Design Example Report

Title	**1650 W 60 V 27.5 A Power Factor Corrected LLC PSU with CV and CC Modes**
Specification	180 VAC – 280 VAC Input; 60 V, 27.5 A Output
Application	3-wheeler EVs and Tool Chargers
Author	Applications Engineering Department
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Revision	A

Summary and Features

- Using HiperLCS™2-HB LCS7269Z, HiperLCS™2-SR LSR2000C-H005, HiperPFS™-3 PFS7539L ICs, CAPZero™-3 CAP300DG and InnoSwitch™-3 EP INN3692C-H606 ICs
- Integrated boost PFC and resonant LLC half-bridge (HB) plus synchronous rectification (SR)
    - Self-biased startup – no bootstrap required
    - Precise control of both SR and HB to optimize efficiency
- >94% full load efficiency at 230 VAC
- Up to 360 kHz switching frequency for LLC minimizes transformer size
- Boost PFC input stage, PF >0.99
- Optimized for battery charging
- Option for external CC/CV control
- Wide output voltage range: 26 - 60 VDC
    - Better than ±1% constant voltage (CV) regulation
- Wide output battery current range: 0 A to 27.5 A
    - Better than ±5% constant current (CC) regulation

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PATENT INFORMATION

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Important Notes:
Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. All testing should be performed using an isolation transformer to provide the AC input to the prototype board.
Since there is no separate bias converter in this design, ~400 VDC is present on bulk capacitor C9, C9A and C9B immediately after the supply is powered down. For safety, this capacitor must be discharged with an appropriate resistor (10 k / 2 W is adequate), or the supply must be allowed to stand ~10 minutes before handling.

1 Introduction

This report describes a Constant Voltage (CV) and Constant Current (CC) power supply. The design includes a boost PFC stage which drives an isolated resonant half-bridge converter and is intended for 3 wheeler EV and power tool charging. The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout and design spreadsheet.

The design has the flexibility to support either a fixed CV/CC configuration or be driven by an MCU and CAN daughter card equipped with a DAC or PWM output. In the fixed configuration, the CC/CV thresholds can be set using the variable resistor provided on the main board. This defines the default charging characteristic. With the MCU and CAN daughter card configuration – the controller can dynamically adjust the reference voltage, enabling real-time control over the CC / CV charging modes to control the set point for a 60-volt, 27.5-amp output. The report also shows the operation of the power converter using a HiperPFS™-3 IC for PFC and the HiperLCS-2 chipset for the LLC.

The highline-only HiperPFS-3 (PFS7539L) IC is a Continuous Conduction Mode (CCM) boost PFC controller and switcher IC that provides unity PF across the input voltage range. The feedback resistors on the FB pin (Pin 7) of the PFS7539L are selected to deliver a regulated 390 VDC output.

The HiperLCS™2-HB LCS7269Z resonant half-bridge switcher IC uses the POWeDIP™ high power package.

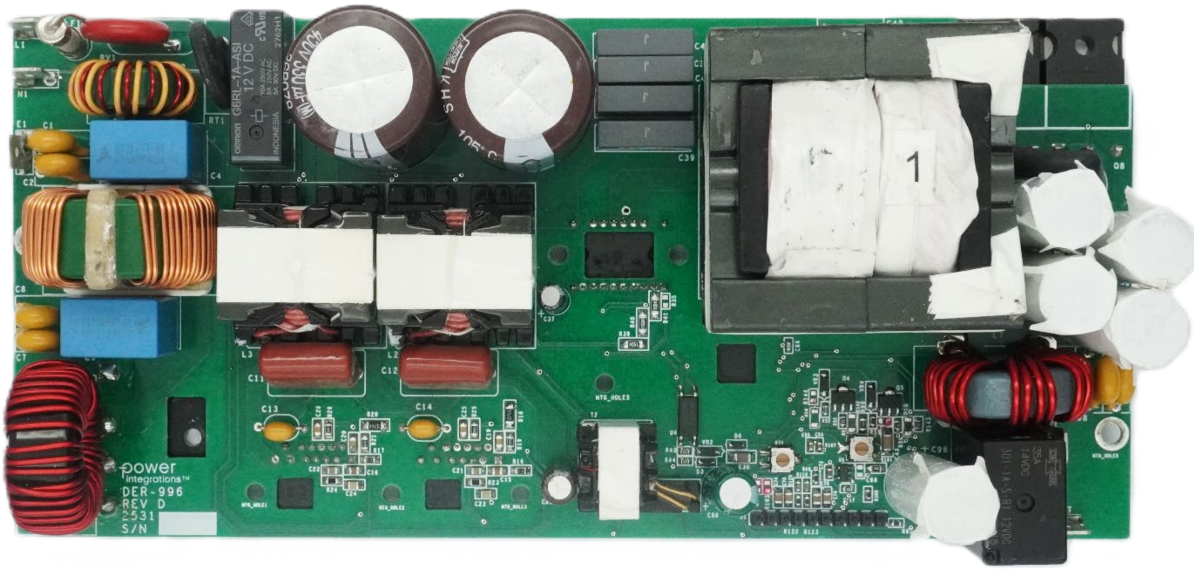


Figure 1 – DER-996 Populated Power Converter Board, Top View.

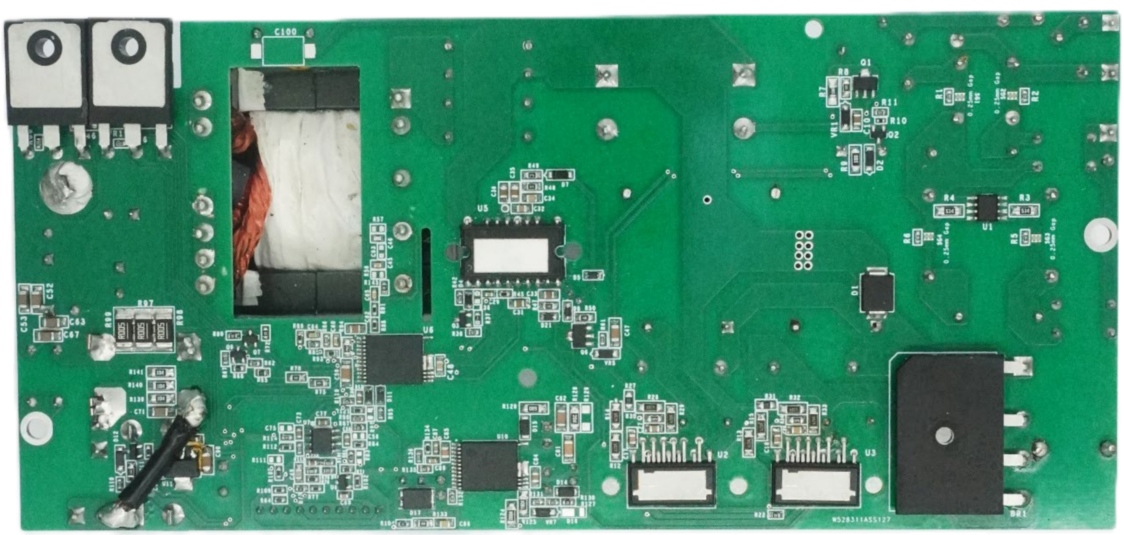


Figure 2 – DER-996 Populated Power Converter Board, Bottom View.

Figure 1 and Figure 2 show the main circuit board containing the HiperPFS-3 and HiperLCS-2 chipset. A horizontal PQ50/50 transformer is mounted on the top side of the main board for the LLC transformer. The LSR2000C barrier crossing IC is located on the bottom of the main board, beside the transformer. The board has a baseplate heatsink mounted on the underside to cool the bridge rectifiers, the PFS7539L IC, the LCS7269Z IC and the secondary-side synchronous rectifier MOSFETs.

For the variable CV and CC operation, external error amps U7A/B is used to control the feedback (pin 5) of U6. The reference operating points for CV and CC are set using variable resistors R74 and R107.

2 Power Supply Specification

The table below represents the typical acceptable performance for the design. Actual performance is listed in the results section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	180	230	280	VAC	Single phase input
Frequency	f_{LINE}	47	50/60	64	Hz	
Power Factor	**PF**	0.9				Full Load, 230 VAC.
Main Converter Output						
Output Voltage	V_{LG}	26	60		V	(1.65 kW) Full Load.
Output Current	I_{LG}		27.5		A	
Total Output Power						
Continuous Output Power	P_{OUT}		1.65		kW	
Power Supply Efficiency						
Full Load 60 V / 27.5 A.	η_{Main}		94.0		%	Measured at 230 VAC, Full Load.
No Load Input Power						
Total System No-Load Consumption for 60 V output	$P_{IN(NO-LOAD)}$		<2		W	Measured at 230 VAC.
Ambient Temperature	T_{AMB}	0		40	°C	See Thermal Section for Conditions.

Table 1 – Power Supply Specifications.

3 Schematic

The schematics for the main board are shown in Figures 3, 4, 5, 6, 7 and 8:

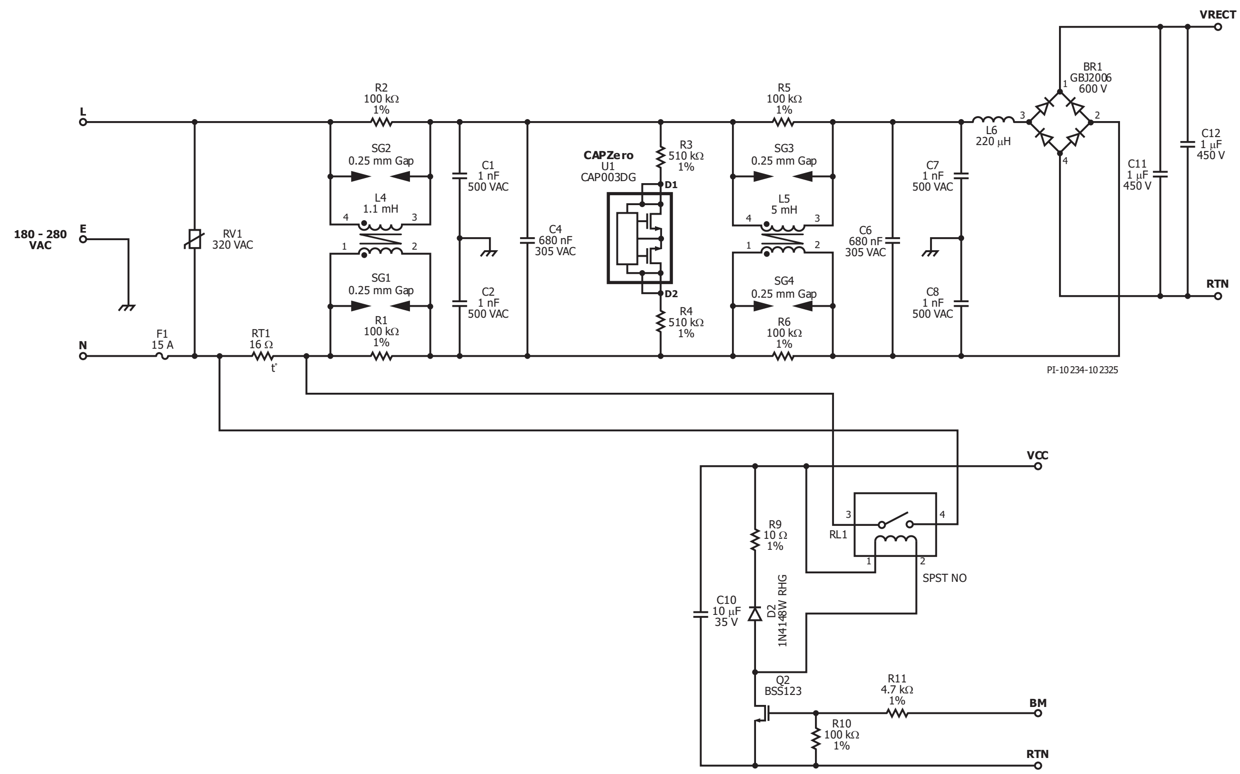


Figure 3 – Input Filter and Bridge Rectifier.

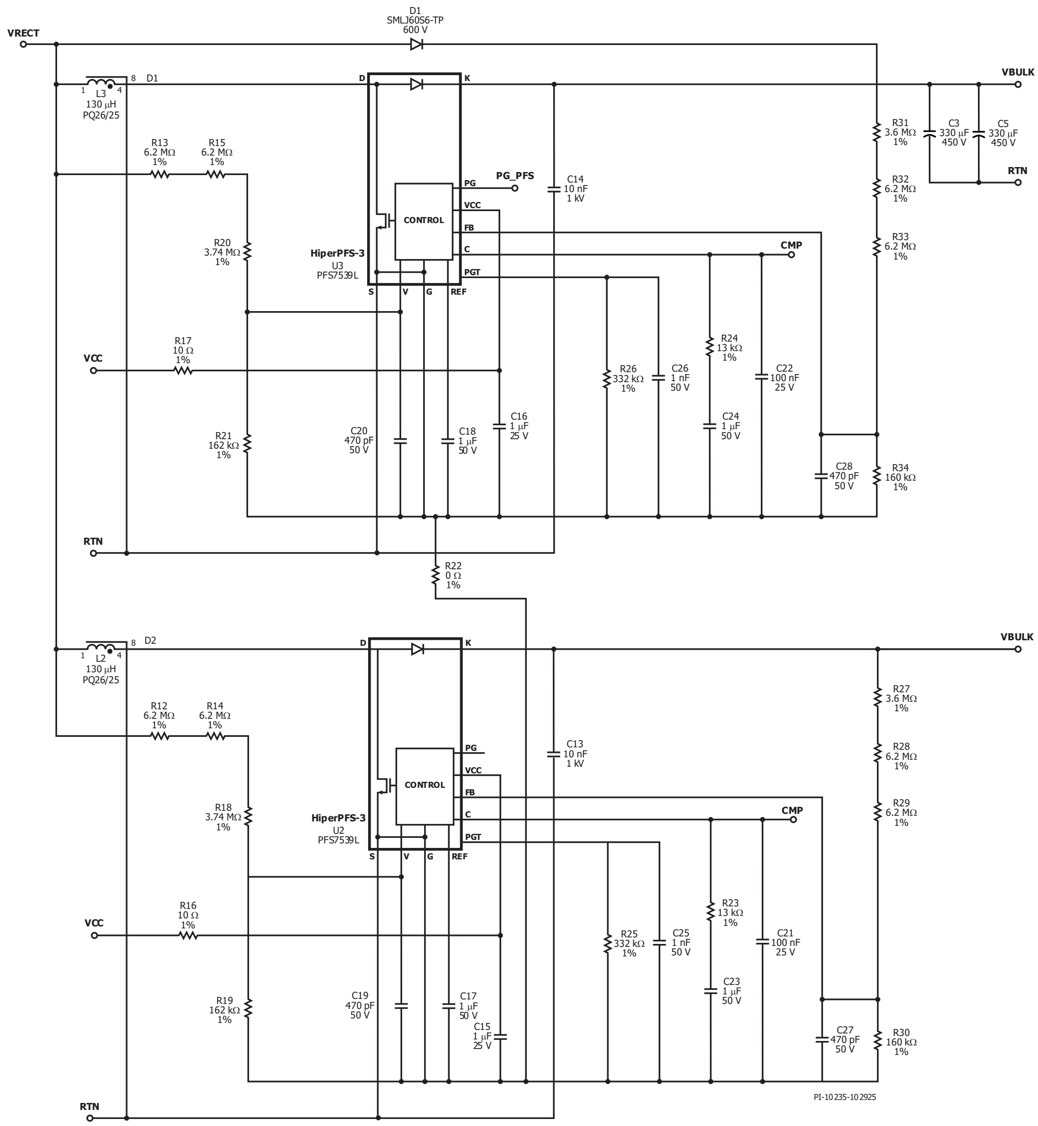


Figure 4 – PFC Stage.

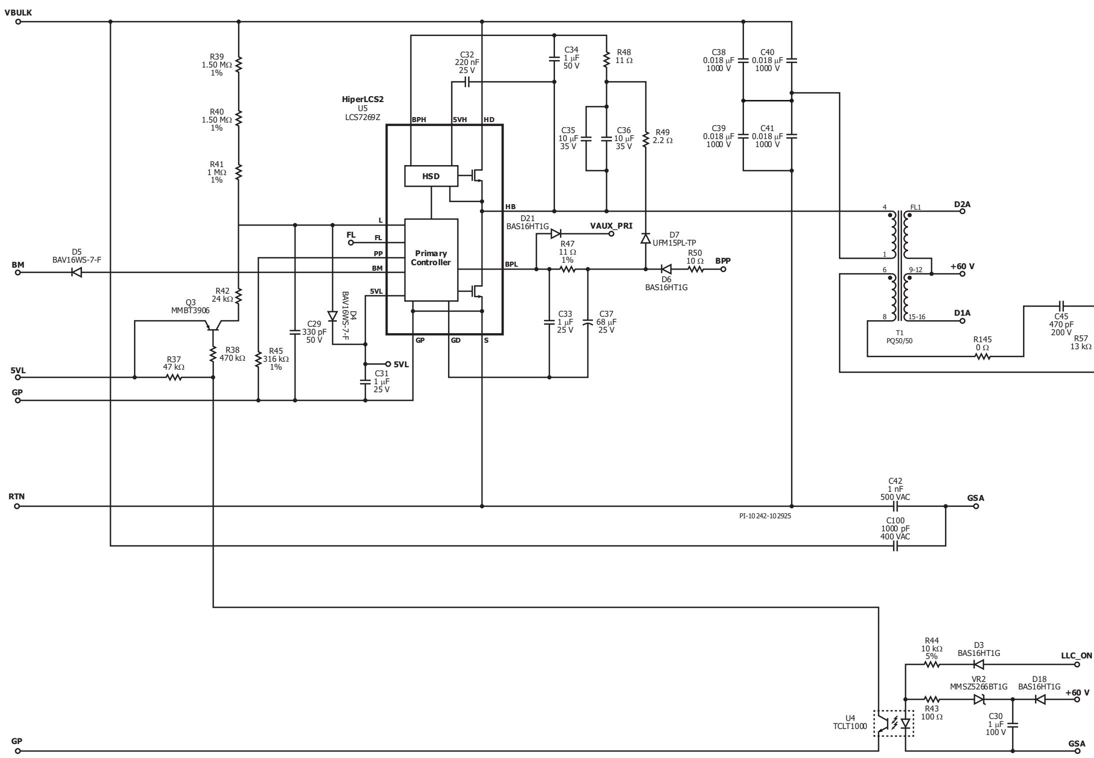


Figure 5 – Primary Side LLC

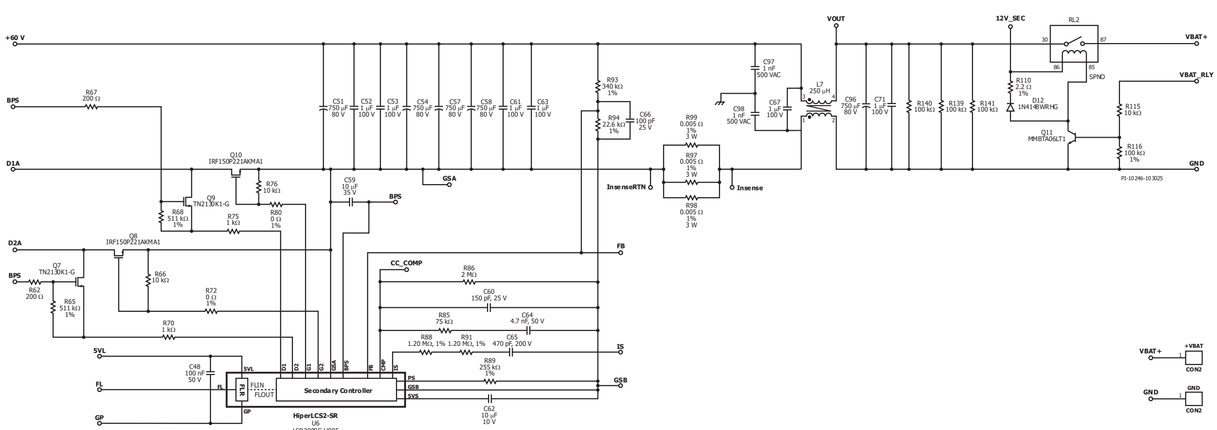


Figure 6 – Secondary Side LLC

Note: The output relay is intended to be controlled by the MCU. For this DER, a temporary jumper wire is used to short 30 and pin 87 of RL2.

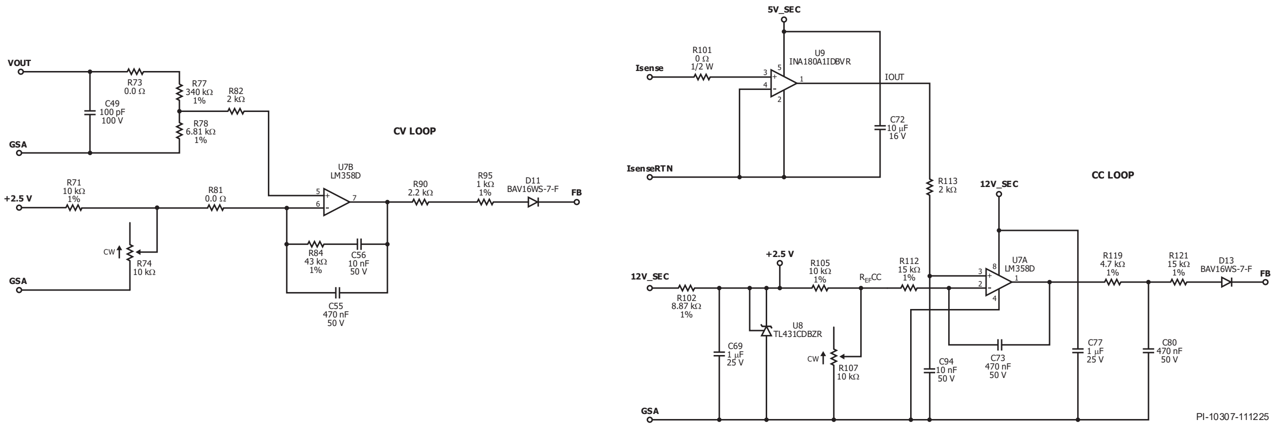


Figure 7 – CV/CC Control

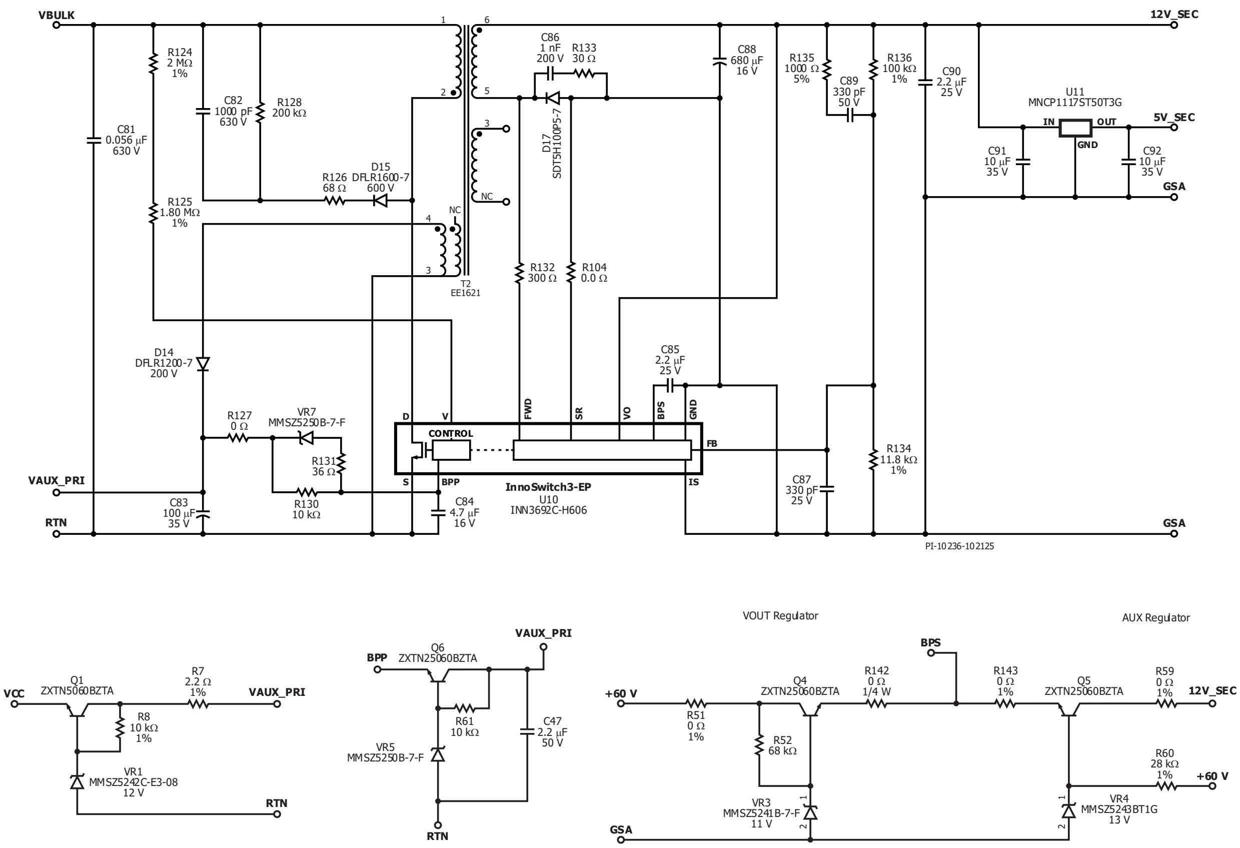


Figure 8 – Auxiliary Circuit

4 Circuit Description

4.1 EMI Filtering / Rectifier Stage

Figure 3 shows the schematic of the EMI and rectifier stage. Fuse F1 protects in the event of a primary overcurrent fault. A 16 Ω thermistor RT1 is used to limit inrush current during start-up. Varistor RV1 protects against differential mode line surge. Inductors L4 and L5 along with C1 and C2 are used to reduce common mode noise, while C4, C5and L6 limit differential mode noise. Resistors R3 and R4 are connected to the integrated X-capacitor discharge CAPZero™-3 CAP300DG IC U1 and quickly reduce the voltage across C4 and C6 to safe levels when the PSU is disconnected from the AC mains. AC input is rectified through bridge diodes BR1. Relay RL1 is used to bypass thermistor RT1 after initial start-up. Its operation is controlled by the BM pin of the HiperLCS™2-HB IC (U5). At higher load, the BM pin will transition from low to high and turn-on Q2. This in turn energizes RL1 which bypasses RT1 and improves circuit efficiency. During very light loads or the no load condition, BM will transition from high to low, de-energizing RL1 to reduce power consumption.

4.2 Main PFC Stage

Figure 4 also shows the PFC stage centered around the HiperPFS-3 controller (U2 and U3). L2 and L3 is the PFC choke. D1 is a bypass diode used to pre-charge bulk capacitors (C3 and C5) which allows the auxiliary converter to start first. A resistor divider comprised of R27, R28, R29, and R30 provide output voltage feedback to U3. Capacitor C27 decouples the FB pin of U2. Components R23, R24, C21, C22, C23 and C24 are for loop compensation, while resistors R12, R15, R20, and R21 provide input voltage information to U2. Capacitor C17 is used to program U2 to support either Full Power or Efficiency modes via the REF pin 3. Resistor R25 and R26 is used to program the output voltage threshold at which the PG signal becomes high-impedance representing PFC going out of regulation to signal the DC-DC stage to turn off. However, for this design, the L-pin of the HiperLCS2-HB IC is used for start-up instead of the PG pin signal, choosing L-pin uses the higher start up current limit which is intended for high power designs.

4.3 LLC Converter

Figure 5 shows the primary section of the LLC converter using HiperLCS2-HB switcher. Figure 6 shows the secondary section of the LLC converter using HiperLCS2-SR, a secondary side master controller with integrated safety rated isolation allowing communication between primary and secondary without using optocouplers. An SR controller and driver are also built into the master controller.

4.4 LLC Primary

The high-voltage input bus is filtered by capacitors C3 and C5. Line sense (L-pin) detects input bus voltage via resistors (R39, R40, R41, and R42). The HiperLCS™2-HB IC, U5, will initiate soft-start when L-pin rises above UV+ threshold. Output overvoltage is sensed via the optocoupler (U4) as set by the Zener diode VR2 with 5VL and R42 coupled to the L pin via Q3. If an output overvoltage occurs, Zener VR2 and U4 conducts, Q3 will turn ON and inject current > I_L(OV+) into L pin from 5VL and switching is interrupted. In normal operation, resistor R45 sets the PP pin primary frequency range and determines fault-response. Diode D5 couples the BM pin to an external in-rush relay drive circuit. Note: BM transitions to a low state when in light load burst mode.

Capacitors C31 and C33 decouple the 5VL and BPL pins, referencing them to the GP and GD pins, respectively. The primary return power-ground (RTN) connects to the SOURCE pin (S-pin), the primary-bias winding and the bias capacitor. RTN ground is Kelvin-connected to the node formed by the negative terminals of bulk-capacitors C3 and C5. To maintain signal integrity, the small signal ground (GP), must remain separated from system power ground (RTN). The RTN power ground provides a low-impedance path for system noise, ensuring that secondary-coupled noise currents are directed to the RTN/bulk-capacitor ground without interfering with the small-signal ground (GP pin).

Capacitor C33 implements high-frequency decoupling for the BPL-pin. During start-up, prior to the commencement of switching, the BPL pin charges capacitors C33 and C37 through resistor R47, which limits the charging current. Capacitor C37 stores sufficient energy to maintain bias until the primary bias winding is energized, which occurs only after switching is established. C37 also provides boot-strap energy to the HiperLCS2-HB high-side bias via diode D7 and resistor R49. Capacitor C33 and C37 should be sized to ensure adequate bias energy during startup. As a design requirement, the combined capacitance of C33 and C47 must be at least five times the capacitance of the high-side bias capacitor C35 and C36.

Resistor R47 limits the current drawn from the BPL pin by the PFC stage. During normal operation, bias current is supplied from the bias winding and charges capacitor C21. The BPL pin includes an internal shunt regulator to clamp its voltage. When clamping occurs, resistor R23 limits the shunt-current, thereby reducing BPL power dissipation.

For optimal no-load performance, the bias supply should be designed to provide at least 15 V at the BPL pin. The internal BPL shunt activates when the pin voltage exceeds 21 V; therefore, careful selection of the steady-state bias winding voltage is required. Operating above the BPL clamp threshold results in increased power dissipation within the HiperLCS2-HB IC.

During low-side power MOSFET on-time, bootstrap capacitor C35 and C36 charges through D7 and R49. At startup, R49 limits current while C35 and C36 is uncharged. Resistor R48 and capacitor C34 provide low-frequency filtering for the BPH pin. Capacitor C32 decouples the 5VH pin, with all high-side decoupling referenced to HB.

The resonant tank is formed by transformer T1, which combines the transformer-integrated-resonant-inductor (L_R) and the magnetizing inductance (L_M), which appear in series between the HB pin and the midpoint node of capacitors C39 and C41 and C38 and C40.

Y-capacitor C42 provides decoupling between primary and secondary grounds effectively reducing the common mode noise.

4.5 LLC Secondary

The HiperLCS2-SR (U6) IC includes primary side pins that are safety-isolated from the secondary side. On the primary side, the 5VL pin of U6 is supplied from the 5 V reference of the HiperLCS2-HB, providing operating power for the primary-side of the HiperLCS2-SR IC. The GP pin of U6 is tied to the small signal ground pin of the HiperLCS2-HB IC on the primary side. Capacitor C48 provides local decoupling between the 5VL and GP pins. The FL pin carries the control signal generated by the secondary-side master controller. The signal is transferred across the isolation barrier via the integrated FluxLink magneto-inductive communication link and is delivered to the HiperLCS2-HB IC.

Transformer T1 output pins 9, 10, 11 and 12 (OUT+) deliver the positive output voltage, which is rectified by synchronous rectifier (SR) MOSFETs Q8 and Q10. The rectified voltage is filtered by capacitors C51, C52, C53, C54, C57, C58, C61 and C63. These capacitors provide low equivalent series resistance (ESR), which is the dominant factor in minimizing output ripple. The total capacitance should be selected to achieve the required off-time during burst-mode operation. All output capacitors are reference to the secondary-side power ground (GSA). For proper load sharing between the two secondary power-phases, it is critical to maintain equal power path lengths for Q8 and Q10 circuits.

Capacitor C59 decouples the BPS pin, connecting it to the secondary SR-drive ground (GSA pin). Capacitor C62 decouples the 5VS pin connecting it to the secondary small signal ground (GSB pin).

Diode D17 and capacitor C88, rectify and filter the output from the secondary side winding of the auxiliary circuit appearing on pin 6 of T2 (with respect to output power ground GSA). Components Q4, R52, VR3 form a linear regulator that provides 11 V bias from the LLC output to U6 during start up ensuring U6 has sufficient bias if the half bridge in U5 start switching before the auxiliary supply provided by U10 becomes available. Q5 and VR4 forms an additional linear regulator that regulates the voltage coming from the auxiliary supply to 13 V, the output of this regulator is gated through R60 and is only available when the main output voltage is present. The values of Zener diodes VR3 and VR4 are chosen so that in steady state, BPS will draw bias current from the auxiliary supply.

The small signal secondary ground GSB is used for feedback and compensation and provides the ground for IS-pin signals. Output voltage is sensed via resistors R93 and R94. Decoupling capacitor C34 attenuates any high-frequency noise and is connected to GSB (small signal secondary ground). The voltage feedback resistor-divider network is scaled to provide 3.75 V at the FB pin of the secondary IC when the DC output voltage is 60 V. The FB pin can also be biased by the CV/CC controller.

The current sensing resistors R97, R98 and R99 develop a voltage drop that is proportional to the output DC current. This voltage is used by the analog controller when providing current control. Compensation is provided between CMP and GSB pins, via R85, C60 and C64 which provide a pole (R93, C64), zero (R85, C64) and a high frequency pole (R85, C60). Resistor R86 is connected across C60 to bleed a small amount of current to ensure $V_{FB(REF)}$ is always slightly lower than $V_{FBREG(TH)}$, this prevents switching frequency locking into Fmax. The transformer (T1) IS winding output that appears on pin 8 (the return is provided by T1 pin 6 which is grounded to GSB the secondary small-signal ground) provides information that together with capacitor C45 that sets the burst threshold for low load. This signal is coupled via C45 and resistors R88, R62, and R91 to the IS pin of U6. C45 and C46 act as capacitor divider network to limit the current going into the IS pin.

Drive for the Q8 and Q10 synchronous MOSFETs is provided by the output pins G1 and G2 pins via resistors R72 and R80 respectively. The drive resistors are optional and reduce high frequency ringing. In the event of an open connection between G1/G2 and the gates of Q8/Q10, local pull-down resistors R66 and R76 ensure that Q8 and Q10 remain off.

There is a maximum pin voltage of 150 V for D1 and D2 pins. Q7 and Q9 protect these pins from possible overvoltage. Pins D1 and D2 sense the drain voltages on the synchronous rectifiers Q8 and Q10 via resistors R70 and R75 and FETs Q7 and Q9, respectively. The resistors limit negative current (WRT GND) into both pins. These resistor values can be increased to adjust the SR turn-off threshold. Increasing the resistor value will cause synchronous rectification to end at a higher current. Q7 and Q9 conduct when there is zero drain voltage on Q8 and Q10. Note: D1 and D2 signal paths go through resistors R70 and R75, drain-source of Q7 and Q9 and through the SR-MOSFETs (Q8, Q10) respectively after which both are returned to GSA. The total path length for both D1 and D2 signals should be equal, to ensure optimum SR operation.

The PS pin resistor R89 is used to program the burst threshold.

4.6 CV/CC Control

The auxiliary power supply controlled by U10 provides supply voltage for the primary and secondary controller and for the CV/CC controller circuits.

The CV/CC control has two variable resistors located on the main board R107 (CC Loop) and R74 (CV Loop) that can be adjusted to change the reference voltage to regulate the

CV/CC set points. The board has the option to control the CV/CC operation using the microcontroller via MCU_IPWM and MCU_VPWM from MCU daughter card pluggable at J1 connector equipped with DAC and PWM function. In the main board, CV/CC control thresholds can be set using the variable resistors R74 and R107. This configuration defines the default charging. In the MCU daughter card configuration, you can dynamically adjust the reference voltage through firmware setting.

For the CC loop, R102 and voltage regulator U8 are used to generate a 2.5 V reference voltage. From this 2.5 V signal, the reference for the current control circuit is generated using the resistive divider network of R105 and R107. R103 and C70 are provisions in case user wants to use MCU to control CC setpoint. The Potentiometer R107 is adjusted to provide a voltage of ~1.2 V, which corresponds to a 24 A output current. The voltage across R107 acts as the reference voltage for the inverting input of error amplifier U7A. Current sense amplifier U9 amplifies the voltage sensed across current sense resistors R9, R98 and R99 which is fed to the non-inverting input of U7A. During CC mode, the amplified voltage across the current sense resistor R97, R98 and R99 will be compared to the reference voltage set by R107 thru U7A and will create an error signal that will regulate the output current thru the FB pin on the selected CC setpoint.

The current control loop is provided using Op-Amp U7A, with a single pole compensation provide by C73. R119 and C80 form a low pass filter that limits the bandwidth of the CC loop which prevents sudden error voltage changes from appearing on the output of U7A, and causing high ripple current at the output.

For the CV loop, the 2.5 V reference voltage is applied to the resistor divider created by R71 and R74 which forms a reference voltage for op-amp U7B. This can be changed by variable resistor R145. R69, R79 and C50 are provisions in case user wants to use MCU to control CV setpoint. ~600 mV across R79 corresponds to ~60 V on the output. During CV mode, the output voltage sensed via resistor divider R77 and R78 is fed into U5B's noninverting input and compared to the reference voltage as set by R74 to regulate the CV set point.

The variable CV loop is provided using Op-Amp U7B, resistors R784, C55, and C56. Capacitor C55 improves dynamic response.

4.7 Auxiliary Circuit

One side of the transformer T2 is connected to the rectified DC Bus, the other is connected to the integrated 900 V power MOSFET inside the InnoSwitch3-EP 900 V IC (U10).

A low-cost RCD clamp formed by D15, C82 and R123 limits the peak drain voltage generated by transformer leakage inductance commutation when the switch turns off.

The U10 IC is self-biased, using an internal high voltage current source to charge the BPP pin capacitor, C84, when AC is first applied. During normal operation, the primary side block is powered from an auxiliary winding on the transformer.

Resistor R123 and R125 provide line voltage sensing and provide a current to U10, which is proportional to the DC Voltage across capacitors C3 and C5.

The secondary side of the U10 IC is self-powered from either the secondary winding forward voltage or the output voltage. The output voltage powers the device and is fed into the VO pin to charge the decoupling capacitor C31 via an internal regulator. The unit enters auto-restart when the sensed output voltage is lower than 3 V.

Resistor R136 and R134 form a voltage divider network that senses the output voltage for regulation. The InnoSwitch3-EP IC has an internal reference of 1.27 V. Capacitor C87 provides decoupling to prevent high frequency noise from affecting power supply operation.

5 PCB Layout

Figure 9 and Figure 10 show the main Printed Circuit Boards (PCBs) used for the power supply.

PCB specifications for the main and daughter boards:

- Layer count: 2 layers
- Solder mask: Green
- Silkscreen: White
- Finish: LF HASL
- Board thickness: 1.6 mm
- Copper thickness: 2 oz (2.8 mils)
- Material: FR4

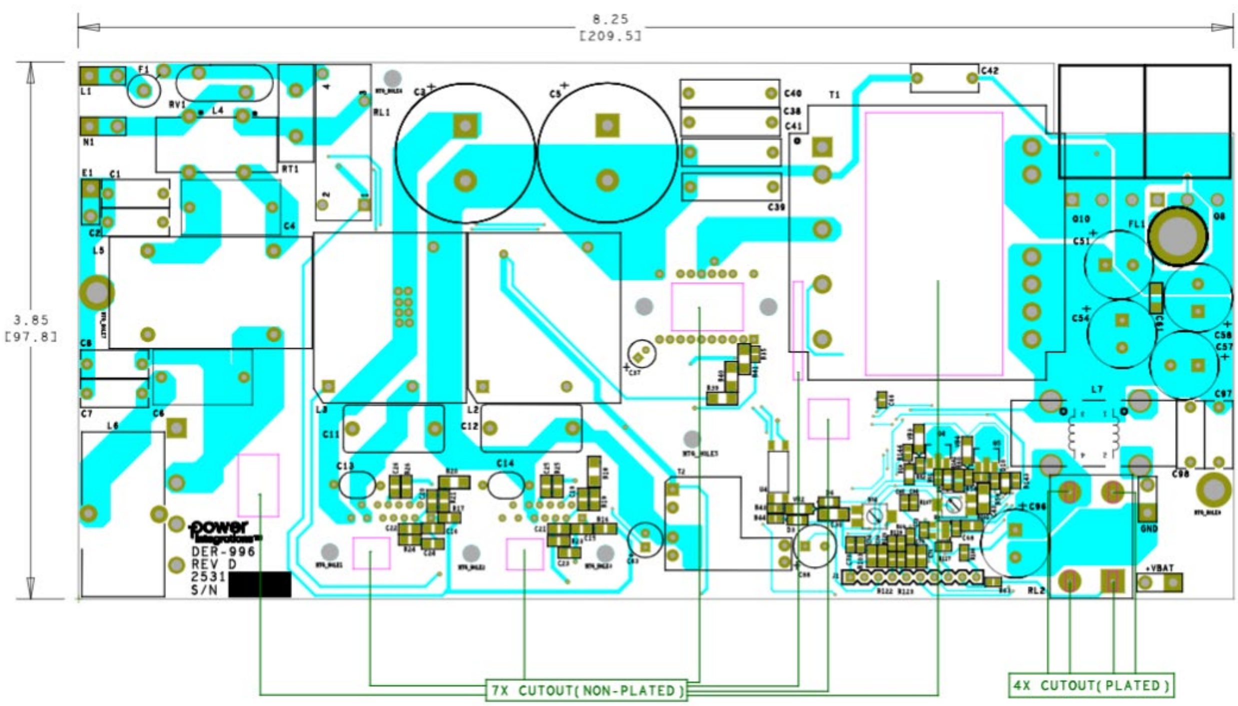


Figure 9 – Main Board, Top Side PCB.

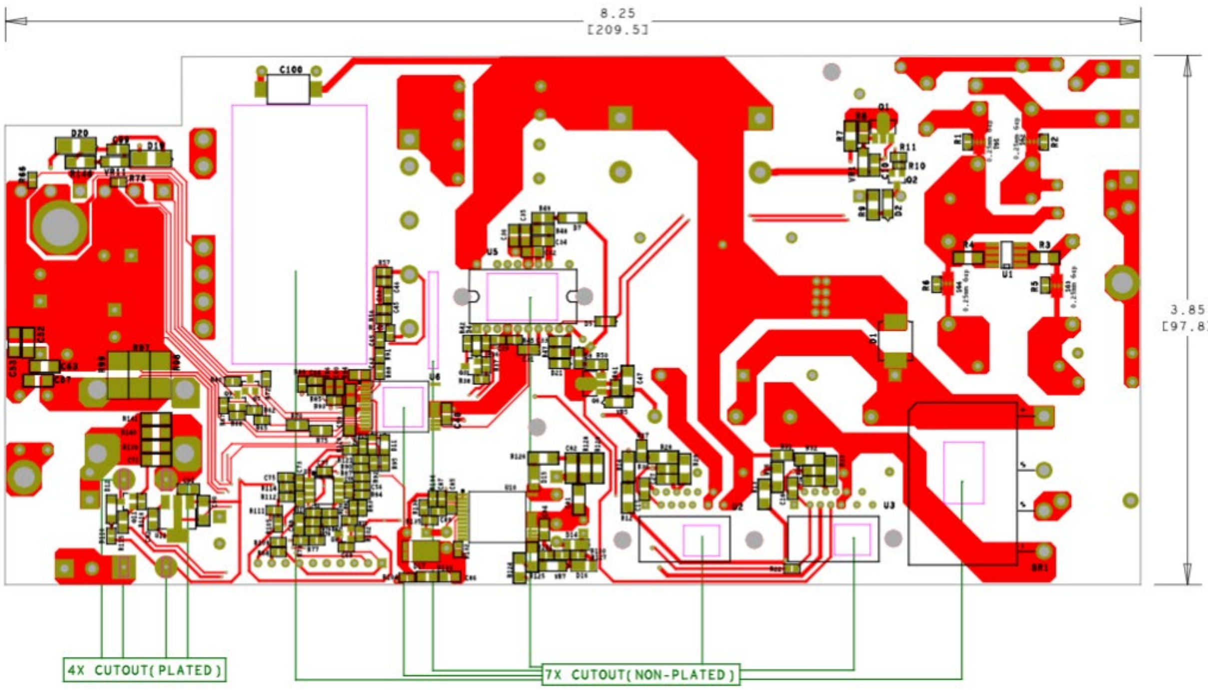


Figure 10 – Main Board, Bottom Side PCB.

6 Bill of Materials

Item	Qty	Part Ref.	Description	Mfg Part Number	Manufacturer
1	5	+VBAT E1 GND L1 N1	0.250" (6.35mm) Quick Connect Male - Solder Connector Non-Insulated	1287-ST	KeyStone Electronics
2	1	BR1	Bridge Rectifier, 600 V, 20 A, Single Phase Standard, Through Hole GBJ,4-ESIP	GBJ2006	SMC Diode Solutions
3	7	C1 C2 C7 C8 C42 C97 C98	1 nF, 500 VAC, Ceramic, Y1	VY1102M35Y5UG63V0	Vishay BC Components
4	2	C3 C5	330 µF, ±20%, 450 V, Aluminum Electrolytic Capacitors, Radial, Can - Snap-In, 2000 Hrs @ 105°C, (25.4 x 40)	EKMZ451VSN331MQ40S	Chemi-Con
5	2	C4 C6	680 nF, ±20%,305 VAC, Polypropylene (PP) Film, X2, -40°C ~ 110°C, Radial, 0.709" L x 0.433" W (18.00mm x 11.00mm), H 0.728" (18.50mm), LS 0.591" (15.00mm)	B32922C3684M000	EPCOS (TDK)
6	5	C10 C35 C36 C91 C92	10 µF ±10% 35 V Ceramic Capacitor X5R 0805 (2012 Metric)	C2012X5R1V106K125AC	TDK Corporation
7	2	C11 C12	1.0 uF, 450 V, Polyester Film	ECQ-E2W105KH	Panasonic
8	2	C13 C14	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX Corp
9	2	C15 C16	1 uF, 25 V, Ceramic, X5R, 0805	C2012X5R1E105K	TDK
10	2	C17 C18	1 uF,±10%, 50 V, Ceramic, X7R, 0805 (2012 Metric)	CL21B105KBFNNNE	Samsung Electro-Mechanics
11	4	C19 C20 C27 C28	470 pF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB471	Yageo
12	2	C21 C22	100 nF, 25 V, Ceramic, X7R, 0805	08053C104KAT2A	AVX Corp
13	3	C23 C24 C34	1 µF, 50 V, Ceramic, X5R, 0805	08055D105KAT2A	AVX Corporation
14	2	C25 C26	1 nF, 50 V, Ceramic, X7R, 0805	08055C102KAT2A	AVX Corp
15	2	C29 C89	330 pF, ±5%, 50 V, Ceramic Capacitor X7R, 0603 (1608 Metric)	CC0603JRX7R9BB331	Yageo
16	1	C30	1 µF, 100 V, Ceramic, X7R, 1206	HMK316B7105KL-T	Taiyo Yuden
17	2	C31 C33	1 µF, ±10%, 25 V, Ceramic, X7R, 0805 (2012 Metric)	GCM21BR71E105KA56L	Murata Electronics North America
18	1	C32	220 nF, 25 V, Ceramic, X7R, 0805	CC0805KRX7R8BB224	Yageo
19	1	C37	68 µF, 25 V, Aluminum Electrolytic Capacitors, Radial, Can - 7000 Hrs @ 105°C (5 x 12.5), LS 2 mm	25ZLJ68M5X11	Rubycon
20	4	C38 C39 C40 C41	0.018 µF, ±5%, Film Capacitor, 600 VAC 1000 VDC (1kV), Polypropylene (PP), Metallized Radial	R76QI218050H4J	KEMET
21	1	C43	1 µF, 25 V, Ceramic, X7R, 1206	C3216X7R1E105K	TDK Corp

22	2	C45 C65	470 pF, 200 V, Ceramic, X7R, 0603	06032C471KAT2A	AVX
23	2	C46 C93	100 pF, 200 V, Ceramic, NP0, 0603	C0603C101J2GAC7867	Kemet
24	1	C47	2.2 µF, ±10%, 50 V, Ceramic, X7R, 1206 (3216 Metric)	CL31B225KBHNNNE	Samsung Electro-Mechanics
25	1	C48	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
26	1	C49	100 pF 100 V 10 % X7R 0805	08051C101JAT2A	AVX Corp
27	1	C50	2.2 µF, ±10% 16 V, Ceramic Capacitor X7S, 0603 (1608 Metric)	CGA3E1X7S1C225K080AE	TDK Corporation
28	5	C51 C54 C57 C58 C96	750 µF, ±20%, 80 V, Automotive, AEC-Q200, Aluminum Electrolytic Capacitors, Radial, Can, 31mOhm @ 100kHz, 2000 Hrs @ 135°C, (12.5 x 40)	EGPD800ELL751MK40H	Chemi-Con
29	6	C52 C53 C61 C63 C67 C71	1 uF, 100 V, Ceramic, X7R, 1206	C3216X7R2A105K	TDK Corp
30	1	C55	0.47 µF, ±10%, 50 V, Ceramic Capacitor X7R, 0603 (1608 Metric)	CGA3E3X7R1H474K080AB	TDK Corporation
31	1	C56	10 nF 50 V, Ceramic, X7R, 0603	C0603C103K5RACTU	Kemet
32	1	C59	10 µF, ±20%, 35 V, Ceramic Capacitor X7R, 1206 (3216 Metric)	GMJ316BB7106MLHT	Taiyo Yuden
33	1	C60	150 pF, ±10%, 25 V, Ceramic Capacitor X7R, 0603 (1608 Metric)	885012206054	Würth Elektronik
34	5	C62 C74 C76 C78 C79	10 µF, ±10%, 10 V, Ceramic Capacitor, Soft Termination, X7R, 0805 (2012 Metric)	C2012X7R1A106K125AE	TDK Corp
35	1	C64	4.7 nF 50 V, Ceramic, X7R, 0603	CL10B472KB8NNNC	Samsung Electro-Mechanics
36	1	C66	100 pF, ±5%, 25 V, Ceramic Capacitor, C0G, NP0, 0603 (1608 Metric)	885012006038	Würth Elektronik
37	3	C68 C94 C95	10000 pF, ±20%, 50 V, Ceramic Capacitor X7R 0603 (1608 Metric), Automotive, AEC-Q200	C0603C103M5RACAUTO	KEMET
38	2	C69 C77	1 µF, ±10%, 25 V, Ceramic, X7R, 0603 (1608 Metric)	CGA3E1X7R1E105K080AE	TDK Corp
39	1	C70	2.2 µF, ±10%, 25 V, Ceramic, X5R, 0603 (1608 Metric)	GRM188R61E225KA12D	Murata Electronics North America
40	1	C72	10 µF, ±10%, 16 V, Ceramic, X5R, 0603 (1608 Metric)	GRM188R61C106KAALD	Murata Electronics North America
41	2	C73 C80	470 nF, ±20%, 50 V, Ceramic, X7R, 0603	CGA3E3X7R1H474M080AB	TDK Corp
42	1	C75	0.47 µF, ±20%, 25 V, Ceramic Capacitor, X7R, 0603 (1608 Metric)	CGA3E3X7R1E474M080AD	TDK Corporation

43	1	C81	0.056 µF, ±10%, 630 V, Ceramic Capacitor X7R, 1206 (3216 Metric)	1206B563K631CT	Walsin Technology Corporation
44	1	C82	1000 pF, 630 V, Ceramic, X7R, 1206	C1206C102KBRACTU	Kemet
45	1	C83	100 µF, 35 V, Electrolytic, Gen. Purpose, (6.3 x 11)	EKMG350ELL101MF11D	Nippon Chemi-Con
46	1	C84	4.7 µF, ±10%, 16 V, Ceramic, X7R, 0805 (2012 Metric)	GRM21BR71C475KE51L	Murata
47	1	C85	2.2 µF, ±20%, 25 V, Ceramic Capacitor X7R, 0805 (2012 Metric)	08053C225MAT2A	KYOCERA AVX
48	1	C86	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX Corp
49	1	C87	330 pF 50 V, Ceramic, X7R, 0603	CC0603KRX7R9BB331	Yageo
50	1	C88	680 uF, 16 V, Electrolytic, Very Low ESR, 38 mOhm, (8 x 20)	EKZE160ELL681MH20D	Nippon Chemi-Con
51	1	C90	2.2 uF, 25 V, Ceramic, X7R, 1206	TMK316B7225KL-T	Taiyo Yuden
52	1	C99	22 nF, 250 V, Ceramic, X7R, 0805	C2012X7R2E223M	TDK Corp
53	1	C100	1000 pF, ±20%, 400 VAC, Ceramic Capacitor, Y1 class, 7.8mm x 5.4mm, gullwing leads	TMY1102M	SHENZHEN JINXU ELECTRONICS TECHNOLOGY
54	1	D1	Diode, 600 V, 6 A, Surface Mount DO-214AB (SMC)	SMLJ60S6-TP	MCC (Micro Commercial Components)
55	2	D2 D12	DIODE, GEN PURP, 100 V, 150MA, SOD123, SOD-123F	1N4148W RHG	Taiwan Semiconductor Corporation
56	4	D3 D6 D8 D21	75 V, 200 mA, Rectifier, SOD323	BAS16HT1G	ON Semiconductor
57	7	D4 D5 D9 D10 D11 D13 D18	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diode Inc.
58	1	D7	600 V, 1 A, Ultrafast Recovery, 75 ns, SOD-123	UFM15PL-TP	Micro Commercial Co Micro Commercial Co
59	2	D14 D16	200 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1200-7	Diodes Inc
60	1	D15	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes Inc
61	1	D17	100 V, 5 A, Schottky, SMD, POWERD15, PowerDI™ 5	SDT5H100P5-7	Diode Inc.
62	2	D19 D20	50 V, 1 A, General Purpose, DO-214AC	ES1A-13-F	Diode Inc.
63	1	F1	15 A, 250 V AC DC, Fuse Cartridge, Ceramic, Through Hole 5mm x 20mm (Axial)	0215015.MXEP	Littelfuse
64	2	L2 L3	Bobbin, PQ26/25, Vertical, 12 pins	CPV-PQ26/25-1S-12P-Z	Ferroxcube
65	1	L4	1.1 mH, HF Common Mode Choke,	30-00550-00	PI

66	1	L5	5 mH, 8.9 A, Common Mode Choke with header (1.45" W x .80" T x 1.5" H)	8113-RC	Bourns Inc.
67	1	L6	220 µH 2 pin Toroidal Choke OD 30 mm, W 15 mm, LS 15 mm	30-00548-00	PI
68	1	L7	250uH, 2 Line Common Mode Choke, Wound on 32-00444-00 core with 15AWG Magnet Wire, 26.55 mm OD x 14.35 mm ID x 8.69 mm H	32-00482-00	PI
69	4	Q1 Q4 Q5 Q6	Bipolar (BJT) Transistor, NPN, 60 V, 5 A, 185 MHz, 2.4 W, Surface Mount SOT-89-3, TO-243AA, SOT-89	ZXTN25060BZTA	Diodes Incorporated
70	1	Q2	MOSFET, N-Channel, 100 V, 200 mA, 350 mW (Ta), Surface Mount SOT-23-3 , TO-236-3, SC-59	BSS123	onsemi
71	1	Q3	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	On Semiconductor
72	2	Q7 Q9	MOSFET, N-Channel, 300 V, 85 mA (Tj), 360 mW (Tc), Surface Mount TO-236AB (SOT23)	TN2130K1-G	Microchip Technology
73	2	Q8 Q10	200 V, 20 A, 180 mOhm. N-Channel, TO-247AC	IRFP240PBF	Vishay/Siliconix
74	1	Q11	NPN, Small Signal BJT, 80 V, 0.5 A, SOT-23	MMBTA06LT1	Infineon Tech
75	4	R1 R2 R5 R6	RES, 100 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
76	2	R3 R4	RES, 510 k, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J514V	Panasonic
77	1	R7	RES, 2.2 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J2R2V	Panasonic
78	2	R8 R115	RES, 10 k, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
79	1	R9	RES, 10 R, 5%, 1/4 W, Pulse Proof, Thick Film, 1206	SR1206JR-0710RL	Yago
80	1	R10	100 kOhms, ±5%, 0.063 W, 1/16 W, Chip Resistor 0402 (1005 Metric), Moisture Resistant Thick Film	RC0402JR-07100KL	YAGEO
81	1	R11	RES, 4.7 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ472V	Panasonic
82	8	R12 R13 R14 R15 R28 R29 R32 R33	RES, 6.2 M, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF6204	Rohm Semi
83	2	R16 R17	RES, 10 R, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF10R0V	Panasonic
84	2	R18 R20	RES, 3.74 M, 1%, 1/4 W, Thick Film, 1206	CRCW12063M74FKEA	Vishay Dale
85	2	R19 R21	RES, 162 k, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1623V	Panasonic
86	8	R22 R51 R59 R72 R80 R127 R143 R145	RES, 0 Ohms Jumper 0.1 W, 1/10 W Chip Resistor 0603 (1608 Metric) Moisture Resistant Thick Film	RC0603FR-070RL	Yageo

87	2	R23 R24	RES, 13.0 k, 1%, 1/8 W, Thick Film, 0805	RC0805FR-0713KL	Yageo
88	2	R25 R26	RES, 332 k, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3323V	Panasonic
89	2	R27 R31	RES, 3.6 M, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ365V	Panasonic
90	2	R30 R34	160 kOhms, ±1%, 0.125W, 1/8 W, Chip Resistor 0805 (2012 Metric), Automotive AEC-Q200, Thick Film	ERJ-6ENF1603V	Panasonic
91	1	R35	RES, 18.2 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1822V	Panasonic
92	1	R36	RES, 20 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF2002V	Panasonic
93	1	R37	RES, 47 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ473V	Panasonic
94	1	R38	RES, 470 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ474V	Panasonic
95	2	R39 R40	RES, 1.50 M, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1504V	Panasonic
96	1	R41	RES, 1.00 M, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1004V	Panasonic
97	1	R42	RES, 24 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ243V	Panasonic
98	1	R43	RES, 100 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ101V	Panasonic
99	1	R44	RES, 10 kOhms, ±5%, 0.1 W, 1/10 W, Chip Resistor 0603 (1608 Metric), Automotive AEC-Q200, Moisture Resistant, Thick Film	AC0603JR-0710KL	YAGEO
100	1	R45	RES, 316 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF3163V	Panasonic
101	2	R47 R48	RES, 11 R, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ110V	Panasonic
102	1	R49	RES, 2.2 R, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ2R2V	Panasonic
103	1	R50	RES, 10 R, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ100V	Panasonic
104	2	R52 R58	RES, 68 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ683V	Panasonic
105	2	R56 R57	RES, 13 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1302V	Panasonic
106	1	R60	RES, 28.0 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF2802V	Panasonic
107	5	R61 R66 R76 R118 R120	RES, 10 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
108	2	R62 R67	RES, 200 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ201V	Panasonic
109	4	R63 R77 R93 R108	RES, 340 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF3403V	Panasonic
110	6	R64 R71 R105 R109 R122 R123	RES, 10 kOhms, ±1%, 0.1 W, 1/10 W, Chip Resistor 0603 (1608 Metric), Automotive, AEC-Q200, Moisture Resistant Thick Film	CRGCQ0603F10K	TE Connectivity Passive Product

111	2	R65 R68	RES, 511 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF5113V	Panasonic
112	1	R69	RES, SMD, 10.0K, 1%, 1/10 W, ±100 ppm/°C, -55°C ~ 155°C, 0603 (1608 Metric), Moisture Resistant, Thick Film	RC0603FR-0710KL	Yageo
113	2	R70 R75	RES, 1 k, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
114	3	R73 R81 R104	RES, 0 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEY0R00V	Panasonic
115	2	R74 R107	POT, 10 K, ±20%, 1/4 W, Gull Wing Surface Mount Trimmer	ST4ETB103	Copal Electronics Inc.
116	1	R78	RES, 6.81 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF6811V	Panasonic
117	1	R79	RES, 150 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1503V	Panasonic
118	2	R82 R113	RES, 2 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ202V	Panasonic
119	2	R83 R111	RES, 100 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1003V	Panasonic
120	2	R84 R87	RES,43 kOhms, ±1%, 0.1W, 1/10 W, Chip Resistor 0603 (1608 Metric), Automotive, AEC-Q200, Thick Film	RK73H1JTTD4302F	KOA Speer Electronics, Inc.
121	1	R85	RES, 75 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ753V	Panasonic
122	1	R86	RES, 2 M, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ205V	Panasonic
123	3	R88 R91 R136	RES, 1.20 M, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1204V	Panasonic
124	1	R89	RES, 255 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF2553V	Panasonic
125	2	R90 R92	RES, 2.2 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ222V	Panasonic
126	1	R94	RES, 22.6 k, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2262V	Panasonic
127	2	R95 R100	RES, 1 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1001V	Panasonic
128	3	R97 R98 R99	RES, 5 mOhms, ±1%, 3 W, Chip Resistor 2512 (6332 Metric), Automotive AEC-Q200, Current Sense, Moisture Resistant Metal Element	MSMA2512R0050FGM	Eaton - Electronics Division
129	1	R101	RES, 0 Ohms Jumper, Chip Resistor, 0805 (2012 Metric) Metal Element	5106	Keystone Electronics
130	1	R102	RES, 8.87 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF8871V	Panasonic
131	1	R103	RES, 11.8 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1182V	Panasonic
132	1	R110	RES, 2.2 R, 1%, 1/16 W, Thick Film, 0603	ERJ-3RQF2R2V	Panasonic
133	2	R112 R121	RES, 15 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1502V	Panasonic
134	1	R114	RES, 43 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ433V	Panasonic

135	1	R116	RES, 100 kOhms, ±1%, 0.1 W, 1/10 W, Chip Resistor 0603 (1608 Metric), Automotive AEC-Q200, Thick Film	ERJ-3EKF1003V	Panasonic Electronic Components
136	2	R117 R135	RES, 1 kOhms ±5% 0.1 W, 1/10 W Chip Resistor 0603 (1608 Metric) Moisture Resistant Thick Film	RC0603JR-071KL	Yageo
137	1	R119	RES, 4.7 kOhms, ±1%, 0.1 W, 1/10 W, Chip Resistor 0603 (1608 Metric), Moisture Resistant, Thick Film	RC0603FR-074K7L	YAGEO
138	1	R124	RES, 2.00 M, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
139	1	R125	RES, 1.80 M, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
140	1	R126	RES, 68 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J680V	Panasonic
141	2	R128 R129	RES, 200 k, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J204V	Panasonic
142	1	R130	RES, 6.2 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ622V	Panasonic
143	1	R131	RES, 36 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ360V	Panasonic
144	1	R132	RES, 47 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ470V	Panasonic
145	1	R133	RES, 30 R, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ300V	Panasonic
146	1	R134	RES, 33.2 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF3322V	Panasonic
147	3	R139 R140 R141	RES, 100 k, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J104V	Panasonic
148	1	R142	RES, 0 Ohms, Jumper, 0.25 W, 1/4 W Chip Resistor, 0805 (2012 Metric), Anti-Sulfur, Moisture Resistant Thick Film	RK73Z2ARTTD	KOA Speer Electronics, Inc.
149	1	R144	RES, 1 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
150	1	R146	RES, 150 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J151V	Panasonic
151	1	RL1	RELAY GEN PURPOSE SPST 8 A 12 V	G6RL-1A-ASI-DC12	OMRON
152	1	RL2	Automotive Relays, SPNO, 35 A, 12 VDC	301-1A-S-R1-12VDC	Song Chuan
153	1	RT1	NTC Thermistor, 16 Ohms, 4 A	CL-70	Thermometrics
154	1	RV1	320 VAC, 80 J, 14 mm, RADIAL	V320LA20AP	Littlefuse
155	1	T1	BOBBIN, COIL FORMER, PQ, 50 X 50, 16 pins	MCT-PQ5050	MyCoilTech
156	1	T2	Bobbin, EE1621, Vertical, 8 pins (4pri/4 sec)	EE-1621	Shen Zhen Xin Yu Jia Tech
157	1	U1	CAPZero, CAP003DG, SO-8C	CAP003DG	Power Integrations
158	2	U2 U3	HiperPFS-3, PFS7539L, L-Bend eSIP	PFS7539L	Power Integrations
159	1	U4	OPTOISOLATOR 5 KV 1 CH TRANS 4-SOP	TCLT1000	Vishay Semiconductor Opto Division

160	1	U5	HiperLCS2-HB, LCS7269Z, POWeDIP-20B	LCS7269Z	Power Integrations
161	1	U6	HiperLCS2-SR, LSR2000C-H005, InSOP-24D	LSR2000C-H005	Power Integrations
162	1	U10	INN3692C-H606, INNO3 Switch Integrated Circuit, InnoSwitch-3EP_900 V, InSOP24D	INN3692C-H606	Power Integrations
163	1	U11	IC, Linear Voltage Regulator, Positive, Fixed, 1 Output, 5 V, 1 A, SOT-223-3	NCP1117ST50T3G	ON Semiconductor
164	1	U7	DUAL Op Amp, Single Supply, SOIC-8	LM358D	Texas Instruments
165	1	U8	IC, Shunt Regulator Adj., 2.495 V, 2.2%, 100 mA, 0°C ~ 70°C (TA), SOT23-3, TO-236-3, SC-59, SOT-23-3	TL431CDBZR	Texas Instruments
166	1	U9	IC, Current Sense Amplifier, 1 Circuit, Rail-to-Rail, SOT-23-5, SC-74A, SOT-753	INA180A1IDBVR	Texas Instruments
167	1	VR1	Zener Diode, 12 V, ±2%, 500 mW, Surface Mount, SOD-123	MMSZ5242C-E3-08	Vishay General Semiconductor - Diodes Division
168	1	VR2	DIODE, ZENER, 68 V, 500 mW, SOD123	MMSZ5266BT1G	ON Semi
169	1	VR3	DIODE ZENER, 11 V, 500 mW, SOD123	MMSZ5241B-7-F	Diodes, Inc
170	1	VR4	13 V, 5%, 500 mW, SOD-123	MMSZ5243BT1G	ON Semiconductor
171	2	VR5 VR7	DIODE ZENER, 20 V, 500 mW, SOD123	MMSZ5250B-7-F	Diodes, Inc
172	1	VR11	Zener Diode, 62 V, 500 mW, ±2%, Surface Mount SOD-123	MMSZ5265C-E3-08	Vishay Semiconductor Diodes Division

Table 2 – Bill of Materials, Main Board Electrical Parts.

Item	Qty.	Part Ref.	Description	Mfr. Part Number	Manufacturer
1	5	+VBAT E1 GND L1 N1	0.250" (6.35mm) Quick Connect Male - Solder Connector Non-Insulated	1287-ST	KeyStone Electronics
2	1	FL1	Flying Lead, Hole size 156mils	N/A	N/A
3	1	HS1	SHTM, Heat Sink, LCS\DER-996_RevD, Composition: AL, 3003, Extrusion	61-00394-00	Custom
4	1	HS3	SHTM, Heat Spreader for LCS\DER-996_RevD, Composition: AL, 3003, 0.060" thick	61-00396-00	Custom
5	1	HS5	SHTM, Heat Spreader for PFS\DER-996_RevD, Composition: AL, 3003, 0.125" thick	61-00397-00	Custom
6	1	J1	10 Position (1 x 10) header, 0.1 pitch, Vertical	PRPC010SFAN-RC	Sullins Connector Solutions

7	4	SG1 SG2 SG3 SG4	Spark Gap 0.25mm		
8	5	MTG_HOLE1 MTG_HOLE2 MTG_HOLE3 MTG_HOLE4 MTG_HOLE5	Mounting Hole No 4		
9	2	MTG_HOLE7 MTG_HOLE8	Mounting Hole M 3		
10	2	MTG_HOLE7 MTG_HOLE8	Mounting Hole M 3		
11	11	SCREW 1 SCREW 2 SCREW 3 SCREW 4 SCREW 5 SCREW 6 SCREW 7 SCREW 8 SCREW 9 SCREW 10 SCREW 11	Screw Machine Phil 4-40 x ½ SS	75-00004-000	
12		TO-247 PAD1 TO-247 PAD2	Thermal Pad for FET	66-00083-00	
13		WASHER1 WASHER2	Washer, Shoulder, #4, 0.125 Shoulder x 0.140 Dia, Polyphenylene Sulfide PPS	7721-3PPSG	Aavid Thermalloy
14		WASHER3 WASHER4 WASHER5 WASHER6 WASHER7 WASHER8 WASHER9	WASHER FLAT #4 Zinc, OD 0.219, ID 0.125, Thk 0.032, Yellow Chromate Finish	5205820-2	Tyco Electronics
15		PAD 1	Thermal Pad for PFS	61-00398-00	
16		INS 1	Insulator for PFS	61-00399-00	

Table 3 – Bill of Materials, Main Board Mechanical Parts.

7 Magnetics

7.1 PFC Choke (L2/L3) Specification

7.1.1 Electrical Diagram

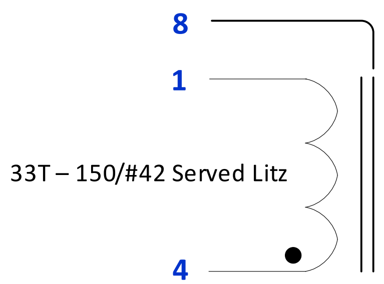


Figure 11 – PFC Choke (L2/L3) Electrical Diagram.

7.1.2 Electrical Specifications

Inductance	Pins 1-4 measured at 100 kHz, 0.4 RMS.	130 μH +5%

Table 4 – Inductor Electrical Diagram

7.1.3 Material List

Item	Description
[1]	Core: Ferrite Core: PC95, PQ26/25
[2]	Bobbin: PQ26/25 (PI# 25-00055-00)
[3]	Magnet wire: 150/#42_Served Litz
[4]	Bus wire: #24 AWG, connects to pin8
[5]	Tape: 3M 1298 Polyester Film, 13mm wide, 2.0 mil thick, or equivalent.
[6]	Varnish: Dolph BC-359, or equivalent.

Table 5 – Inductor Material List

7.1.4 Inductor Build Diagram

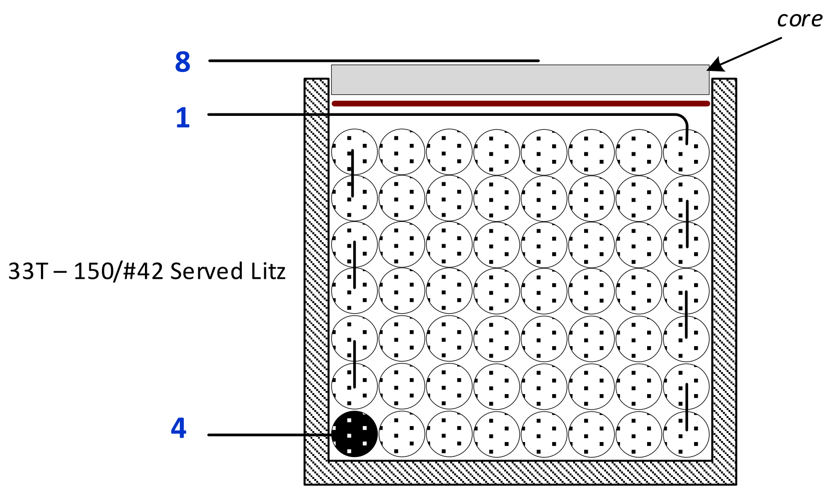


Figure 12 – PFC Inductor Build Diagram.

7.1.5 Winding Preparation

BOBBIN	➢ Pin 1 is the chamfered portion of the bobbin. ➢ Remove pins 2, 3, 5, 6, 7, 9, 10, 11 and 12.

Table 6 – Inductor Winding Preparation.

7.2 Common Mode Choke (L4) Specification

7.2.1 Electrical Diagram

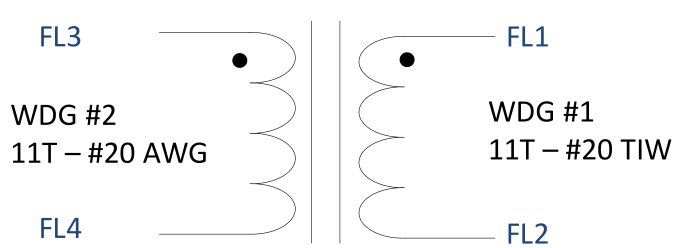


Figure 13 – L4 Inductor Electrical Diagram

7.2.2 Electrical Specifications

Inductance	FL1-FL2 or FL3-FL4, measured at 100 kHz, 0.4 V_{RMS}	1.1 mH +20%

Table 7 – L4 Inductor Electrical Specifications

7.2.3 Material List

Item	Description
[1]	Todoid Core, Ferrite, Coated, High Perm. P/N 30-00398-00
[2]	Magnet wire, 20AWG
[3]	Triple Insulated Wire, Furukawa TEX-E or equivalent, 20 AWG

Table 8 – L4 Inductor Material List.

7.2.4 Construction Details

Winding	Using 1 strand each of magnet wire [2] and triple Insulated wire [3], wind 11 bifilar turns in 1 layer on toroid [1]
Termination	Trim flying leads to ½ in, tin to within 1/8 inch of toroid.

7.2.5 Winding Illustration

Figure 14 – L4 Finished Inductor.

7.3 Differential Choke (L6) Specification

7.3.1 Electrical Diagram

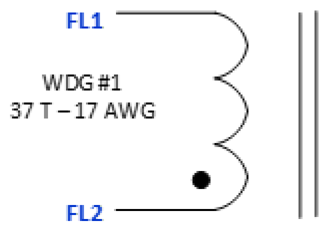


Figure 15 – L6 Inductor Electrical Diagram

7.3.2 Electrical Specifications

Inductance	FL1 - FL2 measured at 100kHz, 0.4 RMS.	220 µH +10%

Table 9 – L6 Inductor Electrical Specifications

7.3.3 Material List

Item	Description
[1]	Core: Sendust, Kool-Mu, 125u, Magnetics, Inc. 77930-A7 or equivalent
[2]	Magnet Wire, 17 AWG, double coated

Table 10 – L6 Inductor Material List.

7.4 Output Common Mode Choke (L7) Specification

7.4.1 Electrical Diagram

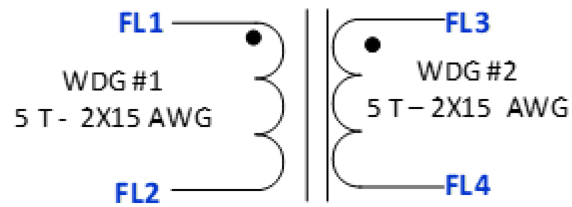


Figure 16 – L7 Inductor Electrical Diagram

7.4.2 Electrical Specifications

Inductance	Pins FL1 – FL2 or FL3-FL4 measured at 100kHz, 0.4 RMS.	250 µH +20%

Table 11 – L7 Inductor Electrical Specifications

7.4.3 Material List

Item	Description
[1]	Todoid Core, Ferrite, Coated, High Perm. P/N 32-00444-00
[2]	Magnet wire, 15AWG

Table 12 – L7 Inductor Material List.

7.5 LLC Transformer (T1) Specification

7.5.1 Electrical Diagram

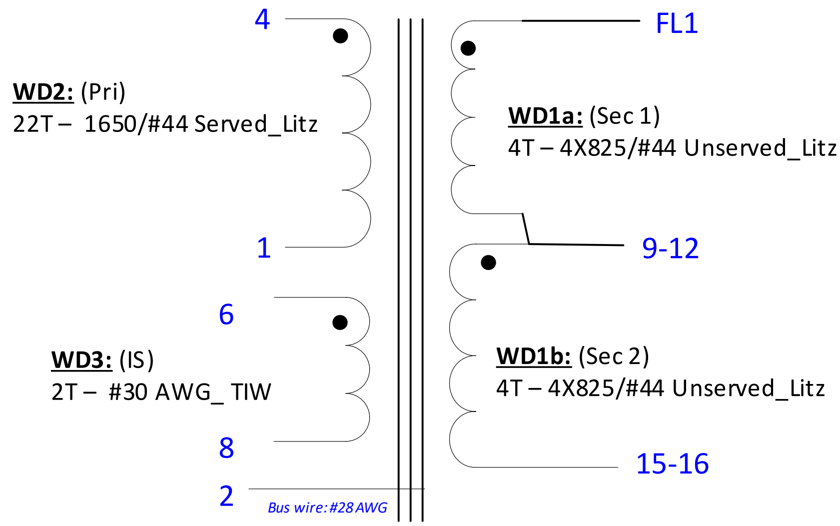


Figure 17 – LLC Transformer Electrical Diagram.

7.5.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1,4 to FL1-FL2, and pins 9,10,11,12.	3000 VAC
Primary Inductance (L_{PRI})	Pins 1-4, all other windings open, measured at 100 kHz, 1 V_{RMS}	120 μH ±5%
Primary Leakage1 (LlkpALL)	Pins 1-4, short **ALL** other pins except IS-winding, measured at 100 kHz, 1 V_{RMS}	42 μH ±5%.

Table 13 – LLC Transformer Electrical Specifications.

7.5.3 Material List

Item	Description
[1]	Core: PQ50/50, PC95 magnetic material or equivalent
[2]	Bobbin: PQ5050 -Horizontal, 16pins (8/8), MyCoilTech, PI#: 25-01262-00
[3]	Litz wire: #44 AWG/1650_Served Litz.
[4]	Litz wire: #44 AWG /825_Unserved Litz, 23” long
[5]	Triple Insulated Wire: #30AWG
[6]	Tape: 3M 1298 Polyester Film, 1 mil thick, 15.0mm wide.
[7]	Tape: 3M 1298 Polyester Film, 1 mil thick, 22.0mm wide.
[8]	Tape: 3M 1298 Polyester Film, 1 mil thick, 17.5mm wide.
[9]	Bus wire, #28AWG, Alpha wire, tinned copper; or equivalent.
[10]	Varnish: Dolph BC-359.

Table 14 – List of Materials.

7.5.4 Transformer Build Diagram

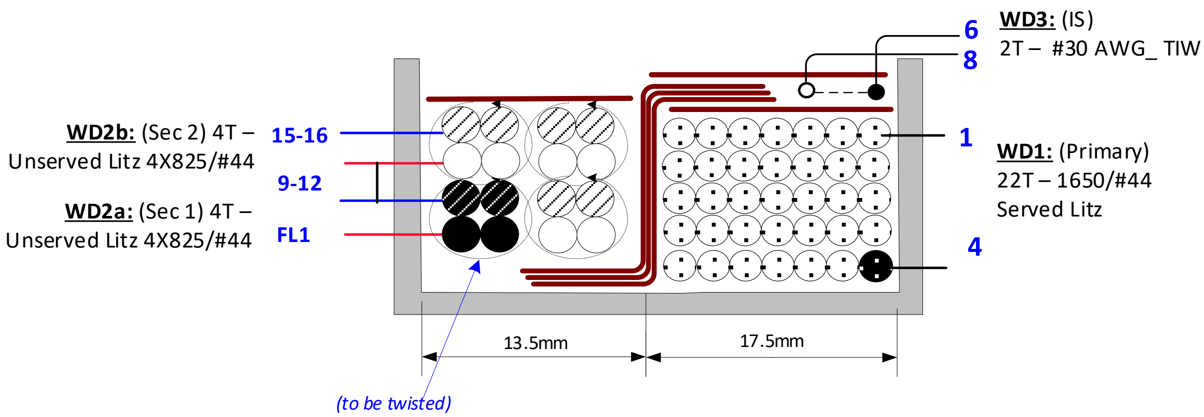


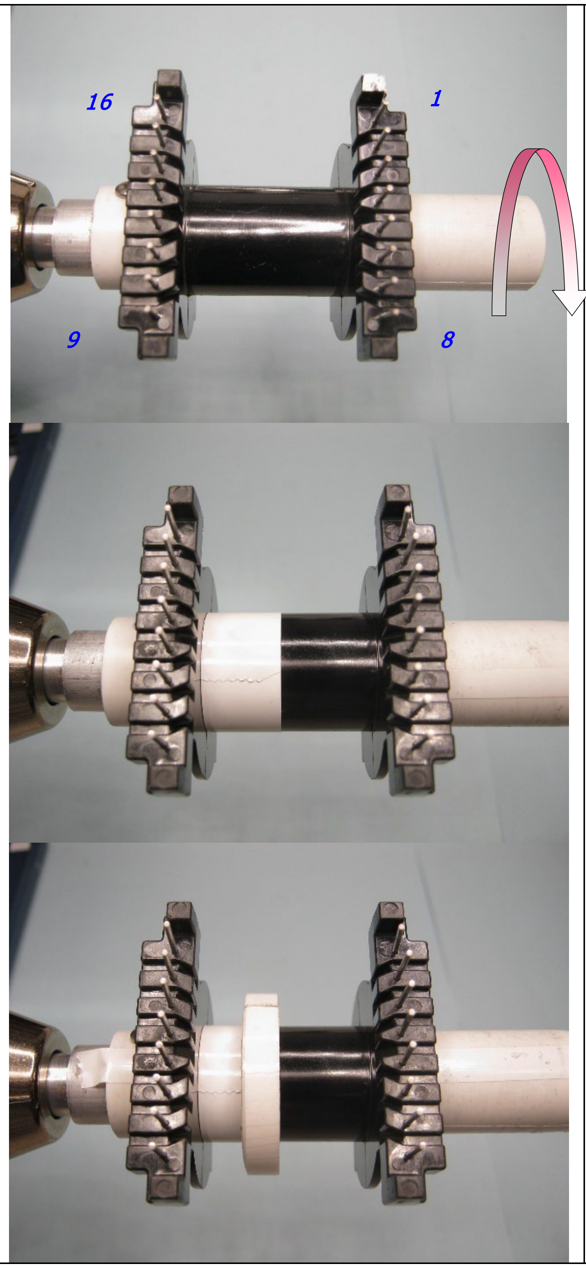
Figure 18 – LLC Transformer Build Diagram.

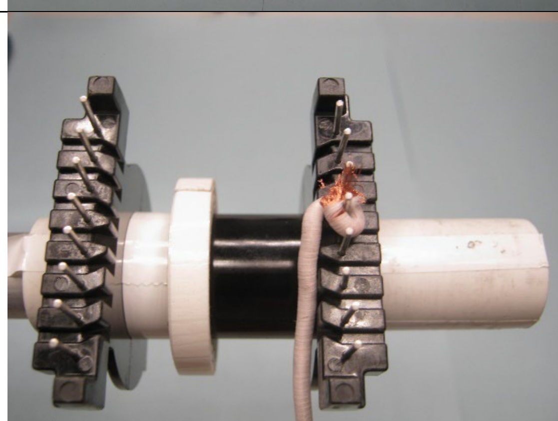
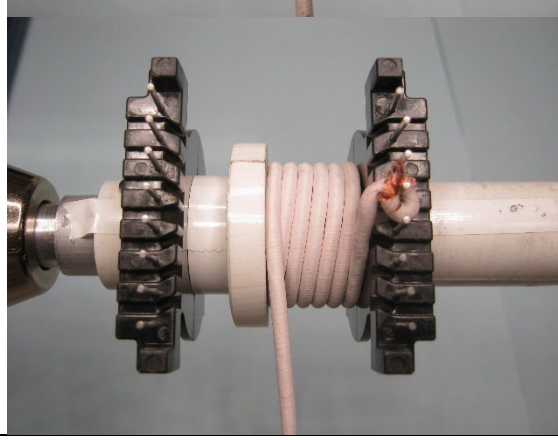
7.5.5 Transformer Instructions

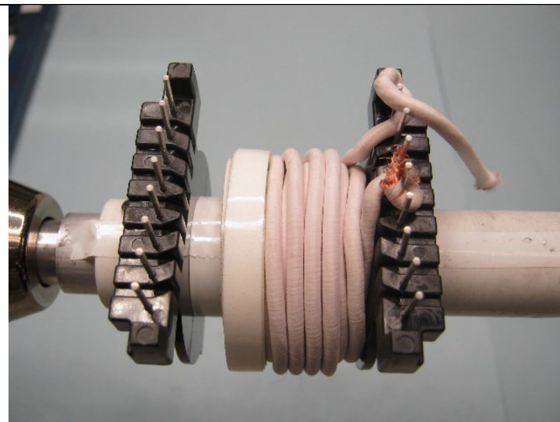
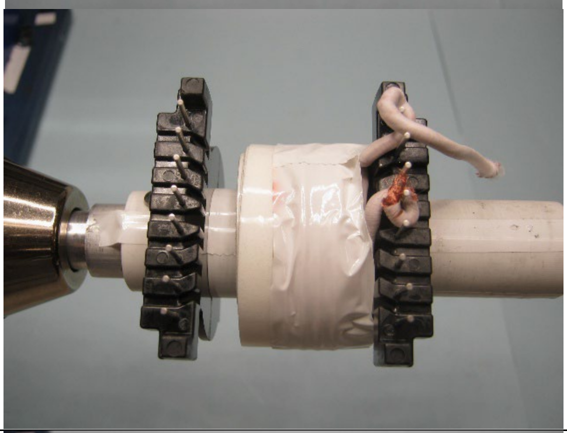
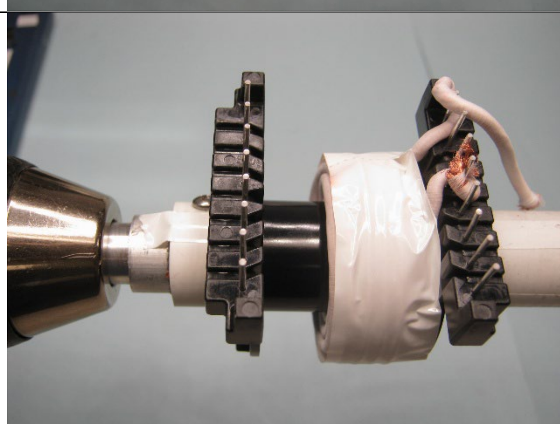
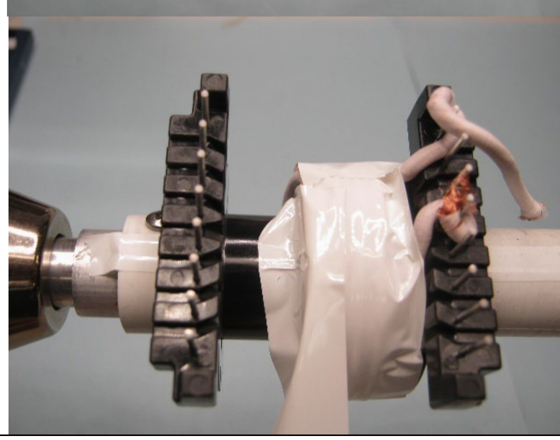
Winding preparation	Position the bobbin item [2] on the mandrel such that the primary side of the bobbin is on the right side. Winding direction is clockwise direction for forward direction. Place 1 layer of tape 14mm width on the left. Place margin tape such as 6.0mm wide align with right edge of tape 14mm and wind with height same as bobbin wall. Now we have right chamber for primary windings. To prepare secondary wires, use 4 wires item [4] with 23" long, twist, and tin both sides, and mark FL1 as start, FL3 as end. Repeat for another as FL4 as start and FL2 as end. Twist these 2 wires together for secondary with FL1 & FL4 for 1 end and FL4 & FL2 for another end, *(see picture below).*
WD1 Primary	Start at pin 4, wind 22 turns of wire item [3], left to right and right to left, with tight tension in 4 layers on the right chamber. At the last turn, terminate on pin 1. 1 layer of tape item [8] to hold primary winding.
Insulation	Remove 6.0mm margin tape and 14mm tape were constructed above and we have left chamber for secondary windings. Place 3 layers item [7] on top and the left side of primary winding (see construction drawing and pictures below) to create insulation between primary winding and secondary windings.
WD2a & WD2b Sec1 & Sec2	Use 2 wires prepared for secondary windings above, start with FL1 &FL4, leave 2" of wires floating, wind 4 turns in 2 layers, with tight tension, from left to right, and right to left. At the last turn, exit the bobbin, and end with FL2, FL3 also floating. 1 layer of tape item [6] to hold these windings.
WD3 IS	Place 1 piece of margin tape ~ 8.0 wide next to divider to create the remain space on the right for WD3-IS. Start at pin 6, use wire item [5], wind 2 turns from right to left on space just created. At the last turn, twist, and end with pin 8. Place 1 layer of tape item [8] to secure primary and IS windings.
Finish	Remove pins 13, 14. Solder floating wires FL3, FL4 to pins 9-12, and FL2 to pins 15-16, so now we have only 1 floating wire FL1. Gap core halves to get 120uH. Place 2 layers of tape item [6] for each corners of ground core (see picture beside). Ground core is placed on secondary winding side. Solder pin 2 with bus-wire item [9] then lean along core halves and secure with tape. Varnish with item [10].Varnish with item [10].

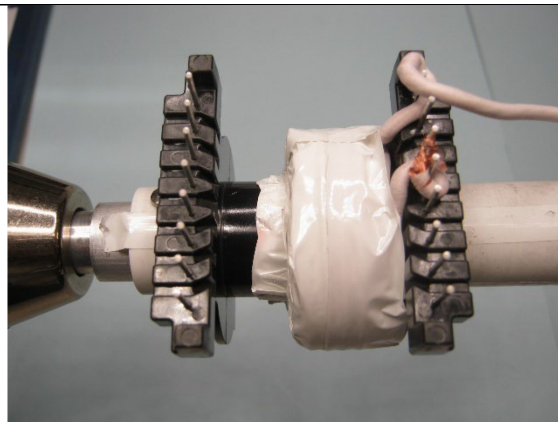
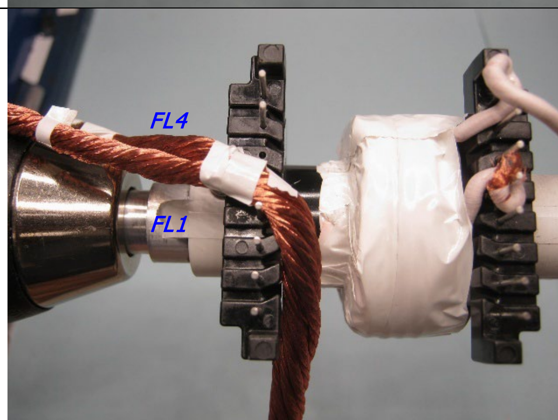
Table 15 – LLC Transformer Winding Preparation.

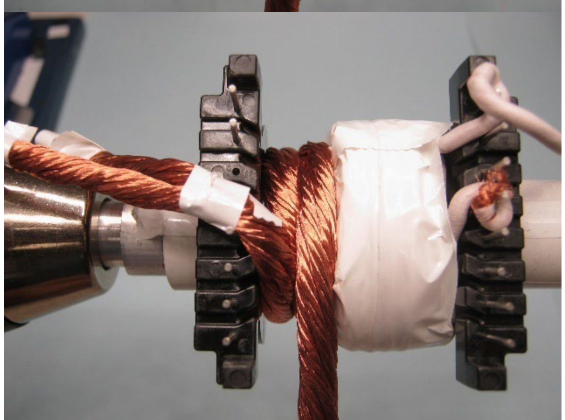
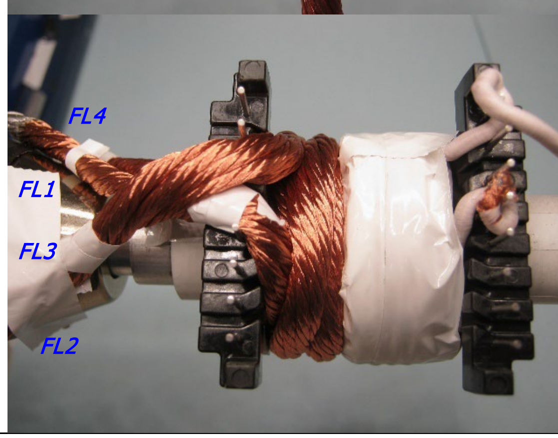
7.5.6 Winding Illustration

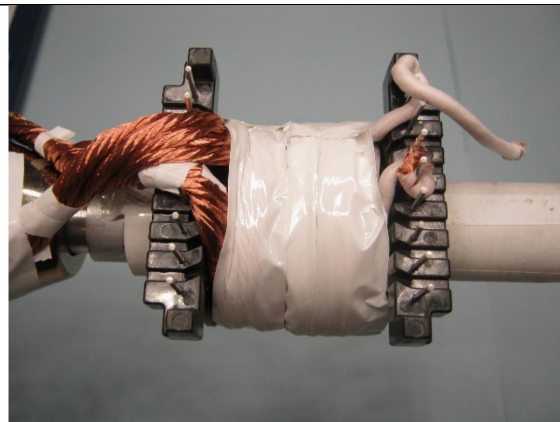
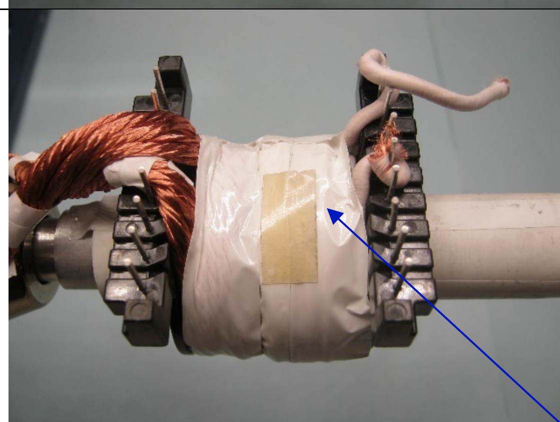
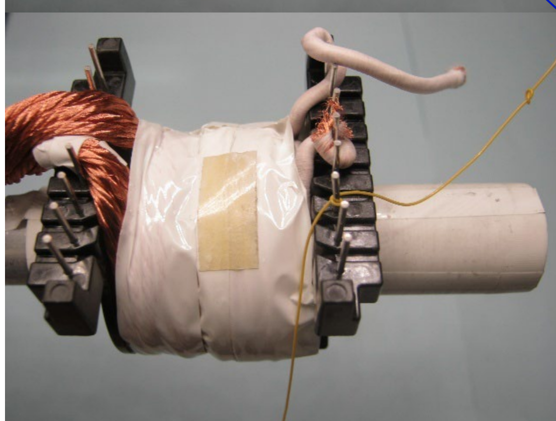
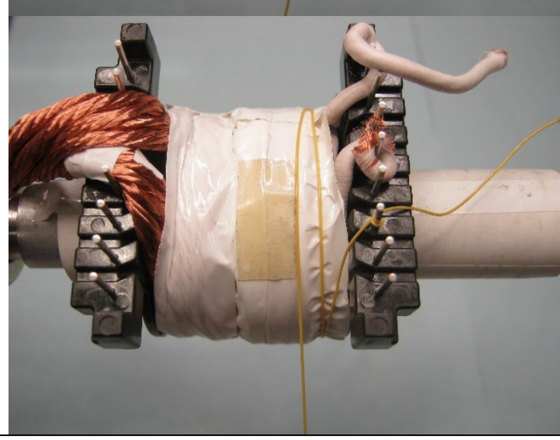
Winding preparation		Position the bobbin item [2] on the mandrel such that the primary side of the bobbin is on the right side. Winding direction is clockwise direction for forward direction. Place 1 layer of tape 14mm width on the left. Place margin tape such as 6.0mm wide align with right edge of tape 14mm and wind with height same as bobbin wall. Now we have right chamber for primary windings.

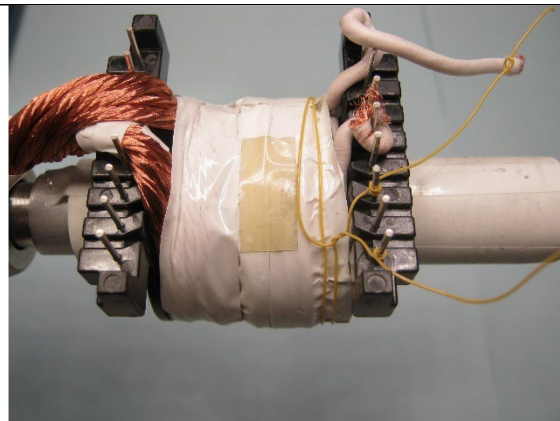
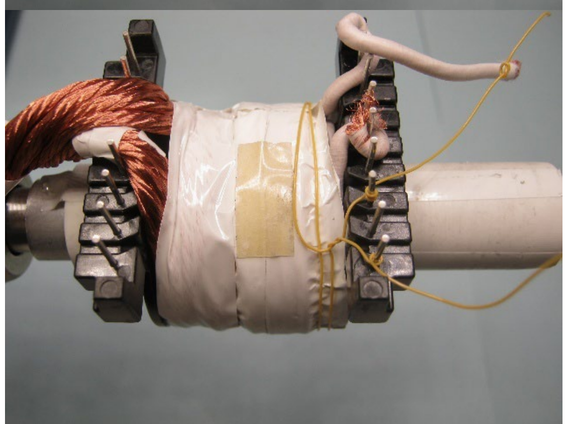
	 	To prepare secondary wires, use 4 wires item [4] with 23” long, twist, and tin both sides, and mark FL1 as start, FL3 as end. Repeat for another as FL4 as start and FL2 as end. Twist these 2 wires together for secondary with FL1 & FL4 for 1 end and FL4 & FL2 for another end, *(see picture beside).*
WD1 **Primary**	 	Use 2 wires prepared for secondary winding above, start with FL1 &FL4, leave 2” of wires floating, wind 4 turns in 2 layers, with tight tension, from left to right, and right to left. At the last turn, exit the bobbin, and end with FL2, FL3 also floating. 1 layer of tape item [6] to hold these windings.

	 	
Insulation	 	Remove 6.0mm margin tape and 14mm tape were constructed above and we have left chamber for secondary windings. Place 3 layers item [7] on top and the left side of primary winding (see construction drawing and pictures beside) to create insulation between primary winding and secondary windings.

<table>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WD2a & WD2b
Sec1 & Sec2</td>
<td>



</td>
<td>Use 2 wires prepared for secondary windings above, start with FL1 &FL4, leave 2” of wires floating, wind 4 turns in 2 layers, with tight tension, from left to right, and right to left. At the last turn, exit the bobbin, and end with FL2, FL3 also floating.
1 layer of tape item [6] to hold these windings.</td>
</tr>
</table>

		
WD3 **IS**	  	<u>Place 1 piece of margin tape ~ 8.0 wide next to divider to</u> create the remain space on the right for WD3-IS. Start at pin 6, use wire item [5], wind 2 turns from right to left on space just created. At the last turn, twist, and end with pin 8. Place 1 layer of tape item [8] to secure primary and IS windings

	 	
Finish		Remove pins 13, 14. Solder floating wires FL3, FL4 to pins 9-12, and FL2 to pins 15-16, so now we have only 1 floating wire FL1. Gap core halves to get 120μH.
		Place 2 layers of tape item [6] for each corner of ground core (see picture beside). Ground core is placed on secondary winding side. Solder pin 2 with bus-wire item [9] then lean along core halves and secure with tape. Varnish with item [10].

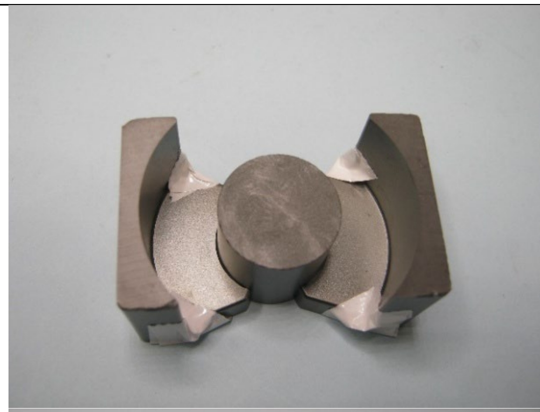
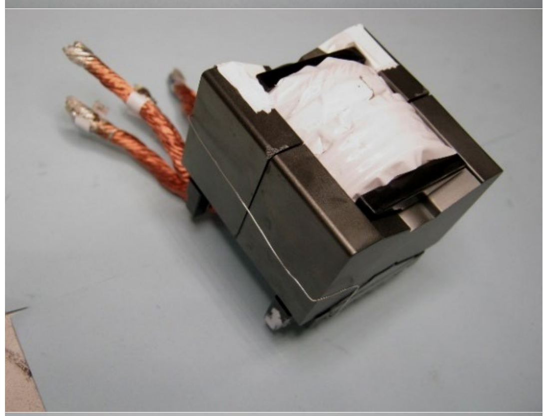
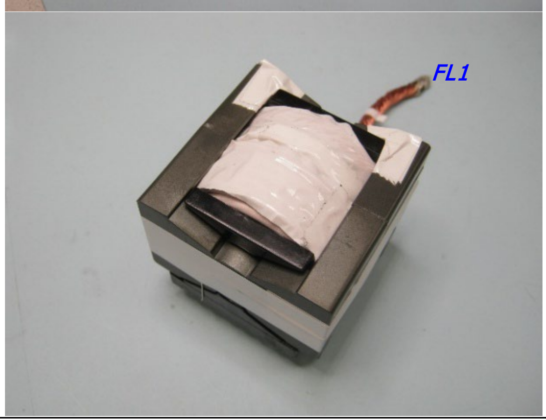
	  	

Table 16 – LLC Transformer Instructions

7.6 Auxiliary Transformer (T2) Specification

7.6.1 Electrical Diagram

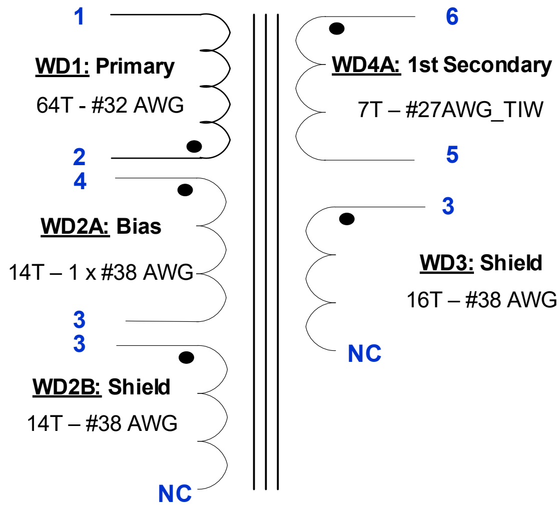


Figure 19 - Auxiliary Transformer Electrical Diagram.

7.6.2 Electrical Specification

Electrical Strength	1 second, 60 Hz, from pins 1-4 to and pins 5-6.	3000 VAC
Primary Inductance (L_{PRI})	Measured at 1 V pk-pk, 100 kHz switching frequency, between pin 1 and 2, with all other windings open.	1180 µH ±7%
Primary Leakage1 (LlkpALL)	Pins 1-2, short **ALL** other pins measured at 100 kHz, 1 V_{RMS}	40 µH (Max)

Table 17 - Auxiliary Transformer Electrical Specifications.

7.6.3 Material List

Item	Description
[1]	Core: EE1621; Hong Kong Magnetics, ME 95 or Equivalent; gapped for ALG of 218nH/T².
[2]	Bobbin: EE1621-Vertical – 8pins (4/4), SHEN ZEN XIN YU JIA Technology LTD.
[3]	Magnet wire: #32 AWG, double coated.
[4]	Magnet wire: #38 AWG, double coated.
[5]	Magnet wire: #27 AWG, Triple Insulated Wire.
[6]	Magnet wire: #30 AWG, Triple Insulated Wire.
[7]	Barrier Tape: 3M 1298 Polyester Film, 1 mil thickness, 5.5 mm wide.
[8]	Copper foil: 2 mil thick, 4.0 mm x 20.0 mm.
[9]	Tape: 3M Polyester Film, 1 mil thick, 7 mm wide.
[10]	Varnish: Dolph BC-359.

Table 18 – List of Materials.

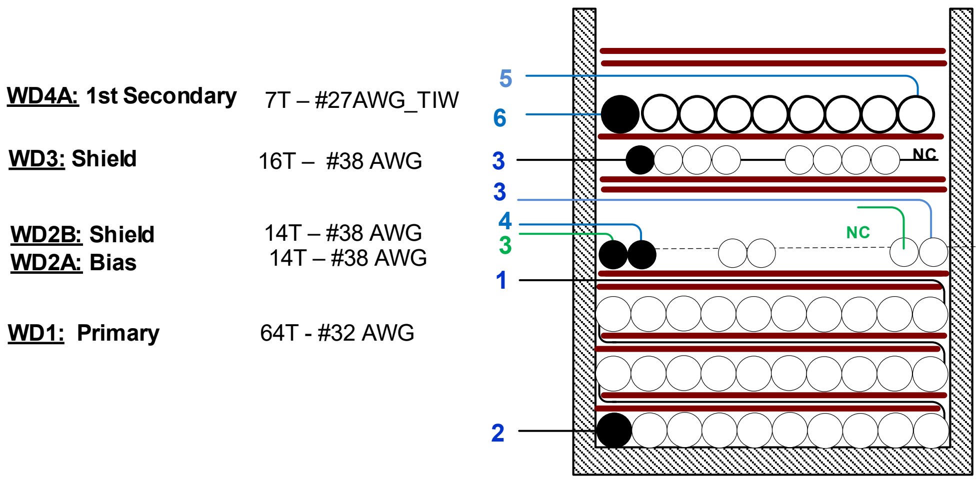


Figure 20 -Transformer Electrical Diagram.

7.6.4 Transformer Instructions

WD1 Primary	Start at pin 1, wind 22 turns of wire item [3] from left to right and bring it back to the left and turn 2 layers of tape item [7] for insulation. Continue to wind 22 turns on the second layer using the same wire from left to right and bring it back to the left and turn 2 layers of tape item [7] for insulation. Continue to wind 20 turns on the third layer using the same wire from left to right and bring it back to the left and terminate the wire on pin 2.
Insulation	2 layer of tape item [7] for insulation.
WD2A Bias & WD2B Shield	Take 2 wires item [4], start at pin 4 for 1 wire (BIAS), start at pin 3 for 1 wire (Shield), wind 14 turns for all 2 wires from left to right, cut 1 wire (Shield)and leave no-connection for WD2B-Shield. Bring other wire (Bias) to the left and terminate to pin3.
Insulation	2 layer of tape item [7] for insulation.
WD3 Shield	Take 1 wire item [4], start at pin 3 wind 16 turns from left to right, leave no-connection for WD3-Shield. Shield should be wind equally spaced and by 4 turns (Please see illustration).
Insulation	1 layer of tape item [7] for insulation.
WD4A 1st Secondary & WD4B 2nd Secondary	Take 1 wire item [5], and start at pin6 for WD4A. Wind 7 turns for WD4A and terminate the finish of WD4A to pin5. 2 layers of tape item [7] for secure windings and insulation
Finish	Gap the core halves to get 1180 μH. Prepare copper foil item [8], solder wire item [3] at the middle to connect to pin 3, and then place on top core halves. Then secure 2 core halves with 2 layers of tape item [9]. Remove pins: 7 and 8. Varnish with item [10].

Table 19 - Transformer Winding Instructions.

8 PFC Design Spreadsheet

In this design, the input AC voltage varies from 180 to 280 VAC. The output DC bus voltage from the PFC stage is specified as 385 V. The DC bus capacitors are chosen as 300 μF, to match a typical customer requirement.

1	***Hiper_PFS-3_Boost_050625; Rev.1.1; Copyright Power Integrations 2025***	***INPUT***	***INFO***	***OUTPUT***	***UNITS***	***Continuous Mode Boost Converter Design Spreadsheet***
2	Enter Application Variables					Design Title
3	Input Voltage Range	High Line		High Line		Input voltage range
4	VACMIN	180		180	VAC	Minimum AC input voltage. Spreadsheet simulation is performed at this voltage. To examine operation at other votlages, enter here, but enter fixed value for LPFC_ACTUAL.
5	VACMAX	280		280	VAC	Maximum AC input voltage
6	VBROWNIN			167	VAC	Expected Typical Brown-in Voltage per IC specifications; Line impedance not accounted.
7	VBROWNOUT			156	VAC	Expected Typical Brown-out voltage per IC specifications; Line impedance not accounted.
8	VO	385		385	VDC	Nominal load voltage
9	PO	850		850	W	Nominal Output power
10	fL			50	Hz	Line frequency
11	TA Max			40	°C	Maximum ambient temperature
12	n	0.98		0.98		Enter the efficiency estimate for the boost converter at VAC MIN. Should approximately match calculated efficiency in Loss Budget section
13	VO_MIN			366	VDC	Minimum Output voltage
14	VO_RIPPLE_MAX			20	VDC	Maximum Output voltage ripple
15	tHOLDUP			20	ms	Holdup time
16	VHOLDUP_MIN			310	VDC	Minimum Voltage Output can drop to during holdup
17	I_INRUSH			40	A	Maximum allowable inrush current
18	Forced Air Cooling	Yes		Yes		Enter "Yes" for Forced air cooling. Otherwise enter "No". Forced air reduces acceptable choke current density and core autopick core size
19						
20	KP and INDUCTANCE					
21	KP_TARGET	0.640	Warning	0.640		Device current capability exceeded. Reduce KP_Target or PO
22	LPFC_TARGET (0 bias)			131	μH	PFC inductance required to hit KP_TARGET at peak of VACMIN and full load
23	LPFC_DESIRED (0 bias)	130		130	μH	LPFC value used for calculations. Leave blank to use LPFC_TARGET. Enter value to hold constant (also enter core selection) while changing VACMIN to examine brownout

						operation. Calculated inductance with rounded (integral) turns for powder core.
24	KP_ACTUAL			0.629		Actual KP calculated from LPFC_ACTUAL
25	LPFC_PEAK			130	μH	Inductance at VACMIN, 90°. For Ferrite, same as LPFC_DESIRED (0 bias)
26						
27	Basic current parameters					
28	IAC_RMS			4.82	A	AC input RMS current at VACMIN and Full Power load
29	IO_DC			2.21	A	Output average current/Average diode current
30						
31						
32	PFS Parameters					
33	PFS Part Number	PFS7539H		PFS7539H		If examining brownout operation, over-ride autopick with desired device size
34	Operating Mode	Full Power		Full Power		Mode of operation of PFS. For Full Power mode enter "Full Power" otherwise enter "EFFICIENCY" to indicate efficiency mode
35	IOCP min			10.0	A	Minimum Current limit
36	IOCP typ			10.5	A	Typical current limit
37	IOCP max			11.0	A	Maximum current limit
38	IP			9.84	A	MOSFET peak current
39	IRMS			3.42	A	PFS MOSFET RMS current
40	RDSON			0.40	Ohms	Typical RDSon at 100 'C
41	FS_PK			103	kHz	Estimated frequency of operation at crest of input voltage (at VACMIN)
42	FS_AVG			98	kHz	Estimated average frequency of operation over line cycle (at VACMIN)
43	PCOND_LOSS_PFS			4.7	W	Estimated PFS conduction losses
44	PSW_LOSS_PFS			5.6	W	Estimated PFS switching losses
45	PFS_TOTAL			10.3	W	Total Estimated PFS losses
46	TJ Max			100	deg C	Maximum steady-state junction temperature
47	Rth-JS			2.80	°C/W	Maximum thermal resistance (Junction to heatsink)
48	HEATSINK Theta-CA		Info	1.45	°C/W	Big heatsink; Consider changing Rth or TJ
49						
50						
51	INDUCTOR DESIGN					
52	Basic Inductor Parameters					
53	LPFC (0 Bias)			130	μH	Value of PFC inductor at zero current. This is the value measured with LCR meter. For powder, it will be different than LPFC.

54	LP_TOL	5.0		5.0	%	Tolerance of PFC Inductor Value (ferrite only)
55	IL_RMS			5.04	A	Inductor RMS current (calculated at VACMIN and Full Power Load)
56	Material and Dimensions					
57	Core Type	Ferrite		Ferrite		Enter "Sendust", "Pow Iron" or "Ferrite"
58	Core Material	Auto		PC44/PC95		Select from 60u, 75u, 90u or 125 u for Sendust cores. Fixed at PC44/PC95 for Ferrite cores. Fixed at -52 material for Pow Iron cores.
59	Core Geometry	Auto		PQ		Toroid only for Sendust and Powdered Iron; EE or PQ for Ferrite cores.
60	Core	PQ26/25		PQ26/25		Core part number
61	Ae			118.00	mm^2	Core cross sectional area
62	Le			55.50	mm	Core mean path length
63	AL			6530.00	nH/t^2	Core AL value
64	Ve			6.53	cm^3	Core volume
65	HT (EE/PQ) / ID (toroid)			3.34	mm	Core height/Height of window; ID if toroid
66	MLT			56.2	mm	Mean length per turn
67	BW			13.80	mm	Bobbin width
68	LG			1.10	mm	Gap length (Ferrite cores only)
69	Flux and MMF calculations					
70	BP_TARGET (ferrite only)			3900	Gauss	Target flux density at worst case: IOCP and maximum tolerance inductance (ferrite only) - drives turns and gap
71	B_OCP (or BP)			3856	Gauss	Target flux density at worst case: IOCP and maximum tolerance inductance (ferrite only) - drives turns and gap
72	B_MAX			3346	Gauss	peak flux density at AC peak, VACMIN and Full Power Load, nominal inductance
73						
74	μ_TARGET (powder only)			N/A	%	%μ at peak current vs. zero current, at VACMIN, Full Power Load, divided by permeability at 0 current (powder only)
75	μ_MAX (powder only)			N/A	%	%μ vs. zero current, at VACMIN Full Power LOAD (powder only)
76	μ_OCP (powder only)			N/A	%	%μ vs. zero current, at IOCP_typ (powder only)
77	I_TEST			10.5	A	Current at which B_TEST and H_TEST are calculated, for checking flux at a current other than IOCP or IP; if blank IOCP_typ is used.
78	B_TEST			3681	Gauss	Flux density at I_TEST and maximum tolerance inductance
79	μ_TEST (powder only)			N/A	%	relative permeability at I_TEST and typical inductance (powder only)
80	Wire					
81	TURNS			33		Inductor turns. To adjust turns, change BP_TARGET (ferrite) or μ_TARGET (powder)

82	ILRMS			5.04	A	Inductor RMS current
93	Loss calculations					
94	BAC-p-p			2157	Gauss	Core AC peak-peak flux excursion at VACMIN, peak of sine wave
95	LPFC_CORE_LOSS			2.10	W	Estimated Inductor core Loss
96	LPFC_COPPER_LOSS			2.95	W	Estimated Inductor copper losses
97	LPFC_TOTAL_LOSS			5.05	W	Total estimated Inductor Losses
98						
99						
100	Built-in PFC Diode					
101	PFC Diode Part Number			INTERNAL2		PFC Diode Part Number
102	Type			SPECIAL		PFD Diode Type
103	Manufacturer			PI		Diode Manufacturer
104	VRRM			530	V	Diode rated reverse voltage
105	IF			6	A	Diode rated forward current
106	Qrr					high temperature
107	VF			1.44	V	Diode rated forward voltage drop
108	PCOND_DIODE			3.18	W	Estimated Diode conduction losses
109	PSW_DIODE			0.68	W	Estimated Diode switching losses
110	P_DIODE			3.86	W	Total estimated Diode losses
111	TJ Max			100	°C	Maximum steady-state operating temperature
112	Rth-JS			3.00	°C/W	Maximum thermal resistance (Junction to heatsink)
113	HEATSINK Theta-CA			1.45	°C/W	Maximum thermal resistance of heatsink
114						
115						
116	Output Capacitor					
117	Output Capacitor	Auto		680	µF	Minimum value of Output capacitance
118	VO_RIPPLE_EXPECTED			10.5	V	Expected ripple voltage on Output with selected Output capacitor
119	T_HOLDUP_EXPECTED			20.9	ms	Expected holdup time with selected Output capacitor
120	ESR_LF			0.24	Ohms	Low Frequency Capacitor ESR
121	ESR_HF			0.09	Ohms	High Frequency Capacitor ESR
122	IC_RMS_LF			1.54	A	Low Frequency Capacitor RMS current
123	IC_RMS_HF			1.91	A	High Frequency Capacitor RMS current
124	CO_LF_LOSS			0.58	W	Estimated Low Frequency ESR loss in Output capacitor
125	CO_HF_LOSS			0.31	W	Estimated High frequency ESR loss in Output capacitor
126	Total CO LOSS			0.89	W	Total estimated losses in Output Capacitor
127						
128						
129	Input Bridge (BR1) and Fuse (F1)					

130	I^2t Rating			53.31	A^2*s	Minimum I^2t rating for fuse
131	Fuse Current rating			6.96	A	Minimum Current rating of fuse
132	VF			0.90	V	Input bridge Diode forward Diode drop
133	IAVG			4.33	A	Input average current at 70 VAC.
134	PIV_INPUT BRIDGE			396	V	Peak inverse voltage of input bridge
135	PCOND_LOSS_BRIDGE			7.81	W	Estimated Bridge Diode conduction loss
136	CIN			1.0	µF	Input capacitor. Use metallized polypropylene or film foil type with high ripple current rating
137	RT			9.90	Ohms	Input Thermistor value
138	D_Precharge			1N5407		Recommended precharge Diode
139						
140						
141	PFS3 small signal components					
142	C_REF			1.0	µF	REF pin capacitor value
143	RV1			4.0	mOhms	Line sense resistor 1
144	RV2			6.0	mOhms	Line sense resistor 2
145	RV3			6.0	mOhms	Typical value of the lower resistor connected to the V-PIN. Use 1% resistor only!
146	RV4			161.6	kOhms	Description pending, could be modified based on feedback chain R1-R4
147	C_V			0.495	nF	V pin decoupling capacitor (RV4 and C_V should have a time constant of 80us) Pick the closest available capacitance.
148	C_VCC			1.0	µF	Supply decoupling capacitor
149	C_C			100	nF	Feedback C pin decoupling capacitor
150	Power good Vo lower threshold VPG(L)			333	V	Vo lower threshold voltage at which power good signal will trigger
151	PGT set resistor			333.0	kOhms	Power good threshold setting resistor
152						
153						
154	Feedback Components					
155	R1			4.0	mOhms	Feedback network, first high voltage divider resistor
156	R2			6.0	mOhms	Feedback network, second high voltage divider resistor
157	R3			6.0	mOhms	Feedback network, third high voltage divider resistor
158	R4			161.6	kOhms	Feedback network, lower divider resistor
159	C1			0.495	nF	Feedback network, loop speedup capacitor. (R4 and C1 should have a time constant of 80us) Pick the closest available capacitance.
160	R5			30.9	kOhms	Feedback network: zero setting resistor
161	C2			1000	nF	Feedback component- noise suppression capacitor
162						

163						
164	Loss Budget (Estimated at VACMIN)					
165	PFS Losses			10.27	W	Total estimated losses in PFS
166	Boost diode Losses			3.86	W	Total estimated losses in Output Diode
167	Input Bridge losses			7.81	W	Total estimated losses in input bridge module
168	Inductor losses			5.05	W	Total estimated losses in PFC choke
169	Output Capacitor Loss			0.89	W	Total estimated losses in Output capacitor
170	EMI choke copper loss			0.50	W	Total estimated losses in EMI choke copper
171	Total losses			27.88	W	Overall loss estimate
172	Efficiency			0.97		Estimated efficiency at VACMIN, full load.
173						
174						
175	CAPZero component selection recommendation					
176	CAPZero Device			CAP005DG		(Optional) Recommended CAPZero device to discharge X-Capacitor with time constant of 1 second
177	Total Series Resistance (R1+R2)			0.48	kOhms	Maximum Total Series resistor value to discharge X-Capacitors
178						
179						
180	EMI filter components recommendation					
181	CIN_RECOMMENDED			1000	nF	Metallized polyester film capacitor after bridge, ratio with Po
182	CX2			680	nF	X capacitor after differencial mode choke and before bridge, ratio with Po
183	LDM_calc			151	µH	estimated minimum differencial inductance to avoid <10kHz resonance in input current
184	CX1			680	nF	X capacitor before common mode choke, ratio with Po
185	LCM			10	mH	typical common mode choke value
186	LCM_leakage			30	µH	estimated leakage inductance of CM choke, typical from 30~60uH
187	CY1 (and CY2)			220	pF	typical Y capacitance for common mode noise suppression
188	LDM_Actual			121	µH	cal_LDM minus LCM_leakage, utilizing CM leakage inductance as DM choke.
189	DCR_LCM	0.10		0.10	Ohms	total DCR of CM choke for estimating copper loss
190	DCR_LDM	0.10		0.10	Ohms	total DCR of DM choke(or CM #2) for estimating copper loss
191						

192	Note: CX2 can be placed between CM chock and DM choke depending on EMI design requirement.					

Table 20 – PFC Design Spreadsheet.

9 LLC Design Spreadsheet

In this design, the LLC is designed to operate with resonance at 600 V input. This ensures that the converter is in deep DCM (below resonance) under full load. As the converter operates with variable current and voltage, the converter is specifically designed to operate across a wide frequency range.

1	*ACDC_HiperLCS2_061225; Rev.2.0; Copyright Power Integrations 2025*	*INPUT*	*INFO*	*OUTPUT*	*UNITS*	*HiperLCS-2 Design Spreadsheet*
2	General					
3	Description			>		LCS7269Z-2100W-60V-35A-SynchRF-22T-4T-77uH-43uH-72nF-78kHz
4	Input Parameters					
5	VIN MIN	350		350	V	Brownout Threshold Voltage
6	VIN RES	600		600	V	Input Voltage at Resonance - lower Vres to lower Npri
7	VIN NOM	400		400	V	Nominal Input Voltage - default CRM Vres=Vnom (or DCM Vres>Vnom, CCM Vres<Vnom)
8	VIN MAX	420		420	V	Maximum Input Voltage - decrease Vmax to lower Fmax
9	PFC	YES		YES		Input Option
10	Output Parameters					
11	Vout1	60.00		60.00	V	Main Output Voltage
12	Iout1 PK	35.0		35.0	A	Peak Main Output Current (Used to select device size - increasing peak power will lower LRES
13	Pout1 PK			2100.0	W	Main Output Peak Power
14	Iout1 CONT	27.5		27.5	A	Continuous Main Output Current (Used for device selection and compute losses)
15	Pout1 CONT			1650.0	W	Continues Main Output Power
16	External CC	YES		YES		Use external CC operation
17	Vout1 Min (CC)	26.0		26.0	V	Minimum Output Voltage when operating in CC - lower VoutMin lowers Lm and also lowers efficiency
18	VCC	0.045		0.045	V	Output current sense resistor voltage when operating at CC-threhsold
19	RCC			2.00	mΩ	Output current sense resistor value
20	RCC Rated Power			3.68	W	Output current sense resistor rated power
21	Estimated Parameters, Design Choices and Selections					
22	FS Range	3		3		Frequency Range
23	FS Vnom (Target)	90.0		90.0	kHz	Switching Frequency at VinNom
24	Output Rectifier	SynchRF		SynchRF		Output Rectifier
25	Ron_SR1			5.0	mΩ	Sync. Rectifier ON Resitance
26	VF_SR1				V	Output Diode Average Voltage Drop
27	Design Results					
28	DESIGN RESULT			Design Passed		Current Design Status
29	Device Variables					
30	DEVNAME	Auto		LCS7269Z		PI Device Name

31	QOSS			604	nC	Equivalent Combined Half-bridge charge (Qoss) at 480 V
32	RDSON			0.130	Ω	RDSON of selected device
33	Fault Responce	NON_LATCHING		NON_LATCHING		..
34	Tank Circuit Components & Operation Frequency Range					
35	Integrated Magnetics	YES		YES		Integrated Transformer Requirements
36	LP Nominal			120.51	µH	Nominal Primary Inductance
37	Lm			77.3	µH	Magnetizing inductance of transformer - modified by Kz, Device size and frequency
38	Lres			43.2	µH	Series resonant or primary leakage inductance - modified by Pmax
39	Cres	72.00		72.00	nF	Series resonant capacitor.
40	f_calc@Vbrownout			73.5	kHz	Frequency at PoutCont at Vbrownout, full load - adjust VinBrownout
41	f_calc@resonance			90.2	kHz	Resonant Frequency (defined by Lres and Cres)
42	f_calc@Vnom			77.6	kHz	Frequency at PoutCont at Vnom - adjust FS Vnom Target or Vnom
43	f_calc@Vinmax			183.0	kHz	Expected frequency at maximum input voltage and full load; Heavily influenced by n_eq and primary turns
44	VINGmaxInversion			174.4	V	Minimum Input Voltage for negative Gain at 100% load. Below this voltage the Gain becomes positive (unstable loop)
45	Core Dimensions/TRF Mechanical Parameters					
46	AE			328.00	mm^2	Transformer Core Cross-sectional area
47	VE			0.0	cm^3	Transformer Core Volume
48	MLT			103.99	mm	Middle Length of a Turn
49	AW			300.96	mm^2	Core Window area
50	BW			30.40	mm	Bobbin Winding Width
51	Bobbin Chambers			2		Bobbin Chambers
52	ChambDist			0.00	mm	Width of bobbin with no windings - empty space between primary/secondary generates leakage inductance
53	Bobbin Height			9.90	mm	Height of the bobbin, maximum Stack height
54	Prim. Bobbin Chamber Width			18.24	mm	Part of the bobbin allocated for primary
55	Sec. Bobbin Chamber Width			12.16	mm	Part of the bobbin allocated for secondary
56	K-PD			0.35		Penetration Depth multiplier (for Single Strand LITZ calulation)
57	Transformer Generic Parameters					
58	CR_TYPE	PQ50		PQ50		Transformer Core Type
59	FR_TYPE			3C95		Magnetic material used
60	BACmax Actual			253.93	mT	Estmated Flux Density at Vnom - increase Ns to reduce Bmax
64	kSecChamb			0.40		Percentage of Bobbin Chamber Width used for Secondary Windings - Adjust to change Used Percentage of Primary/Secondary Windows
65	Transformer Primary Parameters					
66	Npri			22		Calculated Primary Winding Total Number of Turns
67	Iprim RMS			8.31	A	Transformer Primary Winding RMS Current at PoutCont and VinNom
79	Main Output Parameters					
80	NSec	4		4		Secondary Number of Turns
81	ISRMS			51.27	A	Transformer Secondary Winding RMS Current
93	Circuit Losses					

97	CO ESR Loss			1.87	W	Output Capacitor ESR Loss at VinNom and PoutCont
98	PLOSS Switch			4.49	W	Single Primary Switch Conduction Loss at VinNom and PoutCont
99	PLOSS Output Rectifier			2.33	W	Single Output Rectifier Conduction Loss at VinNom and PoutCont
100	PLOSS RCC			2.45	W	Current sense resisitor power loss at VinNom and PoutCont
102	PLOSS Circuit Total			17.96	W	Circuit Total Loss at VinNom and PoutCont
103	Circuit Components					
104	RZ1			150	kOhms	Control Zero (boost high-frequency gain)
105	CP2			100	pF	Control Pole2 (roll-off high-frequency gain)
106	Cp1			2.2	nF	Control Pole1 (roll-off low-frequency gain)
107	Resr CO			1.00	mOhms	ESR of the output capacitor
108	COmin			1510	uF	Min CO to satisfy burst conditions
109	RD1			500	Ω	RD1 Resistor value
110	RD2			500	Ω	RD2 Resistor value
111	CBPL			1	µF	CBPL Capacitor Value / 25 V
112	CBPH			1	µF	CBPH Capacitor Value / 25 V
113	C5VL			1	µF	C5VL Capacitor Value / 10 V
114	C5VH			220	nF	C5VH Capacitor Value / 10 V
115	C5VFL			100	nF	C5VLFL Capacitor Value / 10V
116	C5VS			10	µF	C5VS Capacitor Value / 10 V
117	CBPS			10	µF	CBPS Capacitor Value / 35 V
118	RL_Up			5000	kOhms	L-pin Input Voltage (Vin) Sense Resistor
119	RL_Down			open	Ω	L-pin to Ground Resistor
120	RPP			316	kOhms	RPP Resistor / 1% E96 series
121	RPS			75	Kohms	RPS Resistor / 1% E96 series
122	Bias, IS Circuit & Feedback Components					
123	NPB			2		Primary Bias Turns
124	NSB			1		Secondary Bias Turns
125	NVIS			1		Secondary (Is) Sense Turns
126	RIS			1277	kOhms	Rrs Resistor Value
127	CIS			470	pF	IS sense winding coupling capacitor
128	RFBH			360.6	kOhms	Calulated value of top feedback resistor. use series closest resistor 1% E96
129	RFBL			24.0	kOhms	Calulated value of low feedback resistor. use series closest resistor 1% E96
130	Currents and Winding loss elements					
131	Iprim RMS			8.31	A	Transformer Primary Winding RMS Current at PoutCont at VinNom
132	ISRMS			51.27	A	Transformer Secondary Winding RMS Current at PoutCont at VinNom
133	Irms_SR			21.60	A	Secondary Rectifier RMS Current at PoutCont at VinNom
134	Irms_CO1			43.27	A	Output Capacitor RMS Current at PoutCont at VinNom
139	Advanced Settings					
140	Kz	0.8		0.8		coefficient of surplus ZVS energy @ Vnom - raise Kz to lower Vin(GmaxInv) - Kz should be >= 2.0 to ensure ZVS operation
141	Tdd1_Vinnom	165		165	Ns	Half-bridge slew at 100% load @ Vnom - raise Tdd1 to lower ZVS currents
142	Coupling			0.89		Transformer Coupling
143	Cpri			40.00	pF	Stray Capacitance at transformer

						primary
144	PP or Lpin	L		L		HB Startup current selection
145	R_L_UP_ACT	4000		4000	kOhms	Actual Value of L-pin Input Voltage (Vin) Sense Resistor
146	VLUV-			245	V	..
147	VLUV+			315	V	..
148	VLOV-			540	V	..
149	VLOV+			615	V	..
150	External Resonant Inductor (Ext.Lres) Calculations					
172	Errors, Warnings, Information					
173	Information			0		Number of variables required bench functionality check. Check the variables with "Info" in the third column .
174	Design Warnings			0		Number of variables whose values exceed electrical/datasheet specifications. Check the variables with "Err" in the third column .
175	Design Errors			0		The list of design variables which result in an infeasible design.

Table 21 – LLC Design Spreadsheet.

10 Heat Sink

10.1 Baseplate Heat Sink

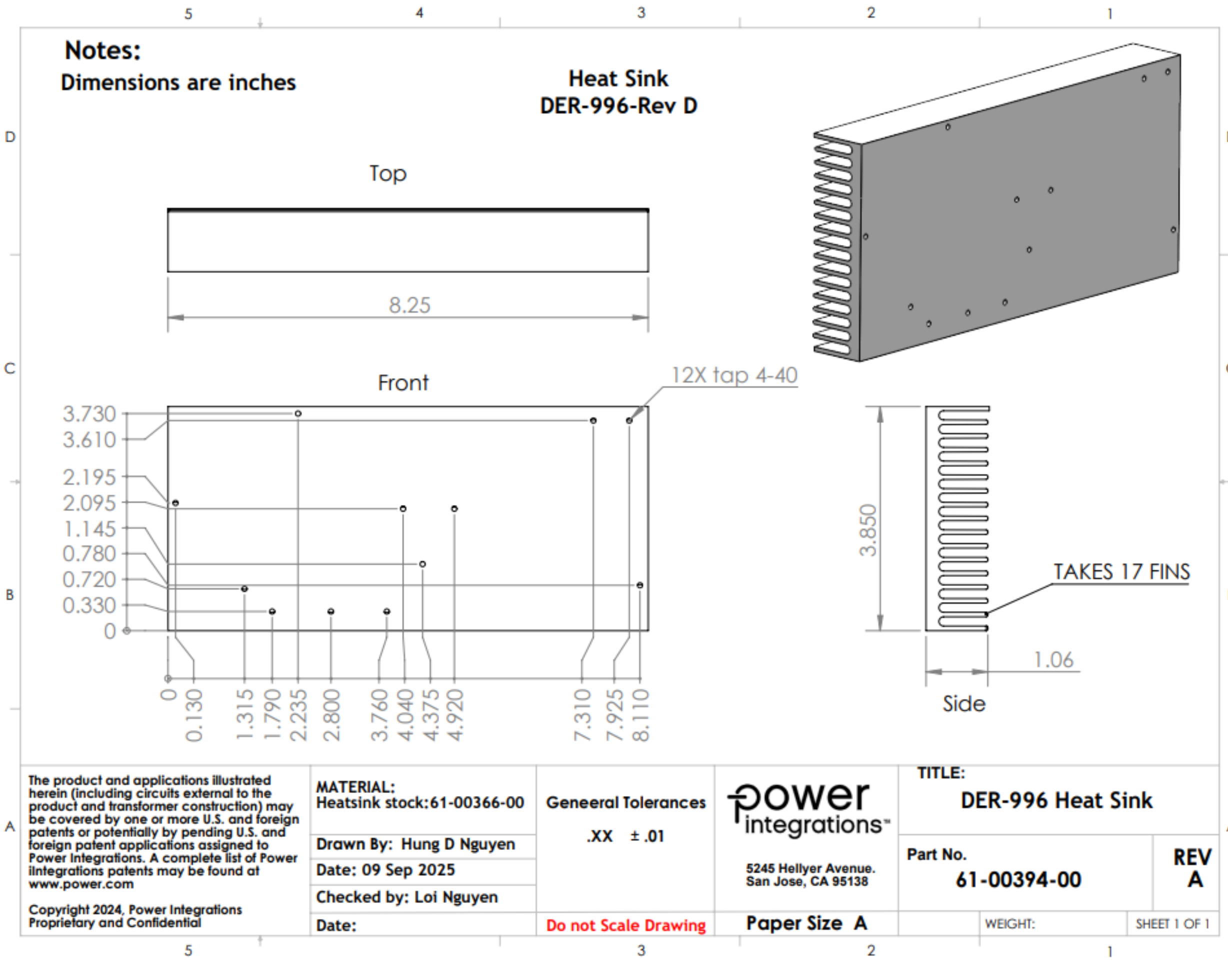
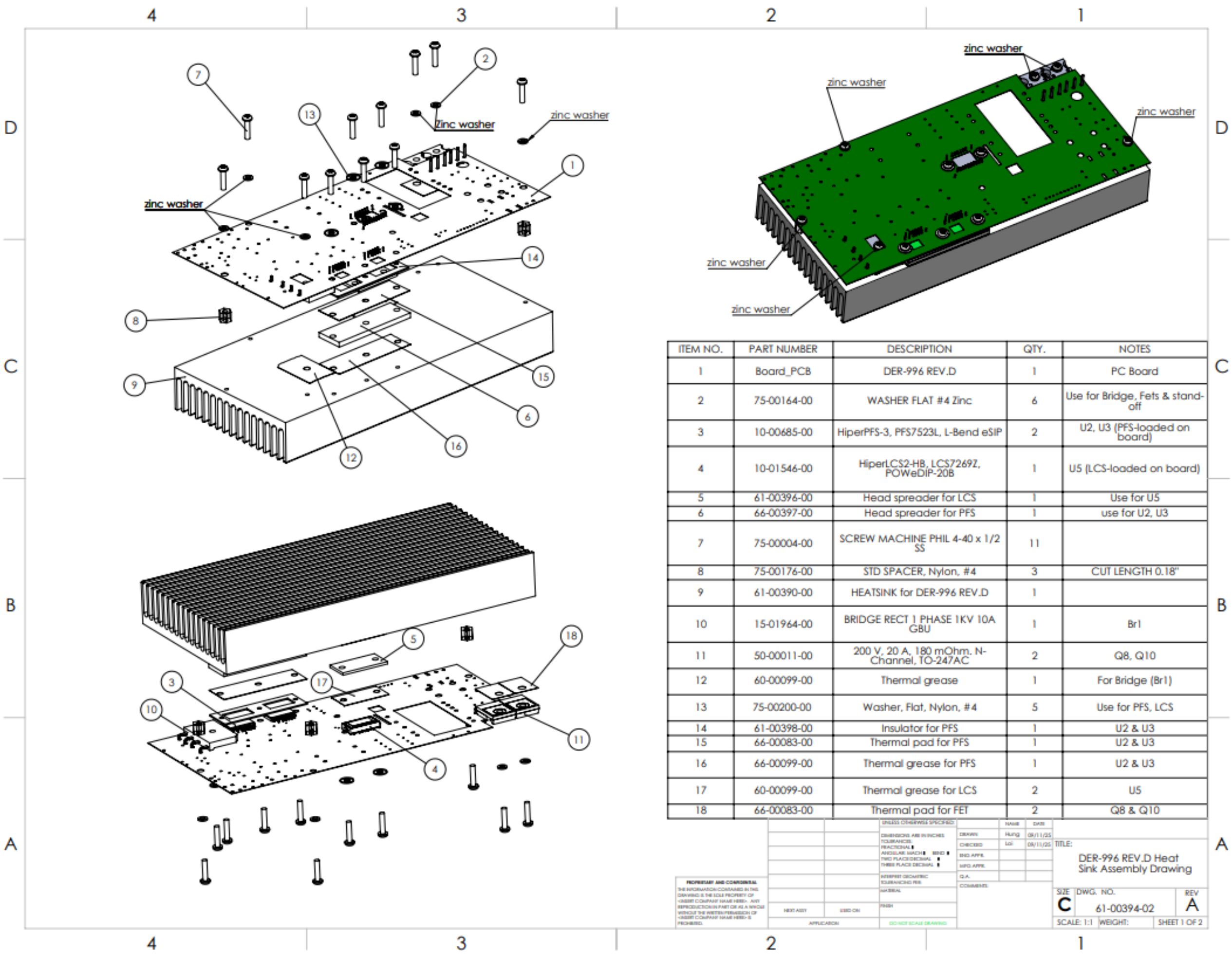


Figure 21 – Baseplate Heat Sink.

10.2 Baseplate Heat Sink Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	NOTES
1	Board_PCB	DER-996 REV.D	1	PC Board
2	75-00164-00	WASHER FLAT #4 Zinc	6	Use for Bridge, Fets & stand-off
3	10-00685-00	HiperPFS-3, PFS7523L, L-Bend eSIP	2	U2, U3 (PFS-loaded on board)
4	10-01546-00	HiperLCS2-HB, LCS7269Z, POWeDIP-20B	1	U5 (LCS-loaded on board)
5	61-00396-00	Head spreader for LCS	1	Use for U5
6	66-00397-00	Head spreader for PFS	1	use for U2, U3
7	75-00004-00	SCREW MACHINE PHIL 4-40 x 1/2 SS	11	
8	75-00176-00	STD SPACER, Nylon, #4	3	CUT LENGTH 0.18"
9	61-00390-00	HEATSINK for DER-996 REV.D	1	
10	15-01964-00	BRIDGE RECT 1 PHASE 1KV 10A GBU	1	Br1
11	50-00011-00	200 V, 20 A, 180 mOhm. N-Channel, TO-247AC	2	Q8, Q10
12	60-00099-00	Thermal grease	1	For Bridge (Br1)
13	75-00200-00	Washer, Flat, Nylon, #4	5	Use for PFS, LCS
14	61-00398-00	Insulator for PFS	1	U2 & U3
15	66-00083-00	Thermal pad for PFS	1	U2 & U3
16	66-00099-00	Thermal grease for PFS	1	U2 & U3
17	60-00099-00	Thermal grease for LCS	2	U5
18	66-00083-00	Thermal pad for FET	2	Q8 & Q10

Figure 22 – Baseplate Heatsink Assembly.

10.3 Heat Spreader for LCS2

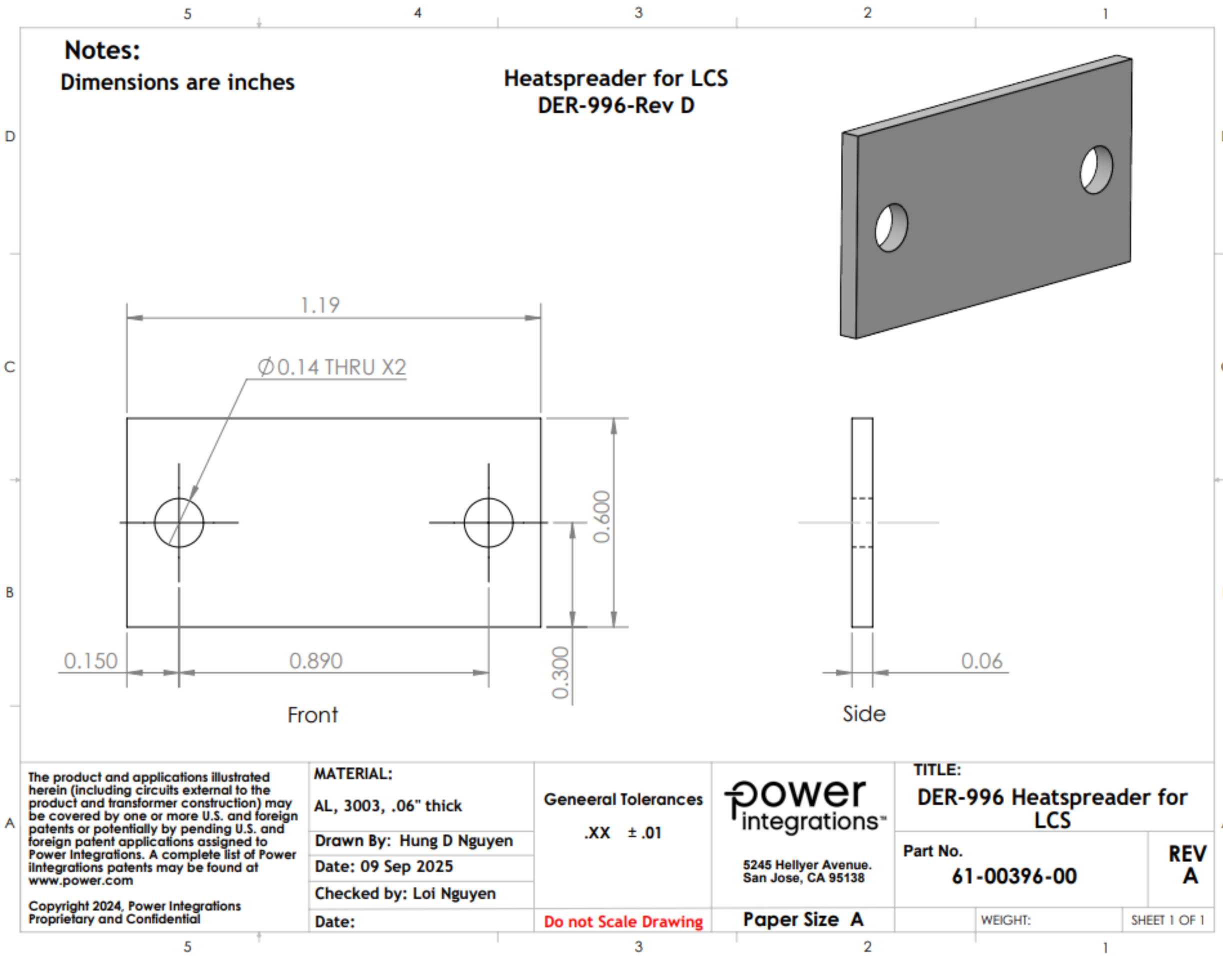


Figure 23 – Head Spreader for LCS2-HB.

10.4 Heat Spreader for PFS3

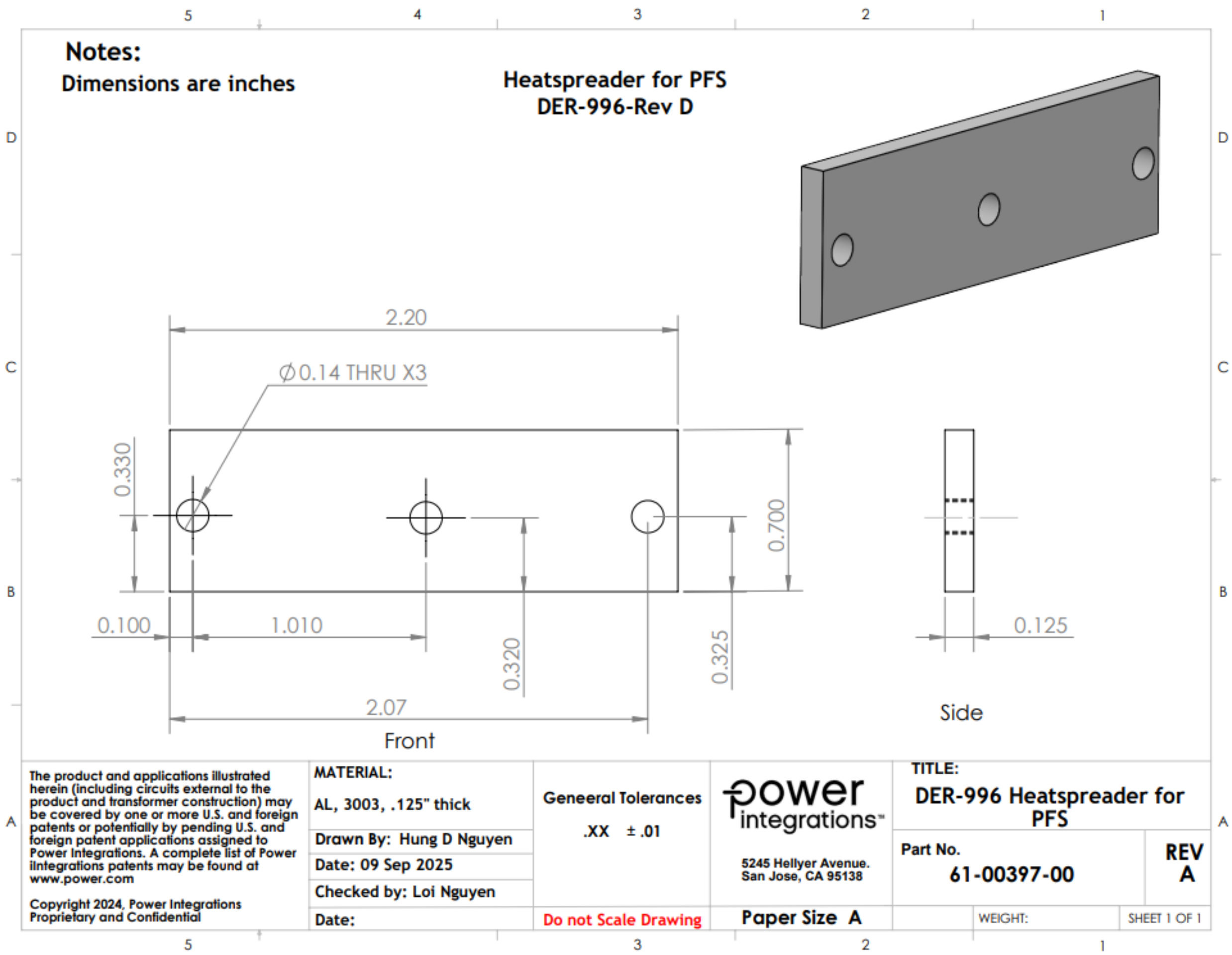


Figure 24 – Heat Spreader for PFS3.

11 Performance Data

This section provides the description of various performance test conducted, to demonstrate the performance of the converter for charger application. All performance data was measured at room temperature unless otherwise specified.

11.1 Constant Voltage (CV) and Constant Current (CC) Mode

The mode of operation (CC or CV) was selected using variable resistor R107 and R74. Under CV mode, the reference voltage was set using the variable resistor R74. Under CC mode, the reference current was set using the variable resistor R107. The performance under CV and CC mode was shown in the Figure 25.

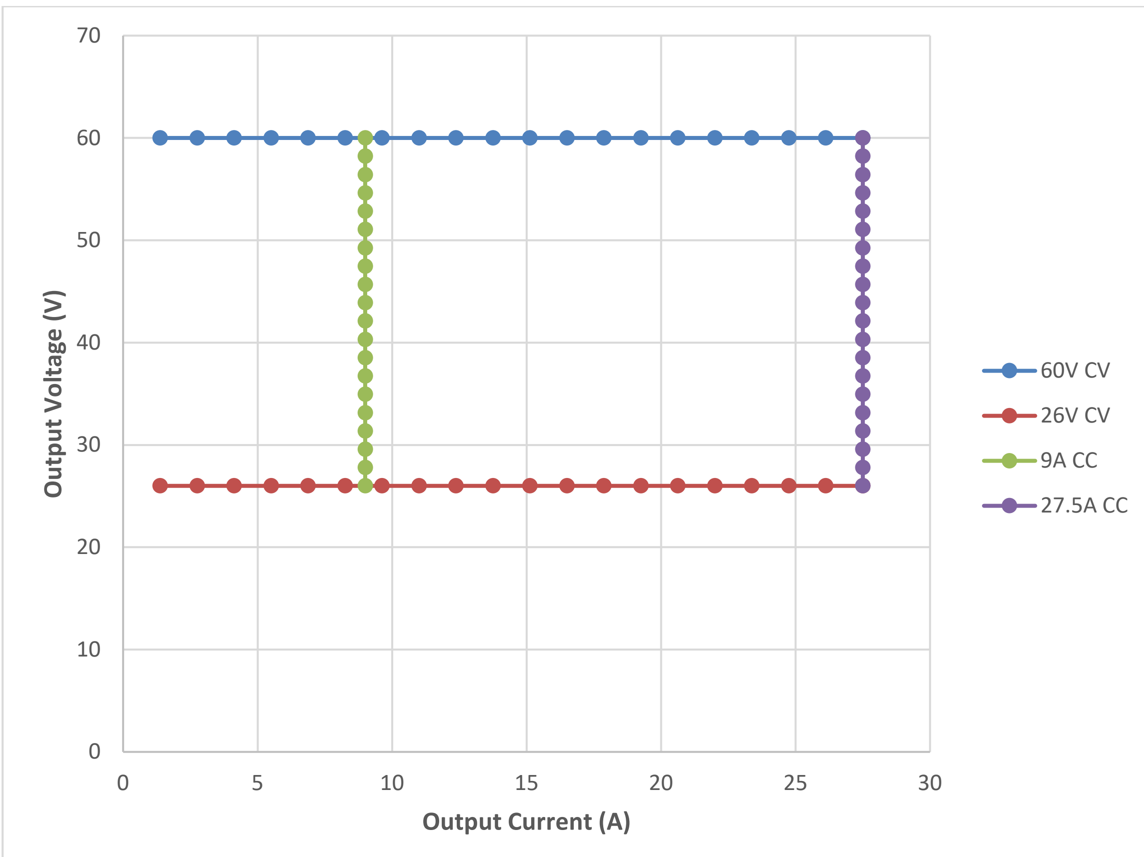


Figure 25 – CV/CC mode of operation with 230 VAC input.

11.2 End to end Efficiency

Figure 26 shows power supply efficiency with respect to output power for different input line voltages.

For maximum CV mode output, the reference voltage set to 60 V using variable resistor R74. A variable AC source was used to supply a sine wave input and a DC electronic load set to CC mode as load on the output.

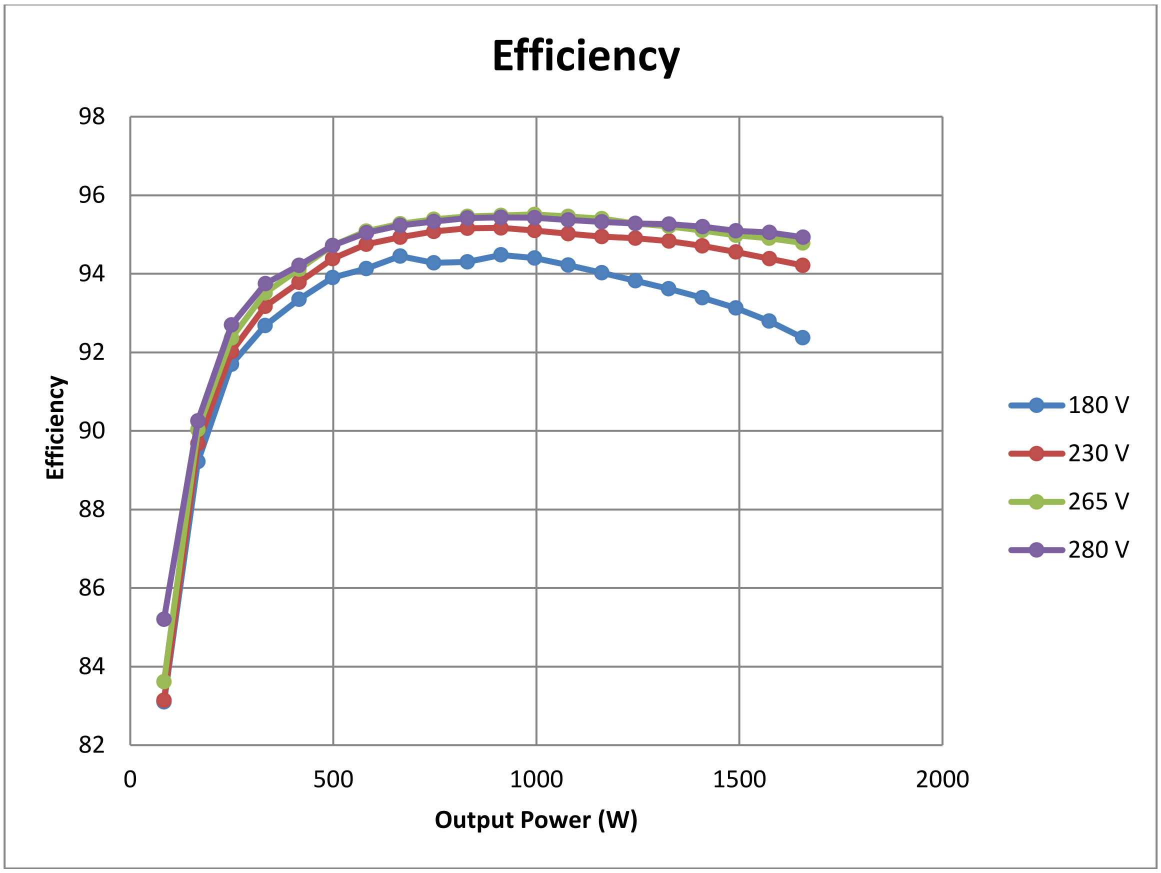


Figure 26 – Total Efficiency vs. Load, 60 V Output CV Mode.

V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	PF	P_{IN} (kW)	V_{OUT} (VDC)	I_{OUT} (ADC)	P_{OUT} (kW)	Efficiency (%)
180	10.03	0.993	1.79	60.2	27.5	1.66	92.4
180	9.44	0.997	1.70	60.2	26.1	1.57	92.8
180	8.91	0.998	1.60	60.3	24.7	1.49	93.1
180	8.40	0.998	1.51	60.3	23.4	1.41	93.4
180	7.89	0.997	1.42	60.3	22.0	1.33	93.6
180	7.38	0.997	1.33	60.3	20.6	1.24	93.8
180	6.88	0.996	1.23	60.3	19.2	1.16	94.0
180	6.39	0.995	1.14	60.3	17.9	1.08	94.2
180	5.89	0.994	1.05	60.3	16.5	0.995	94.4
180	5.40	0.993	0.966	60.4	15.1	0.913	94.5
180	4.93	0.992	0.880	60.4	13.7	0.830	94.3
180	4.44	0.991	0.792	60.4	12.4	0.747	94.3
180	3.96	0.986	0.703	60.4	11.0	0.664	94.5
180	3.48	0.986	0.617	60.4	9.62	0.581	94.1
180	2.99	0.984	0.531	60.4	8.25	0.498	93.9
180	2.51	0.985	0.445	60.4	6.87	0.415	93.4
180	2.01	0.991	0.359	60.4	5.50	0.332	92.7
180	1.52	0.996	0.272	60.5	4.12	0.249	91.7
180	1.04	0.991	0.186	60.5	2.75	0.166	89.2
180	0.580	0.958	0.100	60.5	1.37	0.0831	83.1

Table 22 – Efficiency at 180 VAC, 60 V CV mode.

V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	PF	P_{IN} (kW)	V_{OUT} (VDC)	I_{OUT} (ADC)	P_{OUT} (kW)	Efficiency (%)
230	7.67	0.996	1.76	60.2	27.5	1.66	94.2
230	7.28	0.996	1.67	60.2	26.1	1.57	94.4
230	6.88	0.996	1.58	60.3	24.7	1.49	94.6
230	6.50	0.995	1.49	60.3	23.4	1.41	94.7
230	6.11	0.994	1.40	60.3	22.0	1.33	94.8
230	5.73	0.994	1.31	60.3	20.6	1.24	94.9
230	5.35	0.993	1.22	60.3	19.2	1.16	94.9
230	4.97	0.992	1.13	60.3	17.9	1.08	95.0
230	4.59	0.992	1.05	60.3	16.5	0.995	95.1
230	4.20	0.991	0.959	60.4	15.1	0.913	95.2
230	3.83	0.990	0.872	60.4	13.7	0.830	95.2
230	3.46	0.988	0.786	60.4	12.4	0.747	95.1
230	3.08	0.986	0.700	60.4	11.0	0.664	94.9
230	2.70	0.986	0.613	60.4	9.62	0.581	94.8
230	2.33	0.986	0.528	60.4	8.25	0.498	94.4
230	1.95	0.987	0.443	60.4	6.87	0.415	93.8
230	1.56	0.991	0.357	60.4	5.50	0.332	93.2
230	1.19	0.992	0.271	60.5	4.12	0.249	92.0
230	0.826	0.975	0.185	60.5	2.75	0.166	89.7
230	0.479	0.907	0.100	60.5	1.37	0.0831	83.1

Table 23 – Efficiency at 230 VAC, 60 V CV mode.

V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	PF	P_{IN} (kW)	V_{OUT} (VDC)	I_{OUT} (ADC)	P_{OUT} (kW)	Efficiency (%)
265	6.69	0.985	1.75	60.2	27.5	1.66	94.8
265	6.35	0.984	1.66	60.2	26.1	1.57	94.9
265	6.04	0.981	1.57	60.3	24.7	1.49	95.0
265	5.69	0.981	1.48	60.3	23.4	1.41	95.1
265	5.37	0.979	1.39	60.3	22.0	1.33	95.2
265	5.05	0.975	1.31	60.3	20.6	1.24	95.3
265	4.71	0.974	1.22	60.3	19.2	1.16	95.4
265	4.41	0.966	1.13	60.3	17.9	1.08	95.5
265	4.07	0.965	1.04	60.4	16.5	0.996	95.5
265	3.74	0.964	0.956	60.4	15.1	0.913	95.5
265	3.40	0.964	0.870	60.4	13.7	0.830	95.5
265	3.05	0.969	0.783	60.4	12.4	0.747	95.4
265	2.75	0.956	0.697	60.4	11.0	0.664	95.3
265	2.40	0.962	0.611	60.4	9.62	0.581	95.1
265	2.07	0.957	0.526	60.4	8.25	0.498	94.7
265	1.74	0.957	0.441	60.4	6.87	0.415	94.1
265	1.40	0.960	0.355	60.5	5.50	0.332	93.5
265	1.07	0.948	0.270	60.5	4.12	0.249	92.4
265	0.756	0.922	0.185	60.5	2.75	0.166	90.0
265	0.450	0.833	0.099	60.5	1.37	0.0831	83.6

Table 24 – Efficiency at 265 VAC, 60 V CV mode.

V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	PF	P_{IN} (kW)	V_{OUT} (VDC)	I_{OUT} (ADC)	P_{OUT} (kW)	Efficiency (%)
280	7.02	0.887	1.74	60.2	27.5	1.66	94.9
280	6.77	0.873	1.66	60.3	26.1	1.57	95.1
280	6.52	0.859	1.57	60.3	24.7	1.49	95.1
280	6.32	0.836	1.48	60.3	23.4	1.41	95.2
280	6.15	0.808	1.39	60.3	22.0	1.33	95.3
280	6.00	0.777	1.31	60.3	20.6	1.24	95.3
280	5.85	0.743	1.22	60.3	19.2	1.16	95.3
280	5.52	0.731	1.13	60.3	17.9	1.08	95.4
280	5.20	0.717	1.04	60.4	16.5	0.996	95.4
280	4.87	0.701	0.957	60.4	15.1	0.913	95.4
280	4.55	0.683	0.870	60.4	13.7	0.830	95.4
280	4.20	0.666	0.784	60.4	12.4	0.747	95.3
280	3.83	0.651	0.698	60.4	11.0	0.664	95.2
280	3.38	0.647	0.612	60.4	9.62	0.581	95.0
280	2.97	0.633	0.526	60.4	8.25	0.498	94.7
280	2.65	0.595	0.441	60.5	6.87	0.416	94.2
280	2.18	0.580	0.355	60.5	5.50	0.332	93.8
280	1.60	0.599	0.269	60.5	4.12	0.249	92.7
280	1.60	0.411	0.184	60.5	2.75	0.166	90.3
280	0.918	0.380	0.098	60.5	1.37	0.0831	85.2

Table 25 – Efficiency at 280 VAC, 60 V CV mode.

For minimum CV mode output, the reference voltage set to 26 V using variable resistor R74. A variable AC source was used to supply a sine wave input and a DC electronic load set to CC mode as load on the output.

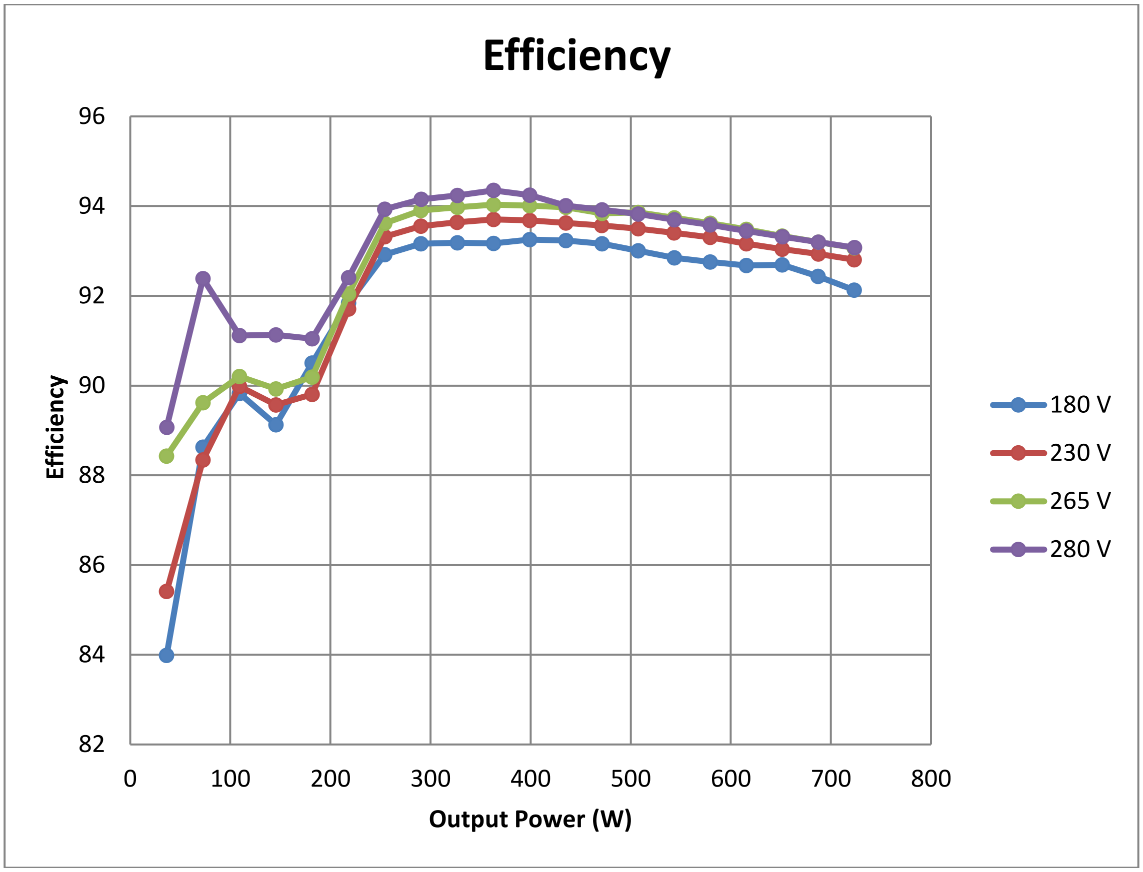


Figure 27 – Total Efficiency vs. Load, 26 V Output CV Mode.

V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	PF	P_{IN} (W)	V_{OUT} (VDC)	I_{OUT} (ADC)	P_{OUT} (W)	Efficiency (%)
180	4.40	0.991	785	26.3	27.5	723	92.1
180	4.17	0.991	744	26.3	26.1	687	92.4
180	3.94	0.991	703	26.3	24.7	651	92.7
180	3.74	0.986	664	26.3	23.4	615	92.7
180	3.52	0.986	625	26.3	22.0	579	92.8
180	3.30	0.985	585	26.4	20.6	543	92.9
180	3.08	0.984	546	26.4	19.2	507	93.0
180	2.86	0.984	506	26.4	17.9	471	93.2
180	2.63	0.984	467	26.4	16.5	435	93.2
180	2.41	0.985	428	26.4	15.1	399	93.3
180	2.19	0.988	389	26.4	13.7	363	93.2
180	1.97	0.991	351	26.4	12.4	327	93.2
180	1.74	0.994	312	26.4	11.0	291	93.2
180	1.53	0.996	274	26.4	9.62	254	92.9
180	1.32	0.996	237	26.4	8.25	218	91.8
180	1.12	0.993	201	26.4	6.87	182	90.5
180	0.919	0.987	163	26.5	5.50	145	89.1
180	0.694	0.972	121	26.5	4.12	109	89.8
180	0.487	0.936	82.1	26.5	2.75	72.8	88.6
180	0.287	0.838	43.3	26.5	1.37	36.4	84.0

Table 26 – Efficiency at 180 VAC, 26 V CV mode.

V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	PF	P_{IN} (W)	V_{OUT} (VDC)	I_{OUT} (ADC)	P_{OUT} (W)	Efficiency (%)
230	3.43	0.988	779	26.3	27.5	723	92.8
230	3.26	0.987	740	26.3	26.1	687	92.9
230	3.09	0.986	700	26.3	24.7	651	93.0
230	2.91	0.986	661	26.3	23.4	615	93.2
230	2.74	0.986	621	26.3	22.0	579	93.3
230	2.56	0.986	582	26.4	20.6	543	93.4
230	2.39	0.986	543	26.4	19.2	507	93.5
230	2.22	0.986	504	26.4	17.9	471	93.6
230	2.05	0.987	465	26.4	16.5	435	93.6
230	1.87	0.987	426	26.4	15.1	399	93.7
230	1.70	0.989	387	26.4	13.7	363	93.7
230	1.53	0.991	349	26.4	12.4	327	93.6
230	1.36	0.993	311	26.4	11.0	291	93.6
230	1.19	0.992	272	26.4	9.62	254	93.3
230	1.05	0.988	238	26.4	8.25	218	91.7
230	0.897	0.981	202	26.5	6.87	182	89.8
230	0.731	0.965	162	26.5	5.50	145	89.6
230	0.564	0.934	121	26.5	4.12	109	90.0
230	0.415	0.863	82.4	26.5	2.75	72.8	88.3
230	0.309	0.598	42.6	26.5	1.37	36.4	85.4

Table 27 – Efficiency at 230 VAC, 26 V CV mode.

V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	PF	P_{IN} (W)	V_{OUT} (VDC)	I_{OUT} (ADC)	P_{OUT} (W)	Efficiency (%)
265	3.06	0.957	777	26.3	27.5	723	93.1
265	2.92	0.953	738	26.3	26.1	687	93.2
265	2.76	0.955	698	26.3	24.7	651	93.3
265	2.59	0.959	658	26.3	23.4	615	93.5
265	2.43	0.960	619	26.3	22.0	579	93.6
265	2.28	0.959	580	26.4	20.6	543	93.7
265	2.13	0.959	541	26.4	19.2	507	93.9
265	1.98	0.957	502	26.4	17.9	471	93.8
265	1.83	0.956	463	26.4	16.5	435	94.0
265	1.67	0.958	425	26.4	15.1	399	94.0
265	1.52	0.959	386	26.4	13.7	363	94.0
265	1.37	0.958	348	26.4	12.4	327	94.0
265	1.22	0.955	309	26.4	11.0	291	93.9
265	1.08	0.949	272	26.4	9.62	254	93.6
265	0.950	0.941	237	26.4	8.25	218	92.0
265	0.820	0.927	202	26.5	6.87	182	90.2
265	0.671	0.909	162	26.5	5.50	145	89.9
265	0.530	0.860	121	26.5	4.12	109	90.2
265	0.430	0.712	81.2	26.5	2.75	72.8	89.6
265	0.308	0.504	41.1	26.5	1.37	36.4	88.4

Table 28 – Efficiency at 265 VAC, 26 V CV mode.

V_{IN} (V_{RMS})	**I_{IN}** (A_{RMS})	**PF**	**P_{IN}** (W)	**V_{OUT}** (VDC)	**I_{OUT}** (ADC)	**P_{OUT}** (W)	**Efficiency** (%)
280	4.12	0.674	777	26.3	27.5	723	93.1
280	3.95	0.667	738	26.3	26.1	687	93.2
280	3.79	0.658	698	26.3	24.7	652	93.3
280	3.61	0.651	659	26.3	23.4	616	93.4
280	3.40	0.650	619	26.4	22.0	580	93.6
280	3.20	0.647	580	26.4	20.6	543	93.7
280	3.02	0.640	541	26.4	19.2	507	93.8
280	2.82	0.634	502	26.4	17.9	471	93.9
280	2.62	0.631	463	26.4	16.5	435	94.0
280	2.56	0.591	424	26.4	15.1	399	94.2
280	2.33	0.589	385	26.4	13.7	363	94.3
280	2.12	0.584	347	26.4	12.4	327	94.2
280	1.88	0.587	309	26.4	11.0	291	94.1
280	1.65	0.585	271	26.4	9.62	254	93.9
280	1.755	0.480	236	26.4	8.25	218	92.4
280	1.736	0.411	200	26.5	6.87	182	91.0
280	1.377	0.414	160	26.5	5.50	145	91.1
280	1.037	0.412	120	26.5	4.12	109	91.1
280	0.737	0.381	78.8	26.5	2.75	72.8	92.4
280	0.387	0.377	40.9	26.5	1.37	36.4	89.1

Table 29 – Efficiency at 280 VAC, 26 V CV mode.

For maximum CC mode output, the reference current set to 27.5 A using variable resistor R107. A variable AC source was used to supply a sine wave input and a DC electronic load set to CV mode as load on the output.

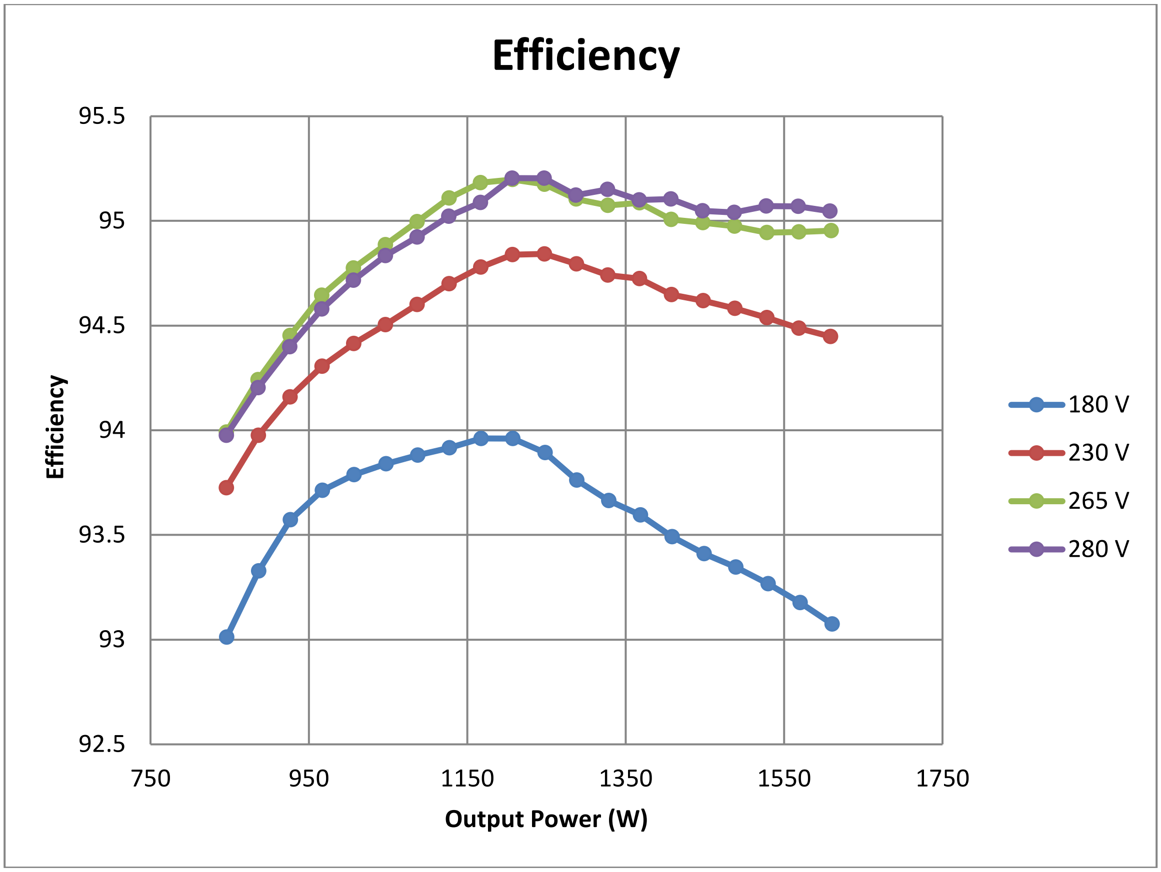


Figure 28 – Total Efficiency vs. Load, 27.5 A Output CC Mode.

V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	PF	P_{IN} (kW)	V_{OUT} (VDC)	I_{OUT} (ADC)	P_{OUT} (kW)	Efficiency (%)
180	9.64	0.997	1.73	58.5	27.5	1.61	93.1
180	9.38	0.998	1.69	57.0	27.5	1.57	93.2
180	9.13	0.998	1.64	55.6	27.5	1.53	93.3
180	8.88	0.998	1.60	54.1	27.5	1.49	93.3
180	8.63	0.998	1.55	52.6	27.5	1.45	93.4
180	8.39	0.998	1.51	51.2	27.5	1.41	93.5
180	8.14	0.997	1.46	49.7	27.5	1.37	93.6
180	7.90	0.997	1.42	48.3	27.5	1.33	93.7
180	7.65	0.997	1.37	46.8	27.5	1.29	93.8
180	7.41	0.997	1.33	45.3	27.5	1.25	93.9
180	7.16	0.996	1.29	43.9	27.5	1.21	94.0
180	6.93	0.996	1.24	42.4	27.5	1.17	94.0
180	6.70	0.996	1.20	40.9	27.5	1.13	93.9
180	6.47	0.995	1.16	39.5	27.5	1.09	93.9
180	6.23	0.994	1.12	38.0	27.5	1.05	93.8
180	6.00	0.994	1.07	36.6	27.5	1.01	93.8
180	5.77	0.993	1.03	35.1	27.5	0.967	93.7
180	5.54	0.993	0.990	33.6	27.6	0.927	93.6
180	5.31	0.993	0.950	32.2	27.6	0.886	93.3
180	5.09	0.992	0.910	30.7	27.6	0.846	93.0

Table 30 – Efficiency at 180 VAC, 27.5 A CC mode.

V_{IN} (V_{RMS})	**I_{IN}** (A_{RMS})	**PF**	**P_{IN}** (kW)	**V_{OUT}** (VDC)	**I_{OUT}** (ADC)	**P_{OUT}** (kW)	**Efficiency** (%)
230	7.43	0.996	1.70	58.5	27.5	1.61	94.4
230	7.25	0.996	1.66	57.0	27.5	1.57	94.5
230	7.06	0.996	1.62	55.6	27.5	1.53	94.5
230	6.87	0.995	1.57	54.1	27.5	1.49	94.6
230	6.68	0.995	1.53	52.6	27.5	1.45	94.6
230	6.50	0.995	1.49	51.2	27.5	1.41	94.6
230	6.31	0.994	1.44	49.7	27.5	1.37	94.7
230	6.13	0.994	1.40	48.3	27.5	1.33	94.7
230	5.94	0.994	1.36	46.8	27.5	1.29	94.8
230	5.75	0.993	1.32	45.3	27.5	1.25	94.8
230	5.57	0.993	1.27	43.9	27.5	1.21	94.8
230	5.39	0.993	1.23	42.4	27.5	1.17	94.8
230	5.21	0.992	1.19	40.9	27.5	1.13	94.7
230	5.03	0.992	1.15	39.5	27.5	1.09	94.6
230	4.85	0.992	1.11	38.0	27.5	1.05	94.5
230	4.67	0.992	1.07	36.6	27.5	1.01	94.4
230	4.49	0.992	1.02	35.1	27.5	0.966	94.3
230	4.31	0.992	0.984	33.6	27.5	0.926	94.2
230	4.14	0.991	0.943	32.2	27.5	0.886	94.0
230	3.96	0.990	0.902	30.7	27.5	0.846	93.7

Table 31 – Efficiency at 230 VAC, 27.5 A CC mode.

V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	PF	P_{IN} (kW)	V_{OUT} (VDC)	I_{OUT} (ADC)	P_{OUT} (kW)	Efficiency (%)
265	6.50	0.984	1.69	58.5	27.5	1.61	95.0
265	6.34	0.983	1.65	57.0	27.5	1.57	94.9
265	6.18	0.982	1.61	55.6	27.5	1.53	94.9
265	6.02	0.982	1.57	54.1	27.5	1.49	95.0
265	5.86	0.981	1.52	52.6	27.5	1.45	95.0
265	5.71	0.979	1.48	51.2	27.5	1.41	95.0
265	5.52	0.982	1.44	49.7	27.5	1.37	95.1
265	5.40	0.976	1.40	48.3	27.5	1.33	95.1
265	5.23	0.976	1.35	46.8	27.5	1.29	95.1
265	5.08	0.973	1.31	45.3	27.5	1.25	95.2
265	4.91	0.974	1.27	43.9	27.5	1.21	95.2
265	4.75	0.973	1.23	42.4	27.5	1.17	95.2
265	4.58	0.975	1.18	40.9	27.5	1.13	95.1
265	4.45	0.971	1.14	39.5	27.5	1.09	95.0
265	4.32	0.962	1.10	38.0	27.5	1.05	94.9
265	4.13	0.969	1.06	36.6	27.5	1.01	94.8
265	3.96	0.973	1.02	35.1	27.5	0.966	94.6
265	3.81	0.972	0.980	33.6	27.5	0.926	94.5
265	3.68	0.964	0.940	32.2	27.5	0.886	94.2
265	3.54	0.958	0.900	30.7	27.5	0.846	94.0

Table 32 – Efficiency at 265 VAC, 27.5 A CC mode.

V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	PF	P_{IN} (kW)	V_{OUT} (VDC)	I_{OUT} (ADC)	P_{OUT} (kW)	Efficiency (%)
280	6.88	0.878	1.69	58.5	27.5	1.61	95.0
280	6.75	0.872	1.65	57.0	27.5	1.57	95.1
280	6.64	0.864	1.61	55.6	27.5	1.53	95.1
280	6.54	0.855	1.56	54.1	27.5	1.49	95.0
280	6.44	0.844	1.52	52.6	27.5	1.45	95.0
280	6.34	0.832	1.48	51.2	27.5	1.41	95.1
280	6.27	0.818	1.44	49.7	27.5	1.37	95.1
280	6.20	0.803	1.39	48.3	27.5	1.33	95.2
280	6.15	0.785	1.35	46.8	27.5	1.29	95.1
280	6.03	0.776	1.31	45.3	27.5	1.25	95.2
280	5.97	0.758	1.27	43.9	27.5	1.21	95.2
280	5.92	0.740	1.23	42.4	27.5	1.17	95.1
280	5.76	0.734	1.19	40.9	27.5	1.13	95.0
280	5.61	0.729	1.14	39.5	27.5	1.09	94.9
280	5.45	0.723	1.10	38.0	27.5	1.05	94.8
280	5.29	0.717	1.06	36.6	27.5	1.01	94.7
280	5.14	0.710	1.02	35.1	27.5	0.966	94.6
280	4.99	0.702	0.981	33.6	27.5	0.926	94.4
280	4.83	0.695	0.940	32.2	27.5	0.886	94.2
280	4.68	0.687	0.900	30.7	27.5	0.846	94.0

Table 33 – Efficiency at 280 VAC, 27.5 A CC mode.

For minimum CC mode output, the reference current set to 9 A using variable resistor R107. A variable AC source was used to supply a sine wave input and a DC electronic load set to CV mode as load on the output.

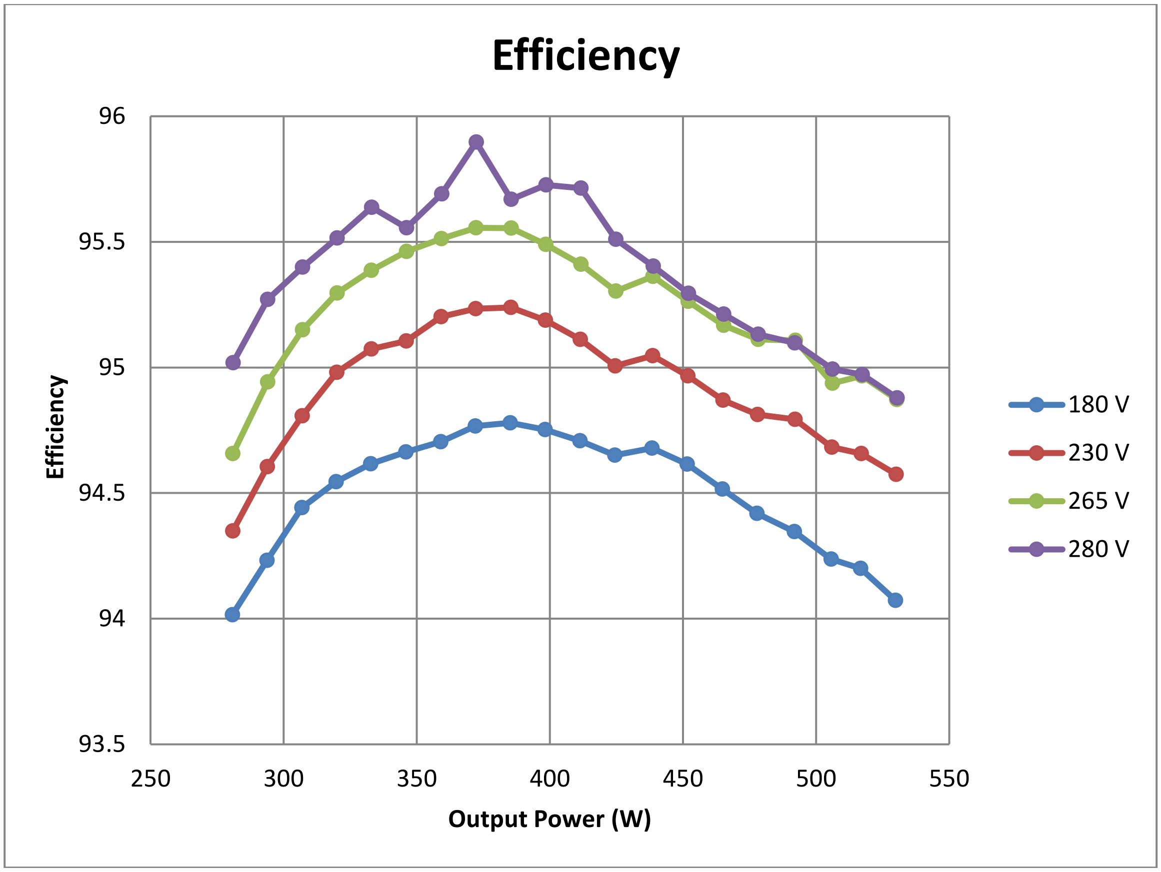


Figure 29 – Total Efficiency vs. Load, 9 A Output CC Mode.

V_{IN} (V_{RMS})	**I_{IN}** (A_{RMS})	**PF**	**P_{IN}** (W)	**V_{OUT}** (VDC)	**I_{OUT}** (ADC)	**P_{OUT}** (W)	**Efficiency** (%)
180	3.18	0.984	563	58.5	9.06	530	94.1
180	3.10	0.984	548	57.0	9.06	517	94.2
180	3.03	0.984	537	55.6	9.10	506	94.2
180	2.94	0.984	521	54.1	9.09	492	94.3
180	2.86	0.984	506	52.6	9.08	478	94.4
180	2.78	0.984	492	51.2	9.08	465	94.5
180	2.69	0.984	477	49.7	9.08	452	94.6
180	2.61	0.985	463	48.3	9.08	438	94.7
180	2.53	0.985	448	46.8	9.07	424	94.7
180	2.45	0.985	434	45.3	9.07	411	94.7
180	2.37	0.986	420	43.9	9.08	398	94.8
180	2.29	0.986	406	42.4	9.08	385	94.8
180	2.21	0.987	392	40.9	9.08	372	94.8
180	2.13	0.988	379	39.5	9.09	359	94.7
180	2.05	0.990	365	38.0	9.10	346	94.7
180	1.97	0.991	352	36.6	9.10	333	94.6
180	1.89	0.992	338	35.1	9.11	320	94.5
180	1.82	0.993	325	33.6	9.12	307	94.4
180	1.74	0.994	312	32.2	9.13	294	94.2
180	1.67	0.995	299	30.7	9.14	281	94.0

Table 34 – Efficiency at 180 VAC, 9 A CC mode.

V_{IN} (V_{RMS})	**I_{IN}** (A_{RMS})	**PF**	**P_{IN}** (W)	**V_{OUT}** (VDC)	**I_{OUT}** (ADC)	**P_{OUT}** (W)	**Efficiency** (%)
230	2.47	0.986	560	58.5	9.06	530	94.6
230	2.41	0.986	546	57.0	9.06	517	94.7
230	2.35	0.986	534	55.6	9.10	506	94.7
230	2.29	0.986	519	54.1	9.09	492	94.8
230	2.22	0.986	504	52.6	9.08	478	94.8
230	2.16	0.986	490	51.2	9.09	465	94.9
230	2.10	0.987	476	49.7	9.09	452	95.0
230	2.03	0.987	461	48.3	9.09	439	95.0
230	1.97	0.987	447	46.8	9.07	425	95.0
230	1.90	0.987	433	45.3	9.08	411	95.1
230	1.84	0.988	419	43.9	9.08	398	95.2
230	1.78	0.988	405	42.4	9.09	385	95.2
230	1.72	0.989	391	40.9	9.09	372	95.2
230	1.66	0.990	377	39.5	9.10	359	95.2
230	1.60	0.990	364	38.0	9.10	346	95.1
230	1.54	0.991	350	36.6	9.11	333	95.1
230	1.48	0.992	337	35.1	9.12	320	95.0
230	1.42	0.992	324	33.6	9.13	307	94.8
230	1.36	0.993	311	32.2	9.14	294	94.6
230	1.30	0.993	298	30.7	9.15	281	94.3

Table 35 – Efficiency at 230 VAC, 9 A CC mode.

V_{IN} (V_{RMS})	**I_{IN}** (A_{RMS})	**PF**	**P_{IN}** (W)	**V_{OUT}** (VDC)	**I_{OUT}** (ADC)	**P_{OUT}** (W)	**Efficiency** (%)
265	2.20	0.959	559	58.5	9.07	530	94.9
265	2.15	0.957	545	57.0	9.07	517	95.0
265	2.11	0.955	533	55.6	9.11	506	94.9
265	2.04	0.956	518	54.1	9.10	492	95.1
265	1.99	0.955	503	52.6	9.08	478	95.1
265	1.93	0.956	489	51.2	9.09	465	95.2
265	1.87	0.956	474	49.7	9.09	452	95.3
265	1.81	0.958	460	48.3	9.09	439	95.4
265	1.76	0.957	446	46.8	9.08	425	95.3
265	1.70	0.956	431	45.3	9.08	412	95.4
265	1.64	0.957	417	43.9	9.08	398	95.5
265	1.59	0.956	403	42.4	9.09	385	95.6
265	1.53	0.958	390	40.9	9.09	372	95.6
265	1.48	0.958	376	39.5	9.10	359	95.5
265	1.43	0.958	363	38.0	9.11	346	95.5
265	1.38	0.958	349	36.6	9.11	333	95.4
265	1.32	0.958	336	35.1	9.12	320	95.3
265	1.27	0.956	323	33.6	9.13	307	95.1
265	1.22	0.954	310	32.2	9.14	294	94.9
265	1.18	0.953	297	30.7	9.15	281	94.7

Table 36 – Efficiency at 265 VAC, 9 A CC mode.

V_{IN} (V_{RMS})	**I_{IN}** (A_{RMS})	**PF**	**P_{IN}** (W)	**V_{OUT}** (VDC)	**I_{OUT}** (ADC)	**P_{OUT}** (W)	**Efficiency** (%)
280	3.13	0.637	559	58.5	9.07	530	94.9
280	3.06	0.635	545	57.0	9.07	517	95.0
280	3.00	0.633	533	55.6	9.11	506	95.0
280	2.93	0.631	517	54.1	9.09	492	95.1
280	2.85	0.630	503	52.6	9.09	478	95.1
280	2.78	0.629	489	51.2	9.09	465	95.2
280	2.70	0.628	474	49.7	9.09	452	95.3
280	2.62	0.627	460	48.3	9.09	439	95.4
280	2.75	0.577	445	46.8	9.08	425	95.5
280	2.69	0.571	430	45.3	9.08	412	95.7
280	2.62	0.566	416	43.9	9.09	399	95.7
280	2.53	0.570	403	42.4	9.09	385	95.7
280	2.37	0.585	388	40.9	9.09	372	95.9
280	2.26	0.593	376	39.5	9.10	359	95.7
280	2.22	0.584	362	38.0	9.11	346	95.6
280	2.15	0.580	348	36.6	9.11	333	95.6
280	2.07	0.577	335	35.1	9.12	320	95.5
280	1.92	0.600	322	33.6	9.13	307	95.4
280	1.99	0.555	309	32.2	9.14	294	95.3
280	1.92	0.549	296	30.7	9.15	281	95.0

Table 37 – Efficiency at 280 VAC, 9 A CC mode.

11.3 No-Load Input Power

The total no-load input power of both PFC and LLC was measured at room temperature with an integration time of 10 minutes. The output was completely disconnected from the load and the input power meter was the only probe connected. At 60 V CV mode, the converter was operating at Full Frequency (FF) mode during No Load condition. FF causes increased switching loss in the LLC primary and secondary devices. The converter was purposely designed to operate with FF down to very light loads, due to the output current ripple requirement of the charger.

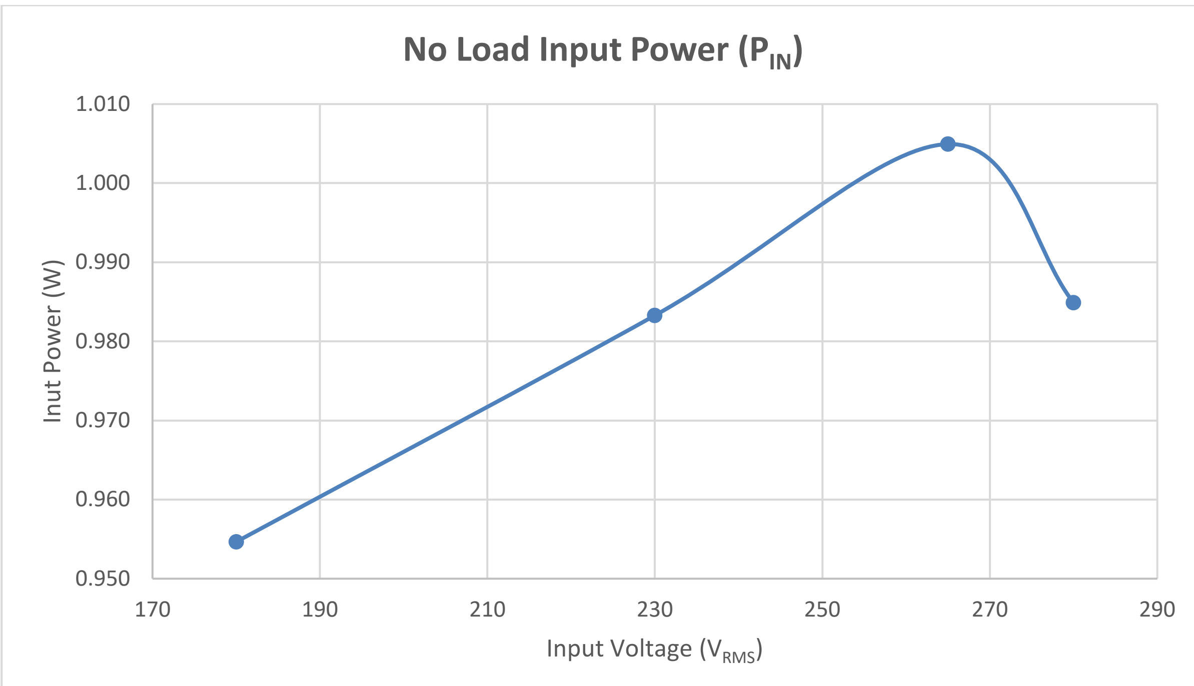


Figure 30 – No Load Input Power.

V_{IN} (V_{RMS})	P_{IN} (W)
180	0.955
230	0.983
265	1.00
280	0.985

Table 38 – No Load Input Power.

11.4 Power Factor

Power Factor was measured at different line voltages with varying loads using a power meter. The converter operated in CV mode with the reference voltage set to 60 V. A variable AC source was used to apply a sinusoidal voltage input and a DC electronic load (set to CC mode) was used as load on the output.

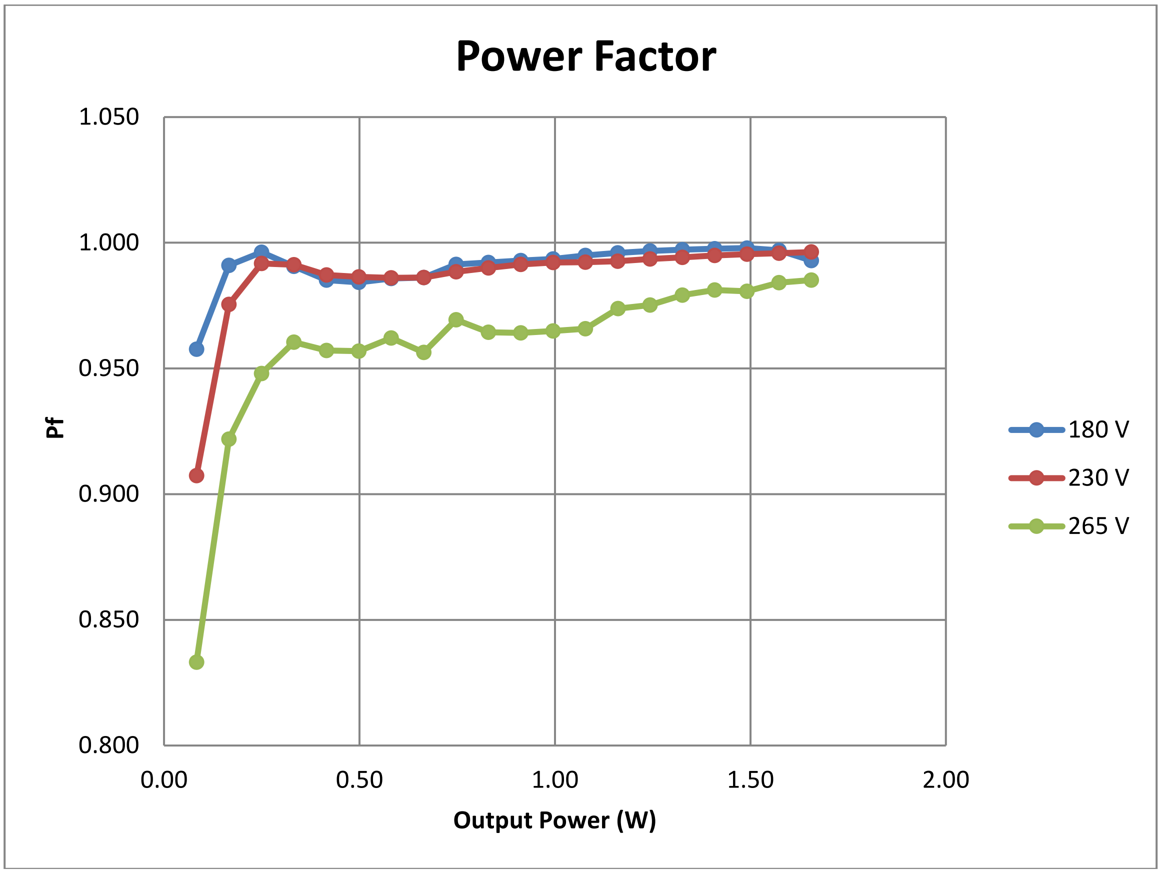


Figure 31 – Power Factor at 60 V CV mode.

V_{IN} (V_{RMS})	PF	P_{OUT} (kW)	V_{IN} (V_{RMS})	PF	P_{OUT} (kW)	V_{IN} (V_{RMS})	PF	P_{OUT} (kW)
180	0.993	1.66	230	0.996	1.66	265	0.985	1.66
180	0.997	1.57	230	0.996	1.57	265	0.984	1.57
180	0.998	1.49	230	0.996	1.49	265	0.981	1.49
180	0.998	1.41	230	0.995	1.41	265	0.981	1.41
180	0.997	1.33	230	0.994	1.33	265	0.979	1.33
180	0.997	1.24	230	0.994	1.24	265	0.975	1.24
180	0.996	1.16	230	0.993	1.16	265	0.974	1.16
180	0.995	1.08	230	0.992	1.08	265	0.966	1.08
180	0.994	0.995	230	0.992	0.995	265	0.965	0.996
180	0.993	0.913	230	0.991	0.913	265	0.964	0.913
180	0.992	0.830	230	0.990	0.830	265	0.964	0.830
180	0.991	0.747	230	0.988	0.747	265	0.969	0.747
180	0.986	0.664	230	0.986	0.664	265	0.956	0.664
180	0.986	0.581	230	0.986	0.581	265	0.962	0.581
180	0.984	0.498	230	0.986	0.498	265	0.957	0.498
180	0.985	0.415	230	0.987	0.415	265	0.957	0.415
180	0.991	0.332	230	0.991	0.332	265	0.960	0.332
180	0.996	0.249	230	0.992	0.249	265	0.948	0.249
180	0.991	0.166	230	0.975	0.166	265	0.922	0.166
180	0.958	0.0831	230	0.907	0.0831	265	0.833	0.0831

Table 39 – Power Factor at 60 V CV mode, V_{IN} at 180 VAC, 230 VAC and 265 VAC.

11.5 Line Regulation

Line regulation was measured with an AC source connected to the input. The electronic load is set in CC mode to draw a constant current output from the power supply. The converter was controlled to be in CV Mode, with the reference set as 60 V. The load was varied with the electronic load and input AC voltage was varied with the AC source.

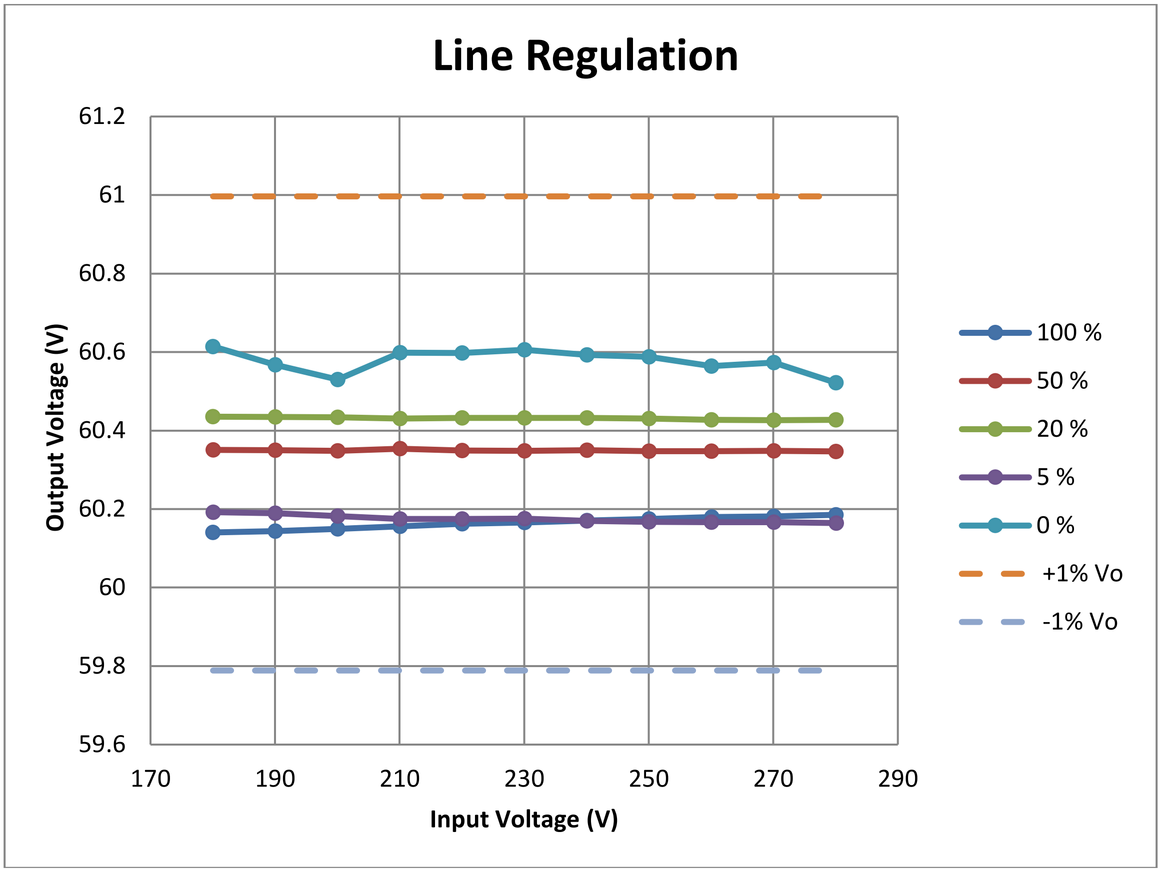


Figure 32 – Line Regulation at 60 V CV mode.

V_{IN} (V_{RMS})	**V_{OUT}** (VDC)				
	100% Load	50% Load	20% Load	5% Load	0% Load
180	60.1	60.4	60.4	60.2	60.6
190	60.1	60.4	60.4	60.2	60.6
200	60.2	60.4	60.4	60.2	60.6
210	60.2	60.4	60.4	60.2	60.6
220	60.2	60.4	60.4	60.2	60.6
230	60.2	60.3	60.4	60.2	60.6
240	60.2	60.3	60.4	60.2	60.6
250	60.2	60.3	60.4	60.2	60.6
260	60.2	60.3	60.4	60.2	60.6
270	60.2	60.3	60.4	60.2	60.6
280	60.2	60.3	60.4	60.2	60.5

Table 40 – Line Regulation at 60 V CV mode.

11.6 Load Regulation

Load regulation was measured by decreasing the load from full load down to zero using an DC electronic load. The test was repeated at different line voltages.

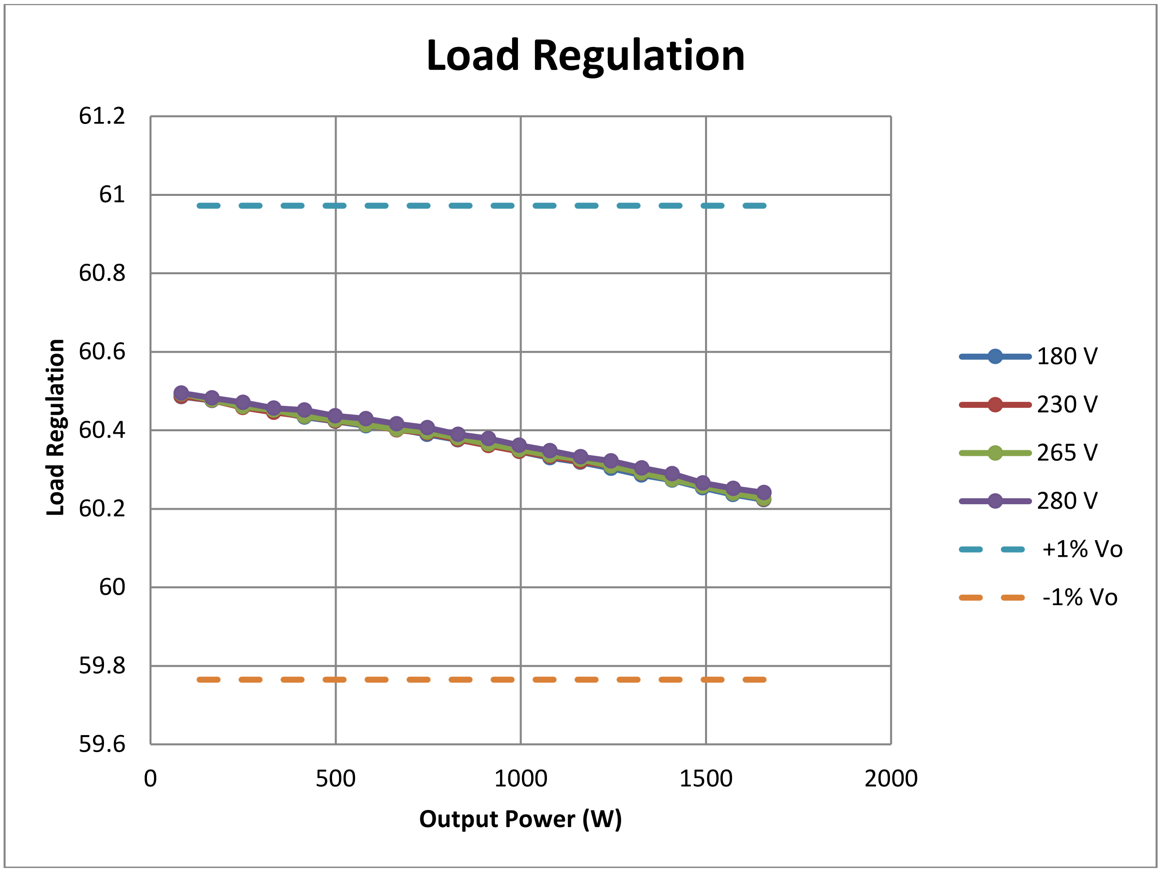


Figure 33 – Load Regulation at 60 V CV mode.

V_{IN} (V_{RMS})	**P_{OUT}** (kW)	**V_{OUT}** (VDC)	**V_{IN}** (V_{RMS})	**P_{OUT}** (kW)	**V_{OUT}** (VDC)
180	1.66	60.2	230	1.66	60.2
180	1.57	60.2	230	1.57	60.2
180	1.49	60.3	230	1.49	60.3
180	1.41	60.3	230	1.41	60.3
180	1.33	60.3	230	1.33	60.3
180	1.24	60.3	230	1.24	60.3
180	1.16	60.3	230	1.16	60.3
180	1.08	60.3	230	1.08	60.3
180	0.995	60.3	230	0.995	60.3
180	0.913	60.4	230	0.913	60.4
180	0.830	60.4	230	0.830	60.4
180	0.747	60.4	230	0.747	60.4
180	0.664	60.4	230	0.664	60.4
180	0.581	60.4	230	0.581	60.4
180	0.498	60.4	230	0.498	60.4
180	0.415	60.4	230	0.415	60.4
180	0.332	60.4	230	0.332	60.4
180	0.249	60.5	230	0.249	60.5
180	0.166	60.5	230	0.166	60.5
180	0.0831	60.5	230	0.0831	60.5

Table 41 – Load Regulation at 60 V CV mode, V_{IN} at 180 VAC and 230 VAC.

V_{IN} (V_{RMS})	P_{OUT} (kW)	V_{OUT} (VDC)	V_{IN} (V_{RMS})	P_{OUT} (kW)	V_{OUT} (VDC)
265	1.66	60.2	280	1.66	60.2
265	1.57	60.2	280	1.57	60.3
265	1.49	60.3	280	1.49	60.3
265	1.41	60.3	280	1.41	60.3
265	1.33	60.3	280	1.33	60.3
265	1.24	60.3	280	1.24	60.3
265	1.16	60.3	280	1.16	60.3
265	1.08	60.3	280	1.08	60.3
265	0.996	60.4	280	0.996	60.4
265	0.913	60.4	280	0.913	60.4
265	0.830	60.4	280	0.830	60.4
265	0.747	60.4	280	0.747	60.4
265	0.664	60.4	280	0.664	60.4
265	0.581	60.4	280	0.581	60.4
265	0.498	60.4	280	0.498	60.4
265	0.415	60.4	280	0.416	60.5
265	0.332	60.5	280	0.332	60.5
265	0.249	60.5	280	0.249	60.5
265	0.166	60.5	280	0.166	60.5
265	0.0831	60.5	280	0.0831	60.5

Table 42 – Load Regulation at 60 V CV mode, V_{IN} at 265 VAC and 280 VAC.

12 Waveforms

The figures below show the expected waveforms for different input voltage and output loading conditions set for the UUT.

12.1 Input AC Current, 100% Load – 60 V / 27.5 A

Input current was measured at varying line voltages with an electronic load set to CC mode at full load, 27.5 A.

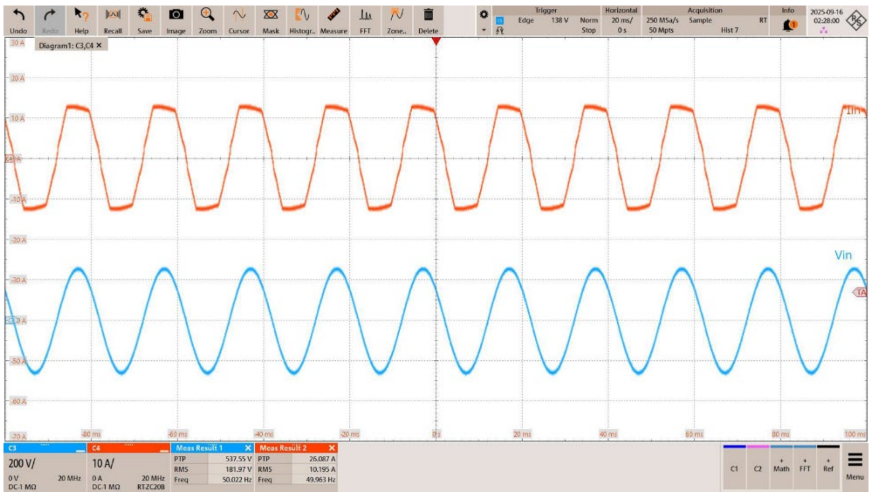


Figure 34 – Input Current, 180 VAC.
Time Division : 20 ms/div.
CH3: V_{IN}, 200 V/div.
CH4: I_{IN}, 10 A/div.

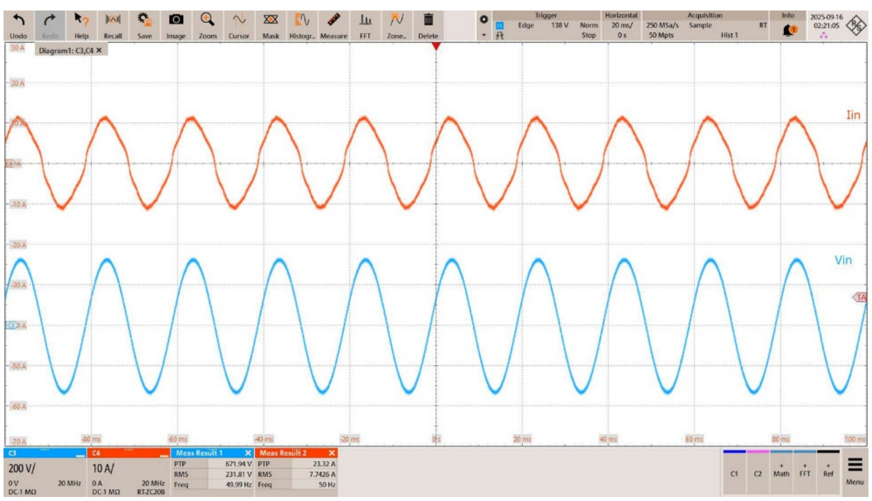


Figure 35 – Input Current, 230 VAC.
Time Division : 20 ms/div.
CH3: V_{IN}, 200 V/div.
CH4: I_{IN}, 10 A/div.

12.2 PFC Voltage and Current, 100% Load

The figures below show the CCM operation of HiperPFS-3 with 230 VAC input. PFC current is clipping at 180 VAC to 200 VAC input voltage. At input voltage of greater than 200 VAC, there is no more clipping that can be observed.

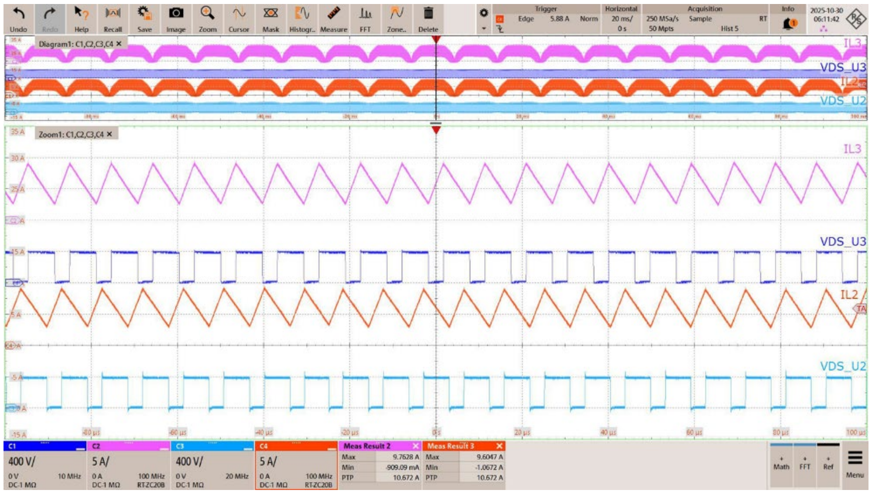


Figure 36 – PFC V_{DS} and Inductor Current, 180 VAC.
Time Division: 20 ms/div.
Zoom Time Division: 10 μs/div.
CH1: V_{DS_U3}, 400 V/div.
CH2: I_{L_L3}, 5 A/div.
CH3: V_{DS_U2}, 400 V/div.
CH4: I_{L_L2}, 5 A/div.

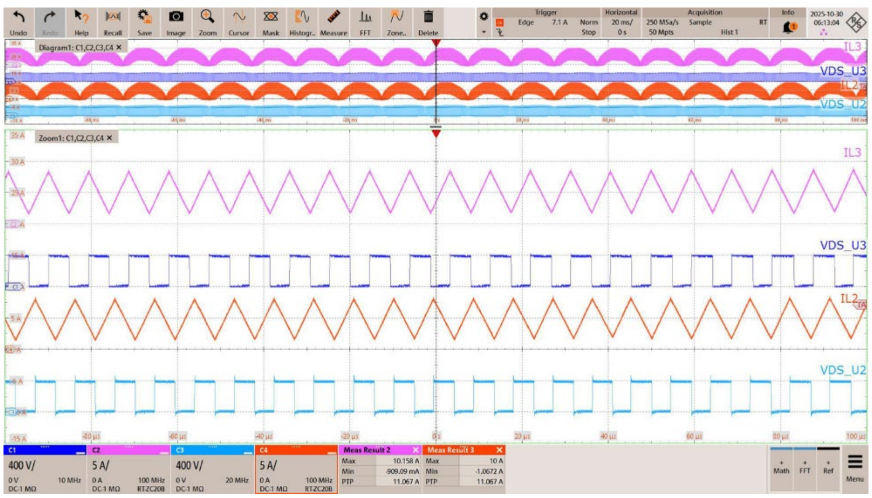


Figure 37 – PFC V_{DS} and Inductor Current, 195 VAC.
Time Division: 20 ms/div.
Zoom Time Division: 10 μs/div.
CH1: V_{DS_U3}, 400 V/div.
CH2: I_{L_L3}, 5 A/div.
CH3: V_{DS_U2}, 400 V/div.
CH4: I_{L_L2}, 5 A/div.

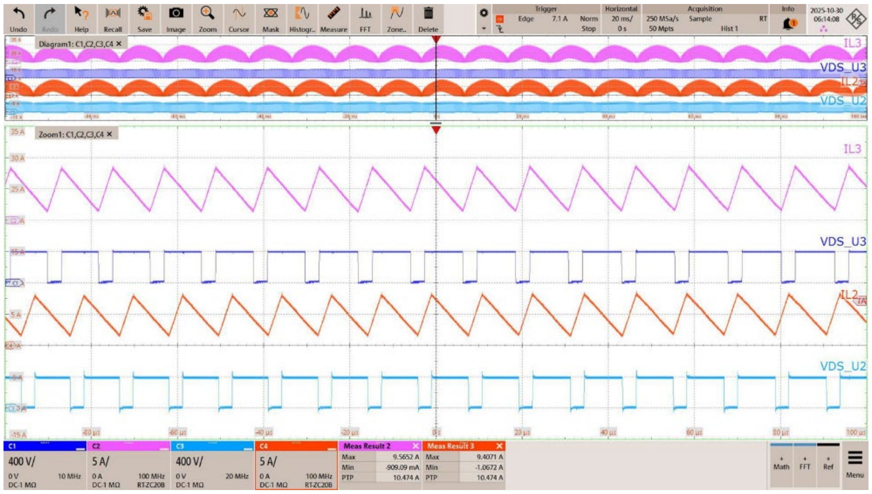


Figure 38 – PFC V_{DS} and Inductor Current, 230 VAC.
Time Division: 20 ms/div.
Zoom Time Division: 10 µs/div.
CH1: V_{DS_U3}, 400 V/div.
CH2: I_{L_L3}, 5 A/div.
CH3: V_{DS_U2}, 400 V/div.
CH4: I_{L_L2}, 5 A/div.

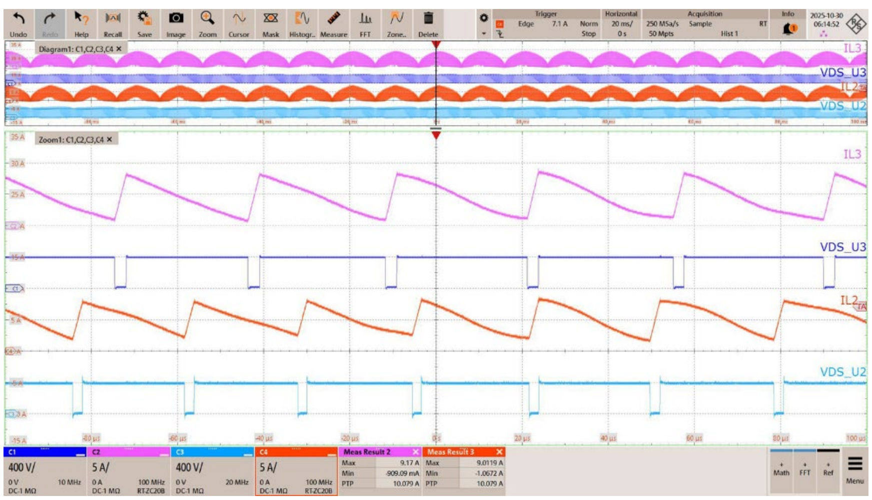


Figure 39 – PFC V_{DS} and Inductor Current, 265 VAC.
Time Division: 20 ms/div.
Zoom Time Division: 10 µs/div.
CH1: V_{DS_U3}, 400 V/div.
CH2: I_{L_L3}, 5 A/div.
CH3: V_{DS_U2}, 400 V/div.
CH4: I_{L_L2}, 5 A/div.

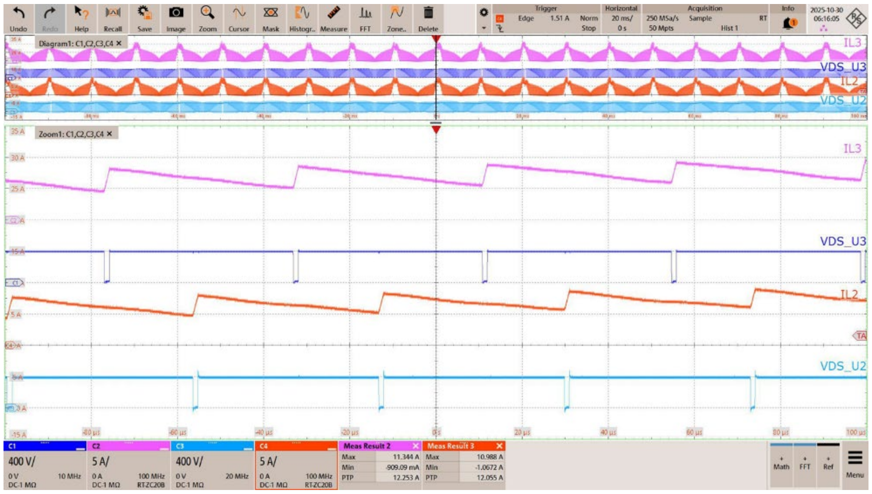


Figure 40 – PFC V_{DS} and Inductor Current, 280 VAC.
Time Division: 20 ms/div.
Zoom Time Division: 10 μs/div.
CH1: V_{DS_U3}, 400 V/div.
CH2: I_{L_L3}, 5 A/div.
CH3: V_{DS_U2}, 400 V/div.
CH4: I_{L_L2}, 5 A/div.

12.3 Start Up Waveforms

Input was supplied from an AC source and the output was connected to an electronic load set to full load CC Mode. 41 and Figure 42 show the waveforms for HB Voltage, HB Current and V_{OUT} during start-up at both full load and no-load condition at 230 VAC.

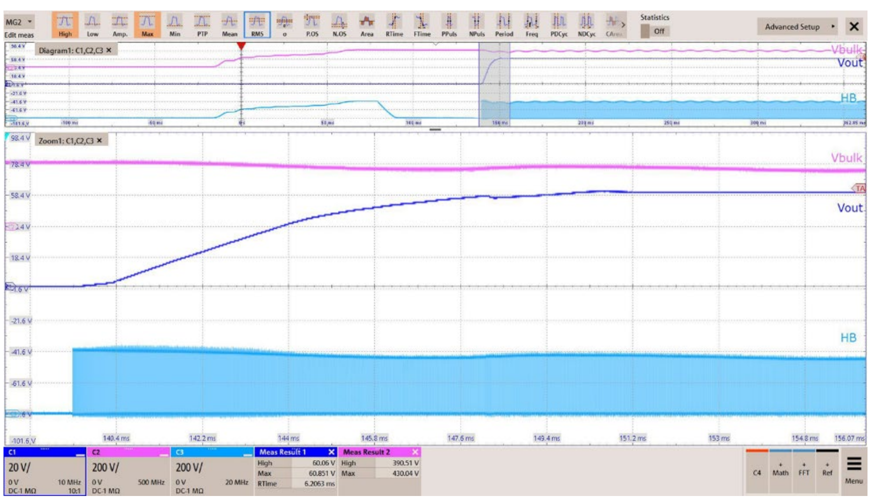


Figure 41 – Unit Start-up, 230 VAC, Full Load.
Time/Division: 50 ms/div.
CH1: V_{OUT}, 20 V/div.
CH2: PFC V_{OUT}, 200 V/div.
CH3: HB, 200 V/div.

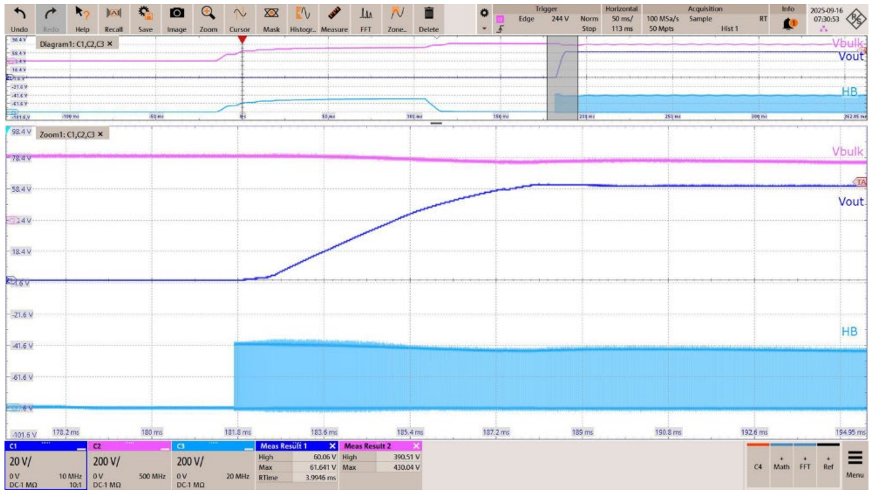


Figure 42 – Unit Start-up, 230 VAC, Half Load.
Time/Division: 50 ms/div.
CH1: V_{OUT}, 20 V/div.
CH2: PFC V_{OUT}, 200 V/div.
CH3: HB, 200 V/div.

12.4 LLC Primary Voltage and Current

Voltage and current of both LLC half-bridge and secondary output section with output loaded using an electronic load set to CC mode and varied at different loading conditions are shown in Figure 43 to Figure 52.

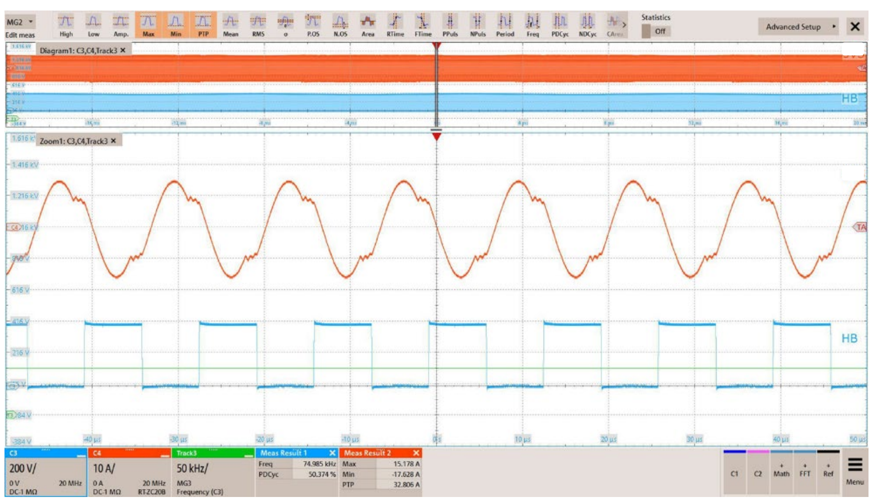


Figure 43 – LLC Stage Primary Voltage and Current, 60 V 27.5 A.
Zoom In Time Division: 10 µs/div.
CH3: HB Voltage, 200 V/div
CH4: HB Current, 10 A/div.

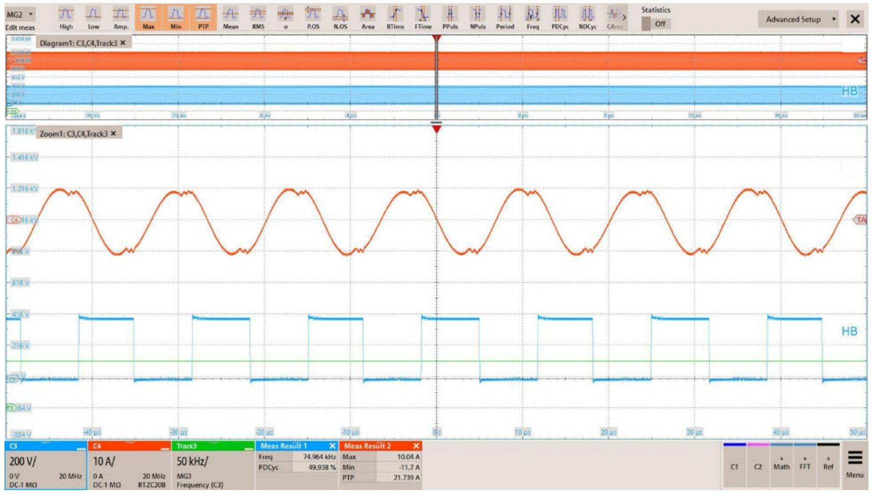


Figure 44 – LLC Stage Primary Voltage and Current, 60 V 13.8 A.
Zoom In Time Division: 10 μs/div.
CH3: HB Voltage, 200 V/div
CH4: HB Current, 10 A/div.

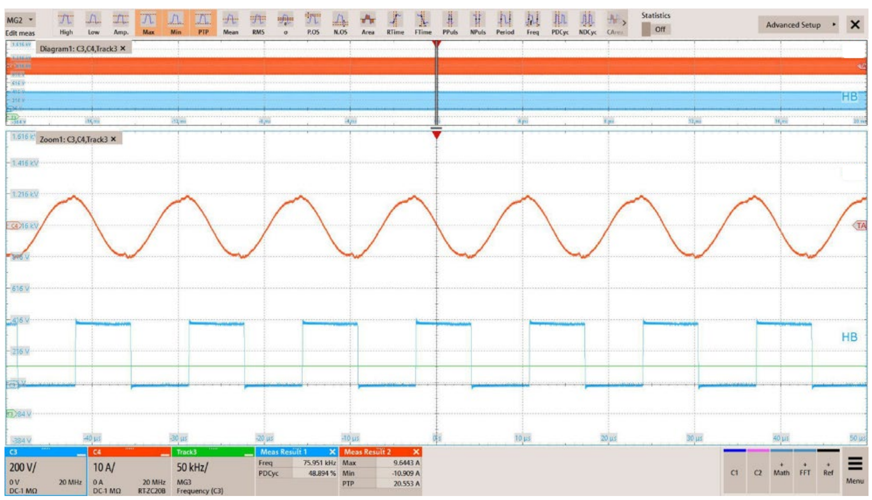


Figure 45 – LLC Stage Primary Voltage and Current, 60 V 5.5 A.
Zoom In Time Division: 10 μs/div.
CH3: HB Voltage, 200 V/div
CH4: HB Current, 10 A/div.

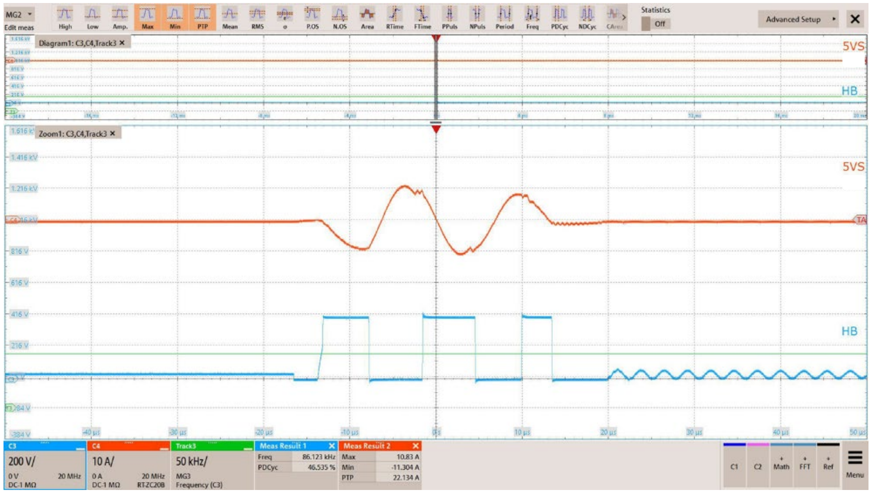


Figure 46 – LLC Stage Primary Voltage and Current, 60 V 0 A.
Zoom In Time Division: 10 μs/div.
CH3: HB Voltage, 200 V/div
CH4: HB Current, 10 A/div.

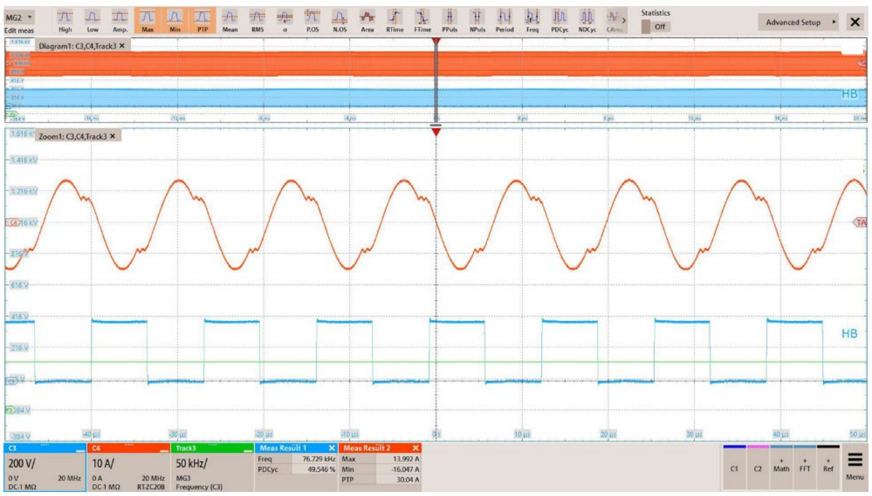


Figure 47 – LLC Stage Primary Voltage and Current, 55 V 27.5 A.
Zoom In Time Division: 10 μs/div.
CH3: HB Voltage, 200 V/div
CH4: HB Current, 10 A/div.

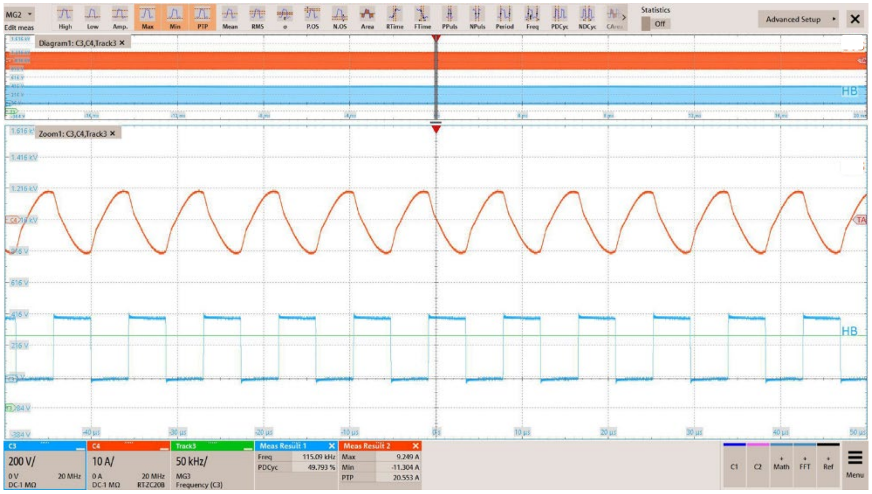


Figure 48 – LLC Stage Primary Voltage and Current, 30 V 27.5 A.
Zoom In Time Division: 10 μs/div.
CH3: HB Voltage, 200 V/div
CH4: HB Current, 10 A/div.

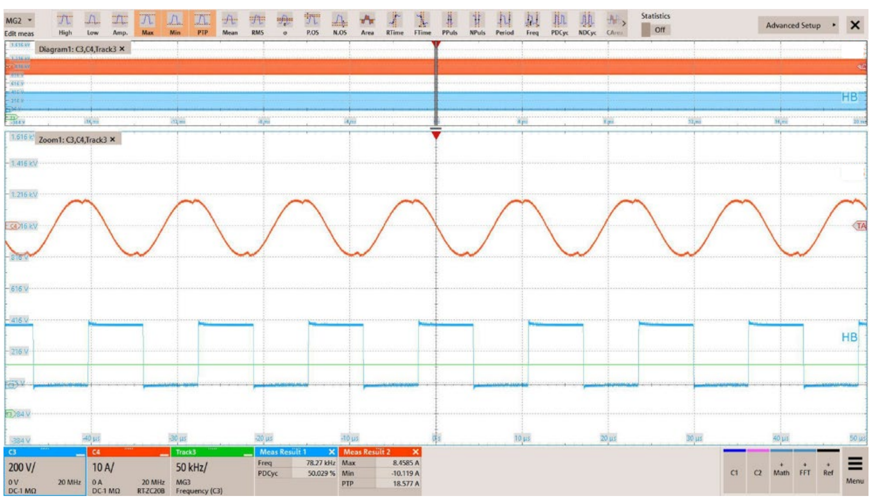


Figure 49 – LLC Stage Primary Voltage and Current, 30 V 9 A.
Zoom In Time Division: 10 μs/div.
CH3: HB Voltage, 200 V/div
CH4: HB Current, 10 A/div.

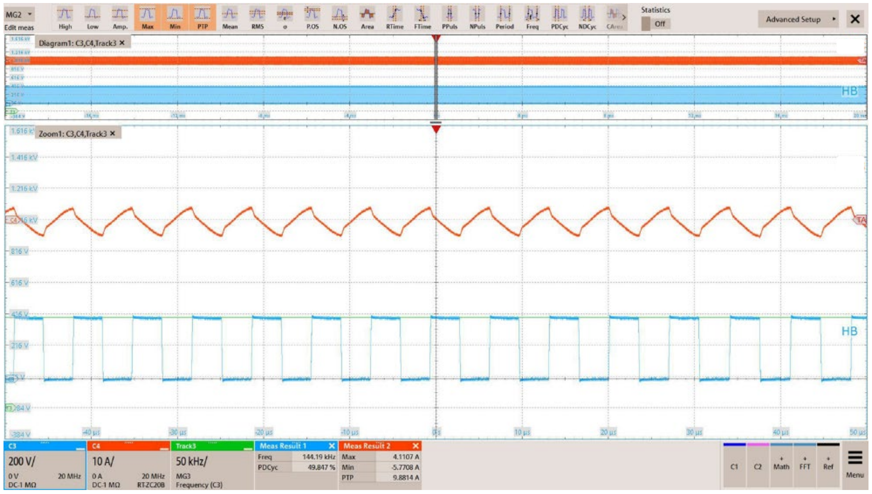


Figure 50 – LLC Stage Primary Voltage and Current, 30 V 9 A.
Zoom In Time Division: 10 μs/div.
CH3: HB Voltage, 200 V/div
CH4: HB Current, 10 A/div.

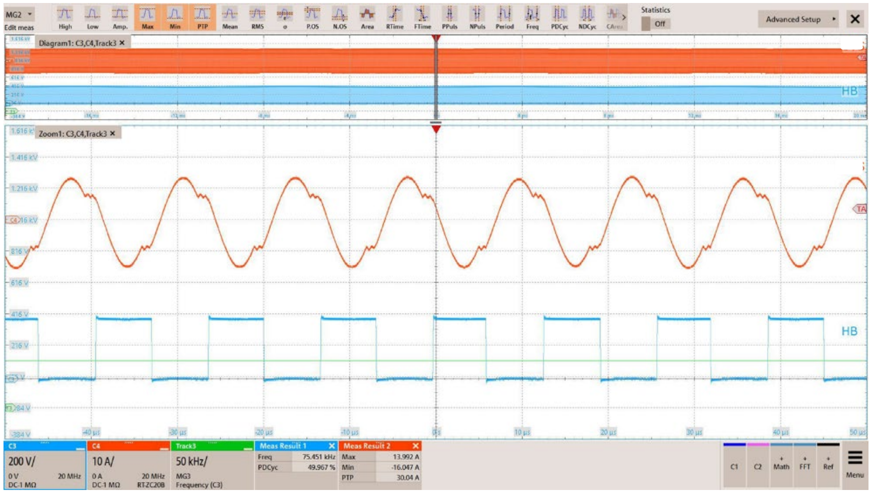


Figure 51 – LLC Stage Primary Voltage and Current, CV Mode, 55 V 27.5 A.
Zoom In Time Division: 10 μs/div.
CH3: HB Voltage, 200 V/div
CH4: HB Current, 10 A/div.

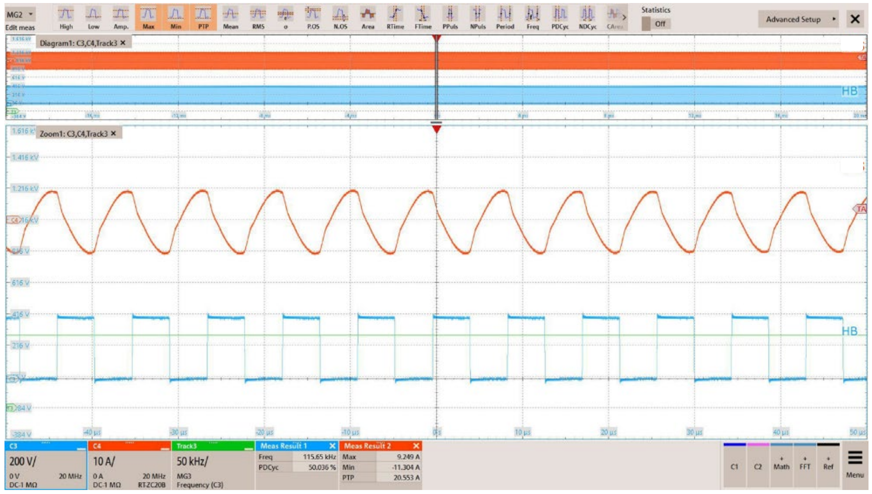


Figure 52 – LLC Stage Primary Voltage and Current, CV Mode, 30 V 27.5 A.
Zoom In Time Division: 10 µs/div.
CH3: HB Voltage, 200 V/div
CH4: HB Current, 10 A/div.

12.5 SR Waveforms

The voltage across the secondary synchronous rectifier MOSFET under continuous and discontinuous mode of operation were recorded at 60 V / 27.5 A and 26 V / 9 A and are shown in Figure 53 and Figure 54 respectively.

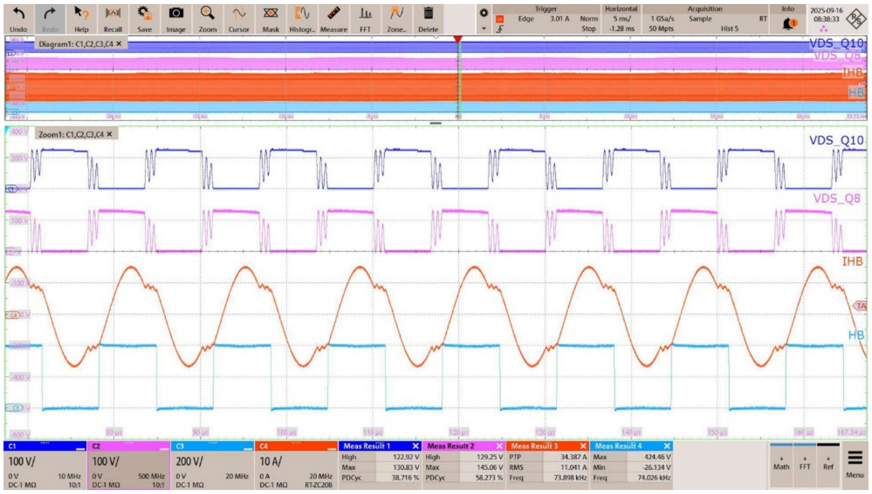


Figure 53 – Output Rectifier Peak Reverse Voltage at 60 V, 27.5 A.
Time Division: 10 µs/div.
CH1: Q_{10} V_{DS}, 100 V/div.
CH2: Q_8 V_{DS}, 100 V/div.
CH3: HB Voltage, 200 V/div.
CH4: HB Current, 10 A/div

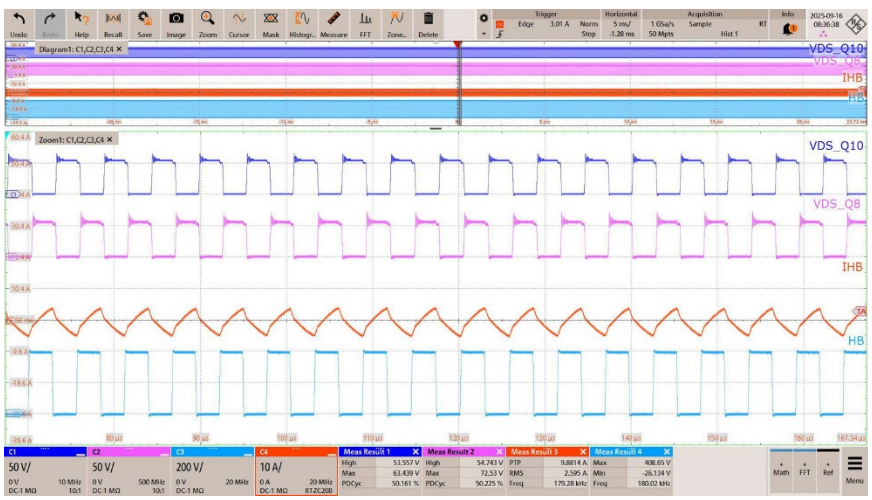


Figure 54 – Output Rectifier Peak Reverse Voltage at 26 V, 9 A.
Time Division: 10 µs/div.
CH1: Q_{10} V_{DS}, 50 V/div.
CH2: Q_8 V_{DS}, 50 V/div.
CH3: HB Voltage, 200 V/div.
CH4: HB Current, 10 A/div

12.6 Dynamic Loading

Figure 55 and Figure 56 show the response of the LLC converter during a dynamic loading at 60 V output in CV mode. Output load current would vary from 50% to 100%.

Electronic Load setting was as follows:
Duty Cycle = 50%, Frequency = 100 Hz, Slew Rate = 800 mA/µs.

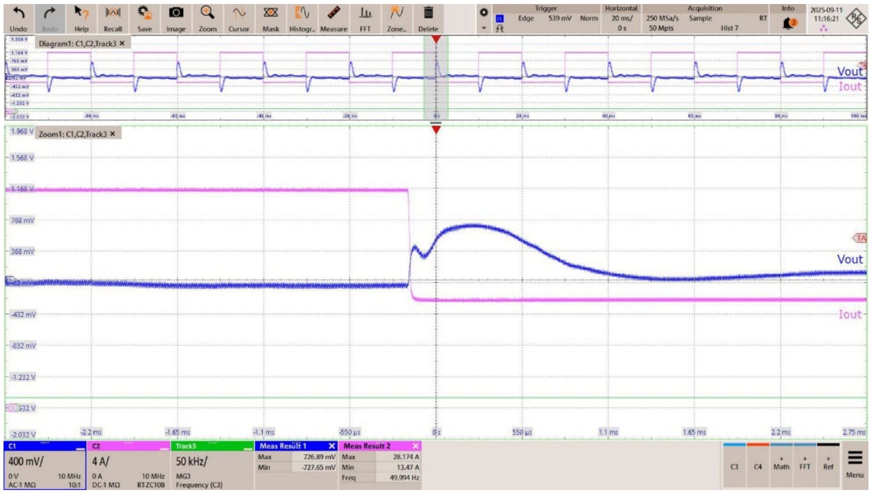


Figure 55 – Dynamic Loading, 50-100% Load.
Zoom In Time Division: 5.5 µs/div.
CH1: Output Voltage, 400 mV/div
CH2: Output Current, 4 A/div.

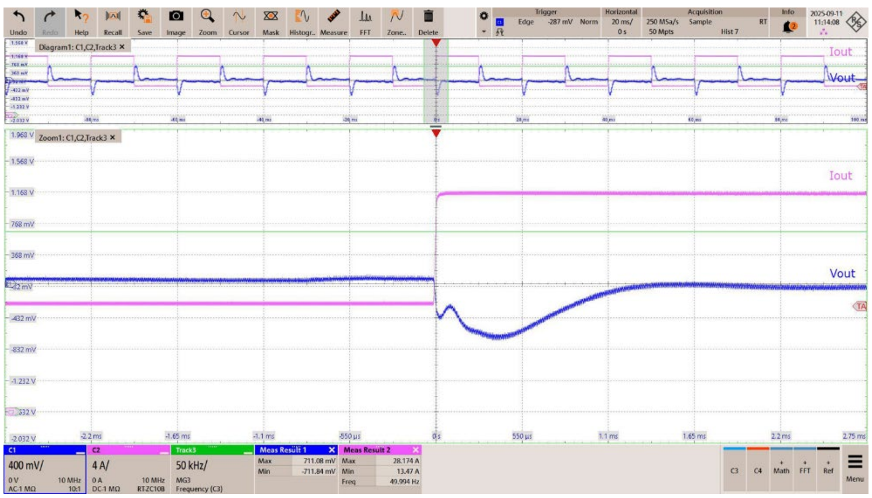


Figure 56 – Dynamic Loading, 50-100% Load.
Zoom In Time Division: 5.5 µs/div.
CH1: Output Voltage, 400 mV/div
CH2: Output Current, 4 A/div.

13 Appendices

This section describes the optional configuration for controlling the CC/CV circuit through an external MCU CAN daughter card. The schematic is applicable only when dynamic control is implemented via the MCU interface, connected through the J10 connector.

In the default configuration, the CC/CV control loop is managed using onboard variable resistors, allowing for manual adjustment of current and voltage thresholds. This setup is intended for fixed operation and does not require external communication.

To enable MCU based control, below provisions have been incorporated into the design to allow selective population of components. Specifically, certain components should be populated accordingly to route PWM signal from the CAN interface to the CC/CV section.

This flexible design approach ensures that users can choose between: Manual control via onboard variable resistors (default configuration) or Digital control via an external MCU CAN daughter card (optional configuration).

Please refer to the schematic section labeled “CV/CC Control via MCU CAN Interface” for the detailed signal routing and component population guidelines. This section should be used exclusively when implementing the MCU-based control mode.

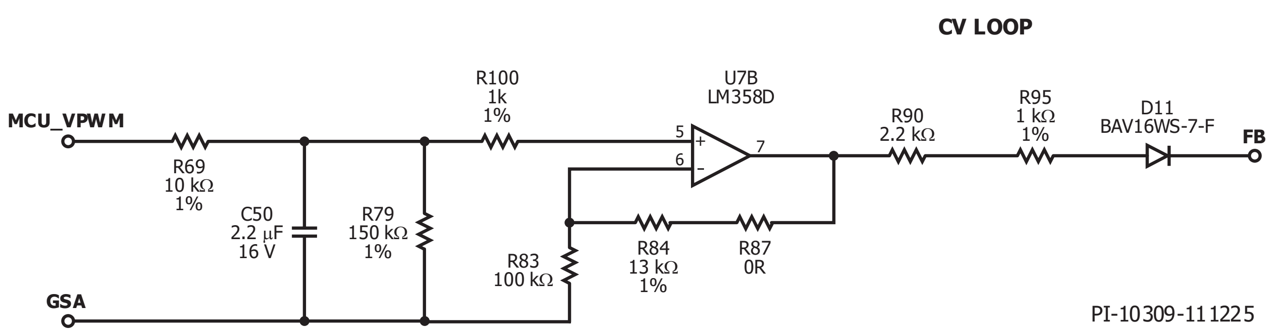


Figure 57 – CAN Interface.

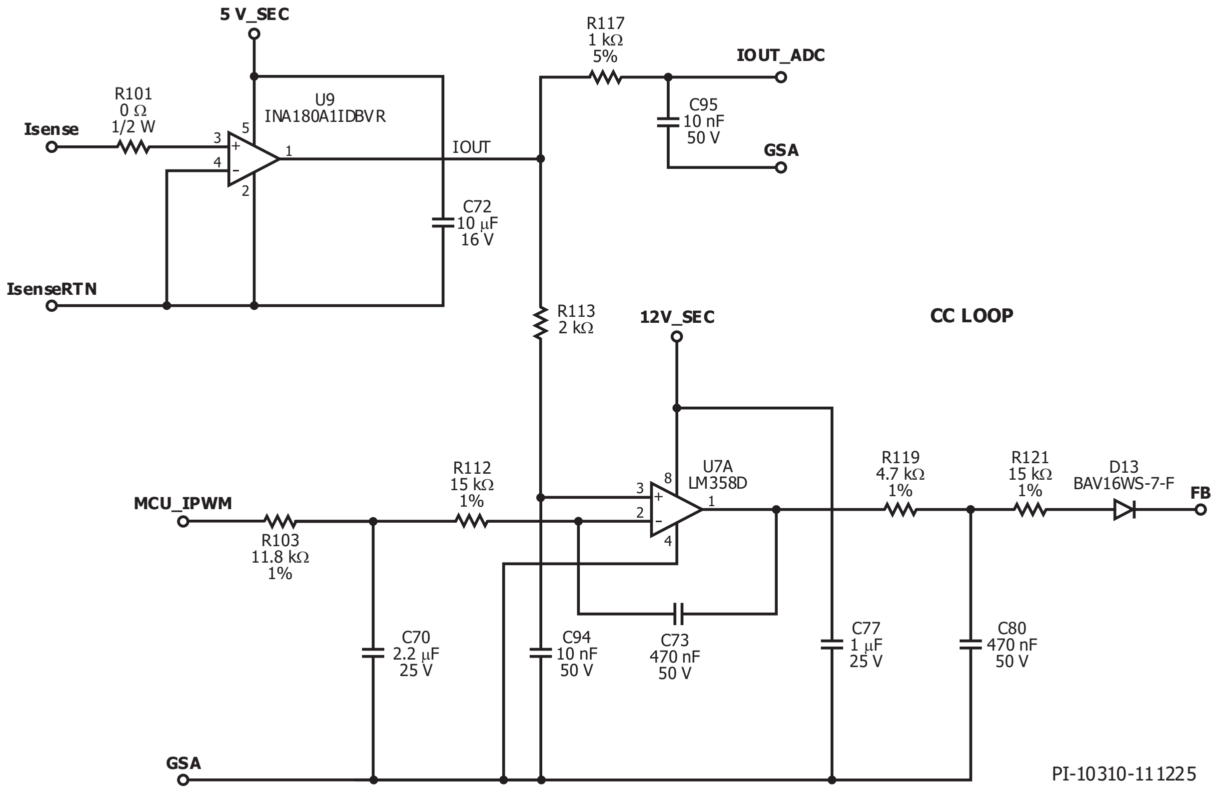


Figure 58 – MCU CAN Interface.

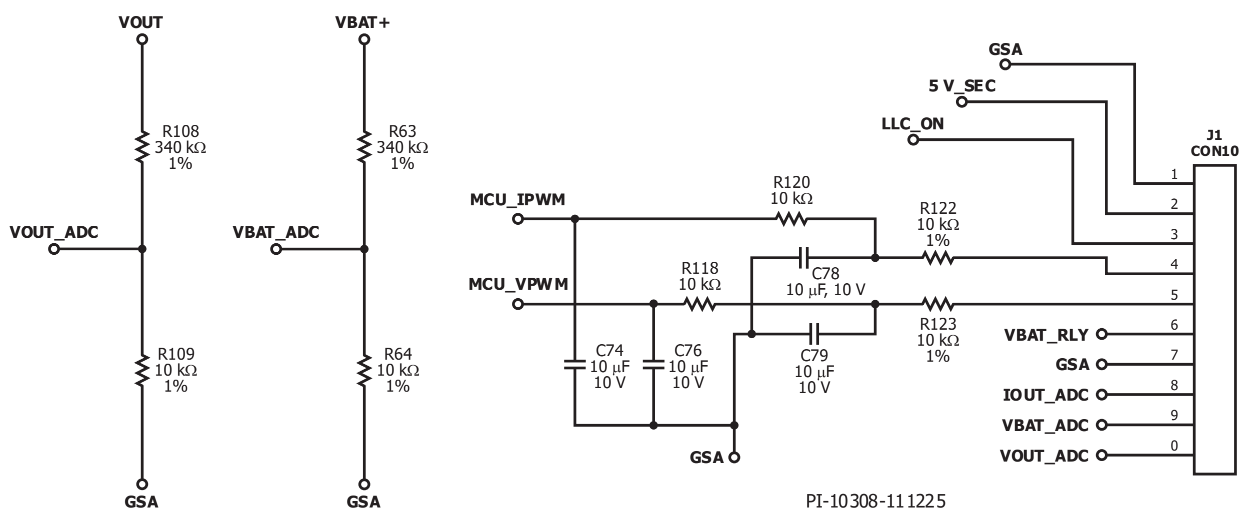


Figure 59 – Provision for MCU.

Revision History

Date	Author	Revision	Description and Changes	Reviewed
11-Nov-2025	RAC/SS	A	Initial release	Apps & Mktg

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