	RL2	12V 10A	Relay	1 Form A	OEG - TE CONNECTIVITY	OJ-SH-112HM,000
5	SK1, SK2, SK3, SK4, SK5	M3x0.5 6mm	Screw M3x6	M3	KEYSTONE	9191-4
6	SP1, SP1A, SP2, SP2A, SP3, SP3A	1.6W/mK	Sil-Pad 2000 thermic isolation	SIL-Pad	BERGQUIST	HF300P-0.001-00-0404
1	SW1	12VDC 0.5A switch	2 contact switch	WS-SLTV	WE	450301014042
1	TR1	150µH 3:1:1	Custom transformer 150µH 3:1:1	RM14	MPS	RM14 - TR1
1	TR2	8.6mH 4.5:1	Custom transformer 8.6mH 4.5:1	EF20	MPS	EF20 - TR2
1	U1	700V 4.5Ω	Flyback Controller	SOIC-8	MPS	HF500GS-15
2	U2, U4	50mA 5000V		SMD-4	ON SEMICONDUCTOR	FOD817A3SD
1	U3	PFC + LLC controller	High-Performance Digital PFC+LLC Combo Controller	SOIC-20/TSSOP-20	MPS	HR1211
1	U5	3V 120mA	Ultra-Low-Noise Low-Dropout, 120mA Linear Regulator	5-SC70	MPS	MP2009EE-3
1	U6	Current sensor	High-Side Current-Sense Amplifier	TSOT23-6L	MPS	MPQ8112AGJ-AEC1-Z
3	U7, U10, U11	2.5V reference voltage	TL431 Precision Programmable Reference	SOT-23-5	Texas Instruments	TL431IDBVT
1	U8	35V SR controller	Synchronous rectifier IC	SOIC-8	MPS	MP6924GS
1	U9	25V/V NS		SC70-6	TI	INA186A1IDCKR
1	U12	20 A	Linear Hall-Effect Current Sensor	SOIC-8	MPS	MCS1802GS-20–Z
1	U13	Current sensor	170 µA, 2 MHz Zero-Drift Op Amps	SOT23-5	Microchip	MCP6V76UT-E/OT
1	VAR1	195J 8KA	Varistor (TVS), 460 V, 615 V, Serial B722, 1240 V, Disc 20mm	Disc 20mm	EPCOS	B72220S0461K101
4	WS1, WS2, WS3, WS4	M3	Brass Hex Threaded Standoff	M3 T10mm	HARWIN	R30-1001002

Transformer Specification (TR1)

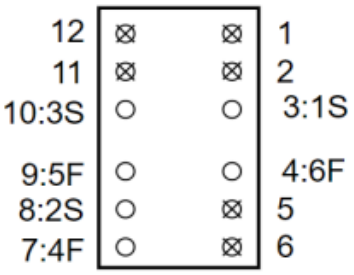
MATERIALS LIST		
Quantity	**Units**	**Description**
1	-	RM14
2	-	Half-core N87 / 3C94
xxx	mm	Gap
-	-	Litz 50x0.2

WINDINGS			Turns	WIRE			PINOUT		TUBE		INSULATORS		ELECTRIC	
#	Start	End		Ø	Class	Color	Start	End	Start	End	Layers	Material	Ω	µH
N1	1S	6F	12	ISO Litz 50x0.2		-	3	4	Yes	Yes	3	Poly.	-	144
N2	2S	4F	4	ISO Litz 50x0.2		-	8	7	Yes	Yes	3	Poly.	-	-
N3	3S	5F	4	ISO Litz 50x0.2		-	10	9	Yes	Yes	3	Poly.	-	-

ELECTRIC SCHEME



BOTTOM VIEW



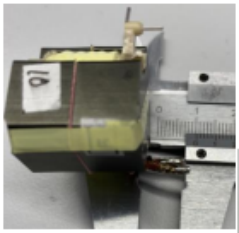
MANUFACTURING NOTES

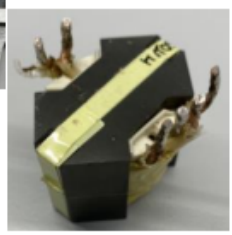
Note 1: Cut pins and plastic for all the terminals.

Note 2: Tin the cable tip and cut 1cm below the core.

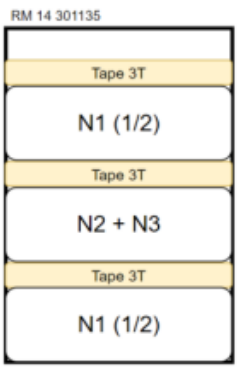
Note 3: Maintain the internal crossing cables within the ferrite free space.

ASSEMBLY DETAILS





WINDOW VIEW



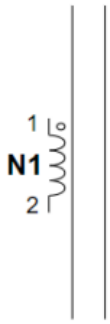
VERIFICATION			
Inductance	144µH (±20%)		
Turns Ratio	n = N1 / N2 = 3		
Dielectric Strengh	**Connect pins**	**Voltage**	**Connect Pins**
	2 and 4	3000VAC	7, 8, 9, and 10

PFC Power Inductor Specification (L2)

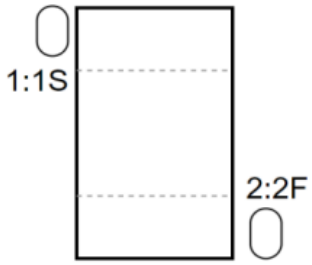
MATERIALS LIST		
Quantity	**Units**	**Description**
2	-	CM330 125
-	-	0.9 Copper cable

WINDINGS			Turns	WIRE			PINOUT		TUBE		INSULATORS		ELECTRIC	
#	Start	End		Ø	Class	Color	Start	End	Start	End	Layers	Material	Ω	µH
N1	1S	2F	34	0.9		-	1	2	No	No	-	-	-	300

ELECTRIC SCHEME



BOTTOM VIEW



MANUFACTURING NOTES

Note 1: Join the two cores with polyester tape.

Note 2: Tin the cable tip and cut 1cm below the core.

ASSEMBLY DETAILS

WINDOW VIEW

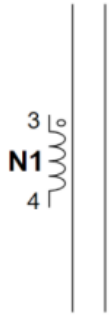
VERIFICATION	
Inductance	300µH (±20%)

L1 spec

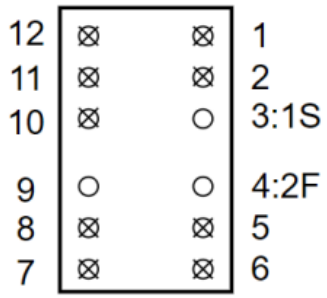
MATERIALS LIST		
Quantity	**Units**	**Description**
1	-	RM12
2	-	Half-core N87 / 3C94
xxx	mm	Gap
-	-	Litz 50x0.2

WINDINGS			Turns	WIRE			PINOUT		TUBE		INSULATORS		ELECTRIC	
#	Start	End		Ø	Class	Color	Start	End	Start	End	Layers	Material	Ω	µH
N1	1S	2F	19	Litz 50x0.2		-	1	2	No	No	3	Poly.	-	90

ELECTRIC SCHEME



BOTTOM VIEW

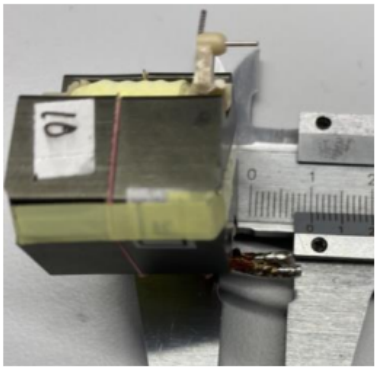


MANUFACTURING NOTES

Note 1: Cut pins and plastic for all the terminals, except pin 9.

Note 2: Tin the cable tip and cut 1cm below the core.

ASSEMBLY DETAILS



WINDOW VIEW

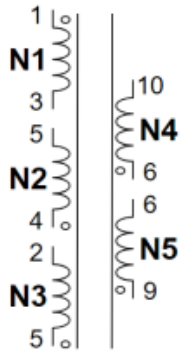
VERIFICATION	
Inductance	90µH (±20%)

TR2 Spec

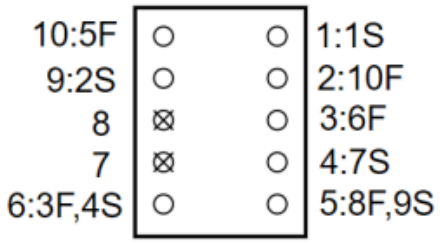
MATERIALS LIST		
Quantity	**Units**	**Description**
1	-	E2005S
2	-	Half-core CF139 (3F3)
-	mm	Gap
-	mm	0.3 Copper cable Triplex
-	mm	0.2 Copper cable

WINDINGS			Turns	WIRE			PINOUT		TUBE		INSULATORS		ELECTRIC	
#	Start	End		Ø	Class	Color	Start	End	Start	End	Layers	Material	Ω	µH
N1	1S	6F	255	0.2		-	1	3	Yes	Yes	3	Poly.	-	8600
N2	7S	8F	57	0.2		-	4	5	Yes	Yes	1	Poly.	-	-
N3	9S	10F	33	0.2		-	5	2	Yes	Yes	1	Poly.	-	-
N5	2S	3F	20	0.3		-	9	6	Yes	Yes	3	Poly.	-	-
N4	4S	5F	26	0.3		-	6	10	Yes	Yes	3	Poly.	-	-

ELECTRIC SCHEME



BOTTOM VIEW



MANUFACTURING NOTES

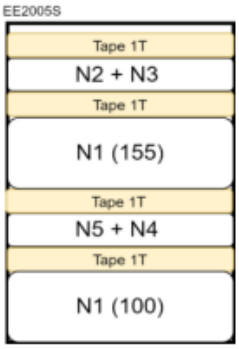
Note 1: Cut pins 7 and 8.

Note 2: Use only the specified polyester tape.

Note 3: Compress the windings if needed.

ASSEMBLY DETAILS

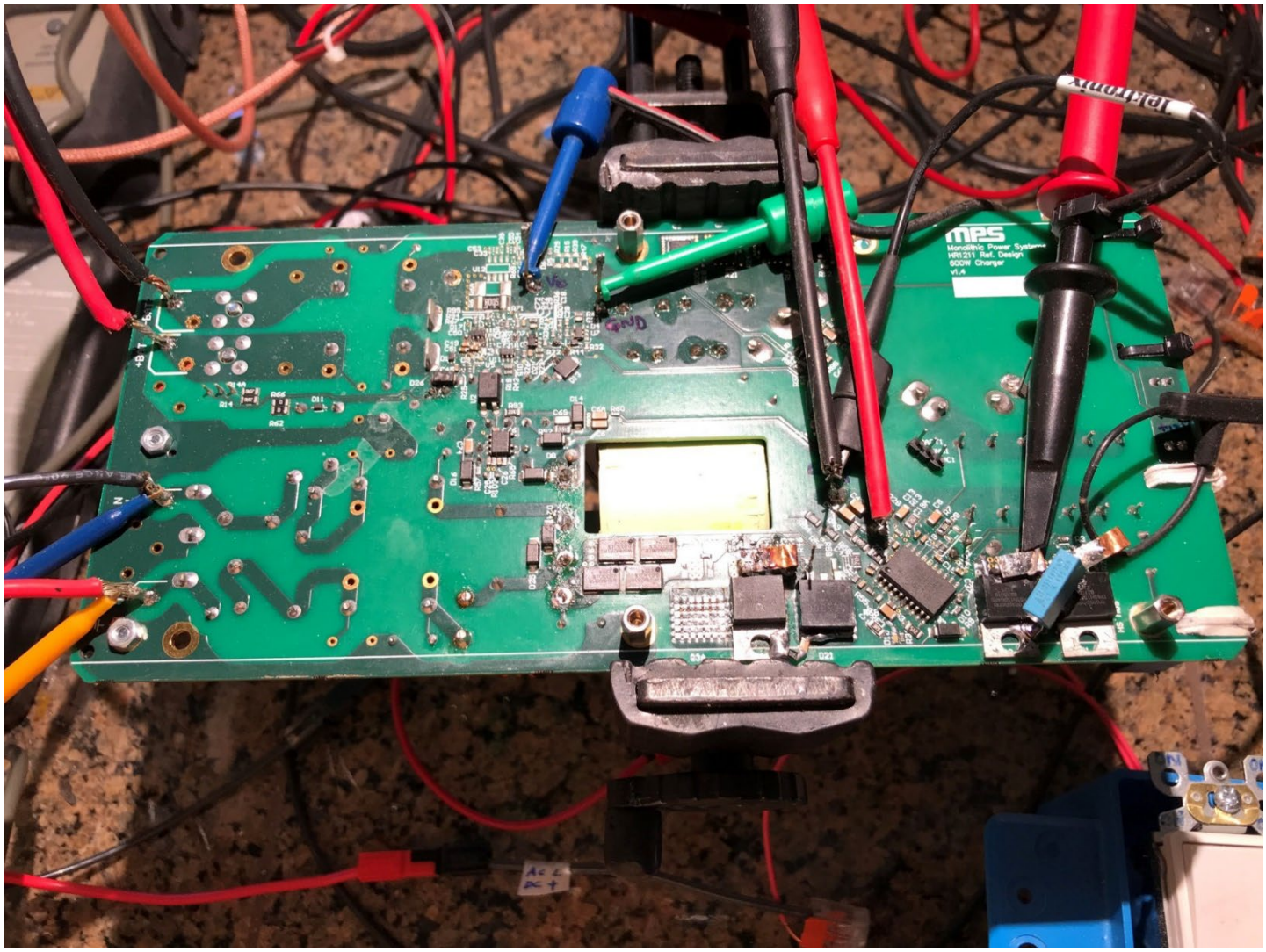
WINDOW VIEW



VERIFICATION			
Inductance	8600µH (±20%)		
Turns Ratio	n = N1 / (N5 + N4) = 5.5		
Dielectric Strengh	**Connect pins**	**Voltage**	**Connect Pins**
	1, 2, 3, 4, and 5	3000VAC	6, 9, and 10

Test Setup

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



The charger is tested by a simulated battery load of a constant voltage load type provided by an electronic load ET5411 in series with a 2 Ω power resistor.

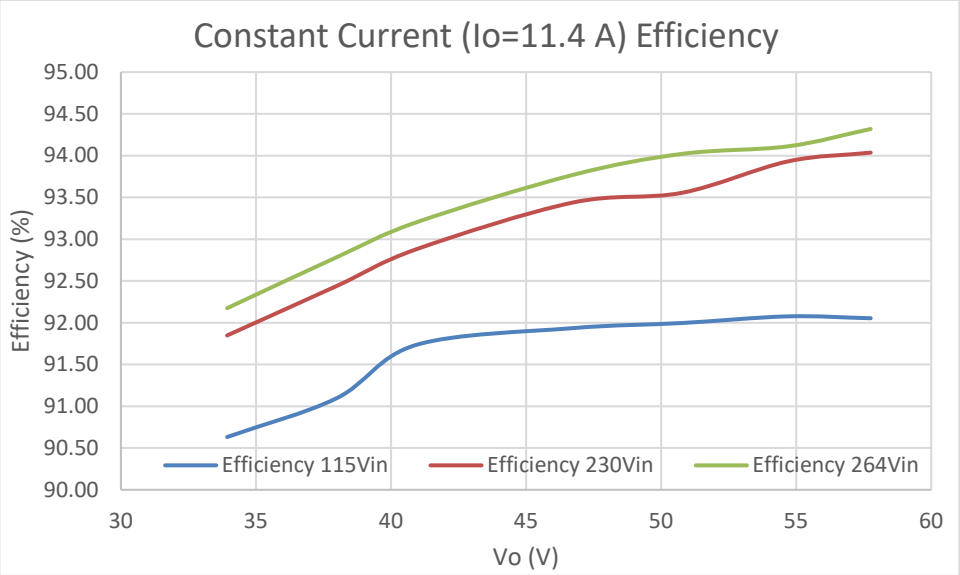
Performance Data

No-Load Power

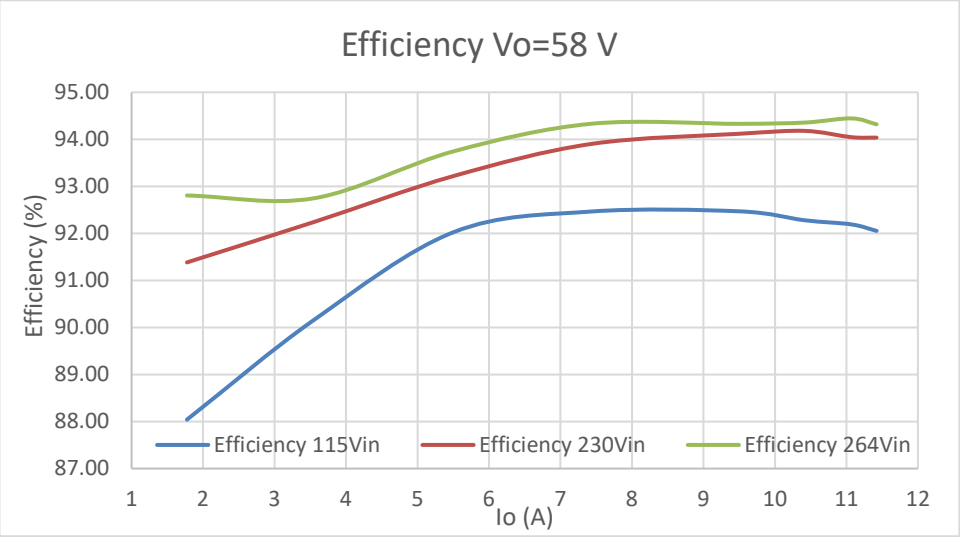
The charger has an on-board auxiliary flyback power supply running input/output relay and colling fans. This power consumption is estimated as 3 W. This 3 W will be subtracted from input power when characterizing the main circuit energy conversion efficiency performance.

Full Load Efficiency

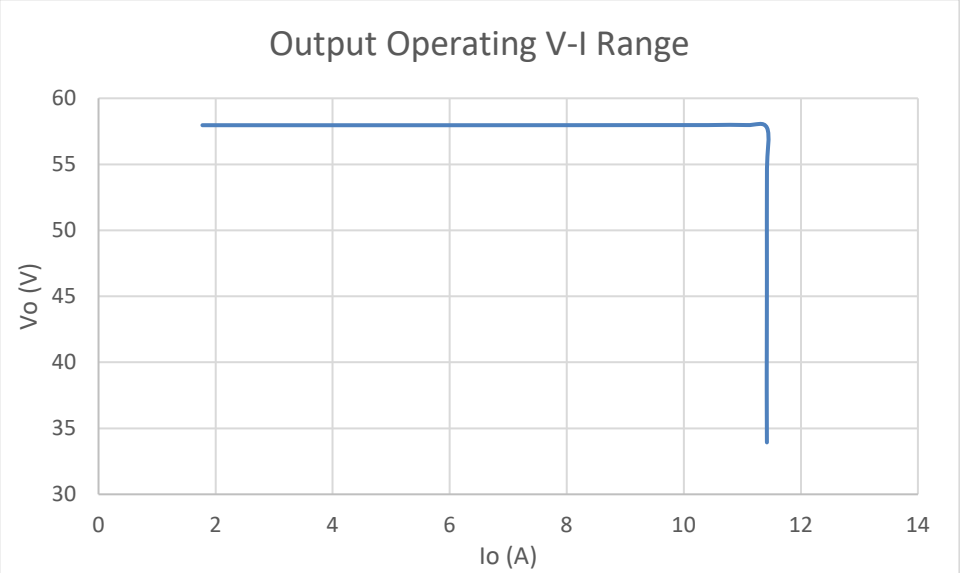
Vbat	Efficiency % @ 115 Vin	Efficiency % @ 230 Vin	Efficiency % @ 264 Vin
58	92.05	94.04	94.3
51	92.0	93.6	94.02
47	91.9	93.4	93.8
41	91.7	92.9	93.2
34	90.6	91.8	92.2



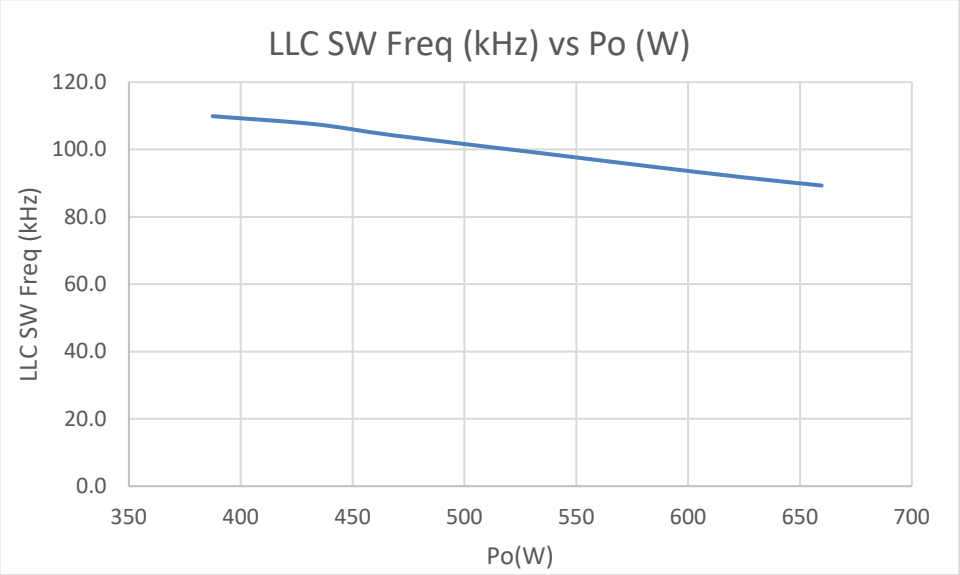
Efficiency at 58 V Battery Voltages with Various Load Current Levels

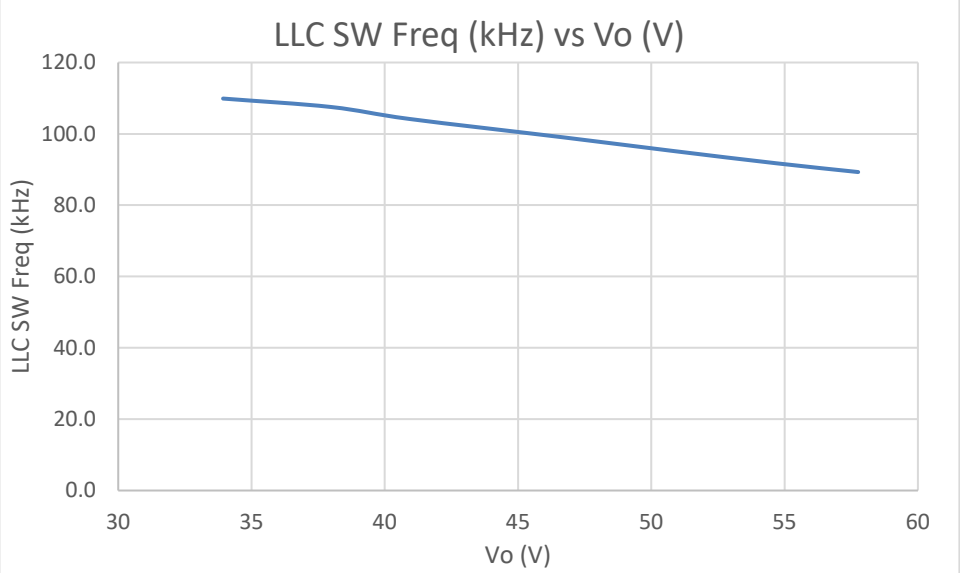


Output Voltage and Current Operation Range



LLC Switching Frequency Plots

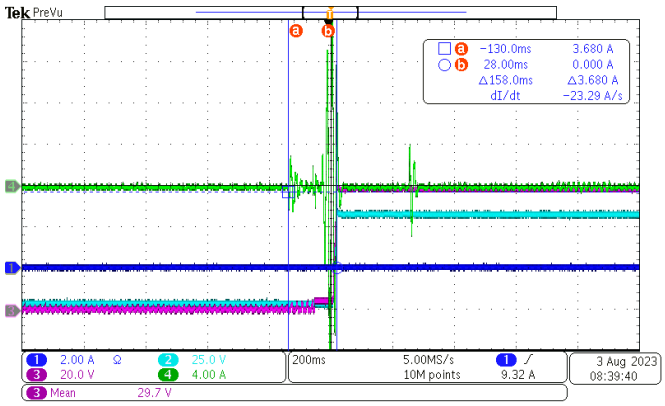




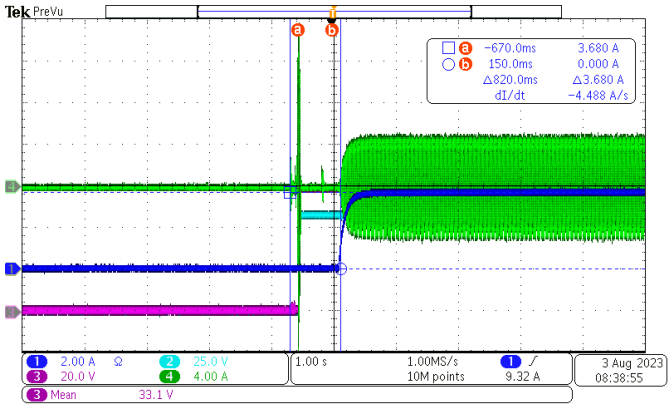
Startup

Vin (Vac)	Io (A)	Startup Time (s)	Vo (V)
90	0	0.158	58
90	3.68	0.82	58
115	0	0.152	58
115	3.68	0.8	58
230	0	0.126	58
230	3.68	0.79	58
264	0	0.11	58
264	3.68	0.78	58

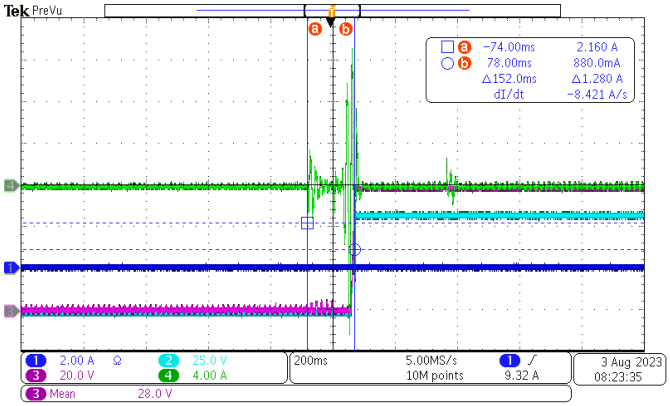
Note: Load is CV electronic load in series with 2 Ω power resistor. Startup into >3.68 A load is not successful.



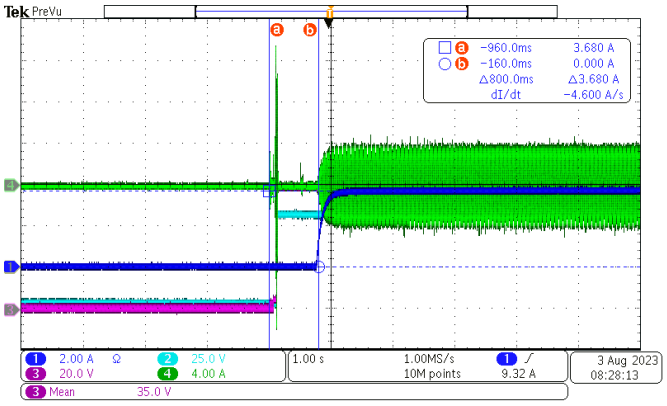
Vin = 90 Vac, 60 Hz; Vout = 58 V; Iout = 0 A



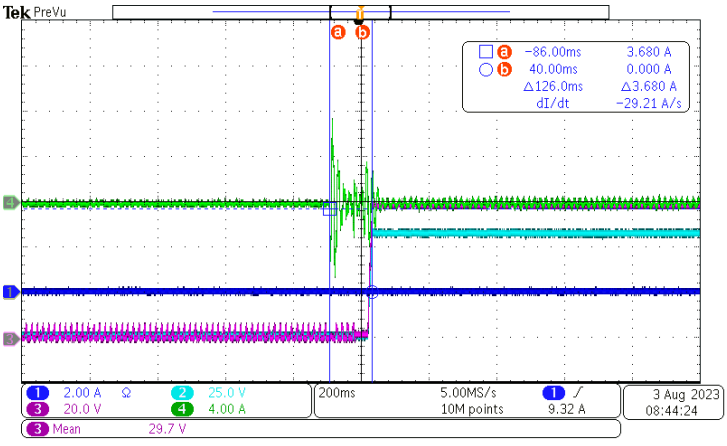
Vin = 90 Vac, 60 Hz; Vout = 58 V; Iout = 3.68 A



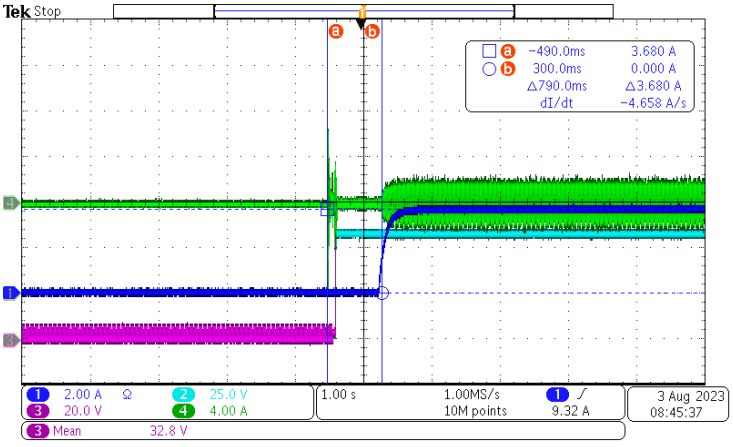
Vin = 115 Vac, 60 Hz; Vout = 58 V; Iout = 0 A



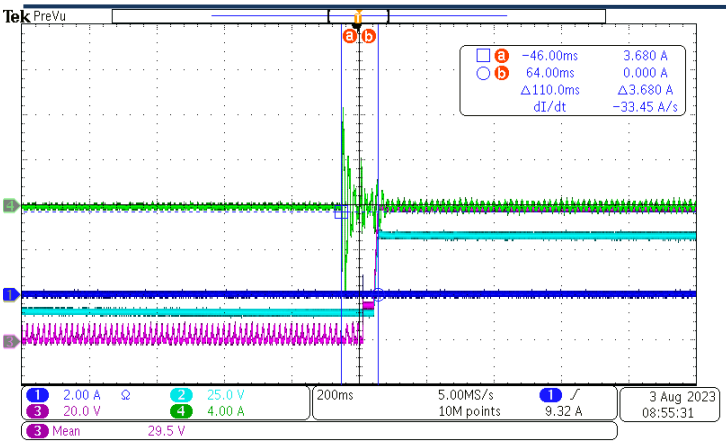
Vin = 115 Vac, 60 Hz; Vout = 58 V; Iout = 3.68 A



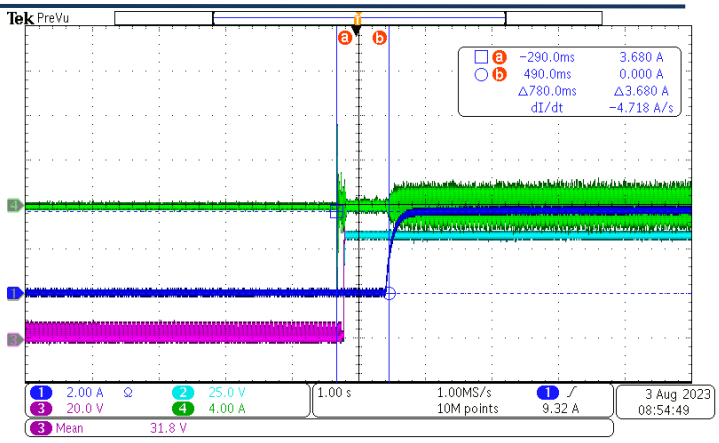
Vin = 230 Vac, 60 Hz; Vout = 58 V; Iout = 0 A



Vin = 230 Vac, 60 Hz; Vout = 58 V; Iout = 3.68 A



Vin = 264 Vac, 60 Hz; Vout = 58 V; Iout = 0 A

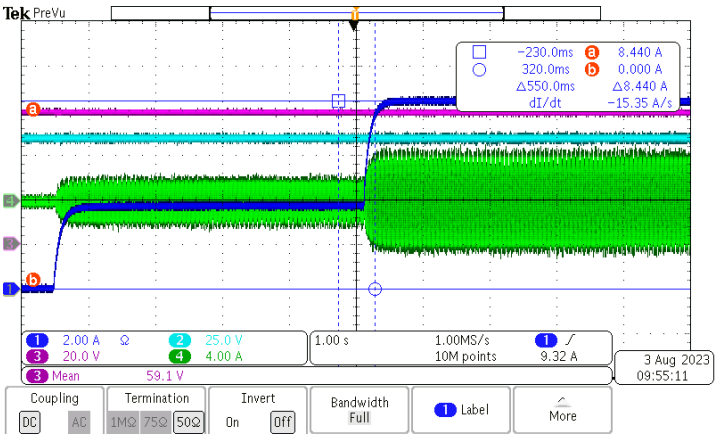


Vin = 264 Vac, 60 Hz; Vout = 58 V; Iout = 3.68 A

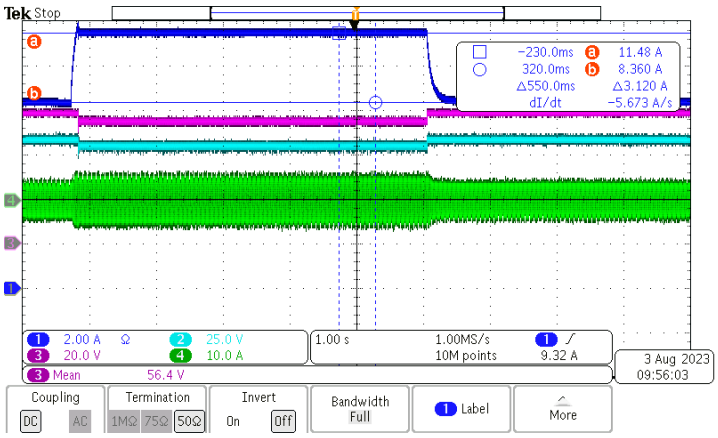
Note: Ch1 (Dark Blue): Io, Ch2 (Light Blue): Vo (before RL1), Ch3 (Purple): Vo (after RL1), Ch4 (Green): Iin.

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 60 Hz only. Load profile is an electronic load ET5411 in CV mode in series with a 2 Ω power resistor.



Vbat = 58 V; Iout = 0 A to 3.68 A to 8.44 A Transitions



Vbat = 58 V to 54 V; Iout = 8.36 A (CV) to 11.48 A (CC) to 8.36 A (CV) Transitions

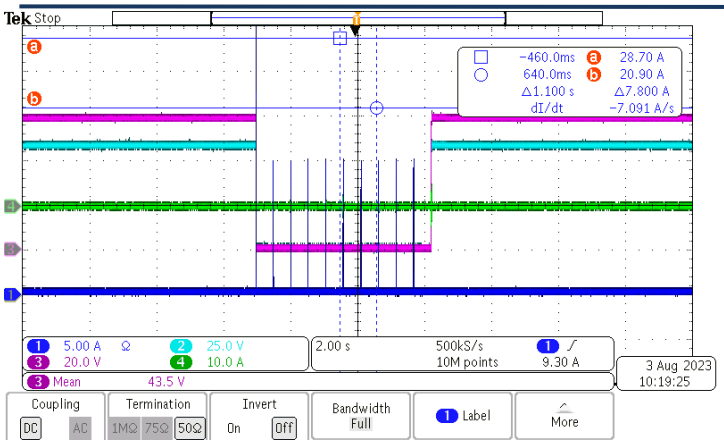
Note: Ch1 (Dark Blue): Io, Ch2 (Light Blue): Vo (before RL1), Ch3 (Purple): Vo (after RL1), Ch4 (Green): Iin.

Output Overcurrent Protection (OCP)

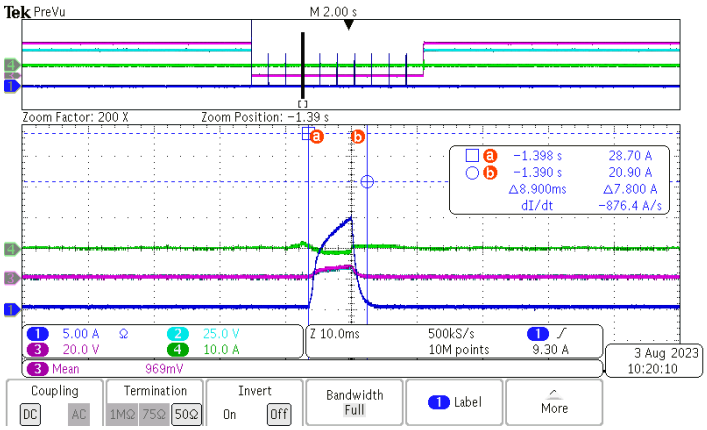
This reference design board can achieve constant current operation. Overcurrent protection (OCP) should not be entered.

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

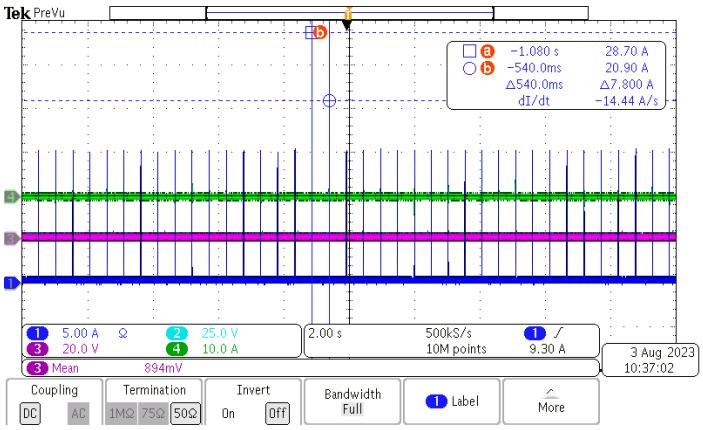


Zoom at short circuit

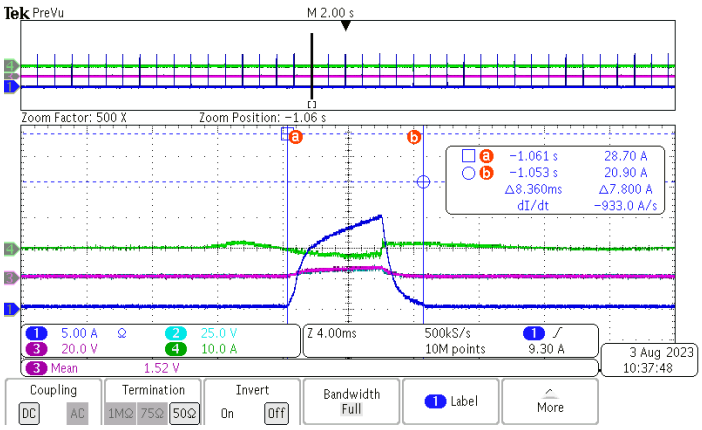
Note: Ch1 (Dark Blue): Io, Ch2 (Light Blue): Vo (before RL1), Ch3 (Purple): Vo (after RL1), Ch4 (Green): Iin.

Output Reverse Polarity Protection

The output reverse polarity test is performed with the electronic load ET5411 by swapping its input two leads. ET5411 is set with CV mode. The CV mode in ET5411 does not need to be enabled for this test. The reference board can recover after a reverse fault is removed.



Output Reverse Polarity



Zoom at Current Pulse

Note: Ch1 (Dark Blue): Io, Ch2 (Light Blue): Vo (before RL1), Ch3 (Purple): Vo (after RL1), Ch4 (Green): Iin.

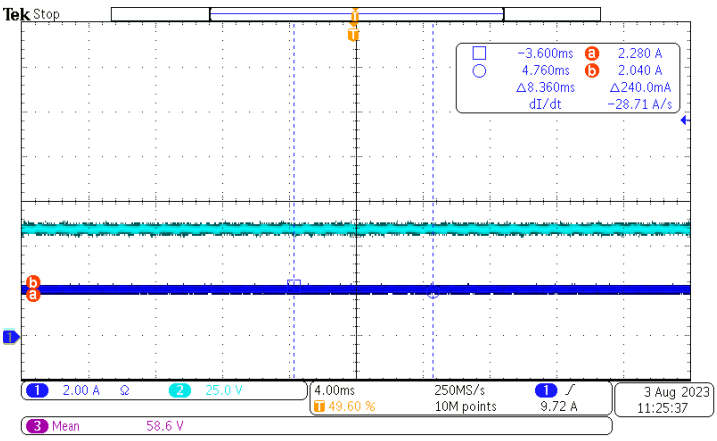
Output Current Ripple

Output ripple is related to LLC and output stage. We don't vary input voltage for this test. Input voltage is set at 115 V 60 Hz.

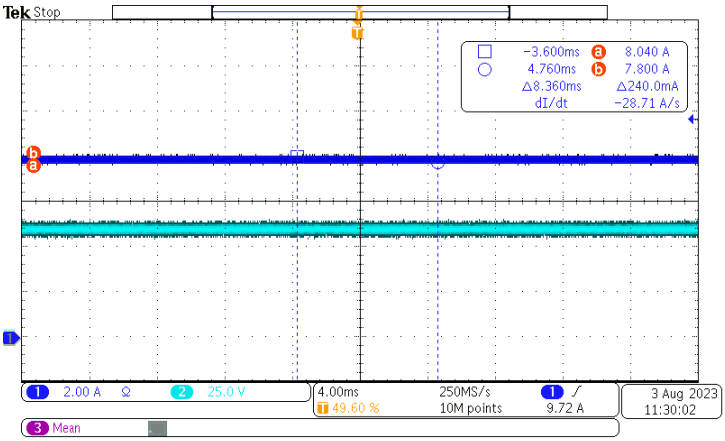
Output Current Ripple Summary

Vo (V)	Io (A)	Io Ripple PK-PK (A)
58	2.08	0.24
58	3.9	0.24
58	5.8	0.24
58	7.7	0.24
58	8.64	0.24
58	9.62	0.24
58	10.656	0.24
58	11.17	0.24
57.15	11.267	0.24
54.265	11.266	0.24
50.263	11.264	0.24
46.214	11.265	0.24
40.725	11.263	0.24
37.603	11.264	0.24
33.643	11.266	0.24

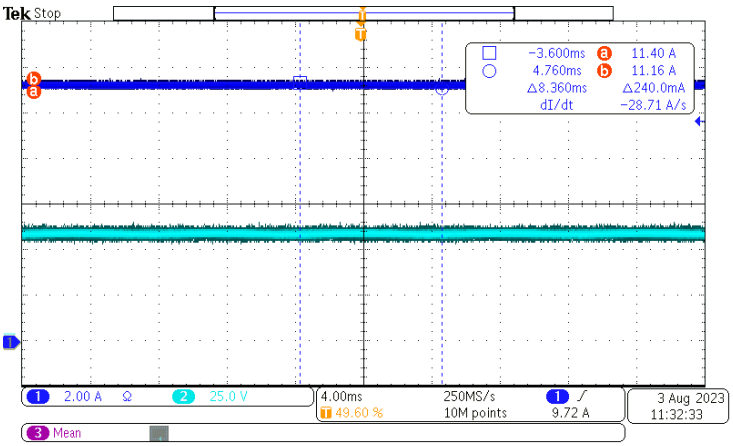
Output Current Plots



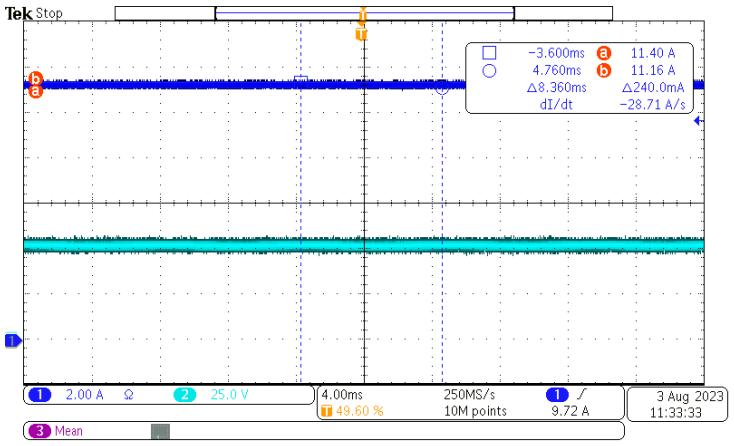
Vo = 58 V; Iout = 2.08 A



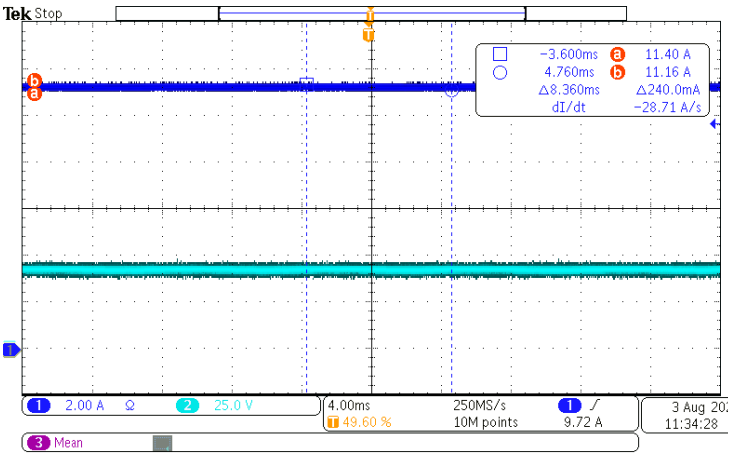
Vo = 58 V; Iout = 7.7 A



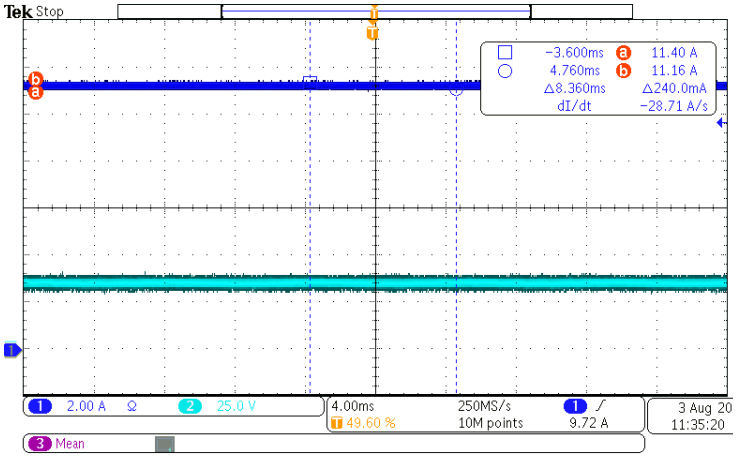
Vo = 57.15 V; Iout = 11.267 A



Vo = 50.263 V; Iout = 11.264 A



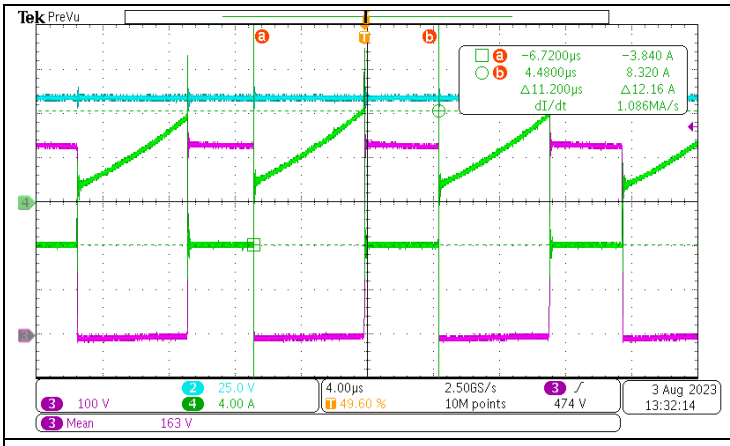
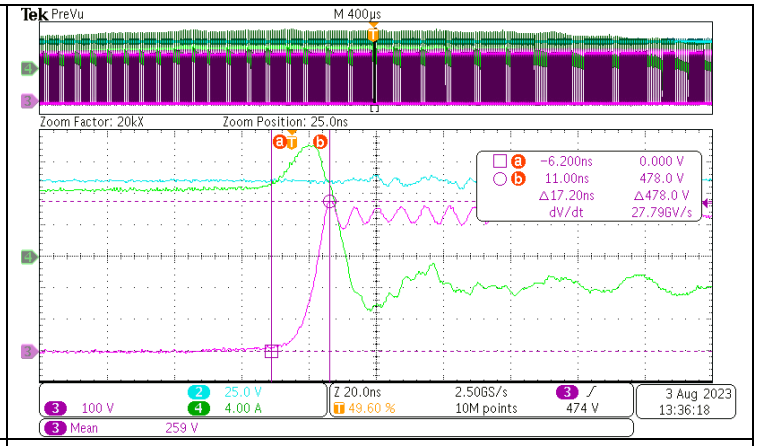
Vo = 40.725 V; Iout = 11.263 A



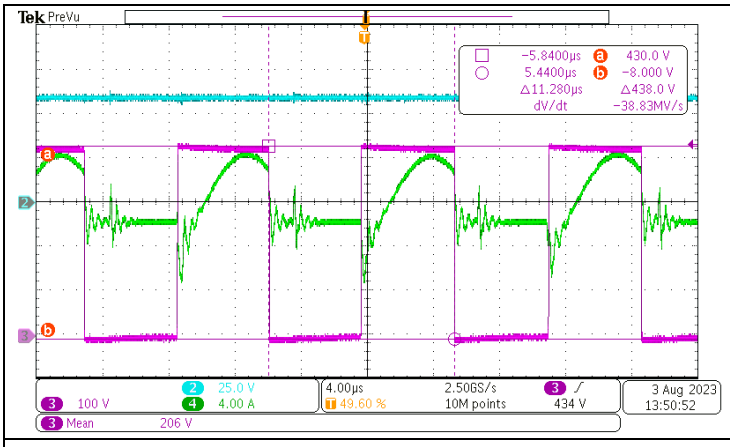
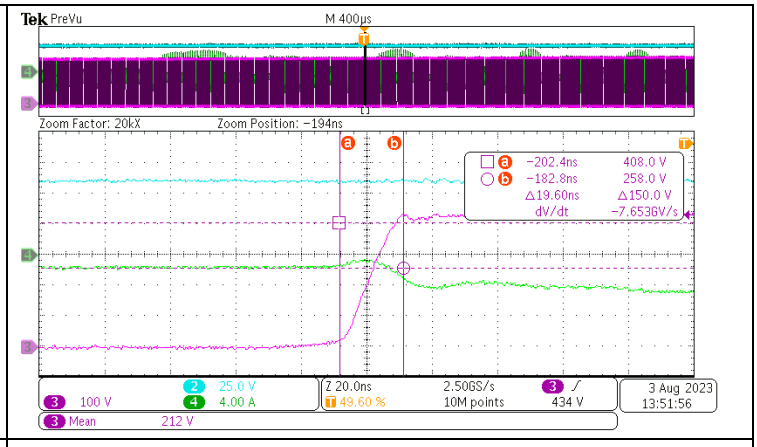
Vo = 33.643 V; Iout = 11.266 A

Key Waveforms

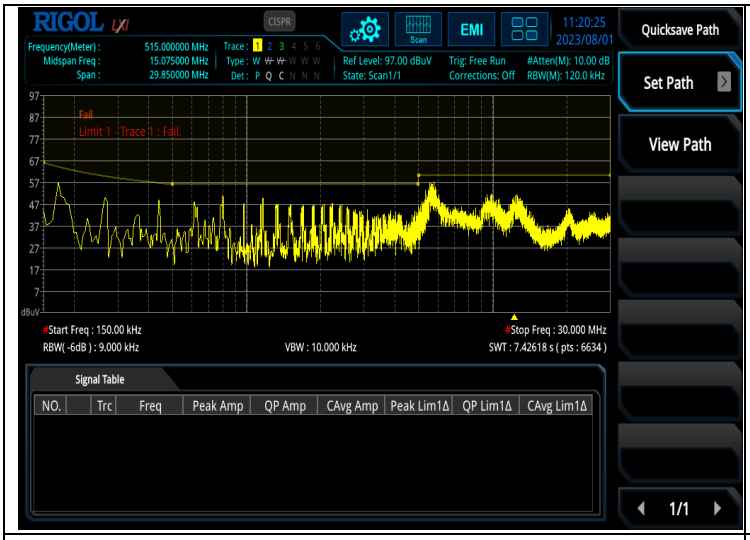
PFC FET Q3 waveforms. ch2: Vo ch3: Vds_q3 ch4: Id_Q3

	
Vin = 115 V, Vout = 58 V, Iout = 11.2 A	**Vin = 115 V, Vout = 58 V, Iout = 11.2 A, Vds_Q3 (max) = 478 V**

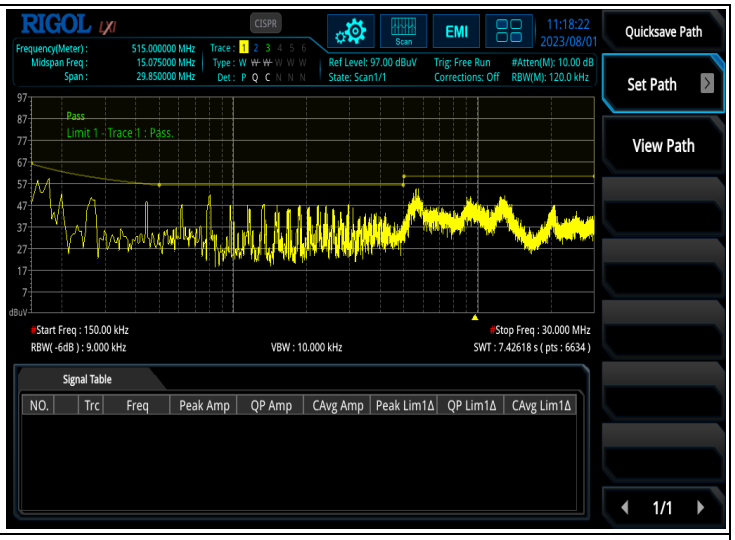
LLC waveforms. ch2: Vo ch3: Vsw ch4: Id_Q1

	
Vin = 115 V, Vout = 58 V, Iout = 11.2 A	**Vin = 115 V, Vout = 58 V, Iout = 11.2 A, Vds_Q3 (max) little overshoot**

Conducted EMI Scans



Input: AC 115 V 60 Hz, Output: DC 58 V 11.4 A



Input: AC 230 V 60 Hz, Output: DC 58 V 11.4 A

Thermal Measurements

Open Air Thermal Tests

Since this is a modification to an MPS charger reference design [1][2], we are only concerned about thermal of the new components, Q1/Q2/Q3. Below data is collected under ambient temperature around 25°C.

Vin (V)	Iout (A)	Po (W)	T_Q1 (°C)	T_Q3 (°C)
115	11.422	659.7	48.3	100.1
230	11.422	657.18	46.2	56.5

Hardware Information

Info	Value
Timestamp	August 3, 2023
Primary Side IC	HR1211, HF500-15
Key FETs	Transphorm 650 V SuperGaN® FET (TP65H070G4PS and TP65H150G4PS)
Secondary Side IC	MP6924A, MPQ8112
AC Supply	AC Line with Step up Transformer
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, 60), (264, 60)]
Output voltages	[33~58]
Electronic Load	ET5411 + 2 Ω Power Resistor

Reference

[1] EVHR1211-Y-00B, 600W, Offline Battery Charger PFC + LLC with the HR1211 Evaluation Board, https://www.monolithicpower.com/en/documentview/productdocument/index/version/2/document_type/Datasheet/lang/en/sku/EVHR1211-Y-00B/document_id/10321/.

[2] MPS Offline 600W Battery Charger, Rev 1.3, https://media.monolithicpower.com/mps_cms_document/r/d/rd00007_offline_600w_battery_charger_r1.3.pdf?_gl=1*178fdo2*_ga*MjAxOTU5NDc4Ny4xNjkxMTgzNzU1*_ga_XNRPF6L9DD*MTY5MTQ1NTY4MS40LjEuMTY5MTQ1NjMyMy40NC4wLjA.&_ga=2.244981057.575375332.1691427183-2019594787.1691183755