Reference Design Report

Title	**720 W 60 V 12 A Power Factor Corrected LLC PSU with CV and CC Modes**
Specification	170 VAC – 280 VAC Input; 60 V, 12 A Output
Application	2-wheeler EVs and Tool Chargers
Author	Applications Engineering Department
Document Number	RDR-1063
Date	October 22, 2025
Revision	B

Summary and Features

- Using HiperLCS™2-HB LCS7268Z, 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 plus synchronous rectification
  - 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
- Better than ±5% constant current (CC) regulation
- Better than ±1% constant voltage (CV) regulation
- Option for external CC/CV control
- Wide output voltage range: 26 - 60 VDC
- Wide output battery current range: 0 A to 12 A

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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 2 wheeler EV and power tool charging. The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, design spreadsheet and performance data.

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, 12-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.

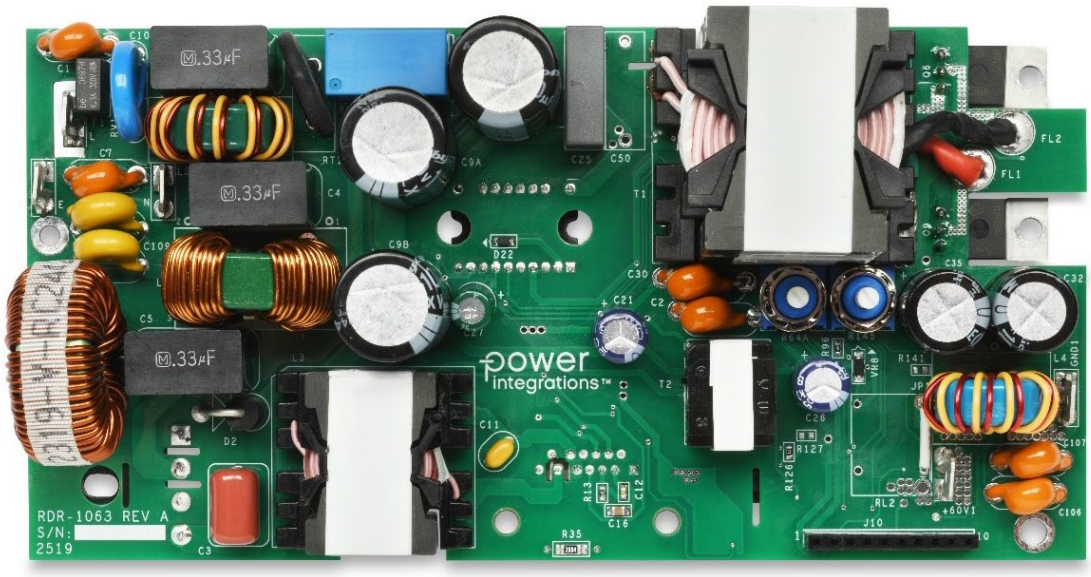


Figure 1 – RDR-1063 Populated Power Converter Board, Top View.

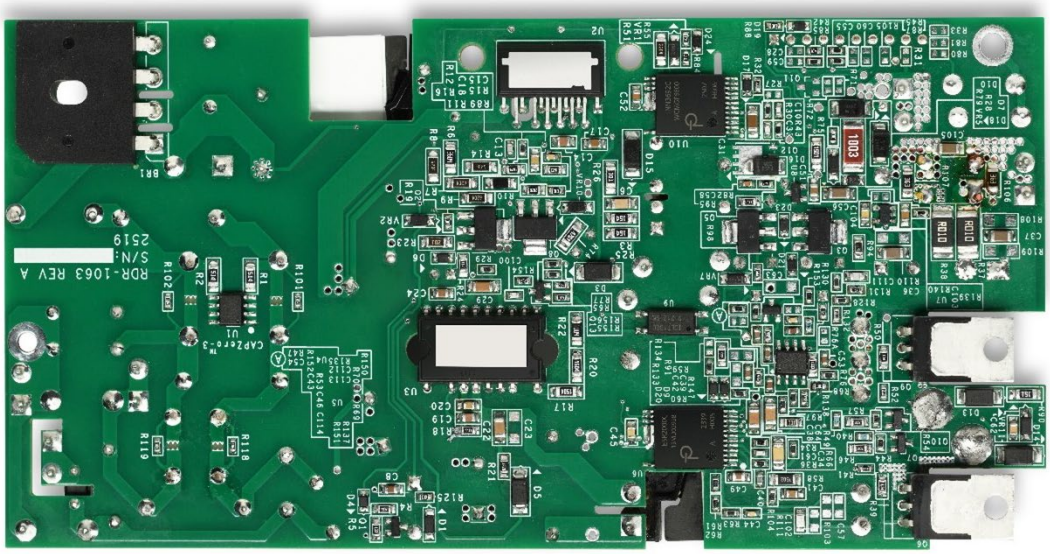


Figure 2 – RDR-1063 Populated Power Converter Board, Bottom View.

Figure 1 and Figure 2 show the main circuit board containing the HiperPFS-3 and HiperLCS-2 chipset. A vertical PQ3535 transformer is mounted on the top side of the main board. The LSR2000C barrier crossing IC is located on the underside of the main board, opposite the transformer. The board has baseplate heatsinks mounted on the underside to cool the bridge rectifiers, the PFS7539L IC, the LCS7268Z IC and the secondary-side synchronous rectifier MOSFETs.

For the variable CV and CC operation, external error amps U5A/B is used to control the feedback (pin 5) of U6. The reference operating points for CV and CC are set using variable resistors R64 and R145.

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	$\mathbf{V_{IN}}$	170	230	280	VAC	Single phase input
Frequency	$\mathbf{f_{LINE}}$	47	50/60	64	Hz	
Power Factor	**PF**	0.9				Full Load, 230 VAC.
Main Converter Output						
Output Voltage	$\mathbf{V_{LG}}$	26	60		V	(720 W) Full Load.
Output Current	$\mathbf{I_{LG}}$		12		A	
Total Output Power						
Continuous Output Power	$\mathbf{P_{OUT}}$		720		W	
Power Supply Efficiency						
			92.9			Measured at 170 VAC, Full Load.
Full Load 60 V / 12 A.	η_{Main}		94.3		%	Measured at 230 VAC, Full Load.
			94.8			Measured at 265 VAC, Full load.
No Load Input Power Total System No-Load Consumption for 60 V output	$P_{IN(NO-LOAD)}$		1.5		W	Measured at 230 VAC.
Ambient Temperature	$\mathbf{T_{AMB}}$	0		40	°C	See Thermal Section for Conditions.

Table 1 – Power Supply Specifications.

3 Schematic

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

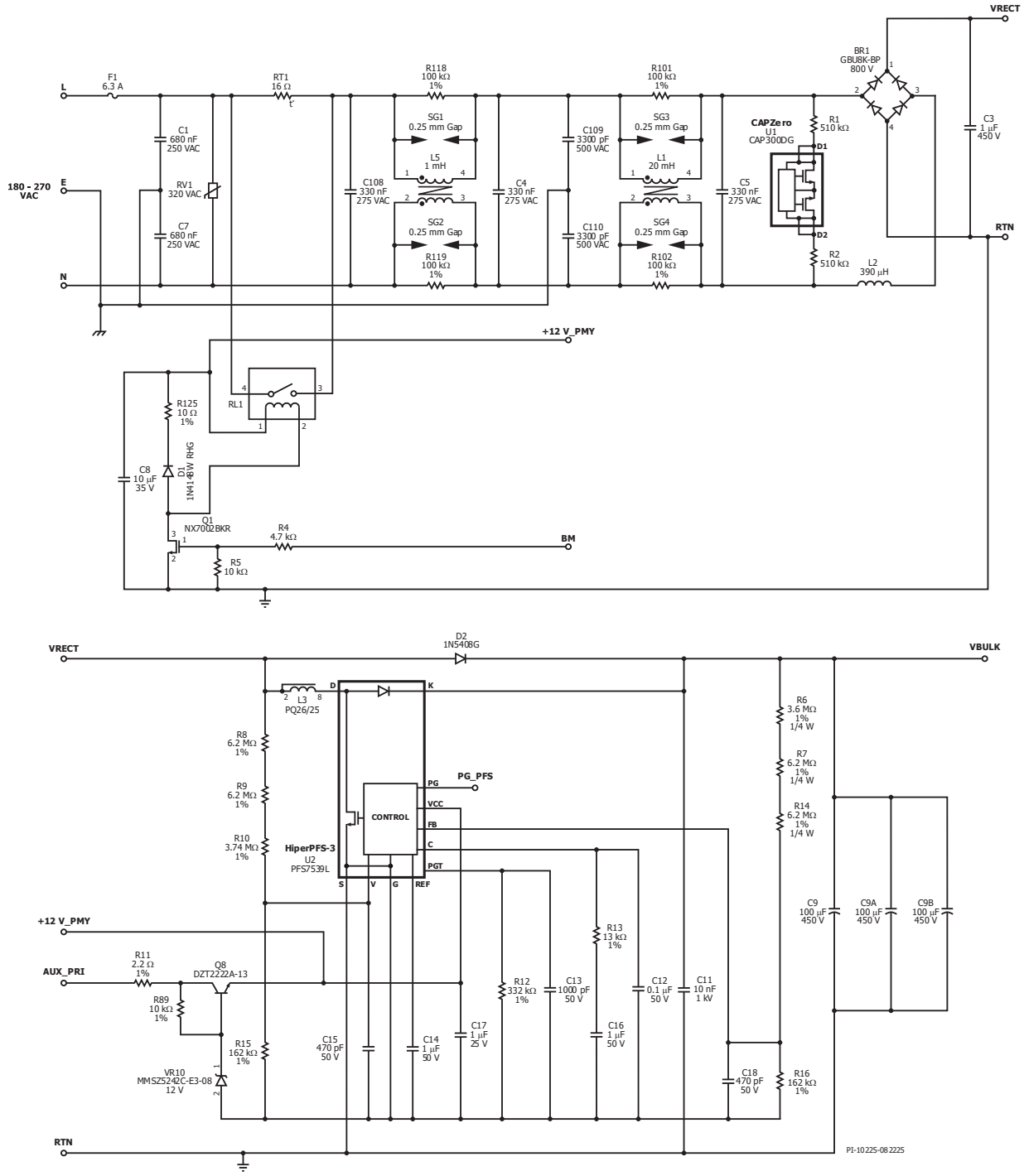


Figure 3 – Input Filter, Bridge Rectifier, and PFC stage.

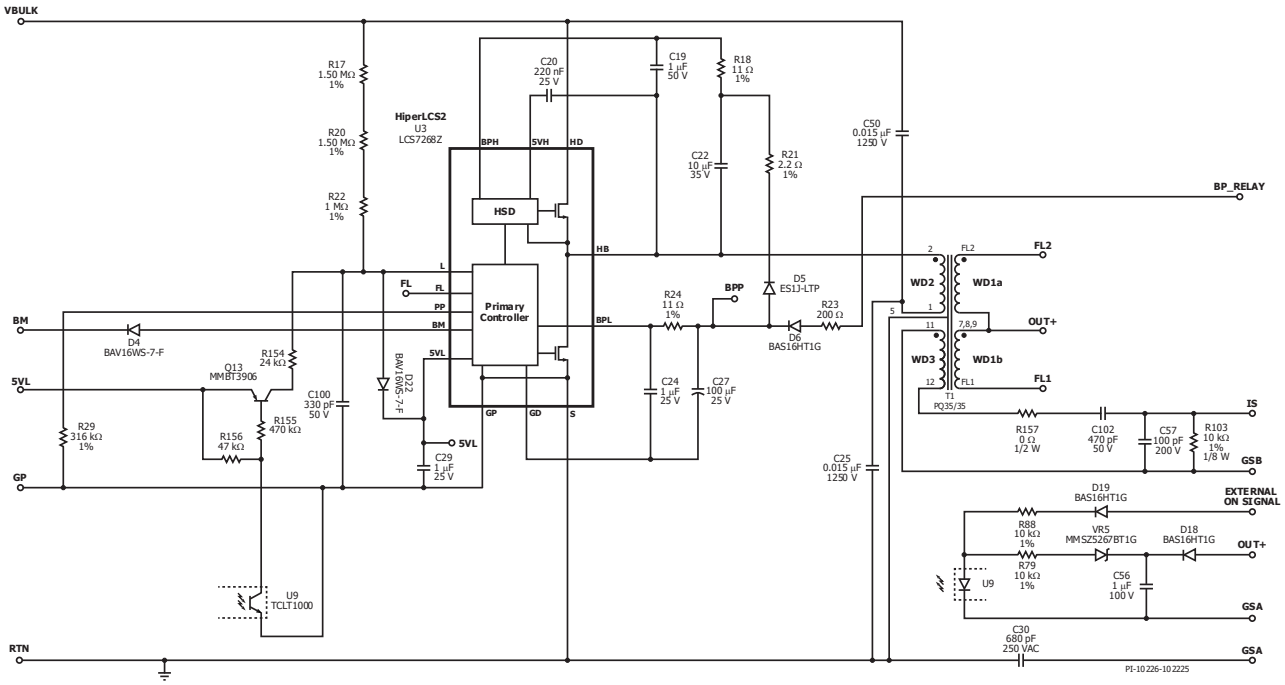


Figure 4 – LLC Stage (Primary Side)

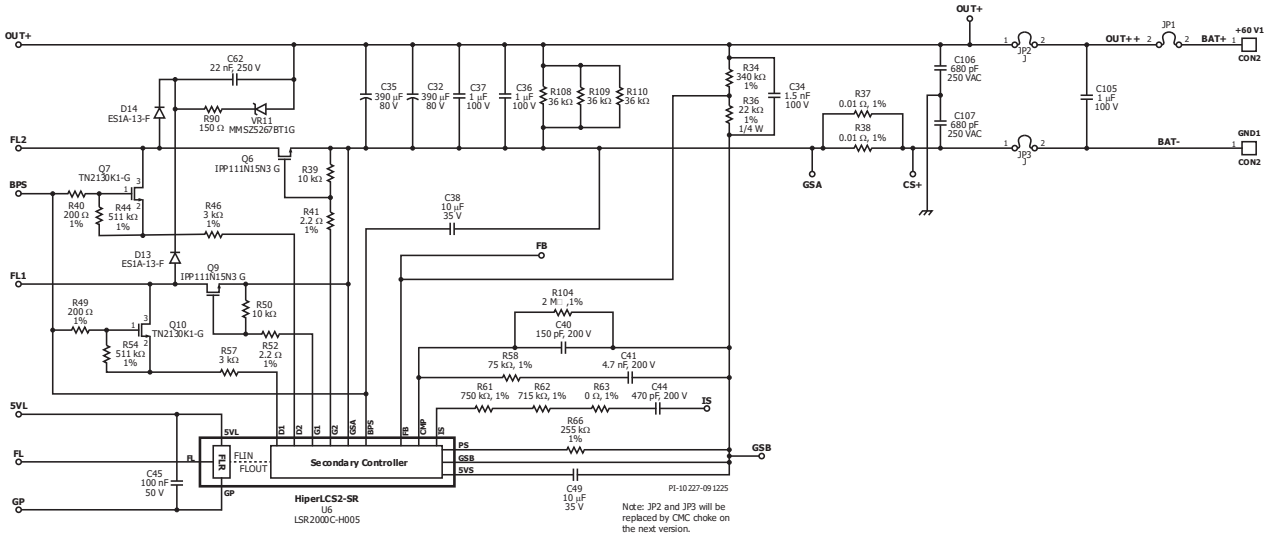


Figure 5 – LLC Stage (Secondary Side)

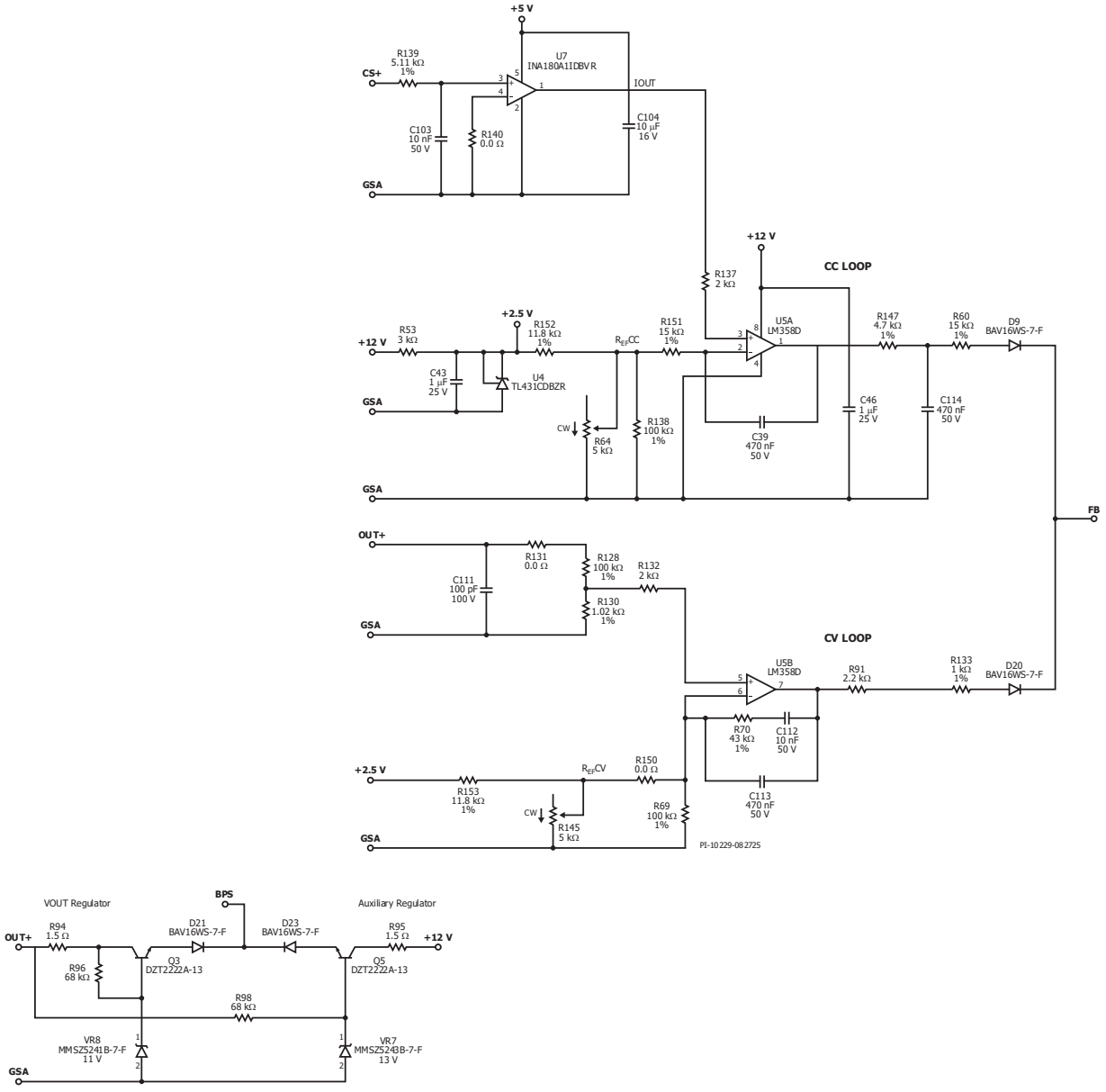


Figure 6 – CV/CC control.

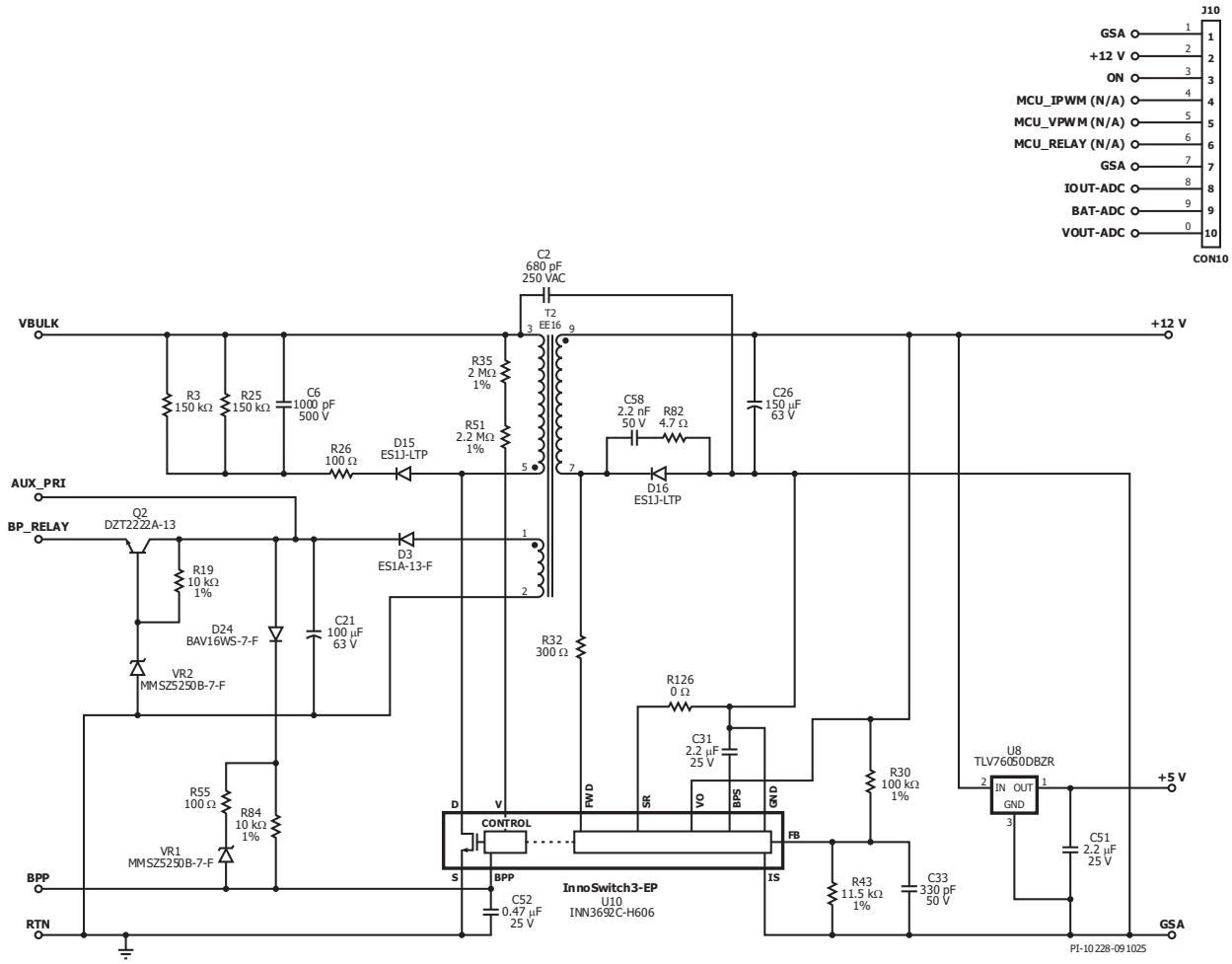


Figure 7 – Auxiliary Circuit and MCU Daughter Card Slot.

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 L5 and L1 along with C1 and C7 are used to reduce common mode noise, while C4, C5, C108, and L2 limit differential mode noise. Resistors R1 and R2 are connected to the integrated X-capacitor discharge CAPZero™-3 CAP300DG IC U1 and quickly reduce the voltage across C4, C5, and C108 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 (U3). At higher load, the BM pin will transition from low to high and turn-on Q1. 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 3 also shows the PFC stage centered around the HiperPFS-3 controller (U2). L3 is the PFC choke. D2 is a bypass diode used to pre-charge bulk capacitors (C9, C9A and C9B) which allows the auxiliary converter to start first. A resistor divider comprised of R6, R7, R14, and R16 provide output voltage feedback to U2. Capacitor C18 decouples the FB pin of U2. Components R13, C16, and C12 are for loop compensation, while resistors R8, R9, R10, and R15 provide input voltage information to U2. Capacitor C14 is used to program U2 to support either Full Power or Efficiency modes via the REF pin 3. Resistor R12 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 4 shows the primary section of the LLC converter using HiperLCS2-HB switcher. Figure 5 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 C9, C9A and C9B. Line sense (L-pin) monitors the input bus voltage via resistors (R17, R20, and R22). The HiperLCS2-HB IC, U3, will initiate soft-start when the L-pin rises above UV+ threshold. Output overvoltage is detected via the optocoupler (U9) and threshold is set by the Zener diode VR5. If an output overvoltage occurs, Zener VR5 and U9 conducts, Q13 will turn ON and inject current > I_L(OV+) into L pin from 5VL and switching is interrupted. In normal operation, resistor R29 sets the PP pin primary frequency range and determines fault-response. Diode D4 couples the BM pin from the in-rush-relay drive circuit. Note: BM transitions to a low state when in light load (burst) mode.

Capacitors C29 and C24 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 C9, C9A and C9B. 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 C24 implements high-frequency decoupling for the BPL-pin. During start-up, prior to the commencement of switching, the BPL pin charges capacitors C24 and C27 through resistor R24, which limits the charging current. Capacitor C27 stores sufficient energy to maintain bias until the primary bias winding is energized, which occurs only after switching is established. C27 also provides boot-strap energy to the HiperLCS2-HB high-side bias via diode D5 and resistor R21. Capacitor C24 and C27 should be sized to ensure adequate bias energy during startup. As a design requirement, the combined capacitance of C24 and C27 must be at least five times the capacitance of the high-side bias capacitor C22.

Resistor R24 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 C22 charges through D5 and R21. At startup, R21 limits current while C22 is uncharged. Resistor R18 and capacitor C19

provide low-frequency filtering for the BPH pin. Capacitor C20 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 C25 and C50.

Y-capacitor C30 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 C45 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 7, 8 and 9 (OUT+) deliver the positive output voltage, which is rectified by synchronous rectifier (SR) MOSFETs Q6 and Q9. The rectified voltage is filtered by capacitors C32, C35, C36 and C37. 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 Q6 and Q9 circuits.

Capacitor C38 decouples the BPS pin, connecting it to the secondary SR-drive ground (GSA pin). Capacitor C49 decouples the 5VS pin connecting it to the secondary small signal ground (GSB pin).

Diode D16 and capacitor C26, rectify and filter the output from the secondary side winding of the auxiliary circuit appearing on pin 9 of T2 (with respect to output power ground GSA). Components Q3, R96, VR8 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 U3 start switching before the auxiliary supply provided by U10 becomes available. Q5 and VR7 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 R98 and is only available when the main output voltage is present. The values of Zener diodes VR7 and VR8 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 R34 and R36. 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 R37 and R38 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 R58, C40 and C41 which provide a pole (R34, C41), zero (R58, C41) and a high frequency pole (R58, C40). Resistor R104 is connected across C40 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 12 (the return is provided by T1 pin 11 which is grounded to GSB the secondary small-signal ground) provides information that together with capacitor C102 that sets the burst threshold for low load. This signal is coupled via C44 and resistors R61, R62, and R63 to the IS pin of U6. C102 and C57 acts as capacitor divider network to limit the current going into the IS pin.

Drive for the Q6 and Q9 synchronous MOSFETs is provided by the output pins G1 and G2 pins via resistors R41 and R52 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 Q6/Q9, local pull-down resistors R39 and R50 ensure that Q6 and Q9 remain off.

There is a maximum pin voltage of 150 V for D1 and D2 pins. Q7 and Q10 protect these pins from possible overvoltage. Pins D1 and D2 sense the drain voltages on the synchronous rectifiers Q6 and Q9 via resistors R46 and R57 and FETs Q7 and Q10, 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 Q10 conduct when there is zero drain voltage on Q6 and Q9. Note: D1 and D2 signal paths go through resistors R46 and R57, drain-source of Q7 and Q10 and through the SR-MOSFETs (Q6, Q9) 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 R66 is used to program the burst threshold.

4.6 CV/CC Control

The CV/CC control has two variable resistors R64 (CC Loop) and R145 (CV Loop) that can be adjusted to change the reference voltage and regulate the CV/CC set points. This configuration defines the default charging. The optional daughter board can control the CV/CC operation using a microcontroller by providing PWM signals on pin 4 (CC) and pin 5

(CV) of connector J10 (see provisional schematic in the Appendix). In an MCU configuration, the designer can dynamically adjust the reference voltage using firmware.

For the CC loop, R53 and voltage regulator U4 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 R152 and R138. The Potentiometer R64 is adjusted to provide a voltage of ~1.2 V, which corresponds to a 12 A output current. The voltage across R138 acts as the reference voltage for the inverting input of error amplifier U5A. Current sense amplifier U7 amplifies the voltage sensed across current sense resistors R37 and R38 which is fed to the non-inverting input of U5A. During CC mode, the amplified voltage across the current sense resistor R37 and R38 will be compared to the reference voltage set by R64 thru U5A 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 U5A, with a single pole compensation provide by C39. R147 and C114 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 U5A, 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 R153 and R69 which forms a reference voltage for op-amp U5B. This can be changed by variable resistor R145. ~600 mV across R69 corresponds to ~60 V on the output. During CV mode, the output voltage sensed via resistor divider R128 and R130 is fed into U5B's noninverting input and compared to the reference voltage as set by R145 to regulate the CV set point.

The variable CV loop is provided using Op-Amp U5B, resistors R70, C112, and C113. Capacitor C113 improves dynamic response.

4.7 Auxiliary Circuit

The auxiliary power supply controlled by InnoSwitch™-3 EP INN3692C-H606 IC (U10) provides bias for the HiperLCS2-HB, HiperLCS2-SR and CV/CC controller circuits.

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, C6, R3, and R25 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, C52, when AC is first applied. During normal operation, the primary side block is powered from an auxiliary winding on the transformer.

Resistor R35 and R51 provide line voltage sensing and provide a current to U10, which is proportional to the DC Voltage across capacitors C9, C9A and C9B.

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 R30 and R43 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 C33 provides decoupling to prevent high frequency noise from affecting power supply operation.

5 PCB Layout

Figure 8 and Figure 9 show the main Printed Circuit Boards (PCBs) used for the power supply.

PCB specifications for the main board:

- 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

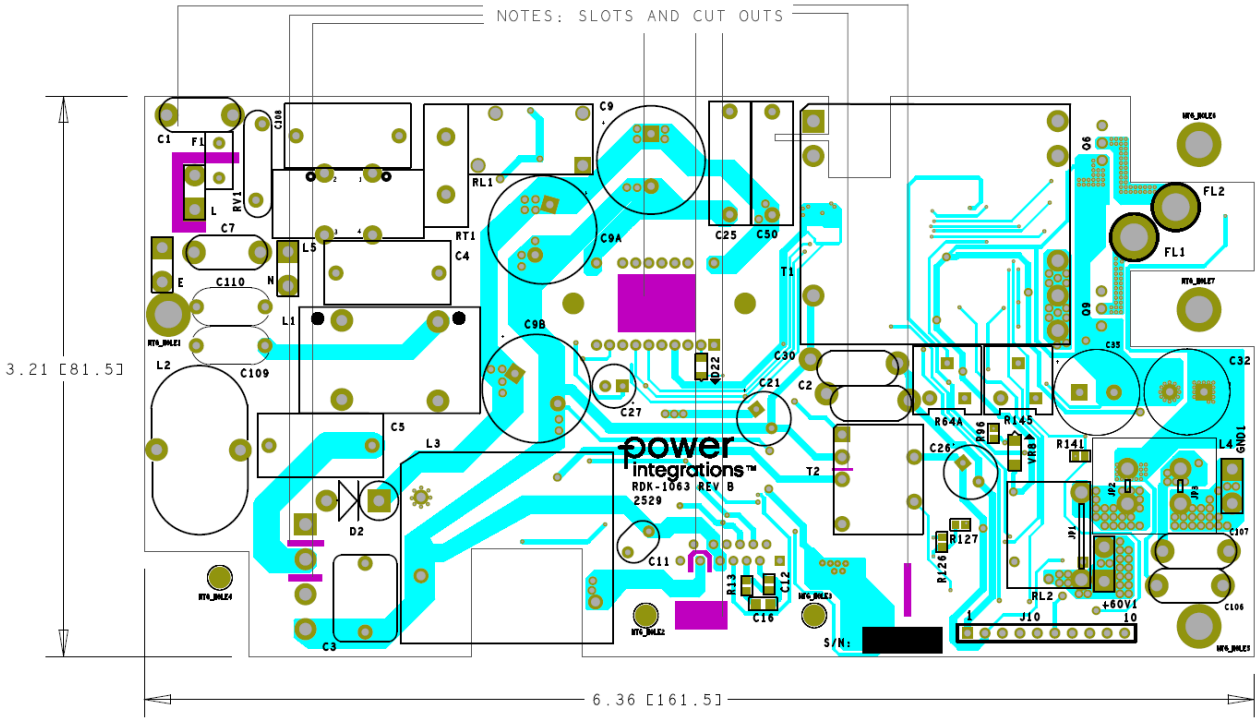


Figure 8 – Main Board, Top Side PCB.

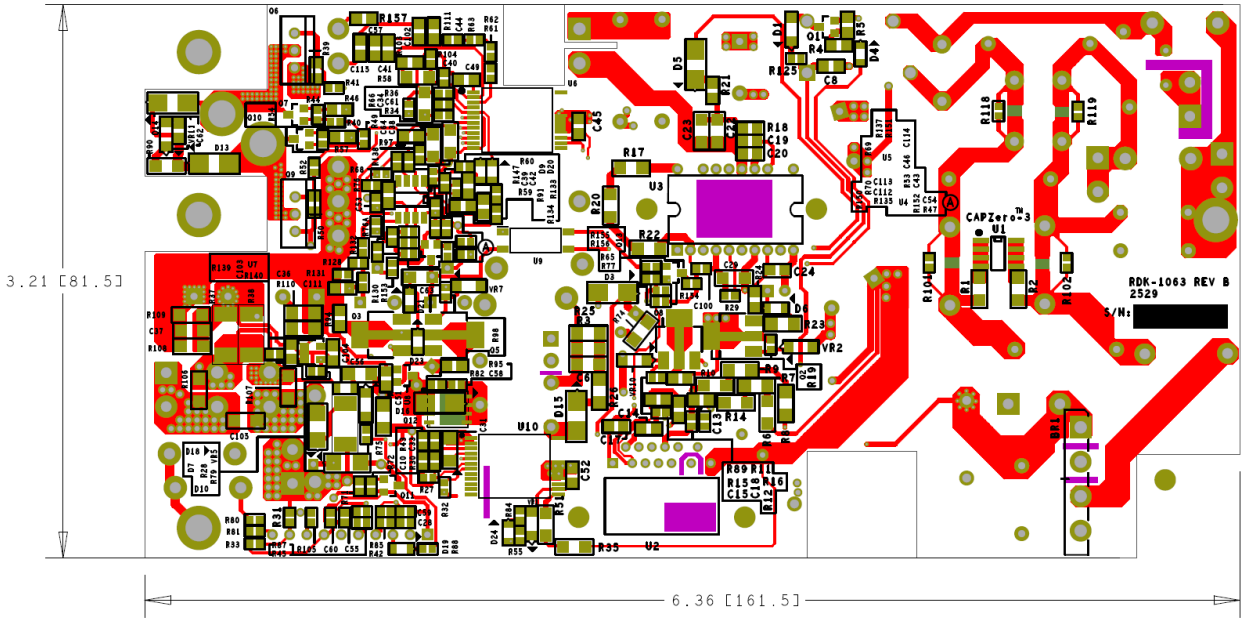


Figure 9 – Main Board, Bottom Side PCB.

6 Bill of Materials

Item	Qty.	Part Ref.	Description	Mfr. Part Number	Manufacturer
1	1	BR1	800 V, 8 A, Bridge Rectifier, GBU Case	GBU8K-BP	Micro Commercial Co.
2	6	C1 C2 C7 C30 C106 C107	680 pF, Ceramic, Y1	440LT68-R	Vishay
3	1	C3	CAP, FILM, 1.0 μF, 10%, 450VDC, RADIAL	ECW-FD2W105Q1	Panasonic
4	3	C4 C5 C108	330 nF, 275 VAC, Film, X2	R46KI333000N1M	Kemet
5	1	C6	1000 pF, 1 nF, ±10%, 500 V, Ceramic Capacitor X7R, 1206 (3216 Metric)	CC1206KKX7RBBB102	Yageo
6	2	C8 C49	10 μF ±10% 35 V Ceramic Capacitor X5R 0805 (2012 Metric)	C2012X5R1V106K125AC	TDK Corporation
7	3	C9 C9A C9B	100 μF 450 V Aluminum Electrolytic Capacitors Radial, Can - 12000 Hrs @ 105 °C, (16 x 37)	450LXW100MEFR16X35	Rubycon
8	1	C11	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX Corp
9	1	C12	0.1 μF, ±10%, 50 V, Ceramic Capacitor X7R 0603, (1608 Metric)	CL10B104KB8NNND	Samsung Electro-Mechanics
10	1	C13	1000 pF, ±5%, 50 V, Ceramic Capacitor, C0G, NP0 0603 (1608 Metric)	GRM1885C1H102JA01D	Murata Electronics
11	3	C14 C16 C19	1 μF, ±10%, 50 V, Ceramic Capacitor X7R, 0805 (2012 Metric), Automotive, AEC-Q200	CGA4J3X7R1H105K125AB	TDK Corporation
12	1	C15	470 pF, ±10%, 50 V, Ceramic, X7R, 0603 (1608 Metric), 0.063" L x 0.031" W (1.60 mm x 0.80 mm)	CL10B471KB8NFNC	Samsung
13	2	C17 C24	1 μF, ±10%, 25 V, Ceramic, X7R, 0805 (2012 Metric)	GCM21BR71E105KA56L	Murata Electronics North America
14	2	C18 C102	470 pF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB471	Yageo
15	1	C20	220 nF, 25 V, Ceramic, X7R, 0805	CC0805KRX7R8BB224	Yageo
16	1	C21	100 μF, 63, Electrolytic, Low ESR, 270 mΩ, (8 x 15)	ELXZ630ELL101MH15D	Nippon Chemi-Con
17	2	C22 C38	10 μF, 10%, 35 V, Ceramic, X7R, -55 °C ~ 125 °C, 1206 (3216 Metric),	CL31B106KLHNNNE	Samsung Electro-Mechanics America, Inc.
18	2	C25 C50	0.015 μF, ±5%, Film Capacitor, 600 VAC 1250 VDC (1.25 kV), Polypropylene (PP), Metallized Radial	R75RI2150DQ30J	KEMET
19	1	C26	150 μF, 63, Electrolytic, Low ESR, 210 mΩ, (8 x 20)	ELXZ630ELL151MH20D	Nippon Chemi-Con

20	1	C27	100 μF, 25 V, Electrolytic, Very Low ESR, 130 mΩ, (6.3 x 11)	EKZE250ELL101MF11D	Nippon Chemi-Con
21	4	C28 C55 C59 C60	2.2 μF, ±10%, 25 V, Ceramic, X5R, 0603 (1608 Metric)	GRM188R61E225KA12D	Murata Electronics North America
22	1	C29	1 μF, 25 V, Ceramic, X7R, 1206	C3216X7R1E105K	TDK Corp
23	1	C31	2.2 μF, 25 V, Ceramic, X7R, 1206	TMK316B7225KL-T	Taiyo Yuden
24	2	C32 C35	390 μF, 80 V, Electrolytic, Low ESR, (12.5 x 26.5)	EKZN800ELL391MK25S	United Chemi-Con
25	1	C33	330 pF, ±5%, 50 V, Ceramic Capacitor, C0G, NP0, 0603 (1608 Metric)	C0603C331J5GACAUTO	KEMET
26	1	C34	1.5 nF, 100 V, Ceramic, X7R, 1206	12061C152KAT2A	AVX Corp
27	4	C36 C37 C56 C105	1 μF, 100 V, Ceramic, X7R, 1206	HMK316B7105KL-T	Taiyo Yuden
28	2	C39 C114	470 nF, ±20%, 50 V, Ceramic, X7R, 0603	CGA3E3X7R1H474M080AB	TDK Corp
29	1	C40	150 pF, 5%, 250 V, Ceramic, COG, 0603	C1608C0G2E151J080AA	TDK Corp
30	1	C41	4700 pF, ±10%, 200 V, Ceramic Capacitor, X7R, 0805 (2012 Metric)	C0805C472K2RECAUTO	KEMET
31	2	C43 C46	1 μf, ±10%, 25 V, Ceramic, X7R, 0603 (1608 Metric)	CGA3E1X7R1E105K080AE	TDK Corp
32	1	C44	470 pF, 200 V, Ceramic, X7R, 0603	06032C471KAT2A	AVX
33	1	C45	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
34	1	C51	2.2 μF, ±10%, 25 V, Ceramic, X7R, 0805 (2012 Metric)	CL21B225KAFNFNE	Samsung Electro-Mechanics
35	1	C52	0.47 μF, ±10%,25 V, Ceramic Capacitor, X7R, 0805 (2012 Metric)	CGA4J2X7R1E474K125AA	TDK Corporation
36	1	C57	100 pF, ±10%, 200 V, Ceramic, C0G, NP0, 0805 (2012 Metric)	C0805C101K2GACAUTO	KEMET
37	1	C58	2.2 nF 50 V, Ceramic, X7R, 0603	C0603C222K5RACTU	Yageo
38	1	C62	22 nF, 250 V, Ceramic, X7R, 0805	C2012X7R2E223M	TDK Corp
39	1	C100	CAP CER 330PF 50V C0G/NP0 0603	C0603C331J5GACAUTO	KEMET
40	1	C103	10 nF, 50 V, Ceramic, X7R, 0805	C0805X103K5RAC7210	Kemet
41	1	C104	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
42	2	C109 C110	3300 pF, ±20%, 500 VAC, Ceramic, Radial, Disc, X1, Y1, Safety, -40 °C ~ 125 °C, 0.433" Dia (11.00 mm)	VY1332M43Y5VQ63V0	Vishay BC Components

43	1	C111	100 pF 100 V 10 % X7R 0805	08051C101JAT2A	AVX Corp
44	1	C112	10 nF 50 V, Ceramic, X7R, 0603	C0603C103K5RACTU	Kemet
45	1	C113	0.47 μF, ±10%, 50 V, Ceramic Capacitor X7R, 0603 (1608 Metric)	CGA3E3X7R1H474K080AB	TDK Corporation
46	1	D1	DIODE, GEN PURP, 100 V, 150 MA, SOD123, SOD-123F	1N4148W RHG	Taiwan Semiconductor Corporation
47	1	D2	1000 V, 3 A, Rectifier, DO-201AD	1N5408G	ON Semiconductor
48	3	D3 D13 D14	50 V, 1 A, General Purpose, DO-214AC	ES1A-13-F	Diode Inc.
49	7	D4 D9 D20 D21 D22 D23 D24	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diode Inc.
50	3	D5 D15 D16	600 V, 1 A, Super Fast, 35 ns, DO-214AC, SMA	ES1J-LTP	Micro Commercial Co.
51	3	D6 D18 D19	75 V, 200 mA, Rectifier, SOD323	BAS16HT1G	ON Semiconductor
52	1	F1	FUSE BRD MNT 6.3 A 350VAC 72VDC	0697H6300-02	Belfuse
53	1	L1	HiperLCS-2 DER-984 20 mH Input CMC wound on TDK B64290L0048X038 core	30-00636-00	PI
54	1	L2	390 μH, 5 A, INDUCTOR TORD HI AMP	2319-V-RC	JW Miller
55	1	L3	Bobbin, PQ26/25, Vertical, 12 pins	PQ26X25	Pin Shine
56	1	L5	1 mH, +/- 10%, Toroidal Common Mode Choke, custom, Wound on Toroid Core: PI# 32-00343-00	32-00448-00	Power Integrations
57	1	Q1	MOSFET, N-CH, 60 V, 270 mA (Ta)), 310 mW (Ta), 1.67 W (Tc), -55 °C ~ 150 °C (TJ), TO-236AB, SOT23, TO-236-3, SC-59, SOT-23-3	NX7002BKR	Nexperia USA Inc.
58	4	Q2 Q3 Q5 Q8	Bipolar (BJT) Transistor, NPN, 40 V, 600 mA, 300 MHz, 1 W, Surface Mount SOT-223-3, TO-261-4, TO-261AA	DZT2222A-13	Diodes Incorporated
59	2	Q6 Q9	150 V 83 A MOSFET N-CH TO220-3	IPP111N15N3 G	Infineon Technologies
60	2	Q7 Q10	MOSFET, N-Channel, 300 V, 85 mA (Tj), 360 mW (Tc), Surface Mount TO-236AB (SOT23)	TN2130K1-G	Microchip Technology
61	1	Q13	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	On Semiconductor
62	2	R1 R2	RES, 510 k, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J514V	Panasonic

63	2	R3 R25	RES, 150 k, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J154V	Panasonic
64	1	R4	RES, 4.7 k, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ472V	Panasonic
65	3	R5 R39 R50	RES, 10 k, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
66	1	R6	RES, 3.6 MΩ, ±1%, 0.25 W, 1/4 W, Chip Resistor 1206 (3216 Metric), Moisture Resistant, Thick Film	RC1206FR-073M6L	YAGEO
67	4	R7 R8 R9 R14	RES, 6.2 M, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF6204	Rohm Semi
68	1	R10	RES, 3.74 M, 1%, 1/4 W, Thick Film, 1206	CRCW12063M74FKEA	Vishay Dale
69	2	R11 R21	RES, 2.2, 1%, 1/8 W, Thick Film, 0805	RC0805FR-072R2L	Yageo
70	1	R12	RES, 332 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF3323V	Panasonic
71	1	R13	RES, 13 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1302V	Panasonic
72	2	R15 R16	RES, 162 k, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1623V	Panasonic
73	2	R17 R20	RES, 1.50 M, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1504V	Panasonic
74	2	R18 R24	RES, 11 R, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF11R0V	Panasonic
75	5	R19 R79 R84 R88 R89	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
76	1	R22	RES, 1 MΩ ±1% 0.25 W, 1/4 W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	RC1206FR-071ML	Yageo
77	1	R23	RES, 200 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J201V	Panasonic
78	1	R26	RES, 100 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J101V	Panasonic
79	1	R29	RES, 316 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF3163V	Panasonic
80	1	R30	RES, 100 kΩ, ±1%, 0.1 W, 1/10 W, Chip Resistor 0603 (1608 Metric), Automotive AEC-Q200, Thick Film	ERJ-3EKF1003V	Panasonic Electronic Components
81	1	R32	RES, 300 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ301V	Panasonic
82	1	R34	RES, 340 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF3403V	Panasonic
83	1	R35	RES, 2.00 M, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
84	1	R36	RES, 22 kΩ, ±1%, 0.25 W, 1/4 W, 0603 (1608 Metric), Pulse Withstanding, Thick Film	ERJ-PA3F2202V	Panasonic

85	2	R37 R38	RES, 10 mΩ, ±1%, 3 W, Chip Resistor 2512 (6432 Metric), Automotive AEC-Q200, Current Sense, Metal Element	LRMAP2512-R01FT4	TT Electronics/Welwyn
86	2	R40 R49	RES, 200 Ω ±1% 0.125 W, 1/8 W Chip Resistor 0603 (1608 Metric), Moisture Resistant Thick Film	RK73H1JTTD2000F	KOA Speer Electronics, Inc.
87	2	R41 R52	RES, 2.2 R, 1%, 1/16 W, Thick Film, 0603	ERJ-3RQF2R2V	Panasonic
88	1	R42	RES, 470 Ω ±5% 0.1 W, 1/10 W Chip Resistor 0603 (1608 Metric) Moisture Resistant Thick Film	RC0603JR-07470RL	Yageo
89	1	R43	RES, 11.5 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1152V	Panasonic
90	2	R44 R54	RES, 511 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF5113V	Panasonic
91	5	R45 R85 R87 R152 R153	RES, 11.8 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1182V	Panasonic
92	2	R46 R57	RES, 3 k, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ302V	Panasonic
93	1	R51	RES, 2.2 M, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF2204	Rohm Semi
94	1	R53	RES, 3 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ302V	Panasonic
95	1	R55	RES, 100 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ101V	Panasonic
96	1	R58	RES, 75 kΩ, ±1%, 0.25 W, 1/4 W, Chip Resistor 1206 (3216 Metric), Automotive AEC-Q200, Thick Film	CRCW120675K0FKTA	Vishay Dale
97	2	R60 R151	RES, 15 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1502V	Panasonic
98	1	R61	RES, 750 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF7503V	Panasonic
99	1	R62	RES, 715 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF7153V	Panasonic
100	2	R63 R66	RES, 255 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF2553V	Panasonic
101	1	R69	RES, 100 k, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1003V	Panasonic
102	1	R70	RES, 43 kΩ, ±1%, 0.1 W, 1/10 W, Chip Resistor 0603 (1608 Metric), Automotive, AEC-Q200, Thick Film	RK73H1JTTD4302F	KOA Speer Electronics, Inc.
103	1	R74	RES, 4.7 k, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J472V	Panasonic
104	1	R75	RES, 1.5 k, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1501V	Panasonic
105	1	R82	RES, 4.7 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ4R7V	Panasonic
106	1	R90	RES, 150 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J151V	Panasonic
107	1	R91	RES, 2.2 k, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ222V	Panasonic

108	2	R94 R95	RES, 1.5 R, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ1R5V	Panasonic
109	2	R96 R98	RES, 68 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ683V	Panasonic
110	4	R101 R102 R118 R119	RES, 100 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
111	1	R103	RES, 10.0 k, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic
112	1	R104	RES, 2.00 M, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF2004V	Panasonic
113	3	R108 R109 R110	RES, 36 k, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J363V	Panasonic
114	1	R125	RES, 10 Ω, ±1%, 0.1W, 1/10W, Chip Resistor 0603 (1608 Metric), Moisture Resistant, Thick Film	RC0603FR-0710RL	Yageo
115	1	R126	RES, 0 Ω Jumper 0.1 W, 1/10 W Chip Resistor 0603 (1608 Metric) Moisture Resistant Thick Film	RC0603FR-070RL	Yageo
116	2	R128 R138	RES, 100 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1003V	Panasonic
117	1	R130	RES, 1.02 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1021V	Panasonic
118	3	R131 R140 R150	RES, 0 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEY0R00V	Panasonic
119	2	R132 R137	RES, 2 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ202V	Panasonic
120	1	R133	RES, 1 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1001V	Panasonic
121	1	R139	RES, 5.11 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF5111V	Panasonic
122	2	R145 R64A	POT, 5 k, 20%, 1/2 W, Square Trimming	3310Y-001-502L	BOURNS
123	1	R147	RES, 4.7 kΩ, ±1%, 0.1 W, 1/10 W, Chip Resistor 0603 (1608 Metric), Moisture Resistant, Thick Film	RC0603FR-074K7L	YAGEO
124	1	R154	RES, 24 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ243V	Panasonic
125	1	R155	RES, 470 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ474V	Panasonic
126	1	R156	RES, 47 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ473V	Panasonic
127	1	R157	RES, 0 Ω Jumper, Chip Resistor, 0805 (2012 Metric) Metal Element	5106	Keystone Electronics
128	1	RL1	RELAY, GP, 12 V coil, SPST, 8 A, 30 VDC, 277 VAC, PCPin	OJE-SH-112LMH,000	TE Connectivity Potter & Brumfield Relays
129	1	RT1	NTC Thermistor, 16 Ω, 4 A	CL-70	Thermometrics
130	1	RV1	470 VAC, 4.5 KA, 14 mm, RADIAL	MOV-14D471K	Bourns
131	1	T1	Bobbin, PQ35/35, Vertical, 12 pins	BQ35/35-1112CPFR	TDK
132	1	T2	Bobbin, EE16 Vertical, 10 pins, DER-839	YW-527-00B	Yih-Hwa Enterprises

133	1	U1	CAPZero-3, CAP300DG, SO-8C	CAP300DG	Power Integrations
134	1	U2	HiperPFS-3, PFS7539L, L-Bend eSIP	PFS7539L	Power Integrations
135	1	U3	HiperLCS2-HB, LCS7268Z, POWeDIP-20B	LCS7268Z	Power Integrations
136	1	U4	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
137	1	U6	HiperLCS2-SR, LSR2000C-H005, InSOP-24D	LSR2000C-H005	Power Integrations
138	1	U7	IC, Current Sense Amplifier, 1 Circuit, Rail-to-Rail, SOT-23-5, SC-74A, SOT-753	INA180A1IDBVR	Texas Instruments
139	1	U8	IC, Linear Voltage Regulator IC, Positive Fixed 5 V,1 Output, 100 mA, SOT-23-3, SOT23A-3, TO-236-3, SC-59	TLV76050DBZR	Texas Instruments
140	1	U9	OPTOISOLATOR 5KV 1CH TRANS 4-SOP	TCLT1000	Vishay Semiconductor Opto Division
141	1	U10	INN3692C-H606, INNO3 Switch Integrated Circuit, InnoSwitch-3 EP_900 V, InSOP-24D	INN3692C-H606	Power Integrations
142	1	U5	DUAL Op Amp, Single Supply, SOIC-8	LM358D	Texas Instruments
143	2	VR1 VR2	DIODE ZENER 20 V 500 MW SOD123	MMSZ5250B-7-F	Diodes, Inc
144	2	VR5 VR11	DIODE, ZENER, 75 V, 500MW, SOD123	MMSZ5267BT1G	ON Semi
145	1	VR7	13 V, 5%, 500 mW, SOD-123	MMSZ5243BT1G	ON Semiconductor
146	1	VR8	DIODE ZENER 11 V 500 MW SOD123	MMSZ5241B-7-F	Diodes, Inc
147	1	VR10	Zener Diode, 12 V, ±2%, 500 mW, Surface Mount, SOD-123	MMSZ5242C-E3-08	Vishay General Semiconductor - Diodes Division

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

Item	Qty.	Part Ref.	Description	Mfr. Part Number	Manufacturer
1	5	+60V1 E GND1 L N	0.250" (6.35 mm) Quick Connect Male - Solder Connector Non-Insulated	1287-ST	KeyStone Electronics
2	2	FL1 FL2	Flying Lead, Hole size 156mils	N/A	N/A
3	1	HS1	SHTM, Heat Sink, RD-1063, Composition: AL, 3003, Extrusion	61-00390-00	Custom

4	1	HS3	SHTM, Heat Spreader for LCS\RD-1063_RevB, Composition: AL, 3003, 0.040" thick	61-00391-00	Custom
5	1	HS5	SHTM, Heat Spreader for PFS\RD-1063_RevB, Composition: AL, 3003, 0.090" thick	61-00392-00	Custom
6	1	J10	10 Position (1 x 10) Female header, 0.1 pitch, 0.126" (3.20 mm), Vertical, Au	PPPC101LFBN-RC	Sullins Connector Solutions
7	1	JP1	Wire Jumper, Insulated, TFE, 16 AWG, 0.5 in	3057/1 WH005	Alpha
8	2	JP2 JP3	Wire Jumper, Insulated, 16 AWG, 0.2 in	3057/1 WH005	Alpha
9	2	LABEL1 LABEL2	Label, High Voltage, Self-Adhesive, 0.9" x 0.25"		
10	7	MTG_HOLE1 MTG_HOLE2 MTG_HOLE3 MTG_HOLE4 MTG_HOLE5 MTG_HOLE6 MTG_HOLE7	Mounting Hole M 3		
11	1	PAD1	Thermal Pad_ Bridge_RD-1063RevB,3M Silicone Pad 1.5 mm thick 66-00377-00	61-00393-00	Power Integrations
12	1	PAD2	Thermal Pad, Gray, Sheet 210.00 mm x 155.00 mm x 0.059" (1.50 mm) thick, Rectangle, Tacky - One Side, 5549S	5549S 210 MM X 155MM X 1.5MM	3M
13	3	SCREW1 SCREW2 SCREW3	SCREW MACHINE PHIL 4-40 X 3/8 SS	PMSSS 440 0038 PH	Building Fasteners
14	6	SCREW4 SCREW5 SCREW6 SCREW7 SCREW8 SCREW9	SCREW MACHINE PHIL 4-40 X 1/2 SS	PMSSS 440 0050 PH	Building Fasteners
15	4	SG1 SG2 SG3 SG4	Spark Gap 0.25 mm		
16	2	TO-220 PAD1 TO-220 PAD2	Thermal Pad Brown 19.05 mm x 12.70 mm Rectangular (TO-220)	SP600-58A15037-002	Laird Technologies - Thermal Materials
17	2	WASHER1 WASHER2	Washer, Shoulder, #4, 0.125 Shoulder x 0.140 Dia, Polyphenylene Sulfide PPS	7721-3PPSG	Aavid Thermalloy
18	7	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 Electonics

19	2	WASHER10 WASHER11	Washer, Int Lk, 4, SS		Building Fasteners
20	2	WASHER12 WASHER13	STD SPACER, Nylon, #4, ID. 0.115" x OD 0.187"	561-KSP4	EAGLE

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

7 Magnetics

7.1 PFC Choke (L3) Specification

7.1.1 Electrical Diagram

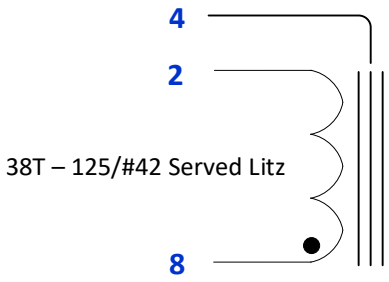


Figure 10 – Inductor Electrical Diagram.

7.1.2 Electrical Specifications

Inductance	Pins 2-8 measured at 100 kHz, 0.4 RMS.	140 μH +5%

Table 4 – Inductor Electrical Specifications.

7.1.3 Material List

Item	Description
[1]	Core: TDK PC95, PQ26/25Z-12.
[2]	Bobbin: PQ 26/25, Vertical, 12 Pins.
[3]	Litz Wire: 150/42, 38 Turns Single Coated Solderable, Served.
[4]	Tape, Polyester Film: 3M 1350-F1 or Equivalent, 9 mm Wide.
[5]	Tape, Copper 3M 1181 or Equivalent. 6.4 mm Wide.
[6]	Varnish: Dolph BC-359, or Equivalent.
[7]	Bus wire: #42 AWG, connects to pin 8

Table 5 – Inductor Material List.

7.1.4 Inductor Build Diagram

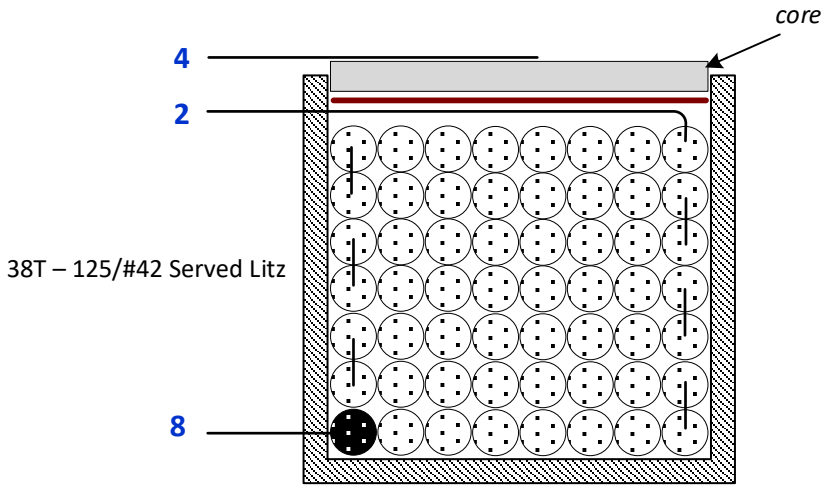


Figure 11 – Inductor Build Diagram.

7.1.5 Winding Preparation

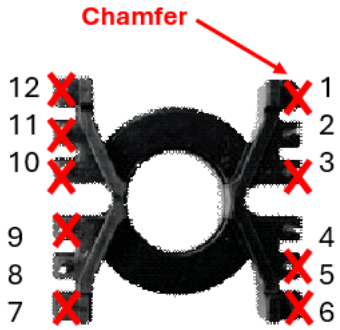
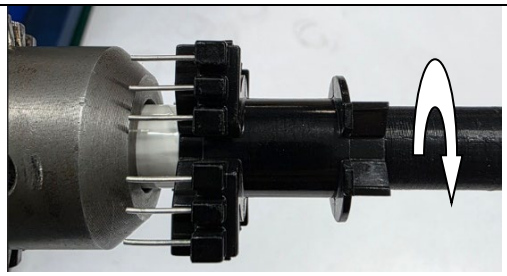
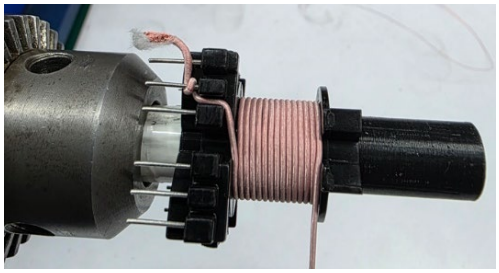
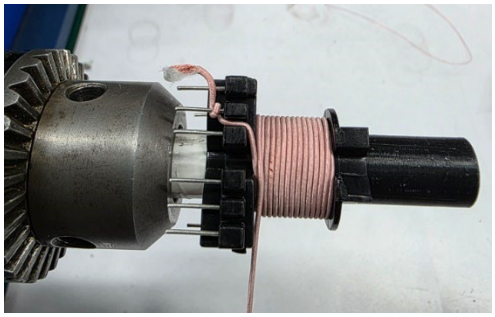
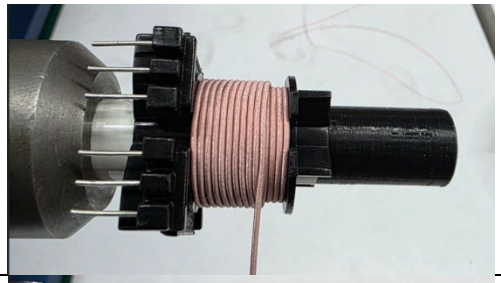
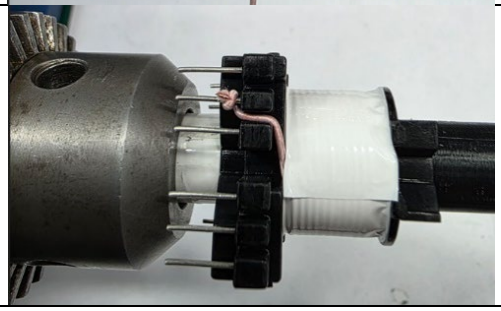
BOBBIN	 **Figure 12** – PFC Choke Bobbin Pin-out (bottom view). ➢ Pin 1 is the chamfered portion of the bobbin. ➢ Remove pins 1, 3, 5, 6, 7, 9, 10, 11 and 12.

Table 6 – Inductor Winding Preparation.

7.1.6 Winding Illustrations

Bobbin Pin-out reference:

Winding		Place the bobbin on the mandrel with the pin side to the left. Rotate the bobbin in a clockwise direction i.e. top side moving away from the operator.
		Start at pin 8, wind 14T of item [3] forming layers with tight tension to fill the bobbin width in a neat flat wind.
		Wind another 14T of item [3] on second layers from right to left with tight tension to fill the bobbin width in a neat flat wind.
		Wind the final 10T of item [3] on third layers from left to right with tight tension to fill the bobbin width in a neat flat wind. Terminate at pin 2.
Insulation Layer		Add 1T of tape of item [4].

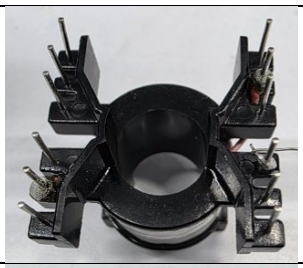
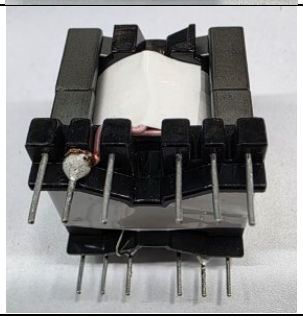
Final Assembly		Solder windings 8 and 2 to their respective pins. Grind core to achieve 140 μH inductance.
		Start at pin 4, wind 1T of item [6] across the middle core and terminate at pin 4 as well.
Finish		Add 2 to 3 layers of item [5] along the outside surface of the core. Dip in varnish of item [7] and cure in oven as required.

Table 7 – Inductor Winding Illustrations.

7.2 Common Mode Choke (L5) Specification

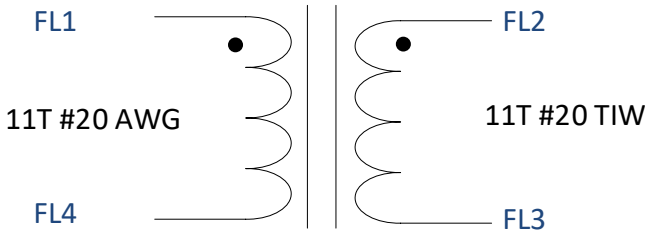


Figure 13 – Inductor Electrical Diagram

7.2.1 Electrical Specifications

Inductance	FL1-4 or FL2-3, measured at 100 kHz, 0.4 V_{RMS}	1 mH +10%

Table 8 – Inductor Electrical Specifications.

7.2.2 Material List

Item	Description
[1]	Ferrite Core Toroid: ENCOM T16/10/7C **PI P/N 32-00343-00**
[2]	Magnet Wire: #20 AWG
[3]	Triple Insulated Wire: #20 AWG, Furukawa TEX-E or Equivalent.

Table 9 – Inductor Material List.

7.2.3 Construction Details

1. Bifilar wind 11 turns of items [2] and [3] together as shown in the figure below.

Figure 14 – Finished Inductor.

7.3 LLC Transformer (T1) Specification

7.3.1 Electrical Diagram

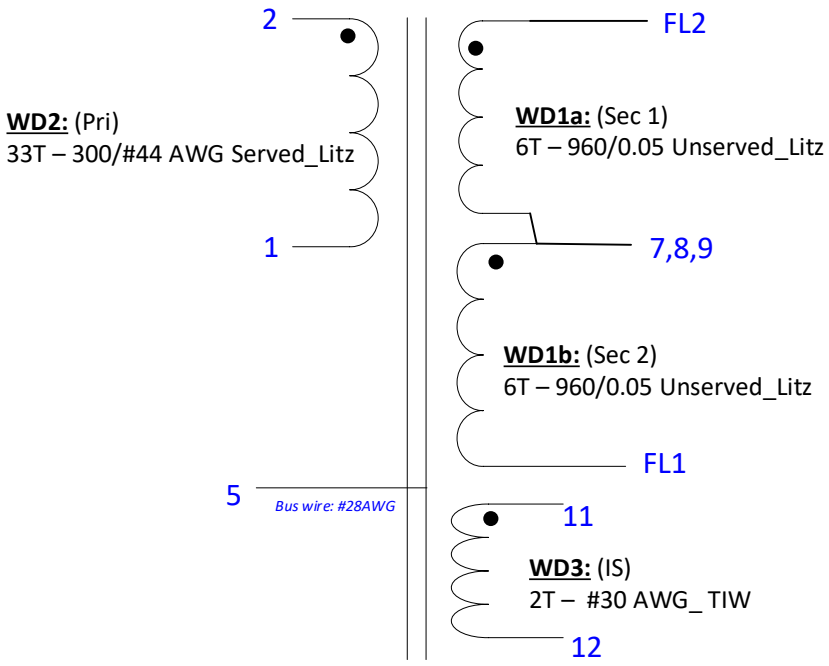


Figure 15 – LLC Transformer Electrical Diagram.

Bobbin: PQ35/35 – Separator between Py and Sy -1.5 **mm** Ground the Transformer core to "Primary bias Ground (pin 5)". 0.05mm metric Unserved Litz = 44 AWG

7.3.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1, 2 ,4, 5, 6 to FL3-FL5, FL2-FL4, pins 7, 8, 11, 12.	3000 VAC
Primary Inductance (L_{PRI})	Pins 1-2, all other windings open, measured at 250 kHz, 1 V_{RMS}	240 µH ±5%
Primary Leakage1 (LlkpALL)	Pins 1-2, short **ALL** other pins except IS-winding, measured at 120 kHz, 1 V_{RMS}	75 µH ±5%.

Table 10 – LLC Transformer Electrical Specifications.

7.3.3 Material List

Item	Description
[1]	Core: PQ35/35, PC95 magnetic material or equivalent
[2]	Bobbin with Cover: PQ3535-V, 12 pins (6/6)
[3]	Litz wire: #44 AWG /300_Served Litz. MWS Wire Industries.
[4]	Litz wire: 0.05 /960_Unserved Litz. Rubadue Wires
[5]	Triple Insulated Wire: #30 AWG
[6]	Tape: 3M 1298 Polyester Film, 1 mil thick, 16 mm wide.
[7]	Tape: 3M 1298 Polyester Film, 1 mil thick, 9 mm wide.
[8]	Tape: 3M 1298 Polyester Film, 1 mil thick, 15 mm wide.
[9]	Separator Tape: 1.5 mm wide.
[10]	#33 Bus Wire
[11]	Varnish: Dolph BC-359, or equivalent.
[12]	Teflon Tube: Must meet >6 kV safety isolation
[13]	Tape: 3M 1298 Polyester Film, 1 mil thick, 15.0 mm wide.

Table 11 – List of Materials.

7.3.4 Transformer Build Diagram

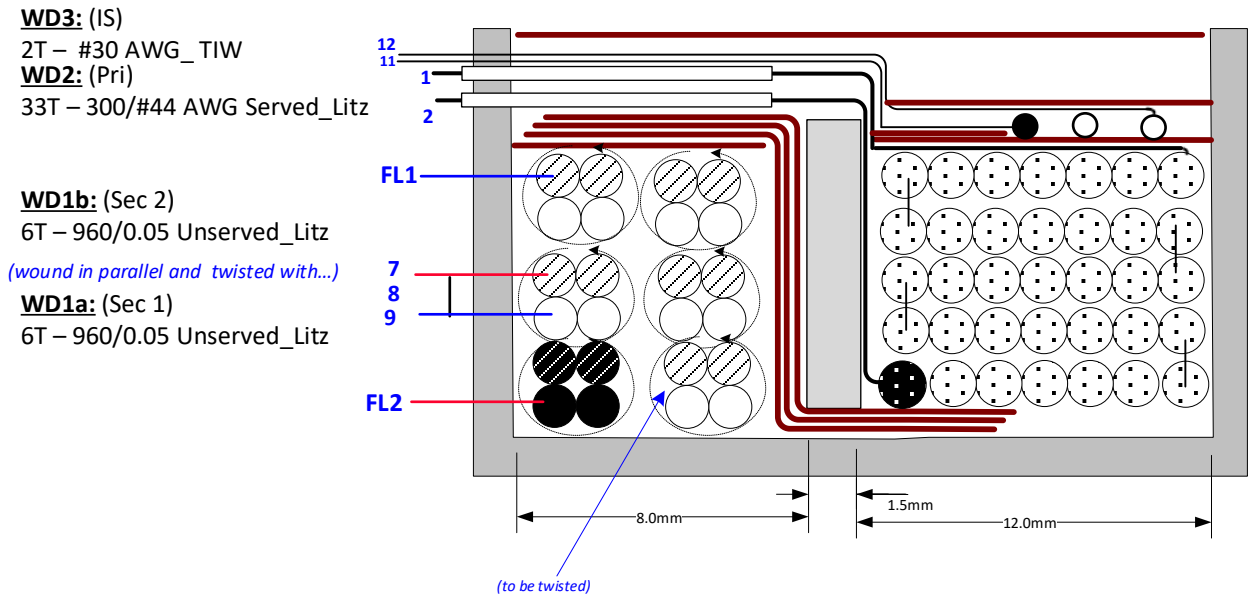


Figure 16 – LLC Transformer Build Diagram.

7.3.5 Winding Preparation

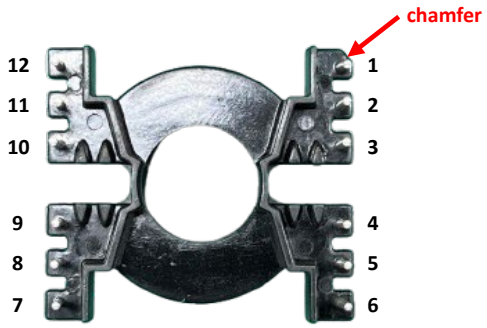
<table>
<tr><td>BOBBIN</td><td>


Figure 17 – PQ 35/35 Bobbin (bottom view).
➢ Pin 1 of the bobbin is where the location of the chamfer.
</td></tr>
<tr><td>CORE</td><td>
➢ For the bottom core, wrap 1 layer of tape in the inner core legs.

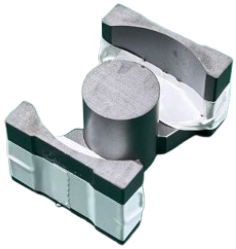



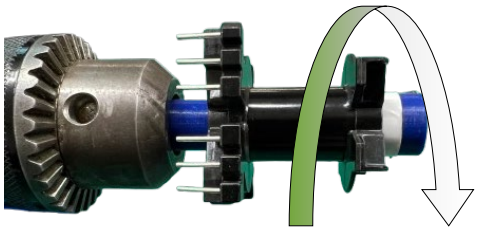
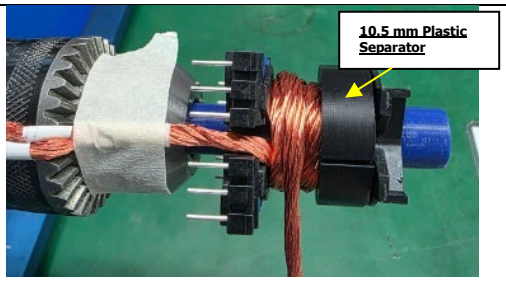
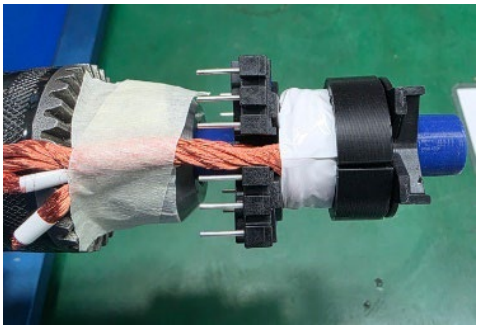
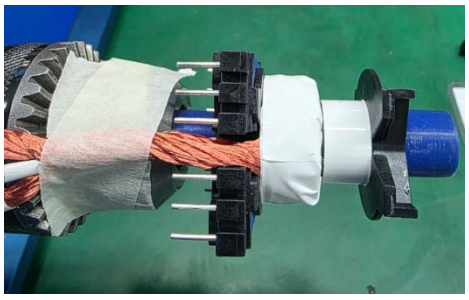
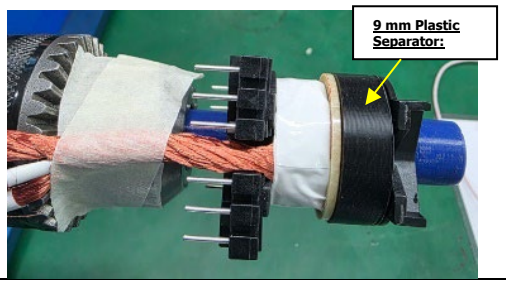
Figure 18 – PQ 35/35 core wrapping.
</td></tr>
<tr><td>SEC WIRE</td><td>
➢ Using item [4] wire in the Material List, prepare 2 sets of wire around 24 inch long.
➢ Mark the ends of the wire and position it as shown in Figure.

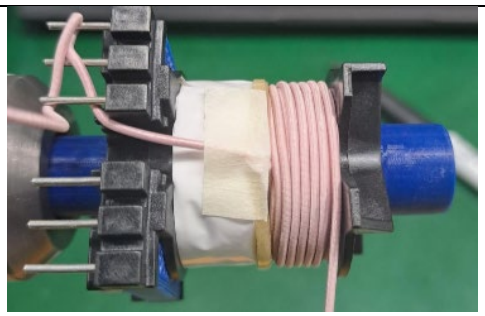
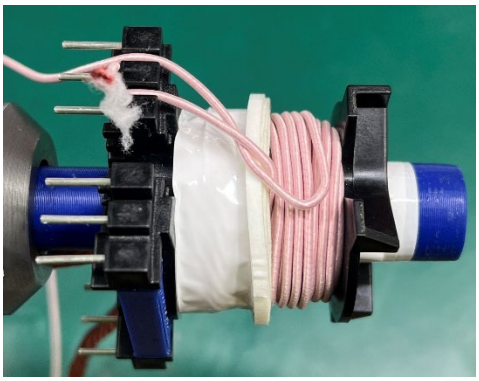
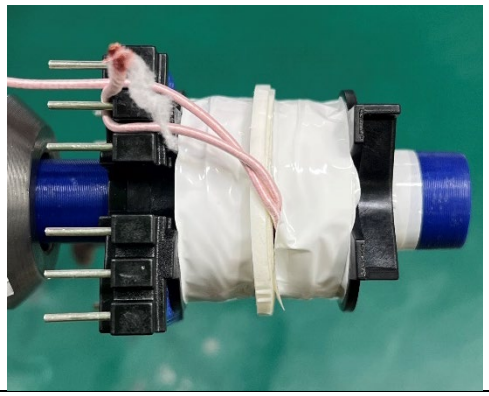
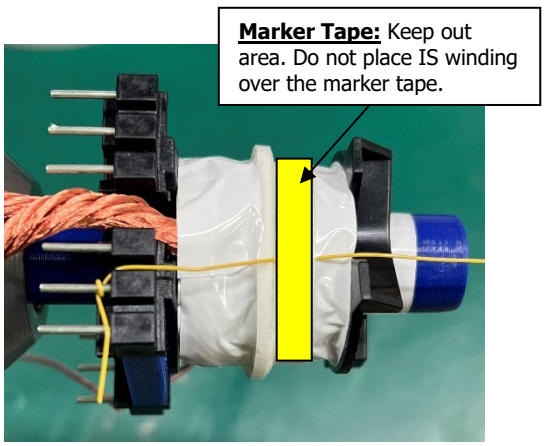
Figure 19 – Marking and positioning of Secondary Wire.
➢ Twist the wires until they are tightly wounded and coupled.

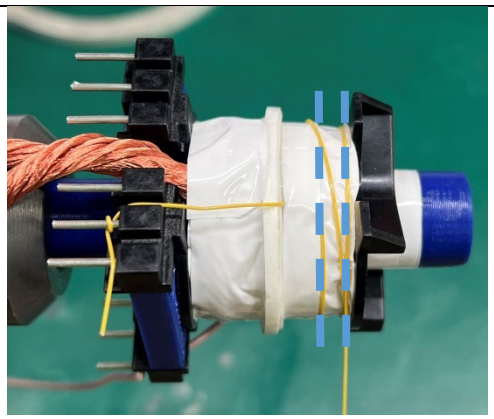
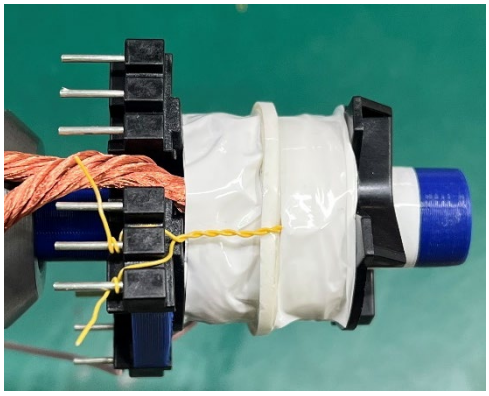
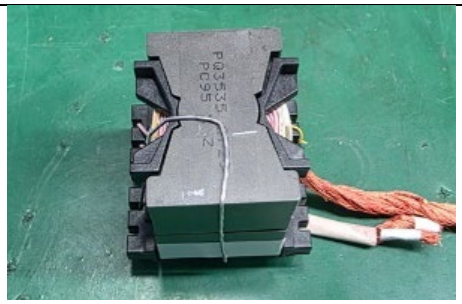
Figure 20 – Secondary Wire preparation.
</td></tr>
</table>

Table 12 – LLC Transformer Winding Preparation.

7.3.6 Transformer Construction

Bobbin position and separator		Position the bobbin on the mandrel such that the primary side of the bobbin is on the right side. Winding direction of the bobbin is clockwise. Use a plastic separator with 10.5 mm thickness and place it on the primary side of the bobbin.
WD1a &WD1b Secondary Windings	   	Using the twisted item [4] secondary wires, wind 6 turns by placing the start and finish between pin 9 and 10. Secure the secondary winding by adding 1 layer of item [7] tape. Remove the 10.5 mm plastic separator. Add 3 layers of item [8] tape and fold the excess. Push the secondary winding downwards ensure the space of the primary side. Use a plastic separator with 9 mm thickness and place it on the primary side of the bobbin. Wind item [9] tape between the secondary winding and plastic separator.

WD2 **Primary Winding**	  	Remove the plastic separator of the primary side. Wind 33T of item [3] wire starting at pin 2 from left to right and right to left in layers. Make sure to twist the two windings before terminating at pin 1. Secure the primary winding with item [8].
WD3 **IS Winding**		Place 1 turn of tape, 5 mm wide on top of the primary winding, next to the 1.5 mm separator, this will serve as a marker tape. Wind 2T of item [5] wire starting at pin 11. Start the winding at the center of the primary chamber, place a small amount of tape to hold the wire and wind 2 turns to the right. Spread the winding evenly.

	 	*Checkpoints:* *1. 1st turn should be wound in the middle of the winding window, aligned with the margin tape, avoid moving it close to the secondary chamber.* *2. 2nd turn should be wound on the top portion of the winding window.* Secure the winding with item [8] and twist the wires before terminating to pin 12. Taping should be tight to ensure better coupling to primary. Solder centers tap secondary wires to pins 7, 8, 9. Gap cores with 240 μH.
Finish		Add 1 layer of item [8] tape covering the whole winding. Insert core with tapes at the bottom and grind the top core to get the desired inductance (245 μH). Solder 3" item [10] wire at pin 5 and lean along the cores before securing the transformer with tape. Wrap the transformer assembly using item [7]

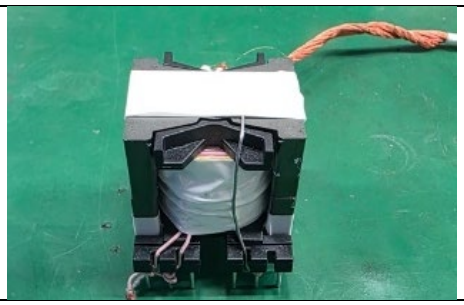
			tape. Dip the transformer using item [11] varnish.

Table 13 – LLC Transformer Construction.

7.4 Auxiliary Transformer (T2) Specification

7.4.1 Electrical Diagram

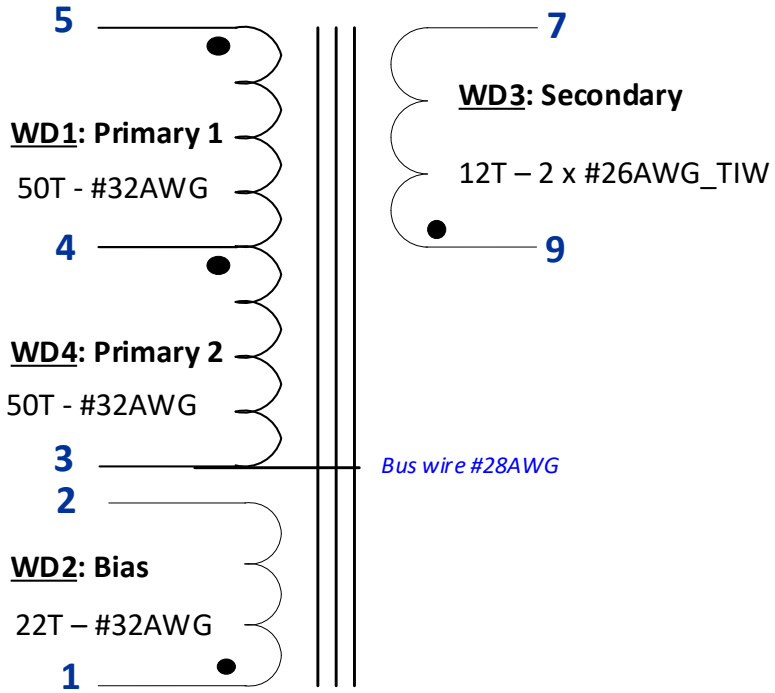


Figure 21 – Auxiliary Transformer Electrical Diagram.

7.4.2 Electrical Specification

Electrical Strength	1 second, 60 Hz, from Pins 3-5 to Pins 9-7	3000 VAC
Primary Inductance	Pins 3-5, all other open, measured at 100 kHz, 0.4 V_{RMS}	1,194 µH, -5/+5%
Resonant Frequency	Pins 3-5, all other open	1,000 kHz (Min.)

Primary Leakage	Pins 3-5, with 9-7 shorted, measured a 100 KHz, 0.4 V_{RMS}	16 μH (Max.)

Table 14 – Auxiliary Transformer Electrical Specifications.

7.4.3 Material List

Item	Description
[1]	Core: EE16, TDK-PC44; or equivalent.
[2]	Bobbin: EE16, Vertical, 10pins (5/5), PI#: 25-01225-00; or equivalent.
[3]	Magnet wire: #32 AWG, double coated.
[4]	Magnet wire: #26 AWG, Triple Insulated Wire.
[5]	Tape: 3M 1298 Polyester Film, 1 mil thick, 8.0 mm wide.
[6]	Bus wire: Alpha wire, #28 AWG.
[7]	Varnish: Dolph BC-359; or equivalent.

Table 15 – List of Materials.

7.4.4 Transformer Build Diagram

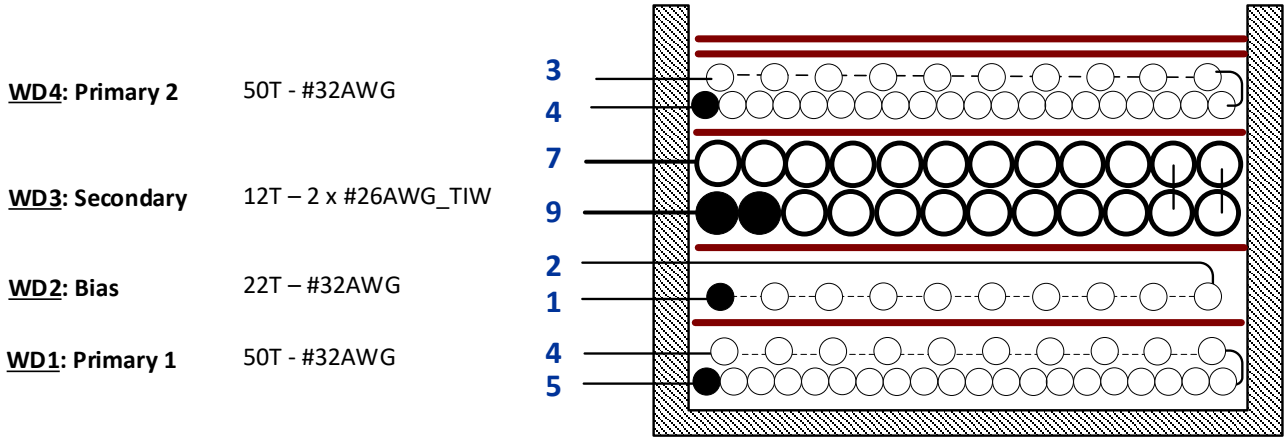


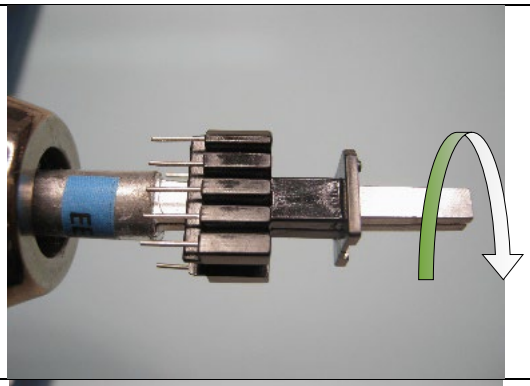
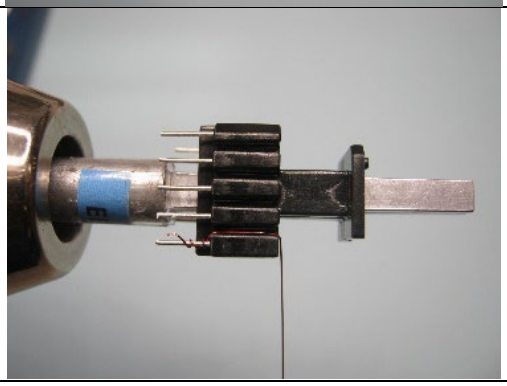
Figure 22 – Auxiliary Transformer Build Diagram.

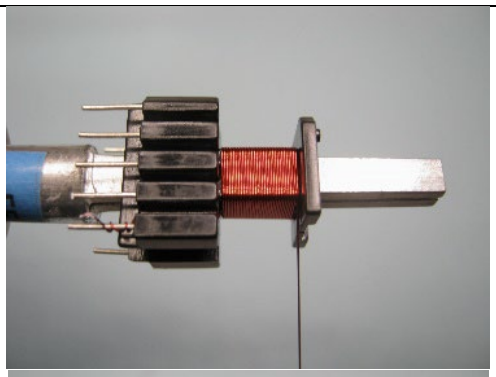
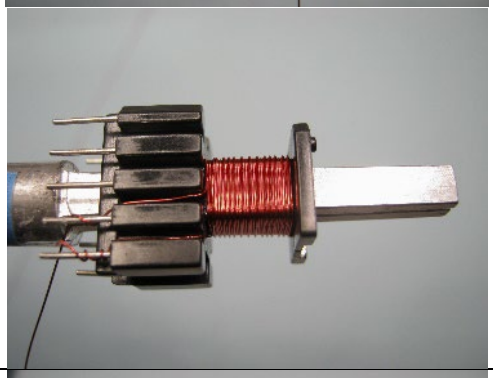
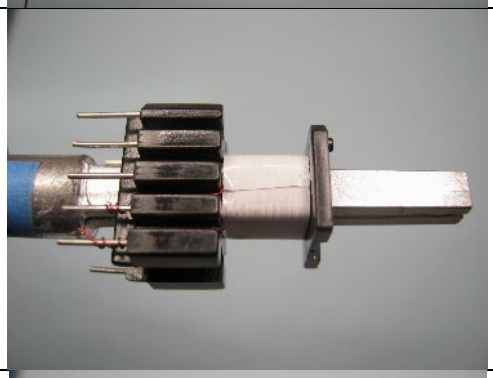
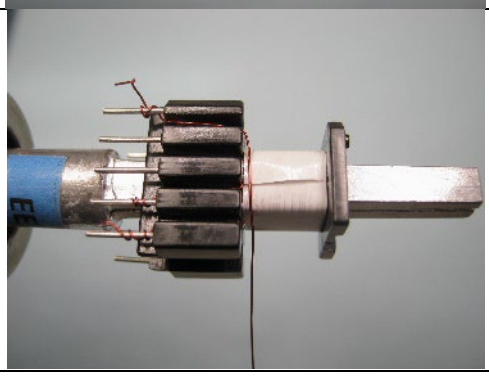
7.4.5 Winding Preparation

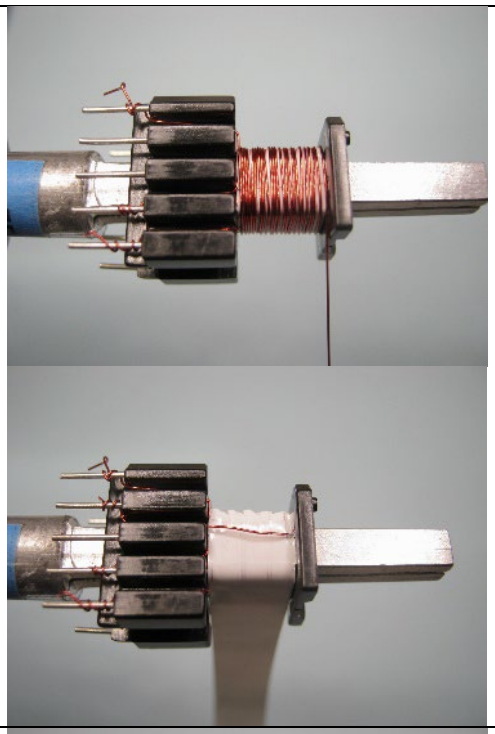
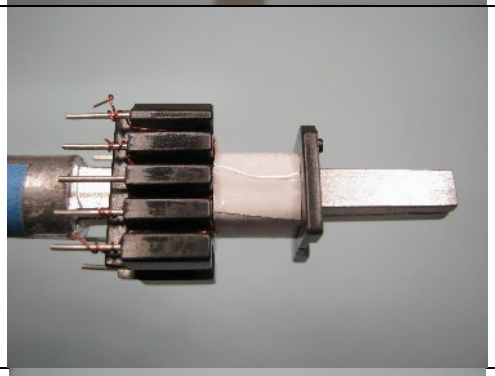
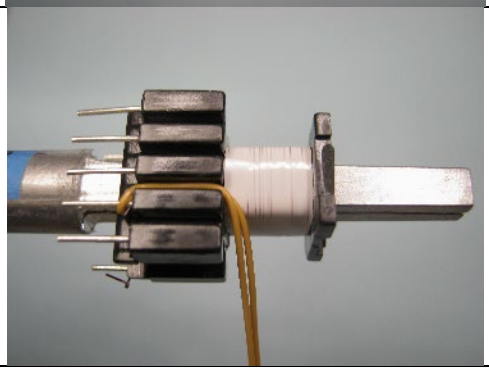
Winding preparation	Position the bobbin item [2] on the mandrel such that the primary side of the bobbin is on the left side. Winding direction is clockwise direction for forward direction.
WD1 Primary 1	Start at pin 5, wind 50 turns of wire item [3] in 2 layers, with tight tension, from left to right for 1st layer, then spread the wire for 2nd layer from right to left and end with pin 4.
Insulation	1 layer of tape item [5].
WD2 Bias	Start at pin 1, use wire item [3], wind 22 turns in 1 layer, from left to right, spread the wires evenly across the bobbin. At the last turn bring the wire back to the left and finish at pin 2.
Insulation	1 layer of tape item [5].
WD3 Secondary	Start at pin 9, use 2 wires item [4], wind 12 turns in 2 layers, from left to right then right to left, with tight tension, and end with pin 7.
Insulation	1 layer of tape item [5].
WD4 Primary 2	Start at pin 4, wind 50 turns of wire item [3] in 2 layers, with tight tension, from left to right for 1st layer, then spread the wire for 2nd layer form right to left and end with pin 3.
Insulation	2 layers of tape item [5] to secure all windings.
Finish	Gap cores to get 1144 μH. Solder 1 piece of wire item [6] (1" length) to pin 3, then lean along with cores (see pics below), and secure with tape. Varnish with item [7].

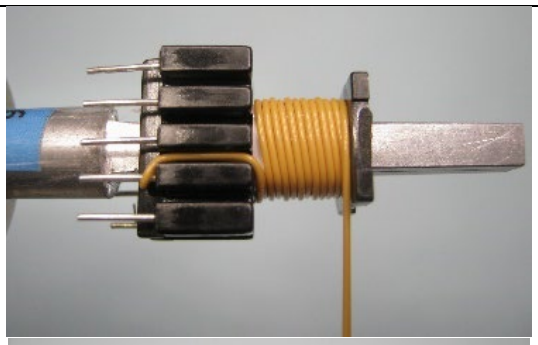
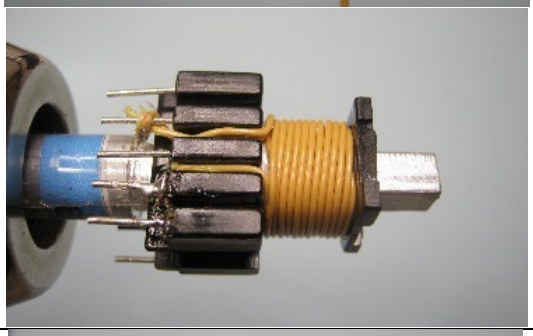
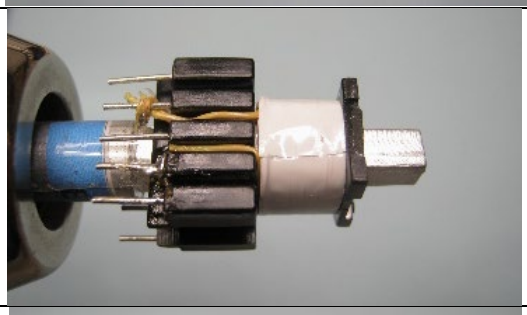
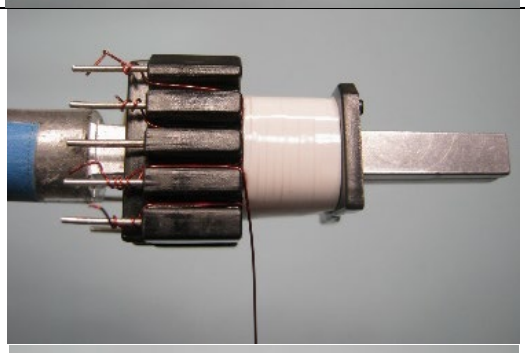
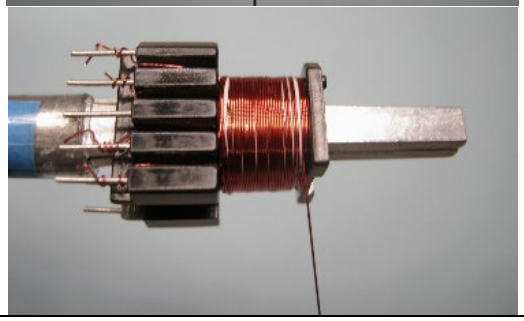
Table 16 – Auxiliary Transformer Winding Preparation.

7.4.6 Transformer Construction

Winding preparation		Position the bobbin item [2] on the mandrel such that the primary side of the bobbin is on the left side. Winding direction is clockwise direction for forward direction.
WD1 1st Primary		Start at pin 5, wind 50 turns of wire item [3] in 2 layers, with tight tension, from left to right for 1st layer, then spread the wire for 2nd layer from right to left and end with pin 4.

	 	
Insulation		1 layer of tape item [5].
WD2 **Bias**		Start at pin 1, use wire item [3], wind 22 turns in 1 layer, from left to right, spread the wires evenly across the bobbin. At the last turn bring the wire back to the left and finish at pin 2.

		
-Insulation		1 layer of tape item [5].
WD3 Secondary		Start at pin 9, use 2 wires item [4], wind 12 turns in 2 layers, from left to right then right to left, with tight tension, and end with pin 7.

	 	
Insulation		1 layer of tape item [5].
WD4 **Primary 2**	 	Start at pin 4, wind 50 turns of wire item [3] in 2 layers, with tight tension, from left to right for 1st layer, then spread the wire for 2nd layer form right to left and end with pin 3.

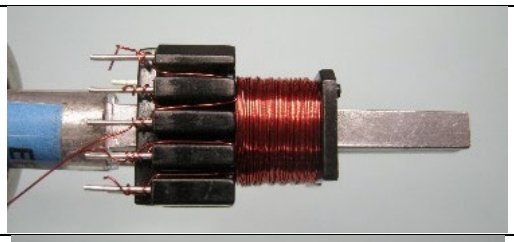
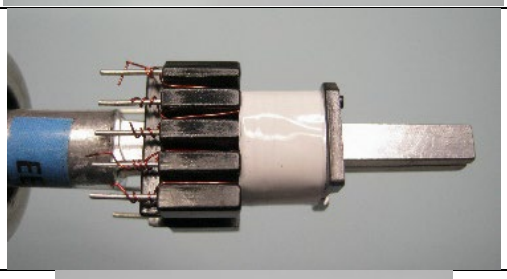
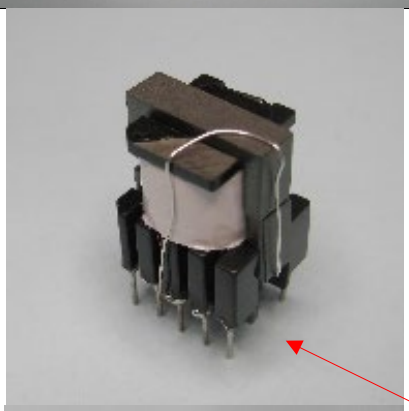
		
Insulation		2 layers of tape item [5] to secure all windings.
Finish		Gap cores to get 1144 μH. Solder 1 piece of wire item [6] (1" length) to pin 3, then lean along with cores (see pics beside), and secure with tape. Varnish with item [7].

Table 17 – Auxiliary Transformer Construction.

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 voltages, 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	760		760	W	Nominal Output power
10	fL			50	Hz	Line frequency
11	TA Max			40	°C	Maximum ambient temperature
12	n	0.96		0.96		Enter the efficiency estimate for the boost converter at VACMIN. Should approximately match calculated efficiency in Loss Budget section
13	VO_MIN			366	VDC	Minimum Output voltage
14	VO_RIPPLE_MAX	30		30	VDC	Maximum Output voltage ripple
15	tHOLDUP	10		10	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	0.662		0.662		Target ripple to peak inductor current ratio at the peak of VACMIN. Affects inductance value
22	LPFC_TARGET (0 bias)			140	μH	PFC inductance required to hit KP_TARGET at peak of VACMIN and full load
23	LPFC_DESIRED (0 bias)			140	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			0.633		Actual KP calculated from LPFC_ACTUAL
25	LPFC_PEAK			140	μH	Inductance at VACMIN, 90°. For Ferrite, same as LPFC_DESIRED (0 bias)

26						
27	Basic current parameters					
28	IAC_RMS			4.40	A	AC input RMS current at VACMIN and Full Power load
29	IO_DC			1.97	A	Output average current/Average diode current
30						
31						
32	PFS Parameters					
33	PFS Part Number	Auto		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			8.90	A	MOSFET peak current
39	IRMS			3.08	A	PFS MOSFET RMS current
40	RDSON			0.40	Ω	Typical RDSon at 100 °C
41	FS_PK			100	kHz	Estimated frequency of operation at crest of input voltage (at VACMIN)
42	FS_AVG			96	kHz	Estimated average frequency of operation over line cycle (at VACMIN)
43	PCOND_LOSS_PFS			3.8	W	Estimated PFS conduction losses
44	PSW_LOSS_PFS			5.1	W	Estimated PFS switching losses
45	PFS_TOTAL			8.9	W	Total Estimated PFS losses
46	TJ Max			100	°C	Maximum steady-state junction temperature
47	Rth-JS			2.80	°C/W	Maximum thermal resistance (Junction to heatsink)
48	HEATSINK Theta-CA			2.08	°C/W	Maximum thermal resistance of heatsink
49						
50						
51	INDUCTOR DESIGN					
52	Basic Inductor Parameters					
53	LPFC (0 Bias)			140	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			10.0	%	Tolerance of PFC Inductor Value (ferrite only)
55	IL_RMS			4.52	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 60µ, 75µ, 90µ or 125µ for Sendust cores. Fixed at PC44/PC95 for Ferrite cores. Fixed at -52 material for Pow Iron cores.
59	Core Geometry	PQ		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			1.19	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)			3889	Gauss	Target flux density at worst case: IOCP and maximum tolerance inductance (ferrite only) - drives turns and gap
72	B_MAX			2988	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			3712	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			37		Inductor turns. To adjust turns, change BP_TARGET (ferrite) or µ_TARGET (powder)
82	ILRMS			4.52	A	Inductor RMS current
93	Loss calculations					
94	BAC-p-p			1978	Gauss	Core AC peak-peak flux excursion at VACMIN, peak of sine wave
95	LPFC_CORE_LOSS			1.57	W	Estimated Inductor core Loss
96	LPFC_COPPER_LOSS			3.07	W	Estimated Inductor copper losses
97	LPFC_TOTAL_LOSS			4.64	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			2.84	W	Estimated Diode conduction losses
109	PSW_DIODE			0.59	W	Estimated Diode switching losses
110	P_DIODE			3.44	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			2.08	°C/W	Maximum thermal resistance of heatsink
114						
115						
116	Output Capacitor					
117	Output Capacitor	Auto		330	µF	Minimum value of Output capacitance
118	VO_RIPPLE_EXPECTED			19.8	V	Expected ripple voltage on Output with selected Output capacitor
119	T_HOLDUP_EXPECTED			11.3	ms	Expected holdup time with selected Output capacitor
120	ESR_LF			0.55	Ω	Low Frequency Capacitor ESR
121	ESR_HF			0.25	Ω	High Frequency Capacitor ESR
122	IC_RMS_LF			1.34	A	Low Frequency Capacitor RMS current
123	IC_RMS_HF			1.74	A	High Frequency Capacitor RMS current
124	CO_LF_LOSS			1.00	W	Estimated Low Frequency ESR loss in Output capacitor
125	CO_HF_LOSS			0.75	W	Estimated High frequency ESR loss in Output capacitor
126	Total CO LOSS			1.75	W	Total estimated losses in Output Capacitor
127						
128						
129	Input Bridge (BR1) and Fuse (F1)					
130	I^2t Rating			25.87	A^2*s	Minimum I^2t rating for fuse
131	Fuse Current rating			6.22	A	Minimum Current rating of fuse
132	VF			0.90	V	Input bridge Diode forward Diode drop
133	IAVG			3.87	A	Input average current at 70 VAC.
134	PIV_INPUT BRIDGE			396	V	Peak inverse voltage of input bridge
135	PCOND_LOSS_BRIDGE			7.13	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	Ω	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	MΩ	Line sense resistor 1
144	RV2			6.0	MΩ	Line sense resistor 2
145	RV3			6.0	MΩ	Typical value of the lower resistor connected to the V-PIN. Use 1% resistor only!
146	RV4			161.6	kΩ	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	kΩ	Power good threshold setting resistor

152						
153						
154	Feedback Components					
155	R1			4.0	MΩ	Feedback network, first high voltage divider resistor
156	R2			6.0	MΩ	Feedback network, second high voltage divider resistor
157	R3			6.0	MΩ	Feedback network, third high voltage divider resistor
158	R4			161.6	kΩ	Feedback network, lower divider resistor
159	C1			0.495	nF	Feedback network, loop speedup capacitor. (R4 and C1 should have a time constant of 80 μs) Pick the closest available capacitance.
160	R5			16.9	kΩ	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			8.86	W	Total estimated losses in PFS
166	Boost diode Losses			3.44	W	Total estimated losses in Output Diode
167	Input Bridge losses			7.13	W	Total estimated losses in input bridge module
168	Inductor losses			4.64	W	Total estimated losses in PFC choke
169	Output Capacitor Loss			1.75	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			25.81	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	kΩ	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 differential mode choke and before bridge, ratio with Po
183	LDM_calc			151	μH	estimated minimum differential inductance to avoid <10 kHz 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 30~60 μH
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	Ω	total DCR of CM choke for estimating copper loss
190	DCR_LDM	0.10		0.10	Ω	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.					
193						

Table 18 – 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			>		LCS7268Z-900 W-60 V-15 A-SynchRF-33T-6T-161 µH-77 µH-30 nF-86 kHz
4	Input Parameters					
5	VIN MIN	600		600	V	Brownout Threshold Voltage
6	VIN RES	600		600	V	Input Voltage at Resonance - lower Vres to lower Npri
7	VIN NOM	385		385	V	Nominal Input Voltage - default CRM Vres=Vnom (or DCM Vres>Vnom, CCM Vres<Vnom)
8	VIN MAX	450		450	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	15.0		15.0	A	Peak Main Output Current (Used to select device size - increasing peak power will lower LRES
13	Pout1 PK			900.0	W	Main Output Peak Power
14	Iout1 CONT	12.0		12.0	A	Continuous Main Output Current (Used for device selection and compute losses)
15	Pout1 CONT			720.0	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			0.125	V	Output current sense resistor voltage when operating at CC-threshold
19	RCC			9.00	mΩ	Output current sense resistor value
20	RCC Rated Power			3.04	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)	105.0		105.0	kHz	Switching Frequency at VinNom
24	Output Rectifier	SynchRF		SynchRF		Output Rectifier
25	Ron_SR1			5.0	mΩ	Sync. Rectifier ON Resistance
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	LCS7268Z		LCS7268Z		PI Device Name
31	QOSS			302	nC	Equivalent Combined Half-bridge charge (Qoss) at 480V
32	RDSON			0.260	Ω	RDSON of selected device
33	Fault Response	NON_LATCHING		NON_LATCHING		..
34	Tank Circuit Components & Operation Frequency Range					
35	Integrated Magnetics	YES		YES		Integrated Transformer Requirements
36	LP Nominal			237.48	µH	Nominal Primary Inductance
37	Lm			160.6	µH	Magnetizing inductance of transformer - modified by Kz, Device size and frequency
38	Lres			76.9	µH	Series resonant or primary leakage inductance - modified by Pmax
39	Cres	30.00		30.00	nF	Series resonant capacitor.
40	f_calc@Vbrownout			82.6	kHz	Frequency at PoutCont at Vbrownout, full load - adjust VinBrownout
41	f_calc@resonance			104.8	kHz	Resonant Frequency (defined by Lres and Cres)
42	f_calc@Vnom			86.2	kHz	Frequency at PoutCont at Vnom - adjust FS Vnom Target or Vnom
43	f_calc@Vinmax			216.2	kHz	Expected frequency at maximum input voltage and full load; Heavily influenced by n_eq and primary turns
44	VINGmaxInversion			175.5	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			171.00	mm^2	Transformer Core Cross-sectional area
47	VE			13.7	cm^3	Transformer Core Volume
48	MLT			75.24	mm	Middle Length of a Turn
49	AW			145.23	mm^2	Core Window area
50	BW			20.60	mm	Bobbin Winding Width
51	Bobbin Chambers			2		Bobbin Chambers
52	ChambDist	1.50		1.50	mm	Width of bobbin with no windings - empty space between primary/secondary generates leakage inductance
53	Bobbin Height			7.05	mm	Height of the bobbin, maximum Stack height
54	Prim. Bobbin Chamber Width			10.86	mm	Part of the bobbin allocated for primary
55	Sec. Bobbin Chamber Width			8.24	mm	Part of the bobbin allocated for secondary
56	K-PD			0.35		Penetration Depth multiplier (for Single Strand LITZ calculation)
57	Transformer Generic Parameters					

58	CR_TYPE	PQ35		PQ35		Transformer Core Type
59	FR_TYPE			N95		Magnetic material used
60	BACmax Actual			279.47	mT	Estimated Flux Density at Vnom - increase Ns to reduce Bmax
64	kSecChamb	0.40		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			33		Calculated Primary Winding Total Number of Turns
67	Iprim RMS			3.73	A	Transformer Primary Winding RMS Current at PoutCont and VinNom
79	Main Output Parameters					
80	NSec	6		6		Secondary Number of Turns
81	ISRMS			24.23	A	Transformer Secondary Winding RMS Current
93	Circuit Losses					
97	CO ESR Loss			0.44	W	Output Capacitor ESR Loss at VinNom and PoutCont
98	PLOSS Switch			1.81	W	Single Primary Switch Conduction Loss at VinNom and PoutCont
99	PLOSS Output Rectifier			0.44	W	Single Output Rectifier Conduction Loss at VinNom and PoutCont
100	PLOSS RCC			2.03	W	Current sense resistor power loss at VinNom and PoutCont
102	PLOSS Circuit Total			6.98	W	Circuit Total Loss at VinNom and PoutCont
103	Circuit Components					
104	RZ1			150	kΩ	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			647	µF	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 /10 V
116	C5VS			10	µF	C5VS Capacitor Value /10 V
117	CBPS			10	µF	CBPS Capacitor Value /35 V
118	RL_Up			open	kΩ	L-pin Input Voltage (Vin) Sense Resistor
119	RL_Down			shorted	Ω	L-pin to Ground Resistor
120	RPP			316	kΩ	RPP Resistor /1% E96 series
121	RPS			75	kΩ	RPS Resistor /1% E96 series
122	Bias, IS Circuit & Feedback Components					

123	NPB			2		Primary Bias Turns
124	NSB			2		Secondary Bias Turns
125	NVIS			2		Secondary (Is) Sense Turns
126	RIS			1702	kΩ	Rrs Resistor Value
127	CIS			470	pF	IS sense winding coupling capacitor
128	RFBH			360.6	kΩ	Calculated value of top feedback resistor. use series closest resistor 1% E96
129	RFBL			24.0	kΩ	Calculated value of low feedback resistor. use series closest resistor 1% E96
130	Currents and Winding loss elements					
131	Iprim RMS			3.73	A	Transformer Primary Winding RMS Current at PoutCont at VinNom
132	ISRMS			24.23	A	Transformer Secondary Winding RMS Current at PoutCont at VinNom
133	Irms_SR			9.42	A	Secondary Rectifier RMS Current at PoutCont at VinNom
134	Irms_CO1			21.05	A	Output Capacitor RMS Current at PoutCont at VinNom
139	Advanced Settings					
140	Kz	1.0		1.0		coefficient of surplus ZVS energy @ Vnom - raise Kz to lower Vin(GmaxInv) - Kz should be >= 2.0 to ensure ZVS operation
141	Tdd1_Vinnom			250	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	PP		PP		HB Startup current selection
145	R_L_UP_ACT				kΩ	Actual Value of L-pin Input Voltage (Vin) Sense Resistor
146	VLUV-				V	..
147	VLUV+				V	..
148	VLOV-				V	..
149	VLOV+				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 19 – LLC Design Spreadsheet.

10 Heat sink

10.1 Baseplate Heat Sink

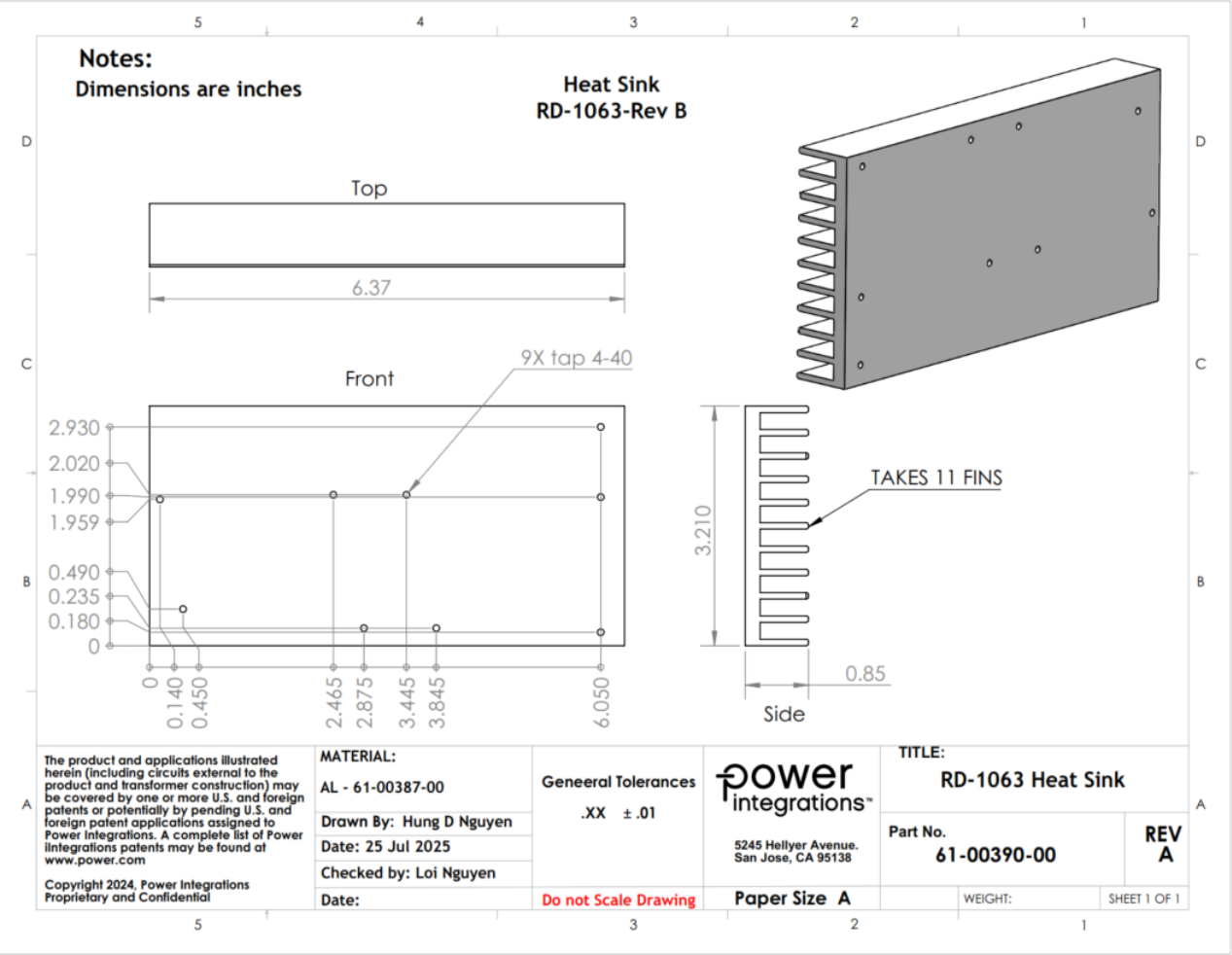
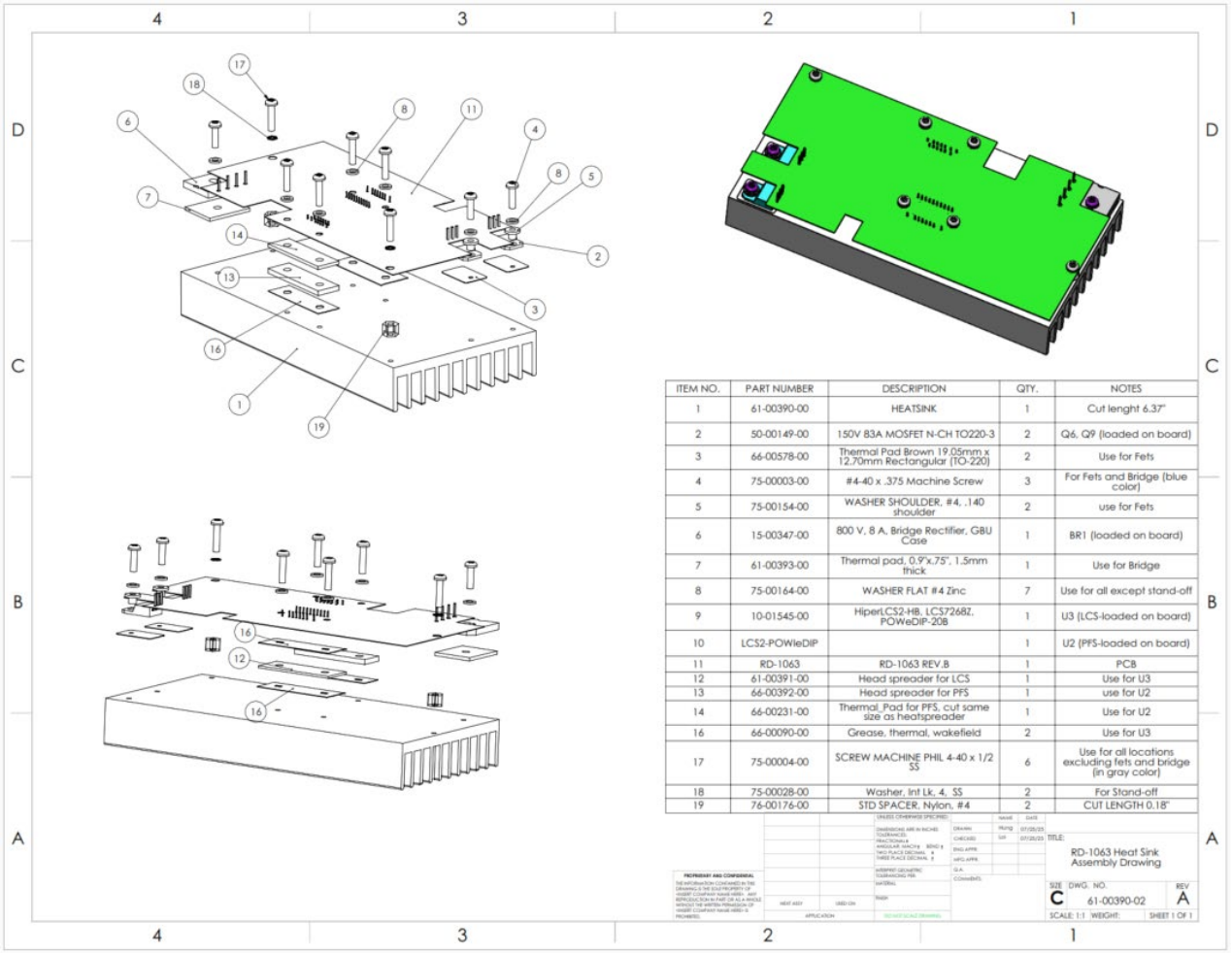


Figure 23 – Baseplate Heat Sink.

10.2 Baseplate Heat Sink Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	NOTES
1	61-00390-00	HEATSINK	1	Cut lenght 6.37"
2	50-00149-00	150V 83A MOSFET N-CH TO220-3	2	Q6, Q9 (loaded on board)
3	66-00578-00	Thermal Pad Brown 19.05mm x 12.70mm Rectangular (TO-220)	2	Use for Fets
4	75-00003-00	#4-40 x .375 Machine Screw	3	For Fets and Bridge (blue color)
5	75-00154-00	WASHER SHOULDER, #4, .140 shoulder	2	use for Fets
6	15-00347-00	800 V, 8 A, Bridge Rectifier, GBU Case	1	BR1 (loaded on board)
7	61-00393-00	Thermal pad, 0.9"x.75", 1.5mm thick	1	Use for Bridge
8	75-00164-00	WASHER FLAT #4 Zinc	7	Use for all except stand-off
9	10-01545-00	HiperLCS2-HB, LCS7268Z, POWeDIP-20B	1	U3 (LCS-loaded on board)
10	LCS2-POWieDIP		1	U2 (PFS-loaded on board)
11	RD-1063	RD-1063 REV.B	1	PCB
12	61-00391-00	Head spreader for LCS	1	Use for U3
13	66-00392-00	Head spreader for PFS	1	use for U2
14	66-00231-00	Thermal_Pad for PFS, cut same size as heatspreader	1	Use for U2
16	66-00090-00	Grease, thermal, wakefield	2	Use for U3
17	75-00004-00	SCREW MACHINE PHIL 4-40 x 1/2 SS	6	Use for all locations excluding fets and bridge (in gray color)
18	75-00028-00	Washer, Int Lk, 4, SS	2	For Stand-off
19	76-00176-00	STD SPACER, Nylon, #4	2	CUT LENGTH 0.18"

RD-1063 Heat Sink Assembly Drawing

SIZE C DWG. NO. 61-00390-02 REV A

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

Figure 24 – Baseplate Heat Sink Assembly.

10.3 Heat Spreader for LCS2

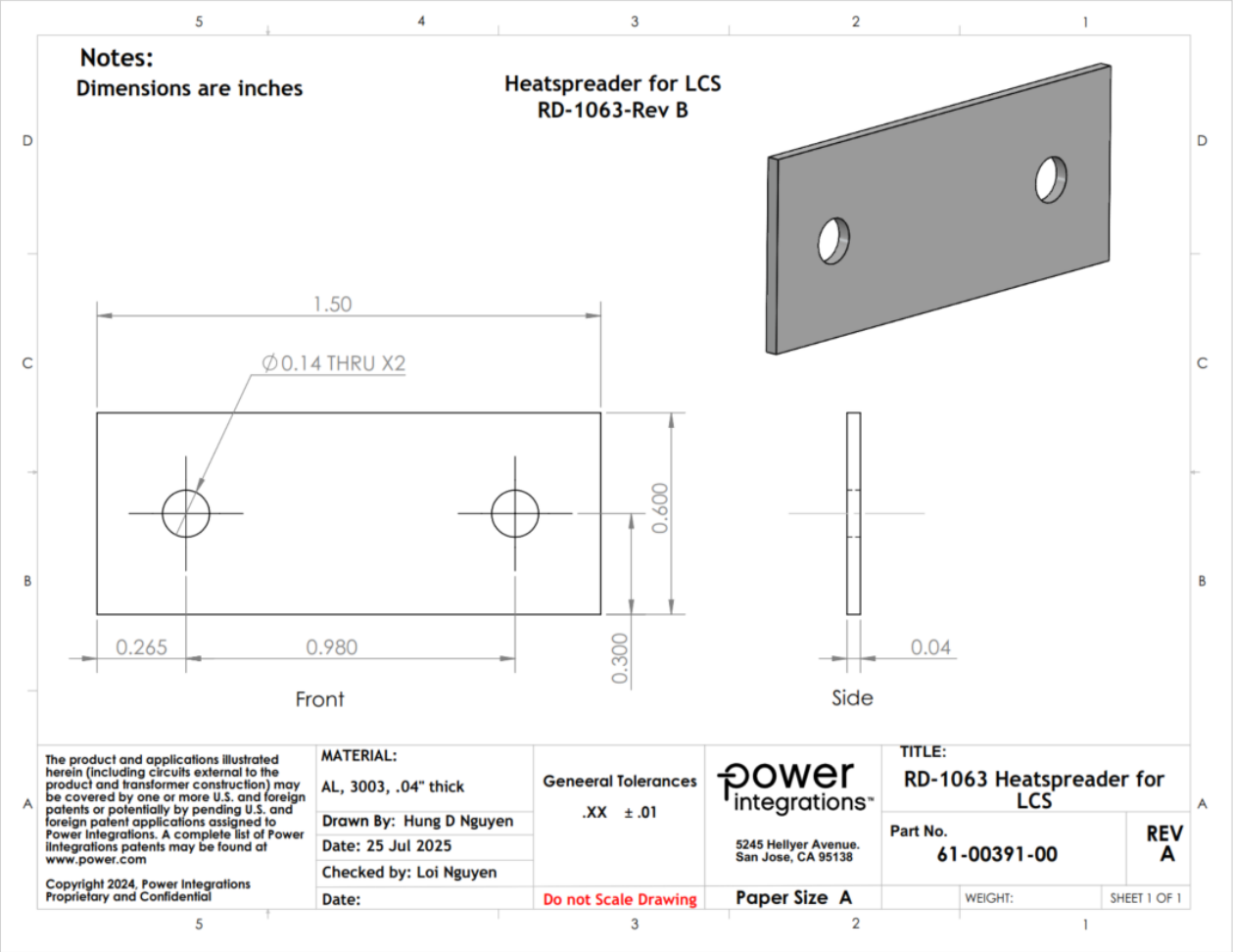


Figure 25 – Heat Spreader for LCS2.

10.4 Heat Spreader for PFS3

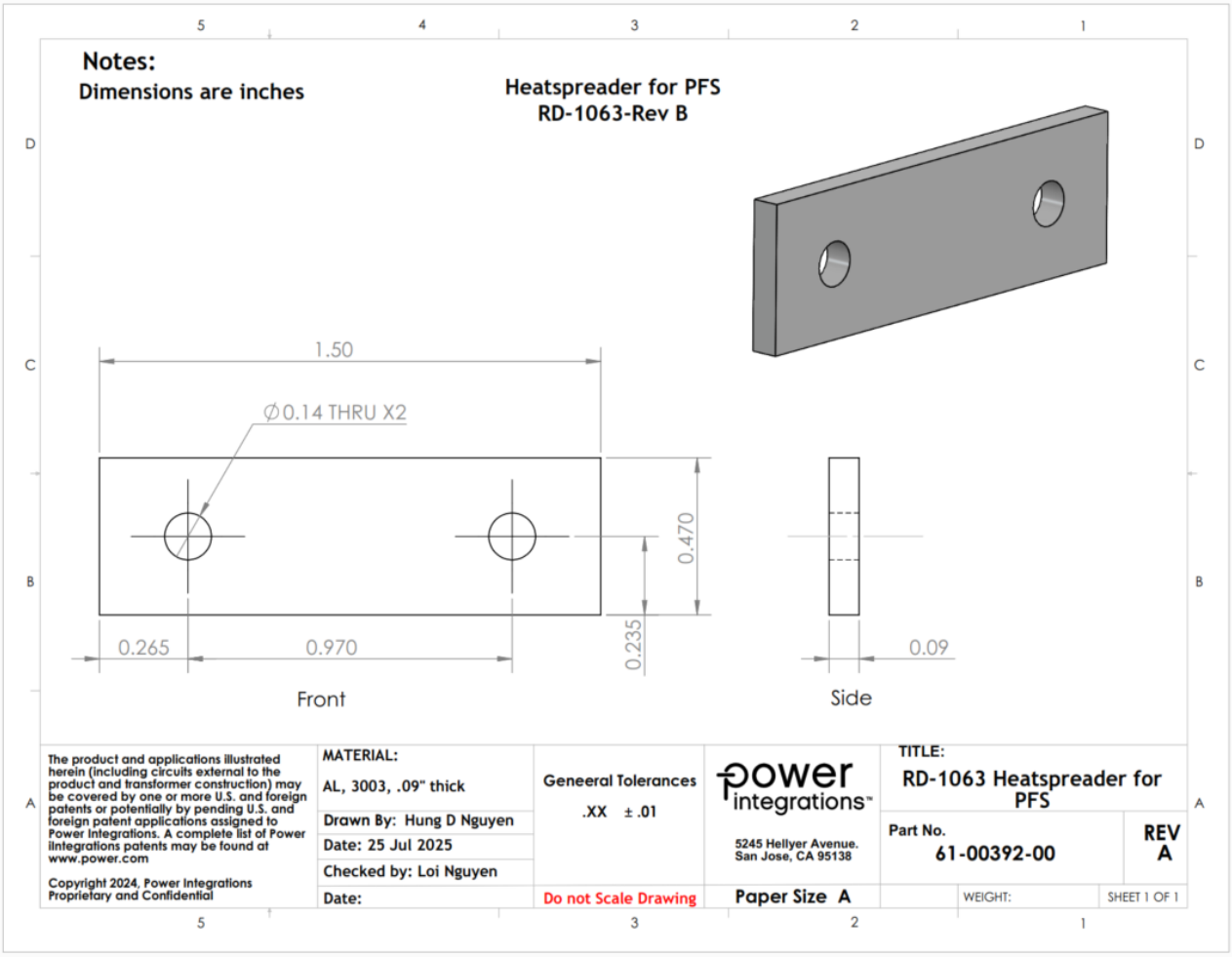


Figure 26 – Heat Spreader for PFS3.

10.5 Thermal Pad for Bridge Rectifier

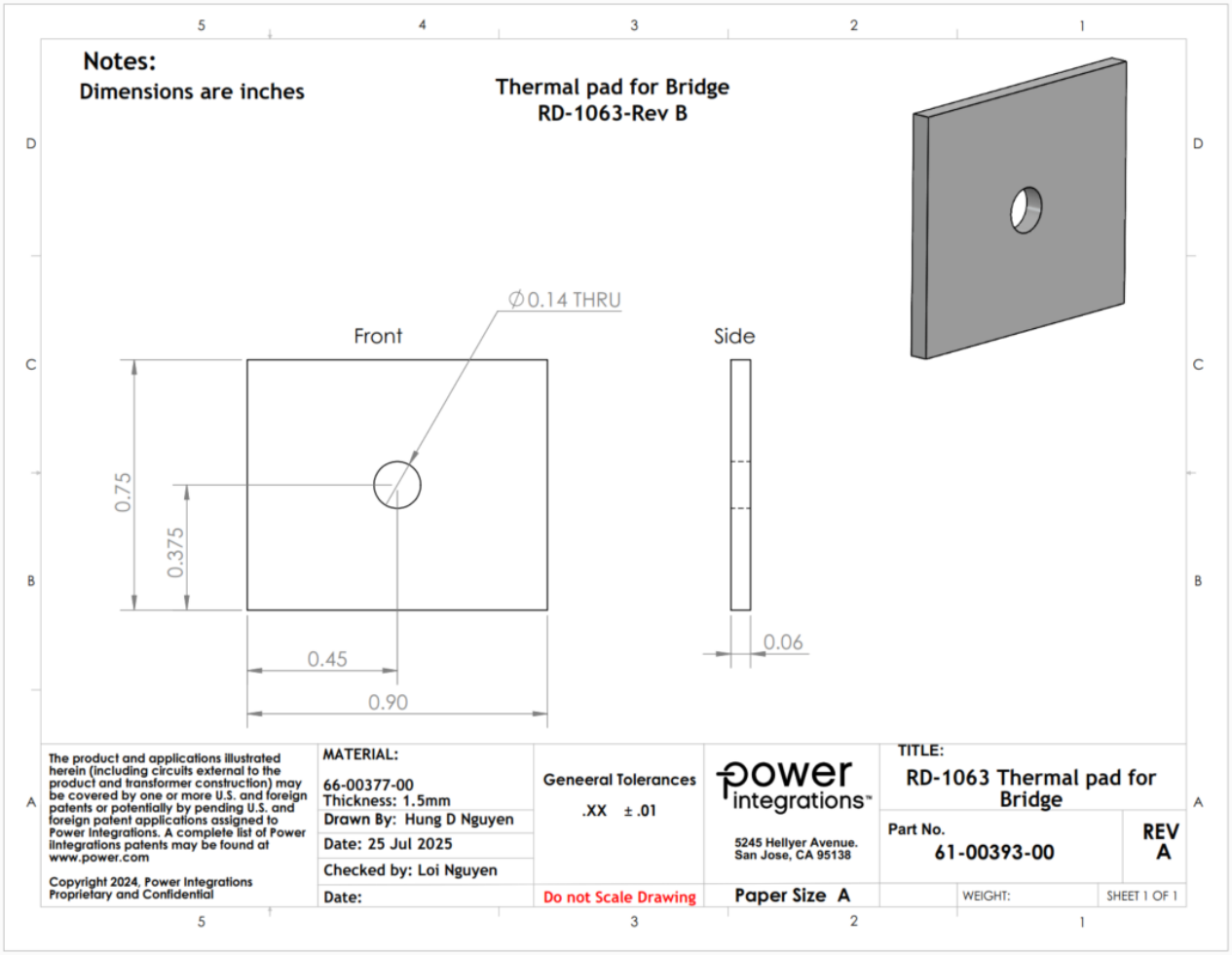


Figure 27 – Thermal Pad for Bridge Rectifier.

11 Performance Data

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 R64A and R145. Under CV mode, the reference voltage was set using the variable resistor R145. Under CC mode, the reference current was set using the variable resistor R64A. The performance in CV and CC modes was shown in the Figure 28.

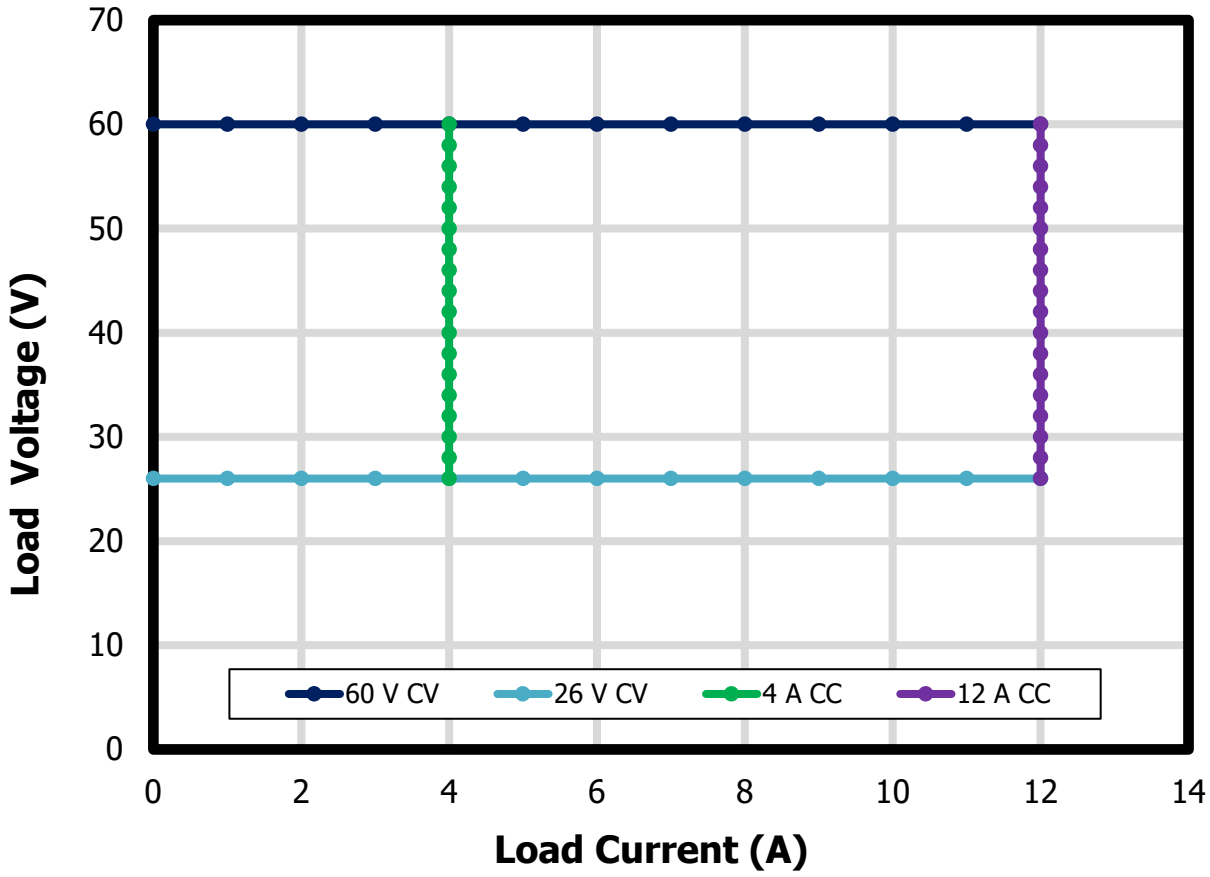


Figure 28 – CV/CC mode of operation with 230 VAC input.

11.2 End to end Efficiency

Figure 29 shows power supply efficiency with respect to output power for different input line voltages.

For CV mode output, the reference voltage was set to 60 V using variable resistor R145. A variable AC source was used to supply a sine wave input and a DC electronic load set to CC mode.

For CC mode output, the reference current set to 12 A using variable resistor R64A. A variable AC source was used to supply a sine wave input and a DC electronic load set to CV mode was connected to the output.

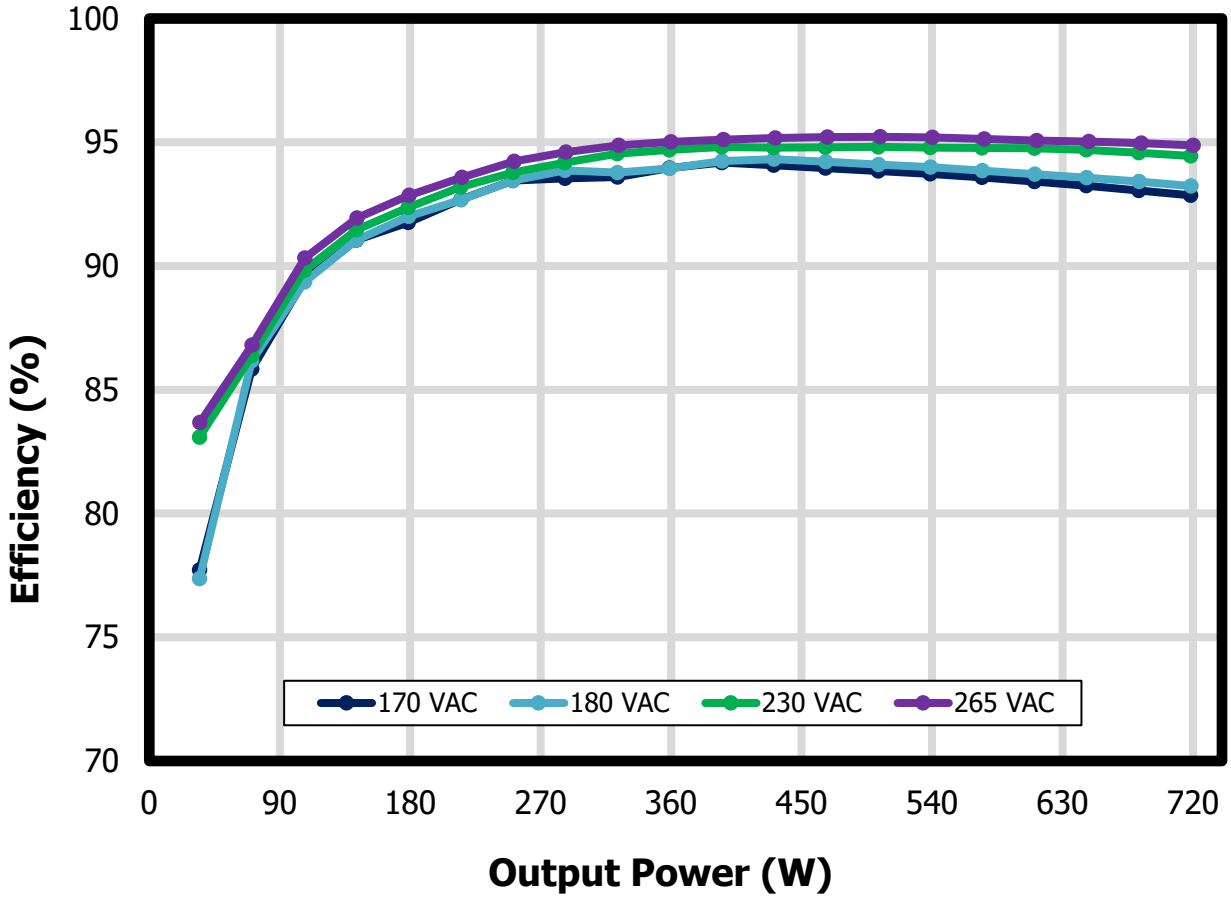


Figure 29 – Total Efficiency vs. Load, 60 V Output CV Mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
170	4.56	0.998	774	60.0	12.0	718	92.9
170	4.32	0.997	733	60.0	11.4	683	93.1
170	4.09	0.997	693	60.0	10.8	646	93.2
170	3.85	0.997	654	60.0	10.2	611	93.4
170	3.62	0.996	614	60.0	9.58	575	93.6
170	3.39	0.996	575	60.0	8.98	539	93.7
170	3.16	0.995	536	60.0	8.38	503	93.8
170	2.93	0.994	496	60.0	7.77	466	94.0
170	2.71	0.992	458	60.0	7.17	431	94.1
170	2.48	0.991	419	60.1	6.58	395	94.2
170	2.27	0.990	382	60.1	5.97	359	94.0
170	2.05	0.988	345	60.1	5.38	322	93.6
170	1.82	0.986	307	60.1	4.77	287	93.5
170	1.60	0.986	268	60.1	4.17	251	93.5
170	1.38	0.986	232	60.1	3.58	215	92.7
170	1.16	0.984	195	60.1	2.97	179	91.8
171	0.94	0.984	157	60.1	2.38	143	91.0
170	0.72	0.977	120	60.1	1.78	107	89.4
171	0.51	0.949	82.3	60.1	1.17	70.6	85.8
170	0.31	0.854	44.6	60.2	0.58	34.7	77.7

Table 20 – Efficiency at 170 VAC, 60 V CV mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
180	4.30	0.997	771	60.0	12.0	719	93.2
180	4.08	0.997	731	60.0	11.4	683	93.4
180	3.86	0.996	691	60.0	10.8	647	93.6
180	3.64	0.996	652	60.0	10.2	611	93.7
180	3.42	0.996	612	60.0	9.58	575	93.9
180	3.20	0.995	573	60.0	8.98	539	94.0
180	2.99	0.994	535	60.0	8.38	503	94.1
180	2.77	0.993	495	60.1	7.77	467	94.2
180	2.56	0.991	457	60.1	7.17	431	94.3
180	2.35	0.990	419	60.1	6.58	395	94.3
180	2.15	0.988	382	60.1	5.97	359	93.9
180	1.94	0.986	344	60.1	5.38	323	93.8
180	1.72	0.986	306	60.1	4.77	287	93.9
180	1.51	0.987	269	60.1	4.18	251	93.5
180	1.31	0.984	232	60.1	3.58	215	92.7
180	1.10	0.982	194	60.1	2.97	179	92.0
180	0.89	0.982	157.0	60.1	2.38	143	91.1
180	0.68	0.971	119.7	60.2	1.78	107	89.4
180	0.49	0.937	82.0	60.2	1.17	70.7	86.2
180	0.30	0.819	44.9	60.2	0.58	34.7	77.4

Table 21 – Efficiency at 200 VAC, 60 V CV mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
230	3.33	0.993	761	60.0	12.0	718	94.4
230	3.16	0.993	722	60.0	11.4	683	94.6
230	2.99	0.992	683	60.0	10.8	646	94.7
230	2.82	0.992	644	60.0	10.2	611	94.8
230	2.66	0.991	606	60.0	9.57	574	94.8
230	2.50	0.989	568	60.0	8.98	539	94.8
230	2.33	0.987	530	60.0	8.38	503	94.8
230	2.17	0.987	492	60.0	7.77	466	94.8
230	2.00	0.986	454	60.1	7.17	431	94.8
230	1.84	0.985	416	60.1	6.57	395	94.8
230	1.67	0.983	379	60.1	5.97	359	94.7
230	1.50	0.986	341	60.1	5.37	323	94.5
230	1.34	0.984	304	60.1	4.77	287	94.2
230	1.18	0.982	267	60.1	4.17	251	93.8
230	1.02	0.978	231	60.1	3.57	215	93.2
230	0.86	0.973	193	60.1	2.97	179	92.4
230	0.70	0.963	156	60.1	2.37	143	91.5
230	0.55	0.935	119	60.2	1.78	107	89.8
230	0.41	0.869	81.7	60.2	1.17	70.6	86.4
230	0.27	0.667	41.6	60.2	0.57	34.6	83.1

Table 22 – Efficiency at 230 VAC, 60 V CV mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
265	2.92	0.981	759	60.1	12.0	720	94.9
265	2.77	0.980	721	60.1	11.4	684	95.0
265	2.63	0.979	682	60.1	10.8	648	95.0
265	2.48	0.978	644	60.1	10.2	612	95.1
265	2.34	0.977	606	60.1	9.58	576	95.1
265	2.19	0.976	567	60.2	8.98	540	95.2
265	2.05	0.974	530	60.2	8.38	504	95.2
265	1.91	0.971	491	60.2	7.77	468	95.2
265	1.76	0.969	454	60.2	7.18	432	95.2
265	1.62	0.971	416	60.2	6.58	396	95.1
265	1.47	0.971	379	60.2	5.98	360	95.0
265	1.33	0.968	341	60.2	5.38	324	94.9
265	1.19	0.964	304	60.2	4.78	288	94.6
265	1.05	0.959	267	60.2	4.18	252	94.2
265	0.91	0.950	230	60.2	3.58	216	93.6
265	0.78	0.933	193	60.2	2.98	179	92.9
265	0.65	0.908	156	60.3	2.38	143	91.9
266	0.52	0.863	119	60.3	1.78	107	90.3
265	0.39	0.788	81.7	60.3	1.18	71.0	86.8
265	0.30	0.526	41.7	60.3	0.58	34.9	83.7

Table 23 – Efficiency at 265 VAC, 60 V CV mode.

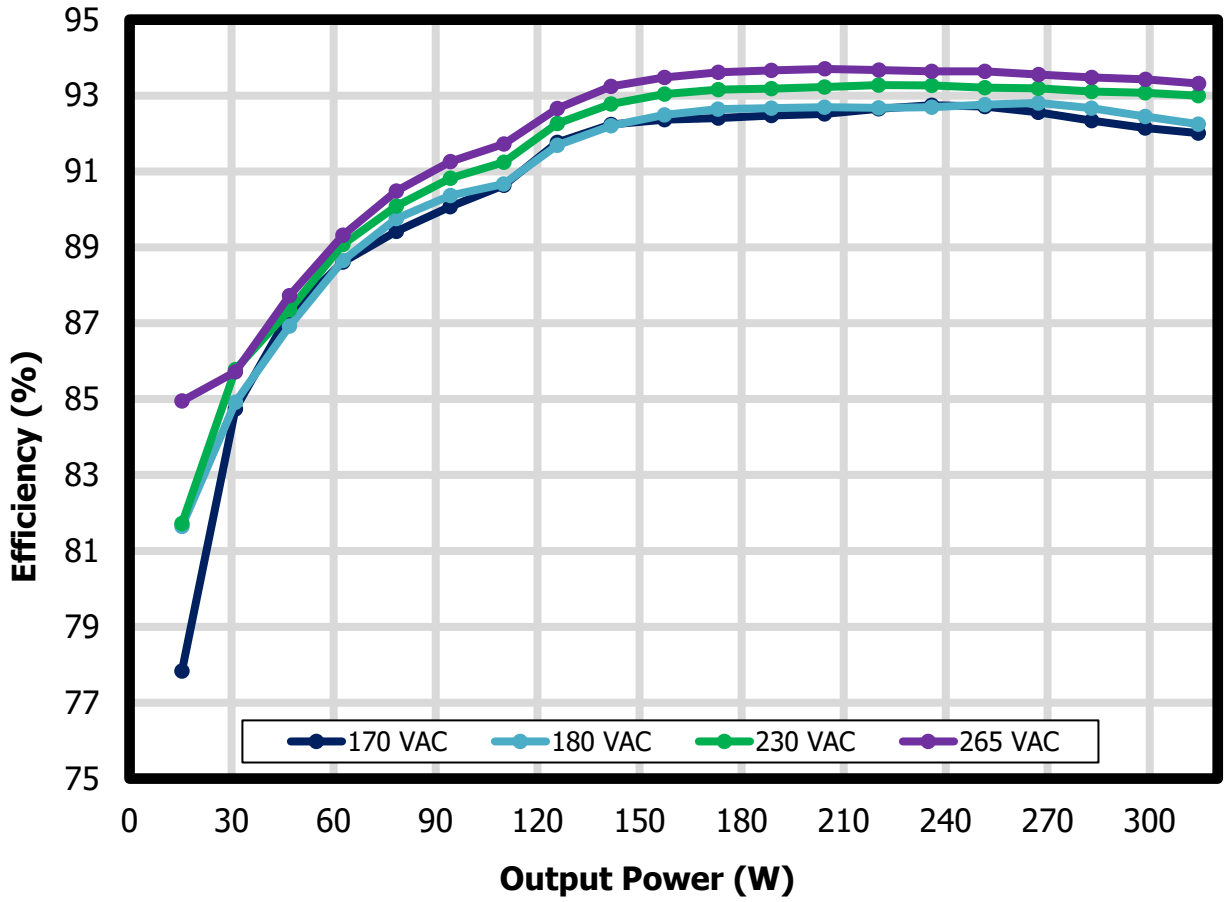


Figure 30 – Total Efficiency vs. Load, 26 V Output CV Mode

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
170	2.03	0.987	342	26.2	12.0	314	92.0
170	1.93	0.986	324	26.2	11.4	299	92.2
170	1.83	0.985	306	26.2	10.8	283	92.3
170	1.72	0.985	289	26.2	10.2	267	92.6
170	1.62	0.986	271	26.2	9.58	252	92.7
170	1.52	0.986	254	26.3	8.99	236	92.8
170	1.42	0.986	238	26.3	8.39	220	92.7
170	1.32	0.985	221	26.3	7.78	204	92.5
170	1.22	0.983	204	26.3	7.18	189	92.5
170	1.12	0.982	187	26.3	6.59	173	92.4
170	1.02	0.983	170	26.3	5.98	157	92.4
170	0.92	0.983	154	26.3	5.38	142	92.2
170	0.82	0.980	137	26.3	4.78	126	91.8
170	0.73	0.976	121	26.3	4.18	110	90.6
170	0.64	0.967	105	26.3	3.59	94.3	90.1
170	0.54	0.953	87.7	26.3	2.98	78.5	89.4
170	0.45	0.930	70.8	26.3	2.38	62.7	88.6
170	0.36	0.878	53.9	26.3	1.79	47.0	87.3
170	0.28	0.783	36.7	26.3	1.18	31.1	84.7
170	0.16	0.748	19.8	26.3	0.58	15.4	77.8

Table 24 – Efficiency at 170 VAC, 26 V CV mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
180	1.92	0.986	341	26.2	12.0	314	92.3
180	1.82	0.986	323	26.2	11.4	299	92.4
180	1.72	0.986	305	26.2	10.8	283	92.7
180	1.62	0.987	288	26.2	10.2	267	92.8
180	1.53	0.986	271	26.2	9.59	252	92.8
180	1.43	0.985	254	26.3	8.99	236	92.7
180	1.34	0.984	238	26.3	8.39	220	92.7
180	1.25	0.982	220	26.3	7.78	204	92.7
180	1.15	0.981	204	26.3	7.18	189	92.7
180	1.06	0.981	187	26.3	6.59	173	92.6
180	0.96	0.982	170	26.3	5.98	157	92.5
180	0.87	0.980	154	26.3	5.38	142	92.2
180	0.78	0.978	137	26.3	4.78	126	91.7
180	0.69	0.972	121	26.3	4.18	110	90.7
180	0.60	0.962	104	26.3	3.59	94.3	90.4
180	0.52	0.942	87.4	26.3	2.98	78.5	89.8
180	0.43	0.915	70.8	26.3	2.38	62.7	88.7
180	0.35	0.865	54.1	26.3	1.79	47.0	86.9
180	0.27	0.761	36.7	26.3	1.18	31.1	84.9
180	0.17	0.618	18.9	26.3	0.59	15.4	81.7

Table 25 – Efficiency at 180 VAC, 26 V CV mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
230	1.49	0.985	338	26.2	12.0	314	93.0
230	1.42	0.984	321	26.2	11.4	299	93.1
230	1.34	0.984	304	26.2	10.8	283	93.1
230	1.27	0.983	287	26.2	10.2	267	93.2
230	1.19	0.981	270	26.2	9.59	252	93.2
230	1.12	0.980	253	26.3	8.99	236	93.3
230	1.05	0.978	236	26.3	8.39	220	93.3
230	0.98	0.976	219	26.3	7.78	204	93.2
230	0.90	0.973	203	26.3	7.18	189	93.2
230	0.83	0.970	186	26.3	6.59	173	93.2
230	0.76	0.966	169	26.3	5.98	157	93.0
230	0.69	0.961	153	26.3	5.39	142	92.8
230	0.62	0.950	137	26.3	4.78	126	92.3
230	0.56	0.936	121	26.3	4.18	110	91.3
230	0.49	0.913	104	26.3	3.59	94.3	90.8
230	0.43	0.881	87.1	26.3	2.98	78.5	90.1
230	0.37	0.829	70.4	26.3	2.39	62.7	89.1
230	0.31	0.752	53.8	26.3	1.79	47.0	87.4
230	0.27	0.577	36.3	26.3	1.18	31.1	85.8
230	0.18	0.467	18.9	26.3	0.59	15.4	81.7

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

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
265	1.32	0.965	337	26.2	12.0	314	93.3
265	1.25	0.966	320	26.2	11.4	299	93.4
265	1.19	0.962	303	26.2	10.8	283	93.5
265	1.12	0.961	286	26.2	10.2	267	93.6
265	1.06	0.957	269	26.3	9.58	252	93.6
265	1.00	0.954	252	26.3	8.99	236	93.6
265	0.93	0.952	235	26.3	8.39	220	93.7
265	0.87	0.944	218	26.3	7.78	204	93.7
265	0.81	0.938	202	26.3	7.18	189	93.7
265	0.75	0.930	185	26.3	6.59	173	93.6
265	0.69	0.915	168	26.3	5.98	157	93.5
265	0.63	0.905	152	26.3	5.38	142	93.2
265	0.58	0.885	136	26.3	4.78	126	92.7
265	0.52	0.863	120	26.3	4.18	110	91.7
265	0.46	0.839	103	26.3	3.59	94.3	91.3
265	0.41	0.797	86.7	26.3	2.98	78.5	90.5
265	0.36	0.740	70.2	26.3	2.38	62.7	89.3
265	0.34	0.597	53.6	26.3	1.79	47.0	87.7
265	0.29	0.472	36.3	26.3	1.18	31.1	85.7
265	0.18	0.384	18.1	26.3	0.59	15.4	85.0

Table 27 – Efficiency at 265 VAC, 26 V CV mode.

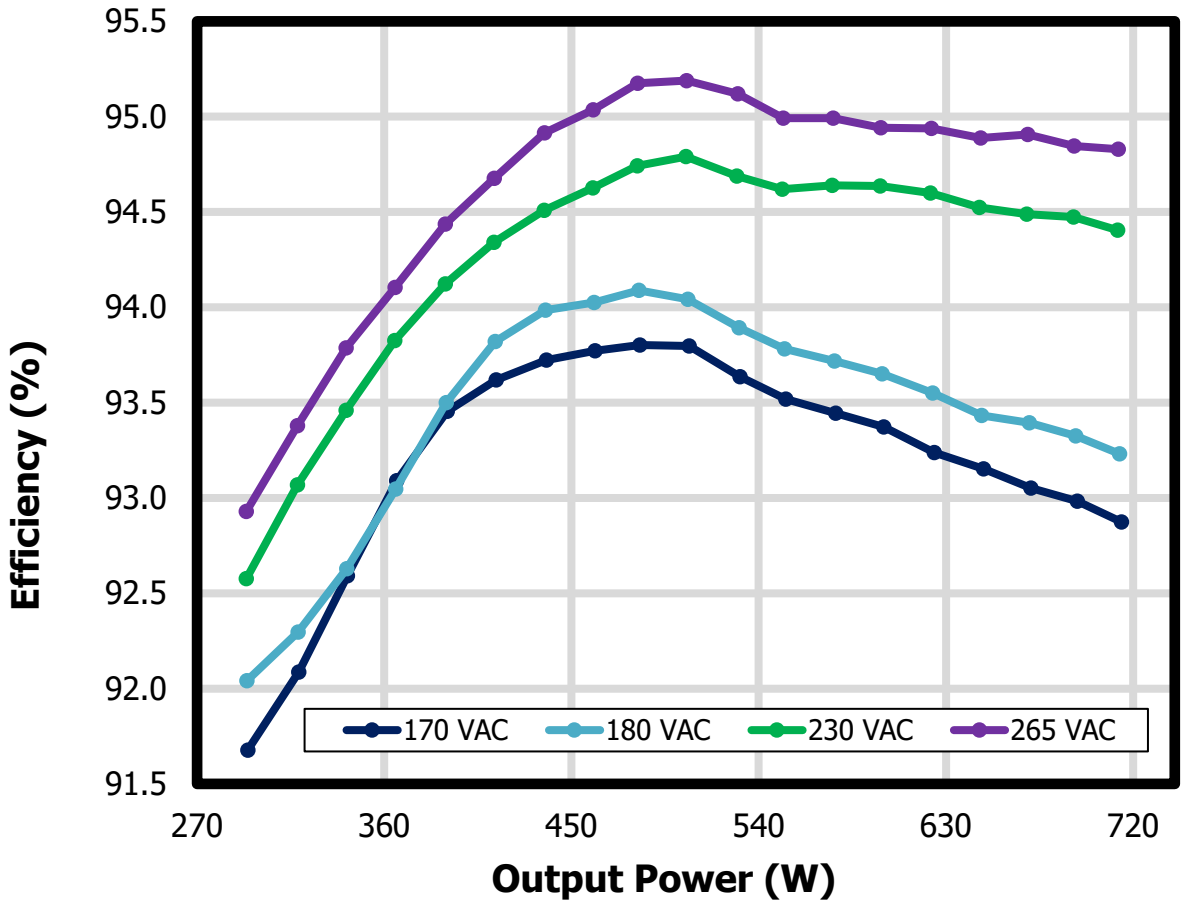


Figure 31 – Efficiency at 12 A CC Mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
170	4.54	0.998	769	59.4	12.0	714	92.9
170	4.40	0.997	745	57.6	12.0	693	93.0
170	4.25	0.997	721	55.8	12.0	671	93.1
170	4.10	0.997	696	53.9	12.0	648	93.2
170	3.95	0.997	670	51.9	12.0	624	93.2
170	3.79	0.996	643	49.9	12.0	600	93.4
170	3.64	0.996	618	48.0	12.0	577	93.4
170	3.49	0.996	591	46.0	12.0	553	93.5
170	3.35	0.995	567	44.2	12.0	531	93.6
170	3.19	0.995	540	42.1	12.0	506	93.8
170	3.04	0.994	515	40.2	12.0	483	93.8
170	2.91	0.993	492	38.4	12.0	461	93.8
170	2.77	0.993	467	36.4	12.0	438	93.7
170	2.62	0.991	442	34.4	12.0	414	93.6
170	2.48	0.991	418	32.4	12.0	390	93.5
170	2.33	0.990	393	30.4	12.0	366	93.1
170	2.20	0.989	370	28.5	12.0	342	92.6
170	2.06	0.987	346	26.5	12.0	319	92.1
170	1.91	0.985	321	24.5	12.0	294	91.7

Table 28 – Efficiency at 170 VAC, 12 A CC mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
180	4.26	0.997	765	59.4	12.0	713	93.2
180	4.13	0.997	742	57.6	12.0	692	93.3
180	4.00	0.997	717	55.7	12.0	670	93.4
180	3.86	0.996	693	53.8	12.0	647	93.4
180	3.71	0.996	667	51.9	12.0	624	93.6
180	3.57	0.996	640	49.9	12.0	599	93.7
180	3.43	0.995	615	47.9	12.0	576	93.7
180	3.28	0.995	589	46.0	12.0	552	93.8
180	3.15	0.995	565	44.2	12.0	530	93.9
180	3.00	0.994	538	42.1	12.0	506	94.0
180	2.86	0.993	513	40.1	12.0	482	94.1
180	2.74	0.992	490	38.3	12.0	461	94.0
180	2.60	0.991	465	36.4	12.0	437	94.0
180	2.47	0.990	440	34.4	12.0	413	93.8
180	2.34	0.990	417	32.4	12.0	390	93.5
180	2.20	0.988	393	30.4	12.0	365	93.1
180	2.07	0.987	369	28.5	12.0	342	92.6
180	1.94	0.986	345	26.5	12.0	319	92.3
180	1.80	0.986	319	24.5	12.0	294	92.0

Table 29 – Efficiency at 180 VAC, 12 A CC mode

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
230	3.30	0.993	755	59.3	12.0	712	94.4
230	3.20	0.993	732	57.6	12.0	691	94.5
230	3.10	0.993	708	55.7	12.0	669	94.5
230	2.99	0.992	684	53.8	12.0	646	94.5
230	2.88	0.992	658	51.8	12.0	623	94.6
230	2.77	0.991	632	49.8	12.0	598	94.6
230	2.67	0.990	608	47.9	12.0	575	94.6
230	2.56	0.990	583	45.9	12.0	551	94.6
230	2.46	0.988	559	44.1	12.0	529	94.7
230	2.34	0.987	533	42.1	12.0	505	94.8
230	2.24	0.987	508	40.1	12.0	482	94.7
230	2.14	0.986	486	38.3	12.0	460	94.6
230	2.04	0.986	462	36.4	12.0	437	94.5
230	1.93	0.985	438	34.4	12.0	413	94.3
230	1.82	0.984	414	32.4	12.0	389	94.1
230	1.72	0.983	389	30.4	12.0	365	93.8
230	1.62	0.981	365	28.4	12.0	342	93.5
230	1.51	0.986	342	26.5	12.0	318	93.1
230	1.40	0.984	317	24.5	12.0	294	92.6

Table 30 – Efficiency at 230 VAC, 12 A CC mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
265	2.89	0.981	752	59.3	12.0	713	94.8
265	2.81	0.979	729	57.6	12.0	692	94.9
265	2.72	0.979	705	55.7	12.0	669	94.9
265	2.63	0.977	681	53.8	12.0	647	94.9
265	2.53	0.977	656	51.9	12.0	623	94.9
265	2.44	0.976	631	49.8	12.0	599	94.9
265	2.34	0.976	606	48.0	12.0	576	95.0
265	2.25	0.974	581	46.0	12.0	552	95.0
265	2.16	0.974	557	44.1	12.0	530	95.1
265	2.06	0.971	531	42.1	12.0	505	95.2
265	1.96	0.972	506	40.1	12.0	482	95.2
265	1.89	0.968	484	38.3	12.0	460	95.0
265	1.79	0.968	460	36.4	12.0	437	94.9
265	1.70	0.965	436	34.4	12.0	413	94.7
265	1.61	0.964	412	32.4	12.0	390	94.4
265	1.51	0.968	388	30.4	12.0	365	94.1
265	1.42	0.968	364	28.4	12.0	342	93.8
265	1.33	0.965	341	26.5	12.0	318	93.4
265	1.24	0.963	316	24.5	12.0	294	92.9

Table 31 – Efficiency at 265 VAC, 12 A CC mode.

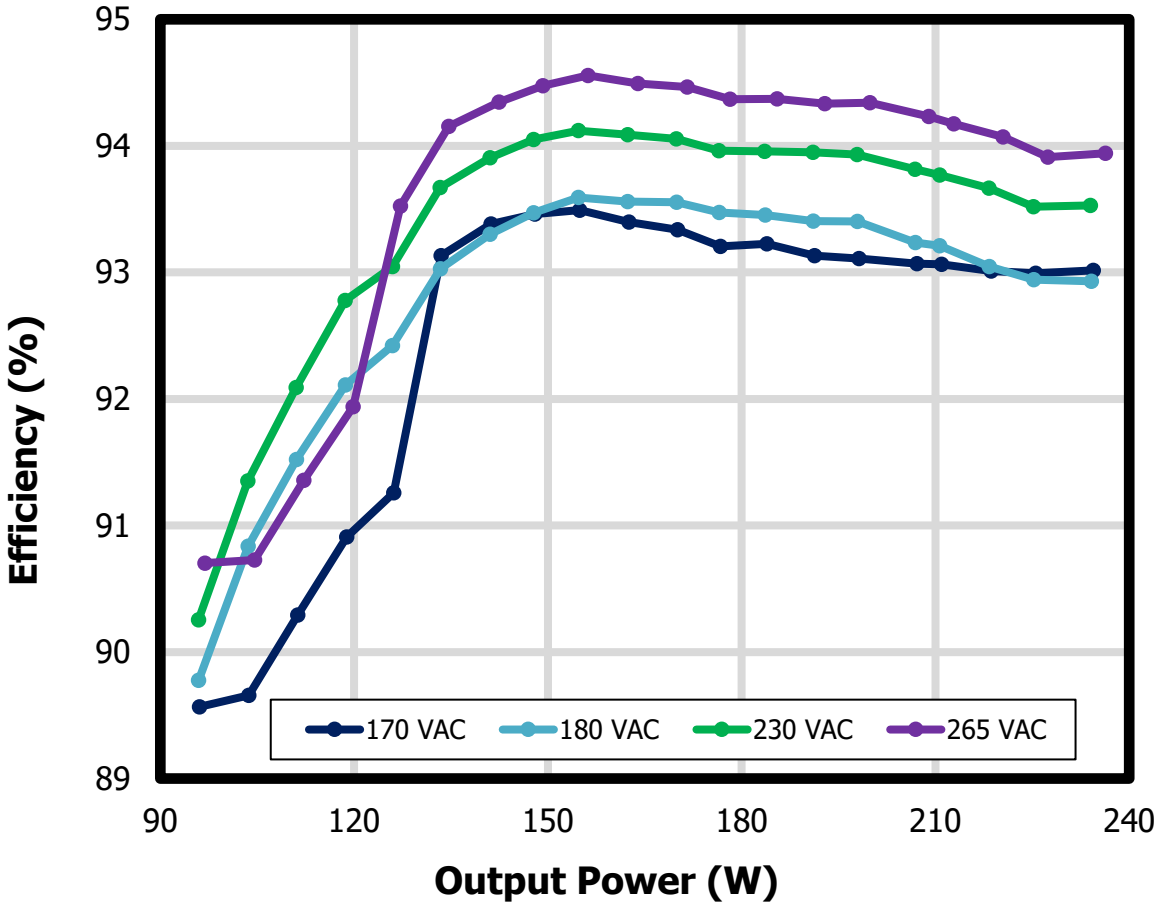


Figure 32 – Efficiency at 4 A CC Mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
170	1.50	0.986	252	58.5	4.01	234	93.0
170	1.45	0.986	243	56.3	4.00	226	93.0
170	1.40	0.986	235	54.6	4.00	219	93.0
170	1.35	0.985	227	52.7	4.00	211	93.1
170	1.33	0.985	223	51.8	4.00	207	93.1
170	1.27	0.984	213	49.5	4.00	198	93.1
170	1.23	0.983	205	47.8	4.01	191	93.1
170	1.18	0.983	197	46.0	4.00	184	93.2
170	1.13	0.983	190	44.2	4.00	177	93.2
170	1.09	0.982	182	42.5	4.00	170	93.3
170	1.04	0.983	174	40.7	4.00	163	93.4
170	0.99	0.983	166	38.7	4.00	155	93.5
170	0.95	0.983	158	37.0	4.00	148	93.5
170	0.90	0.983	151	35.3	4.00	141	93.4
170	0.86	0.982	143	33.4	4.00	133	93.1
170	0.83	0.981	138	31.5	4.00	126	91.3
170	0.78	0.980	131	29.7	4.00	119	90.9
170	0.74	0.977	123	27.8	4.00	111	90.3
170	0.70	0.974	116	25.9	4.00	104	89.7
170	0.65	0.970	107	24.0	4.00	96.1	89.6

Table 32 – Efficiency at 170 VAC, 4 A CC mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
180	1.42	0.985	252	58.5	4.00	234	92.9
180	1.37	0.985	242	56.3	4.00	225	93.0
180	1.32	0.984	235	54.6	4.00	218	93.1
180	1.28	0.983	226	52.7	4.00	211	93.2
180	1.25	0.983	222	51.8	4.00	207	93.2
180	1.20	0.982	212	49.5	4.00	198	93.4
180	1.16	0.982	205	47.7	4.00	191	93.4
180	1.11	0.982	197	46.0	4.00	184	93.5
180	1.07	0.982	189	44.2	4.00	177	93.5
180	1.03	0.982	182	42.5	4.00	170	93.6
180	0.98	0.982	174	40.6	4.00	162	93.6
180	0.93	0.982	165	38.7	4.00	155	93.6
180	0.89	0.981	158	37.0	4.00	148	93.5
180	0.86	0.980	151	35.3	4.00	141	93.3
180	0.81	0.979	143	33.4	4.00	133	93.0
180	0.77	0.977	136	31.5	4.00	126	92.4
180	0.73	0.975	129	29.7	4.00	119	92.1
180	0.69	0.972	121	27.8	4.00	111	91.5
180	0.65	0.967	114	25.9	4.00	104	90.8
180	0.62	0.963	107	24.0	4.00	95.9	89.8

Table 33 – Efficiency at 180 VAC, 4 A CC mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
230	1.11	0.980	250	58.5	4.00	234	93.5
230	1.07	0.979	241	56.3	4.00	225	93.5
230	1.04	0.978	233	54.6	4.00	218	93.7
230	1.00	0.977	225	52.7	4.00	211	93.8
230	0.98	0.976	221	51.8	4.00	207	93.8
230	0.94	0.974	211	49.5	4.00	198	93.9
230	0.91	0.973	203	47.7	4.00	191	94.0
230	0.87	0.972	195	46.0	3.99	184	94.0
230	0.84	0.971	188	44.2	4.00	176	94.0
230	0.81	0.970	181	42.5	4.00	170	94.1
230	0.77	0.968	172	40.6	4.00	162	94.1
230	0.74	0.965	164	38.7	4.00	155	94.1
230	0.71	0.962	157	37.0	4.00	148	94.1
230	0.68	0.959	150	35.3	4.00	141	93.9
230	0.65	0.955	142	33.4	4.00	133	93.7
230	0.62	0.950	135	31.5	4.00	126	93.1
230	0.59	0.943	128	29.7	4.00	119	92.8
230	0.56	0.936	121	27.8	4.00	111	92.1
230	0.53	0.926	113	25.9	4.00	104	91.4
230	0.50	0.916	106	24.0	4.00	95.9	90.3

Table 34 – Efficiency at 170 VAC, 4 A CC mode.

V_{IN}	I_{IN}	PF	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency
265	0.99	0.957	252	58.8	4.02	236	93.9
265	0.96	0.951	242	56.6	4.02	227	93.9
265	0.93	0.952	234	54.8	4.02	220	94.1
265	0.90	0.947	226	52.9	4.02	213	94.2
265	0.88	0.946	222	52.0	4.02	209	94.2
265	0.85	0.940	212	49.7	4.02	200	94.3
265	0.82	0.937	204	48.0	4.02	193	94.3
265	0.79	0.935	197	46.2	4.02	186	94.4
265	0.76	0.931	189	44.4	4.02	178	94.4
265	0.74	0.924	182	42.7	4.02	172	94.5
265	0.71	0.921	173	40.8	4.02	164	94.5
265	0.68	0.915	165	38.9	4.02	156	94.6
265	0.66	0.907	158	37.2	4.02	149	94.5
265	0.63	0.900	151	35.5	4.02	142	94.4
265	0.60	0.893	143	33.5	4.02	135	94.2
265	0.58	0.884	136	31.7	4.02	127	93.5
265	0.56	0.880	130	29.8	4.02	120	91.9
265	0.53	0.869	123	27.9	4.02	112	91.4
265	0.51	0.856	115	26.0	4.02	105	90.7
265	0.48	0.840	107	24.1	4.02	96.9	90.7

Table 35 – Efficiency at 170 VAC, 4 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.

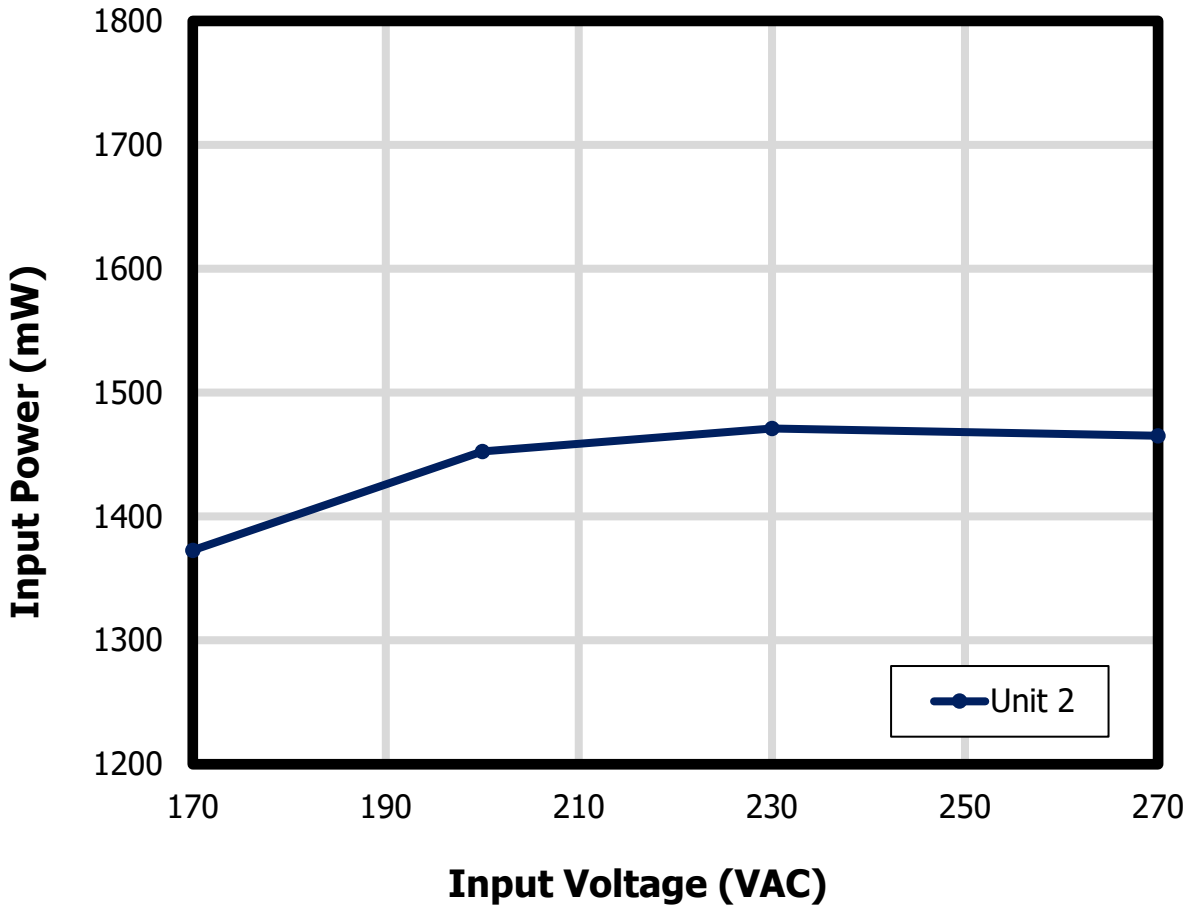


Figure 33 – No-Load Input Power.

VAC	Pin (mW)
170	1373
200	1453
230	1471
270	1465

Table 36 – 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 connected the output.

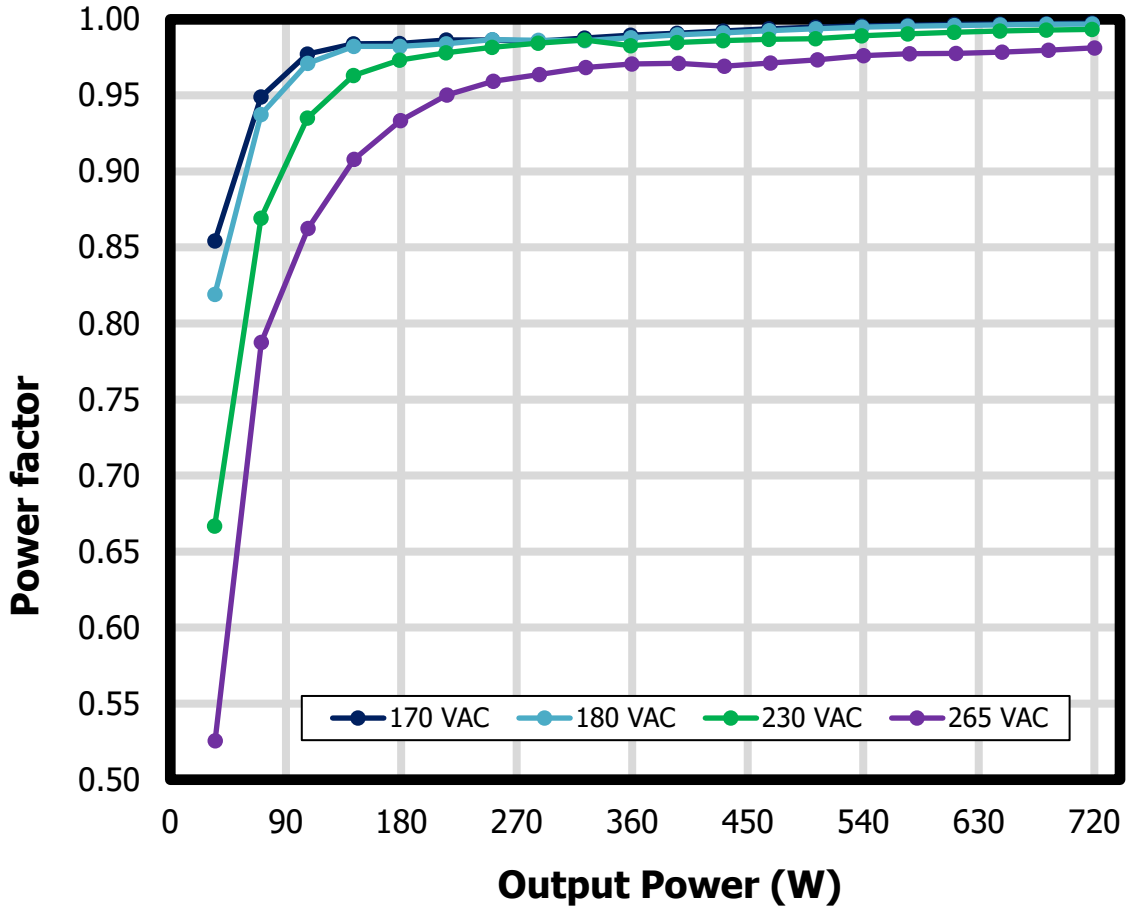


Figure 34 – Power Factor at 60 V CV Mode.

Load (W)	%	170 VAC	200 VAC	230 VAC	265 VAC
36	5%	0.834	0.817	0.683	0.524
144	20%	0.97	0.981	0.961	0.904
360	50%	0.989	0.988	0.982	0.968
720	100%	0.997	0.997	0.993	0.981

Table 37 – Power Factor across load at 60 V CV Mode.

11.5 Total Harmonic Distortion

Total harmonic distortion (THD) in the AC Current was measured at different line voltages with varying loads using a power meter. The converter operated in CV mode with a reference voltage of 60 V. A variable AC source was used to apply a sinusoidal voltage input and a DC electronic load (set to CC mode) was connected the output.

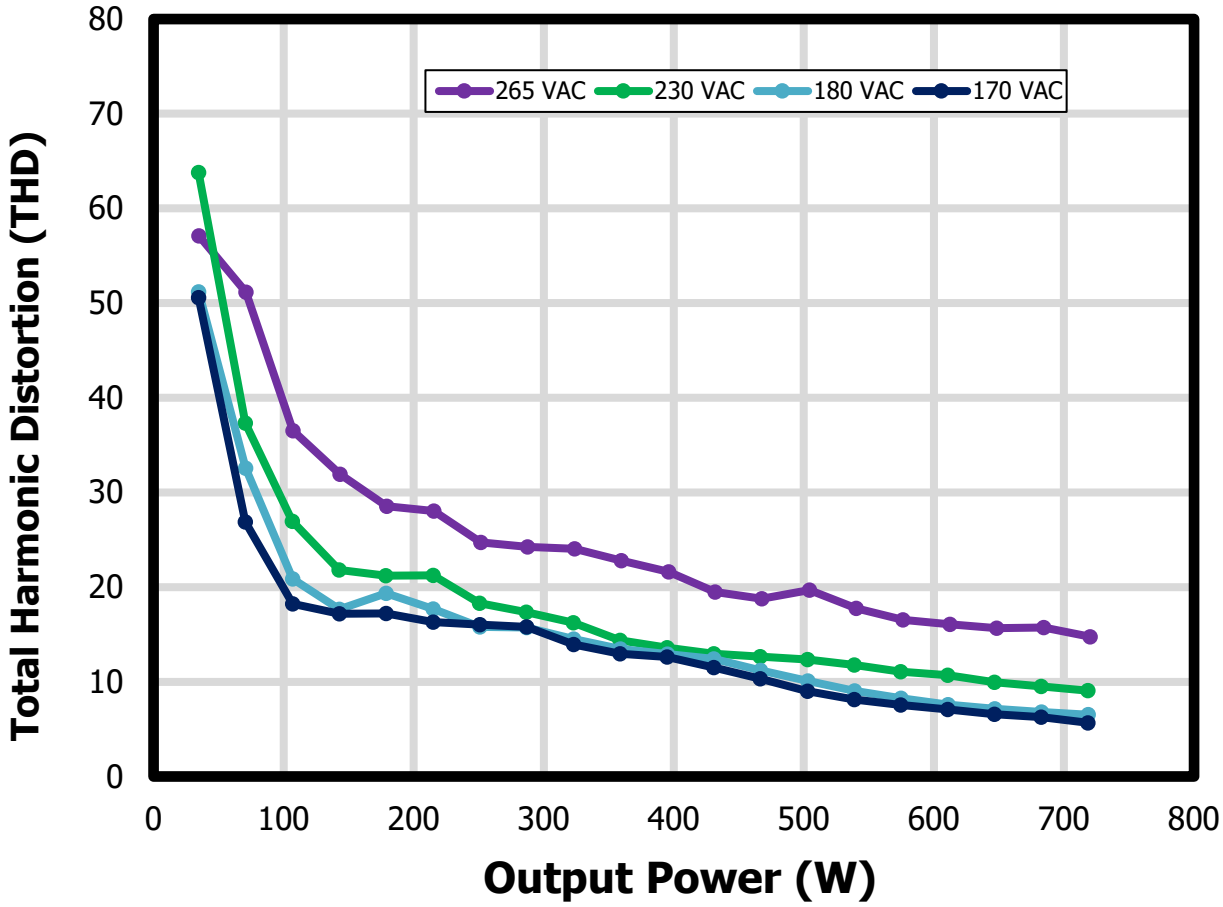


Figure 35 – Total Harmonic Distortion at 60 V CV Mode.

11.6 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 in CV Mode, with the reference set as 60 V. An electronic load was used to adjust power output and input AC voltage was varied with the AC source.

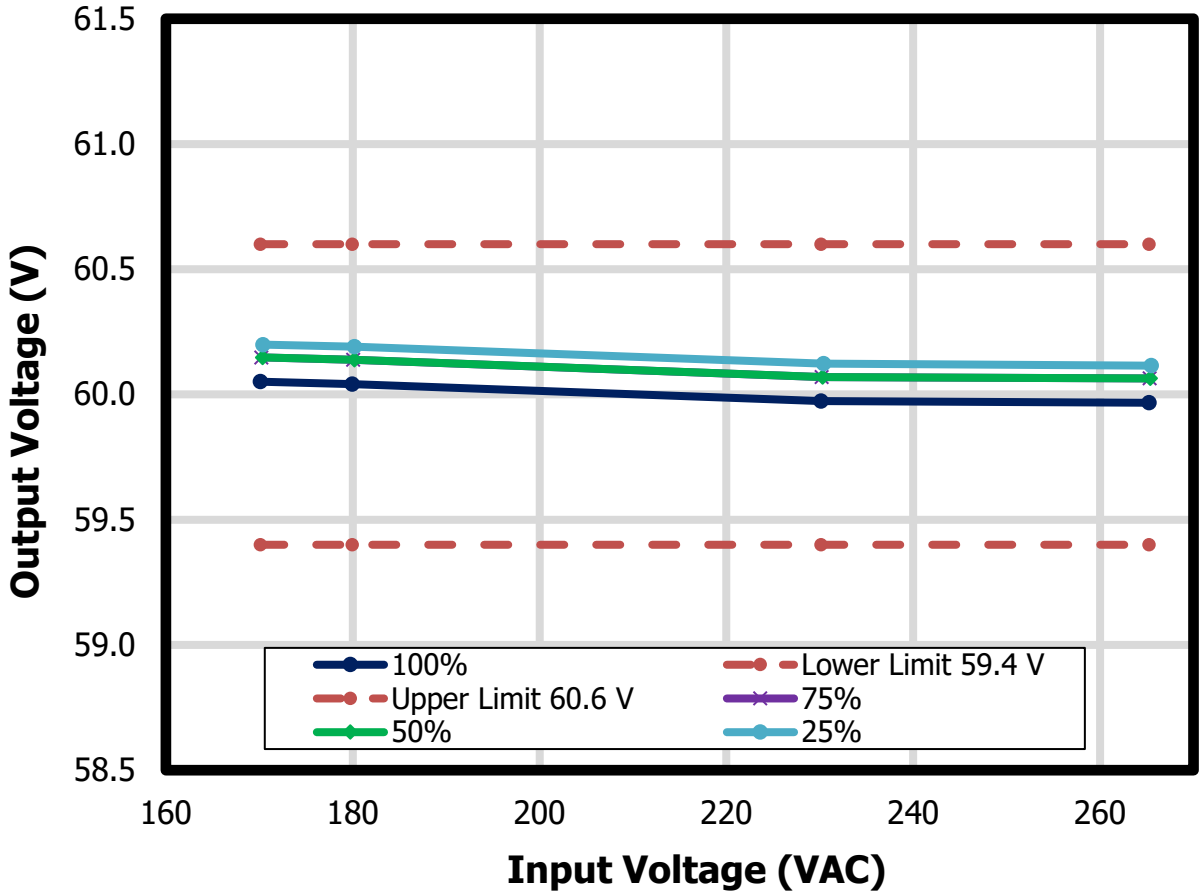


Figure 36 – Line Regulation at 60 V CV Mode for Different Output Load Percentage.

Input Voltage	25% Load	50% Load	75% Load	100% Load
170	60.2	60.2	60.1	60.1
180	60.2	60.1	60.1	60
230	60.1	60.1	60	60
265	60.1	60.1	60	60

Table 38 – Line Regulation across load at 60 V CV Mode.

11.7 Load Regulation

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

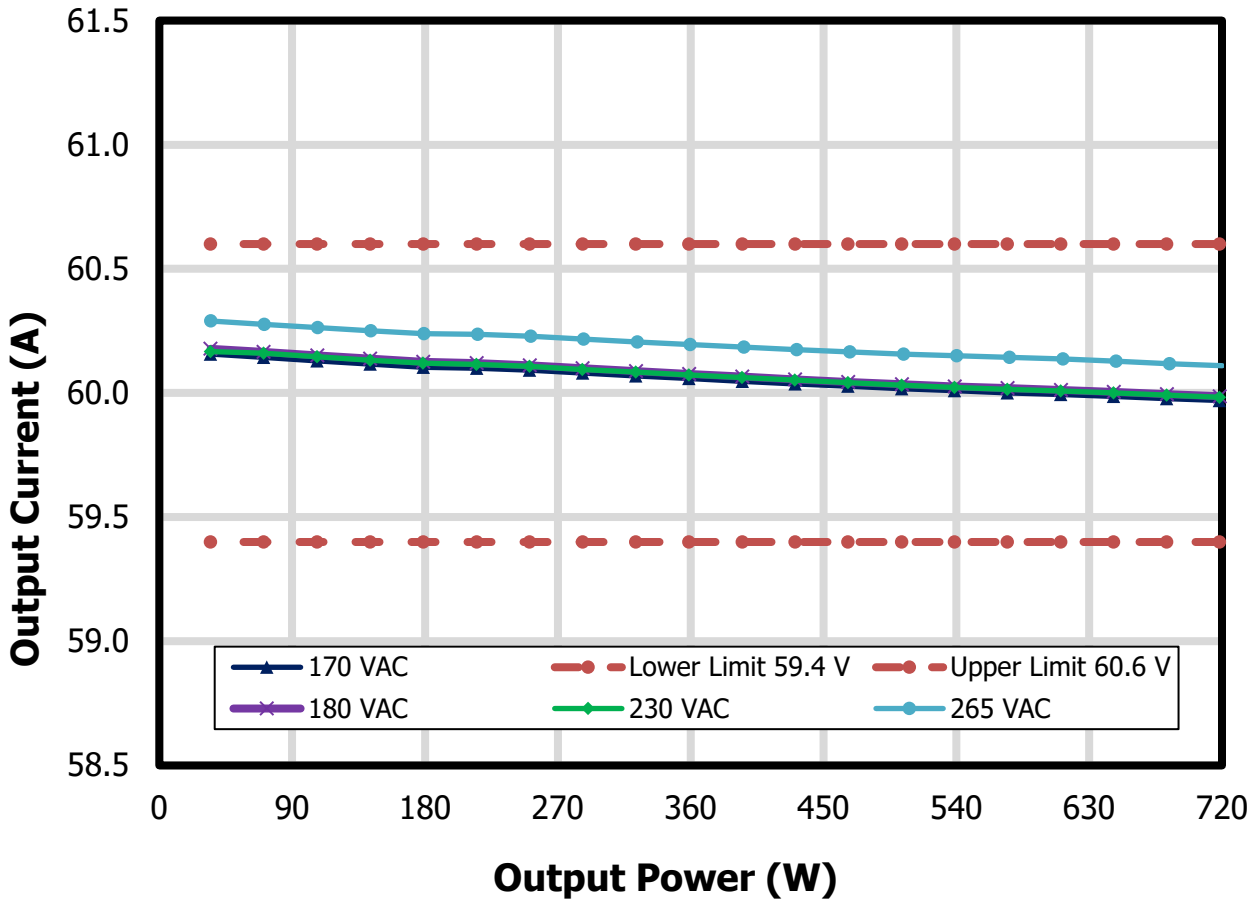


Figure 37 – Load Regulation at 60 V CV Mode.

V_{IN}	P_{OUT}	V_{OUT}
170	719	60.1
170	684	60.1
170	648	60.1
170	612	60.1
170	576	60.1
170	540	60.1
170	504	60.1
170	467	60.1
170	431	60.1
170	396	60.1
170	360	60.2
170	324	60.2
170	287	60.2
170	251	60.2
170	215	60.2
170	179	60.2
170	143	60.2
170	107	60.2
170	71.0	60.2
170	34.9	60.3

V_{IN}	P_{OUT}	V_{OUT}
180	719	60.0
179	684	60.1
180	647	60.1
180	612	60.1
180	575	60.1
180	540	60.1
180	504	60.1
180	467	60.1
180	431	60.1
180	396	60.1
180	359	60.1
180	323	60.2
180	287	60.2
180	251	60.2
180	215	60.2
180	179	60.2
180	143	60.2
180	107	60.2
180	70.9	60.2
180	34.9	60.3

Table 39 – Load Regulation at 170 VAC and 180 VAC (60 V CV Mode)

V_{IN}	P_{OUT}	V_{OUT}
230	718	60.0
230	682	60.0
230	646	60.0
230	611	60.0
230	574	60.0
230	539	60.0
230	503	60.0
230	466	60.0
230	431	60.1
230	395	60.1
230	359	60.1
230	323	60.1
230	287	60.1
230	251	60.1
230	215	60.1
230	179	60.1
230	143	60.1
230	107	60.2
230	70.6	60.2
230	34.6	60.2

V_{IN}	P_{OUT}	V_{OUT}
265	718	60.0
265	682	60.0
265	646	60.0
265	611	60.0
265	574	60.0
265	539	60.0
265	503	60.0
265	466	60.0
265	431	60.0
265	395	60.1
265	359	60.1
265	323	60.1
265	287	60.1
265	251	60.1
265	215	60.1
266	179	60.1
266	143	60.1
266	107	60.1
266	70.7	60.2
266	34.7	60.2

Table 40 – Load Regulation at 230 VAC and 265 VAC (60 V CV Mode)

12 Waveforms

The figures below show the waveforms recorded for different input voltage and output loading conditions.

12.1 Input AC Current, 100% Load – 60 V / 12 A

Input current was measured at different line voltages with an electronic load set to CC mode at full load, 12 A.

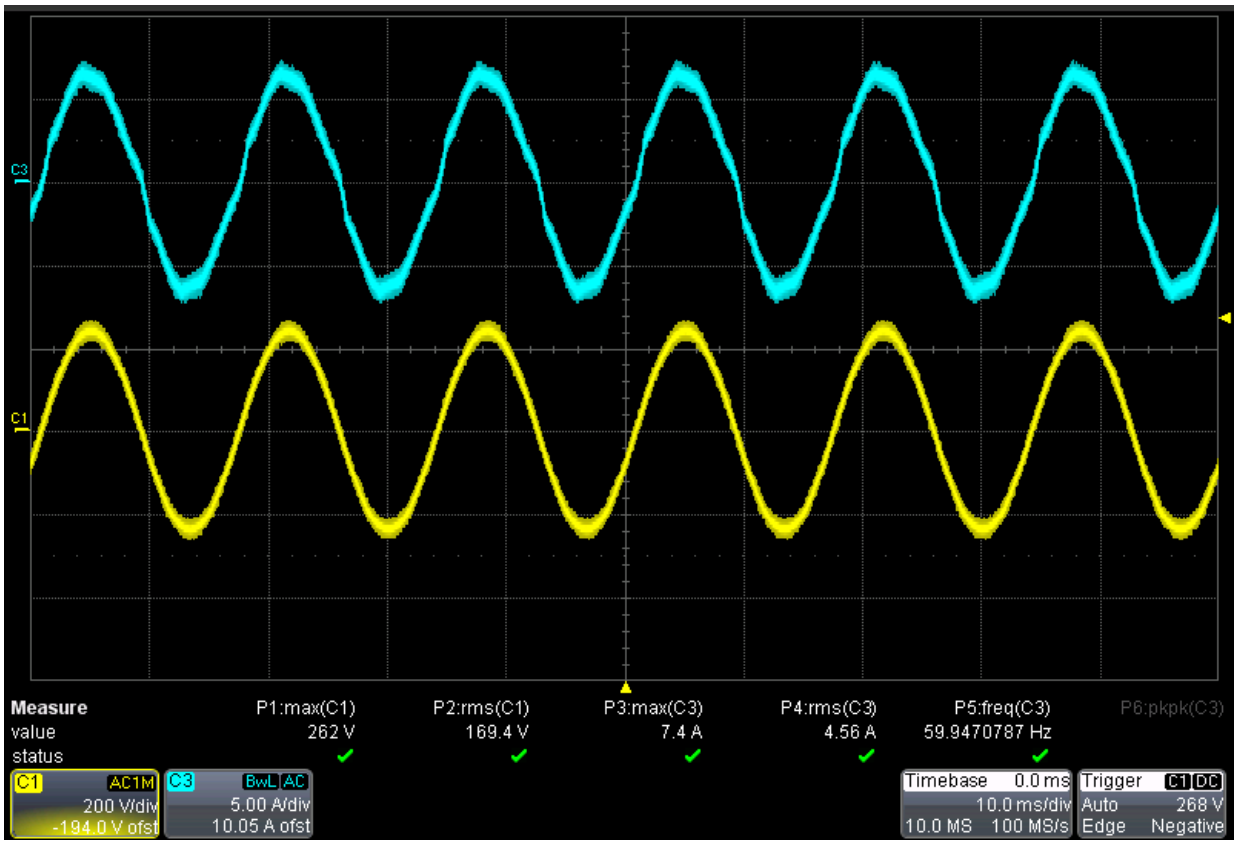


Figure 38 – Input Current, 170 VAC.
50 Hz, 10 ms/div.
CH1: V_{IN}, 200 V/div.
CH3: I_{IN}, 5 A/div.

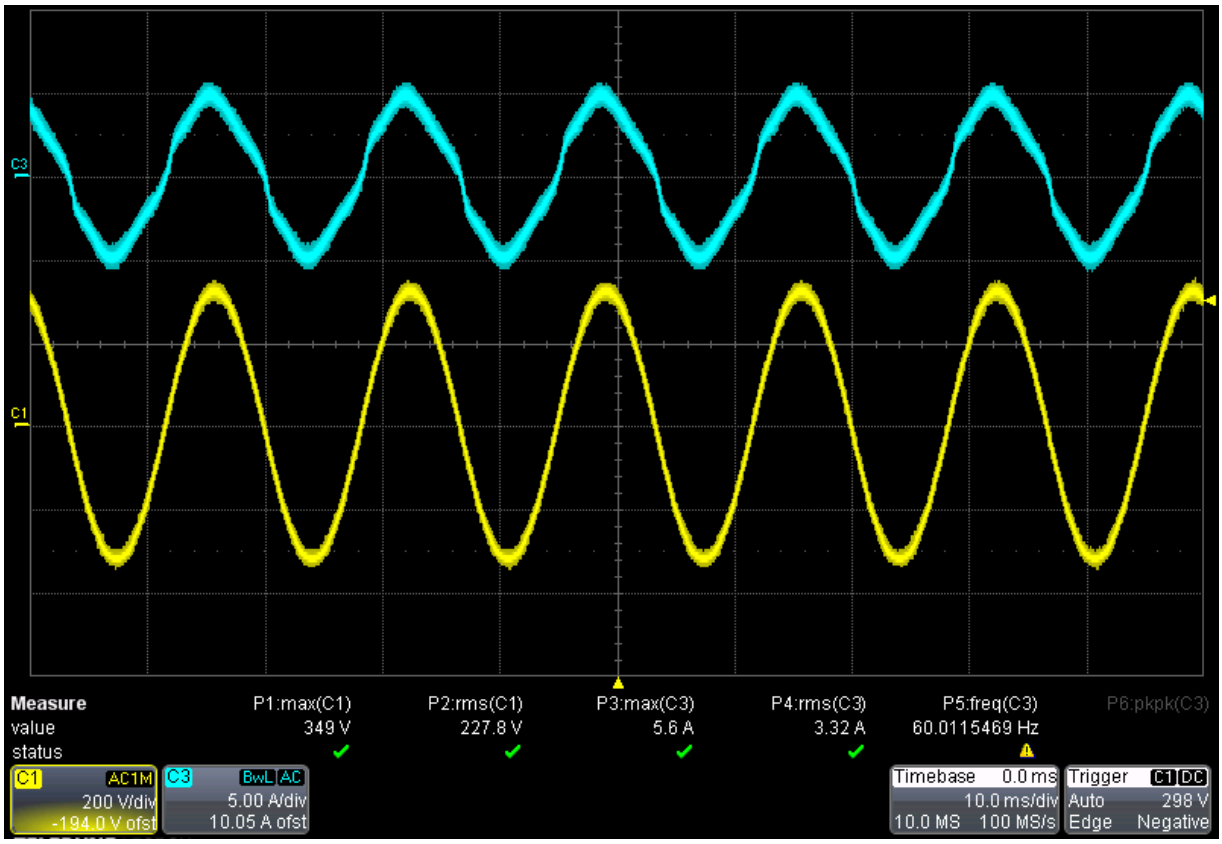


Figure 39 – Input Current, 230 VAC.
50 Hz, 10 ms/div.
CH1: V_{IN}, 200 V/div.
CH3: I_{IN}, 5 A/div.

12.2 PFC Voltage and Current, 100% Load

Figure 40 shows CCM operation of the HiperPFS-3 IC with 230 VAC input.

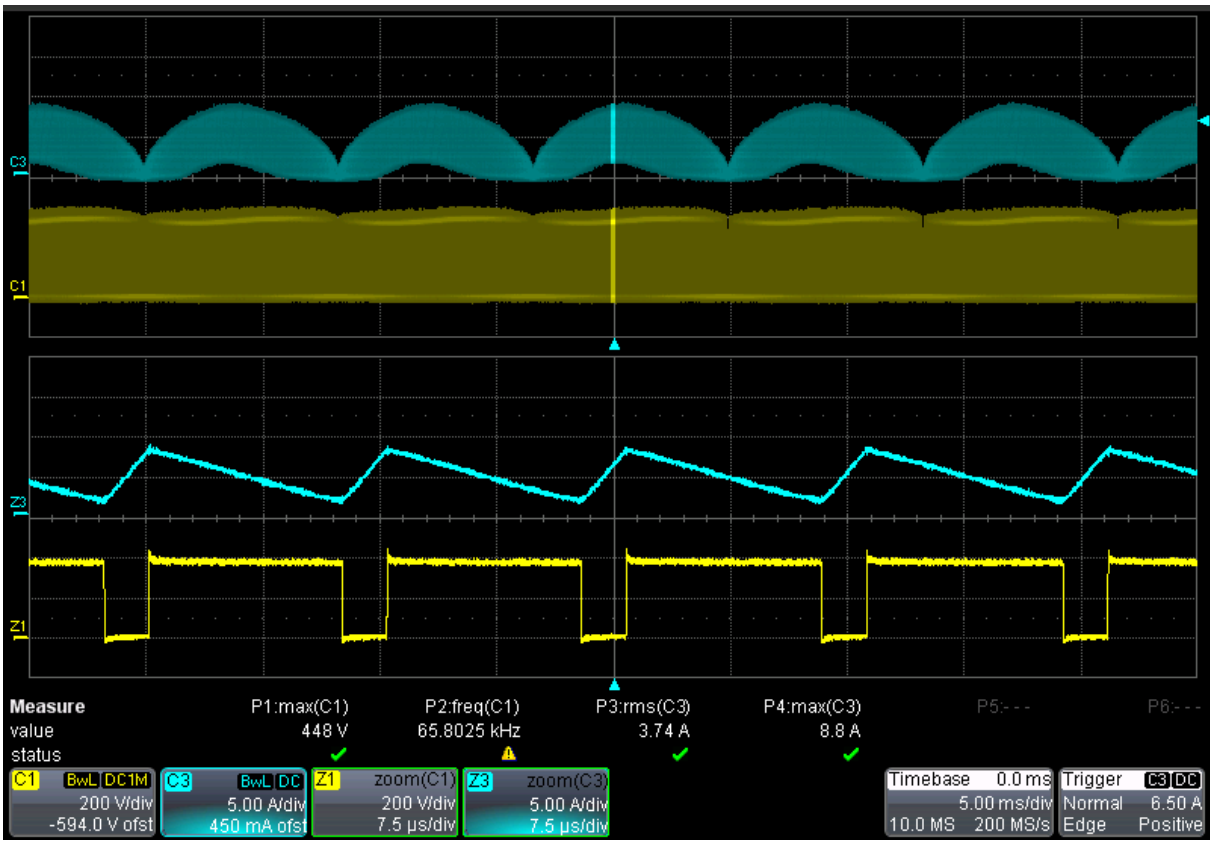


Figure 40 – V_{DS} and Choke Current, 230 VAC.
Time Division: 5 ms/div.
Zoom Time Division: 6 µs/div.
CH1: V_{DS_PFC}, 200 V/div.
CH2: IL_PFC, 5 A/div.

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 in CC Mode. Figure 40 and Figure 41 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.

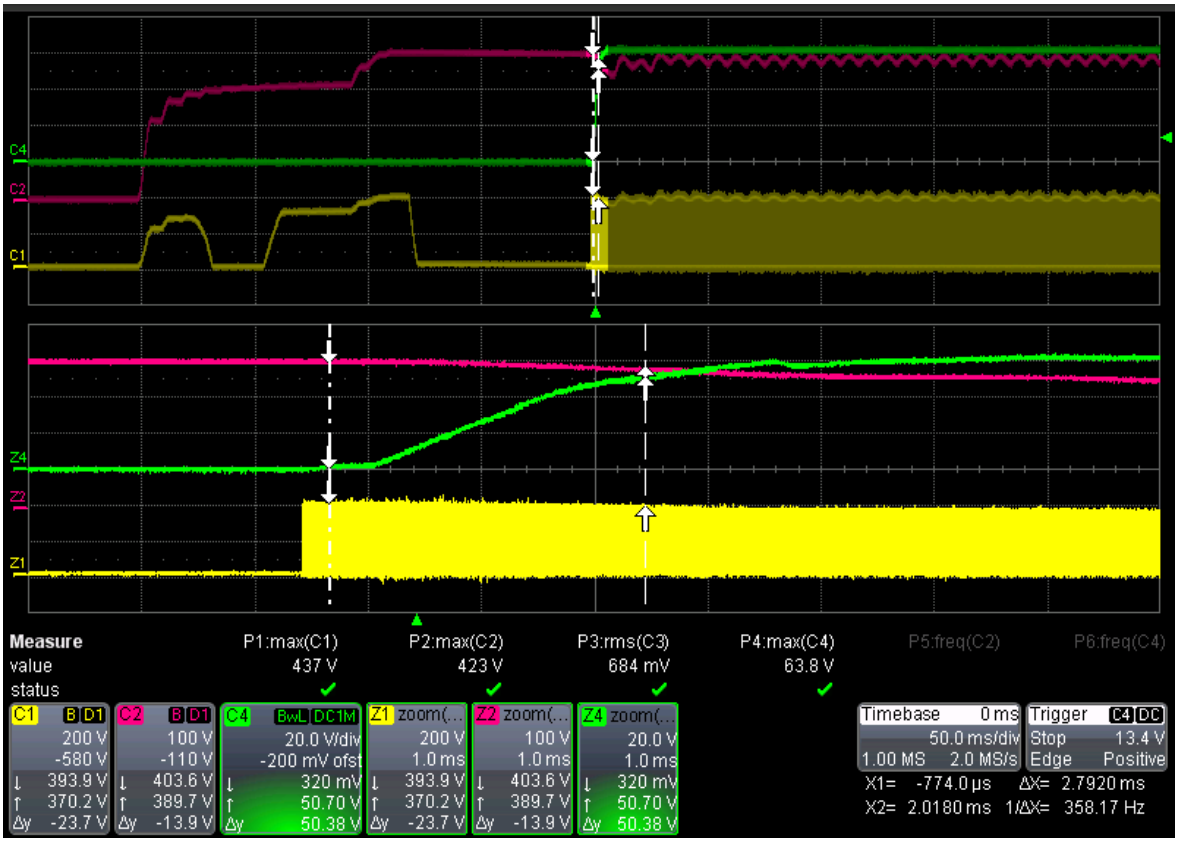


Figure 41 – Unit Start-up, 230 VAC, Full Load.
Zoom In Time/Division: 1 ms/div.
CH1: HB Voltage, 200 V/div.
CH2: PFC V_{OUT}, 100 V/div.
CH4: V_{OUT}, 20 V/div.

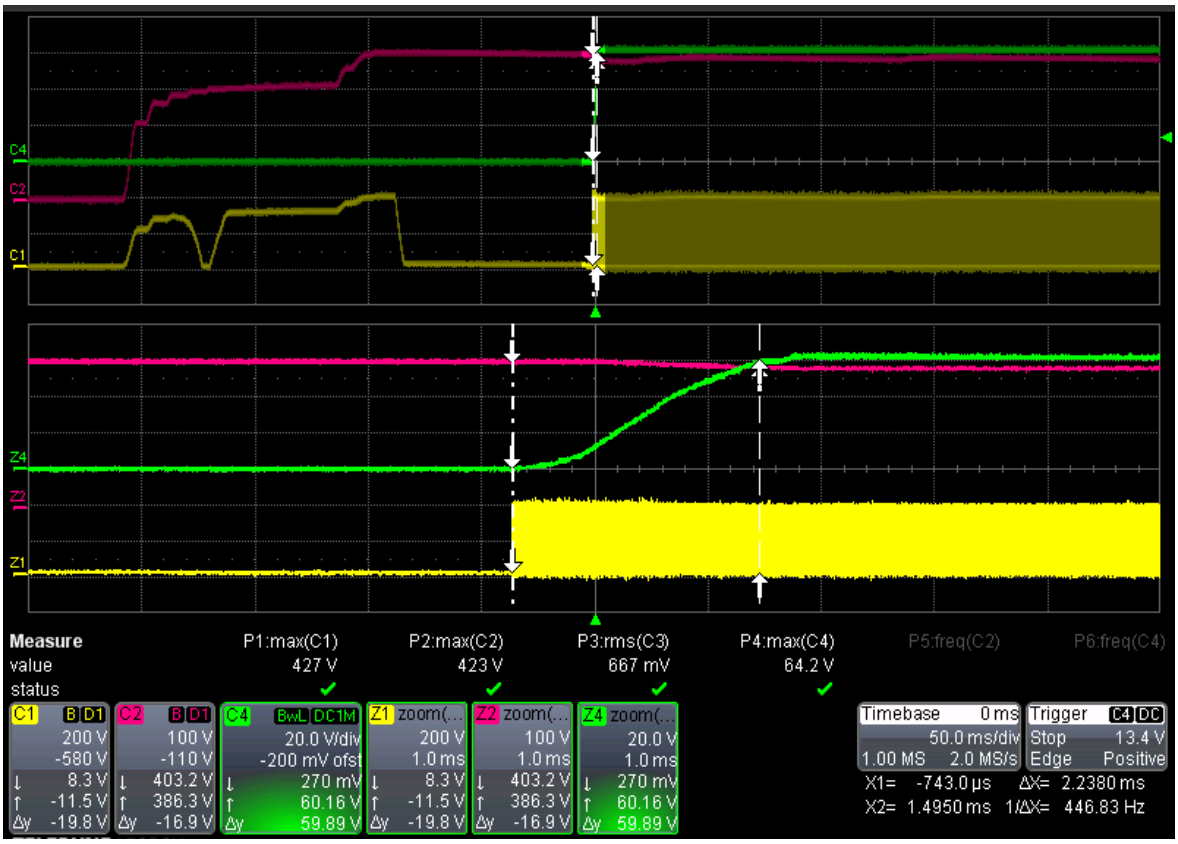


Figure 42 – Unit Start-up, 230 VAC, Half Load.
Zoom In Time/Division: 1 ms/div.
CH1: HB Voltage, 200 V/div.
CH2: PFC V_{OUT}, 100 V/div.
CH4: V_{OUT}, 20 V/div.

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 are shown in Figure 42 to Figure 48.

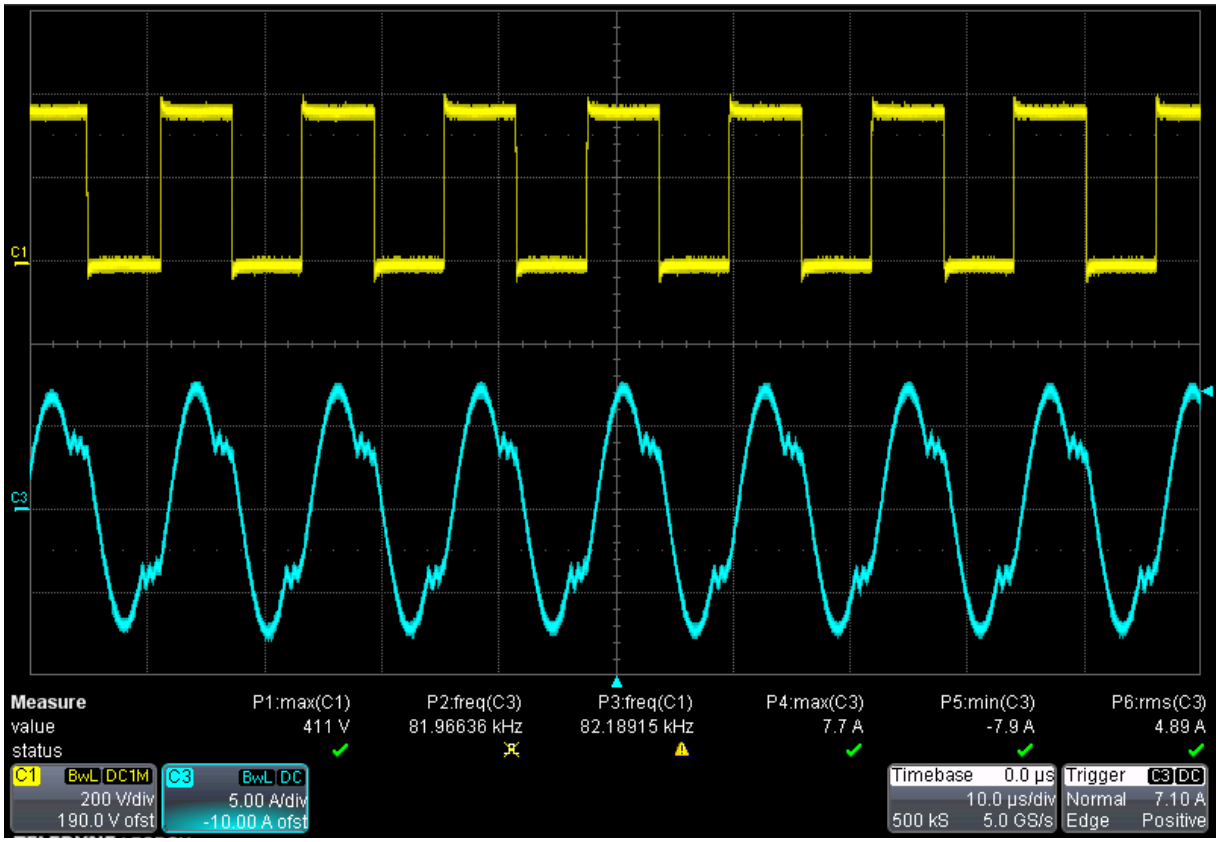


Figure 43 – LLC Stage Primary Voltage and Current, 60 V 12 A.
Time Division: 10 µs/div.
CH1: HB Voltage, 200 V/div
CH3: HB Current, 5 A/div.

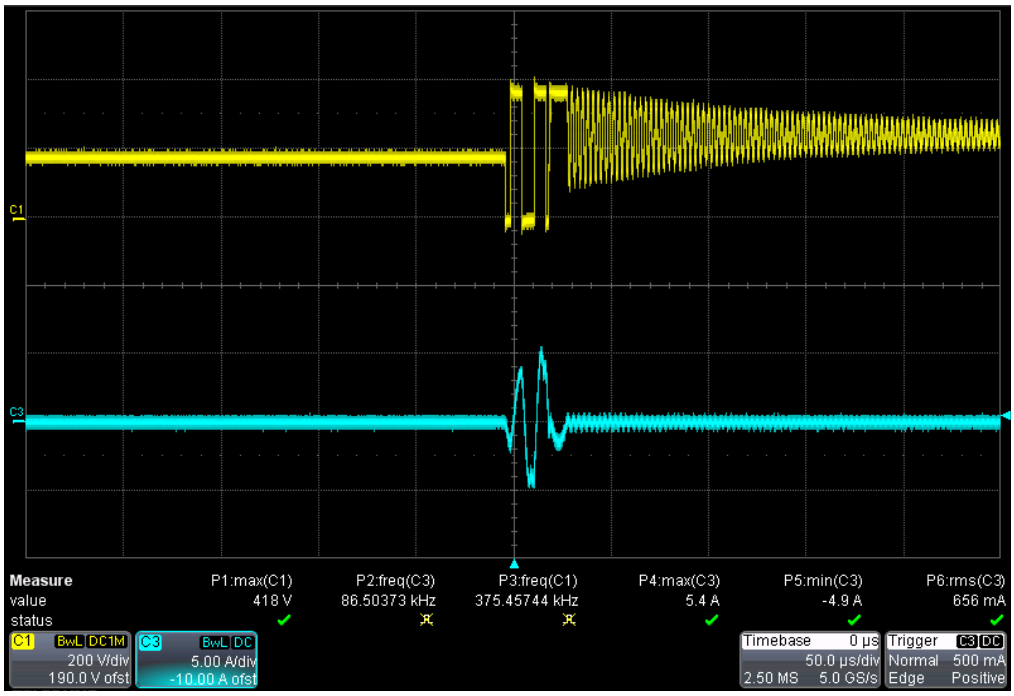


Figure 44 – LLC Stage Primary Voltage and Current, 60 V 0 A.
Time Division: 100 µs/div.
CH1: HB Voltage, 200 V/div
CH3: HB Current, 5 A/div.

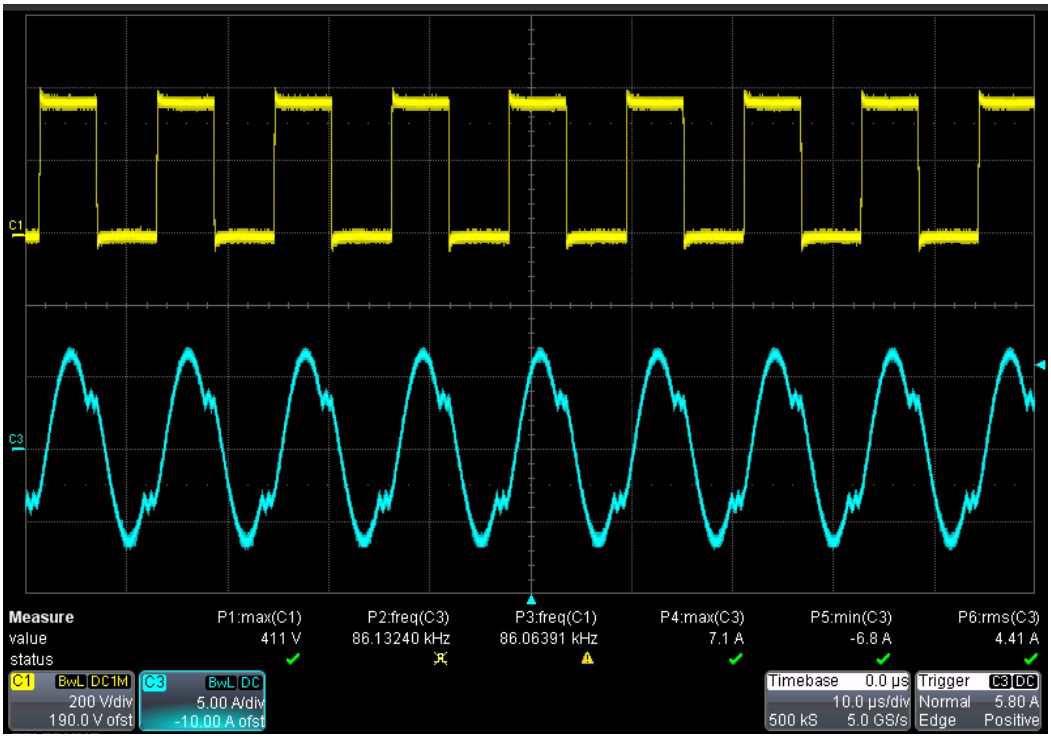


Figure 45 – LLC Stage Primary Voltage and Current, 55 V 12 A.
Time Division: 10 µs/div.
CH1: HB Voltage, 200 V/div
CH3: HB Current, 5 A/div.

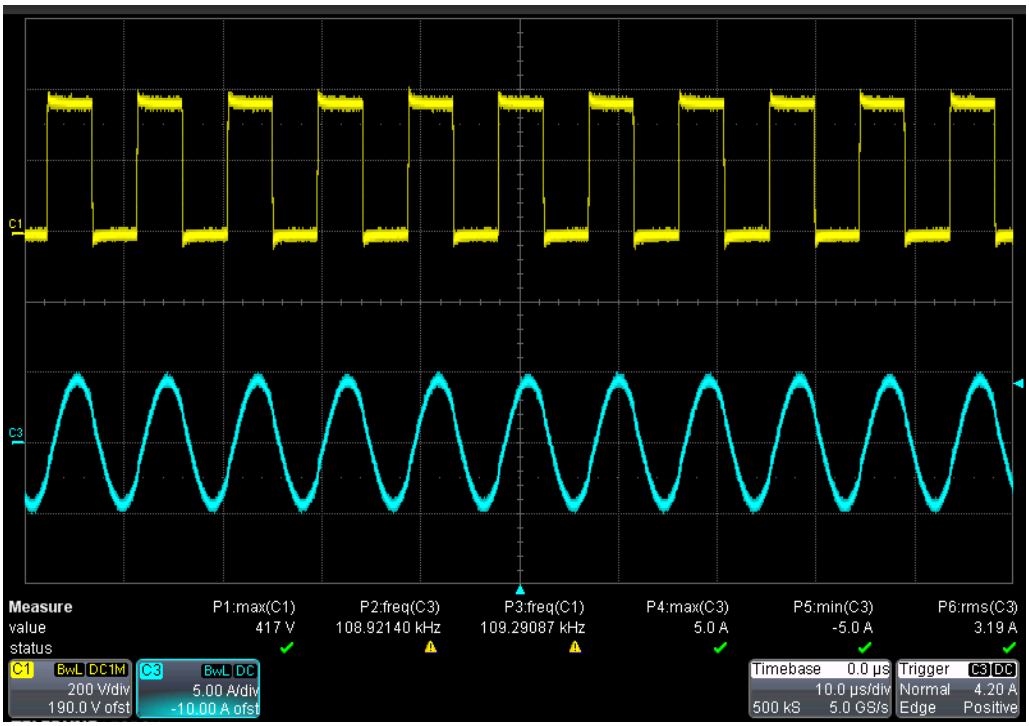


Figure 46 – LLC Stage Primary Voltage and Current, 40 V 12 A.
Time Division: 10 µs/div.
CH1: HB Voltage, 200 V/div
CH3: HB Current, 5 A/div.

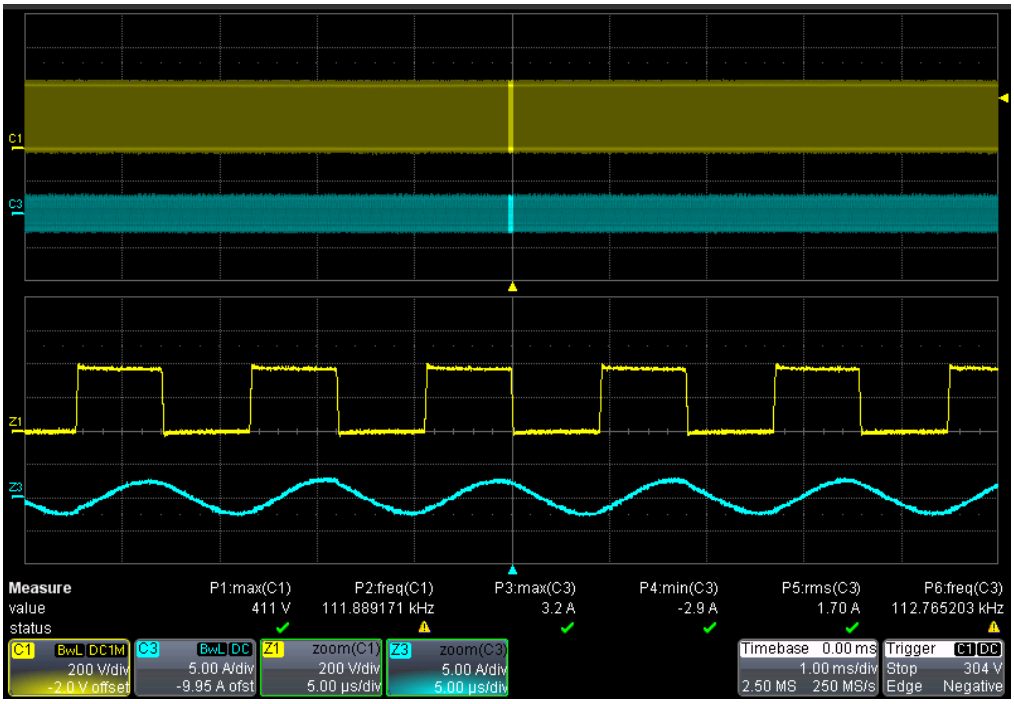


Figure 47 – LLC Stage Primary Voltage and Current, 40 V 4 A.
Zoom In Time Division: 5 µs/div.
CH1: HB Voltage, 200 V/div
CH3: HB Current, 5 A/div.

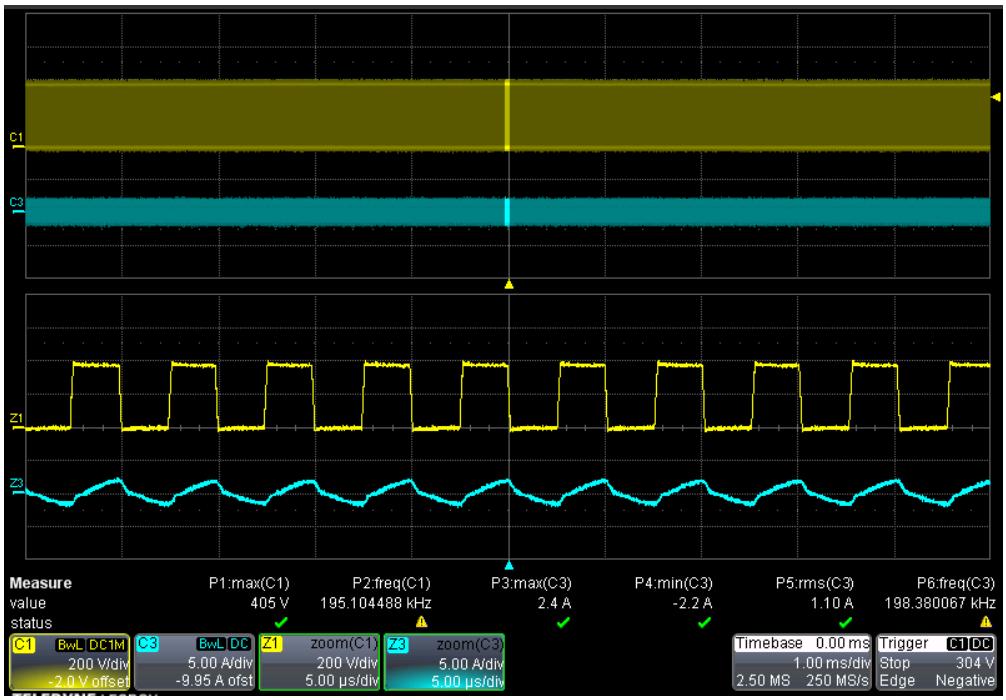


Figure 48 – LLC Stage Primary Voltage and Current, 30 V 4 A.
Zoom in Time Division: 5 µs/div.
CH1: HB Voltage, 200 V/div
CH3: HB Current, 5 A/div.

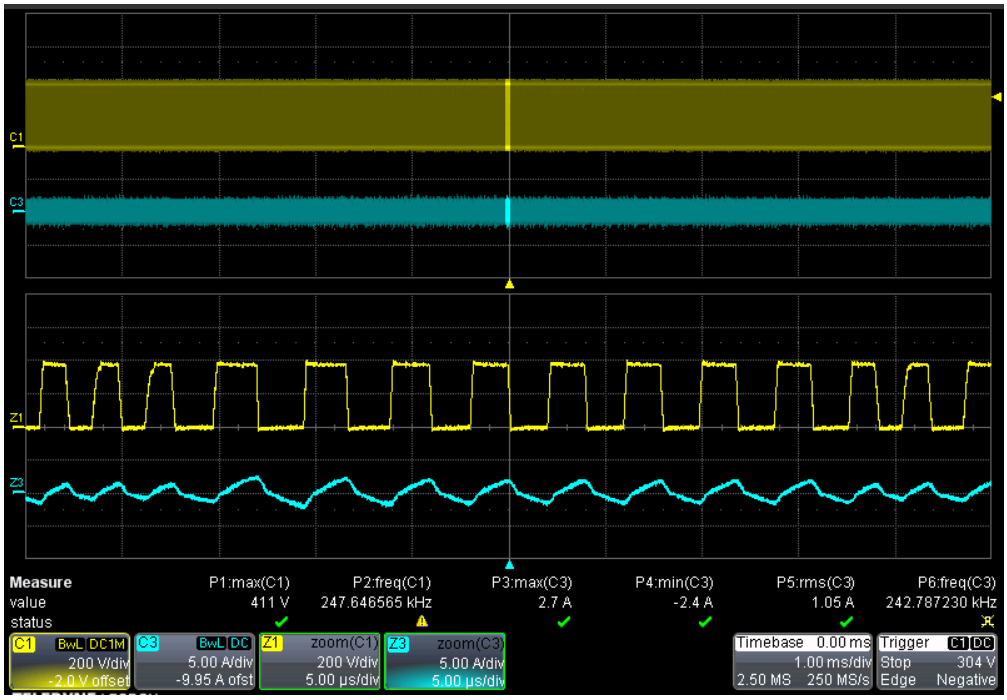


Figure 49 – LLC Stage Primary Voltage and Current, 26 V 4 A.
Zoom In Time Division: 5 µs/div.
CH1: HB Voltage, 200 V/div
CH3: HB Current, 5 A/div.

12.5 SR Waveforms

The voltage across the secondary synchronous rectifier MOSFET under continuous and discontinuous mode of operation were recorded at 60 V / 12 A and 26 V / 4 A and are shown in Figure 49 and Figure 50 respectively.

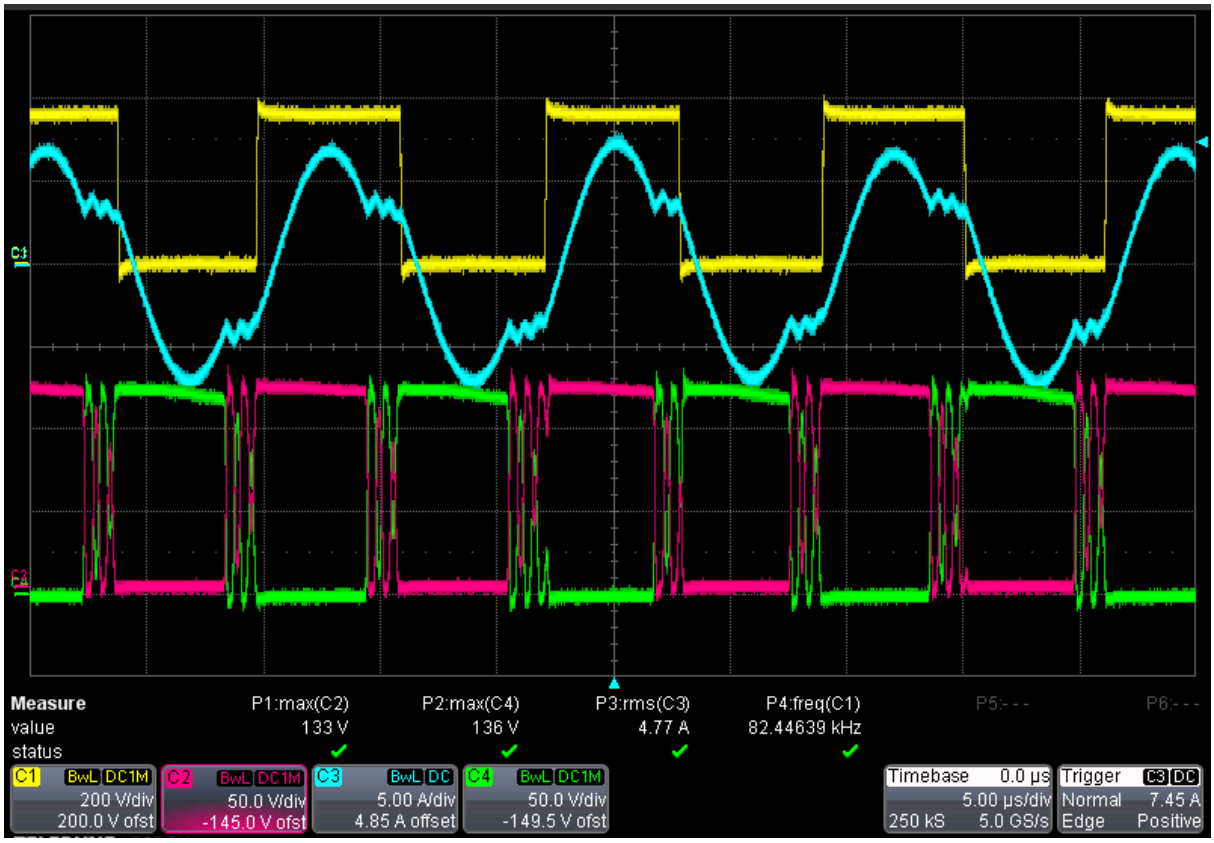


Figure 50 – Output Rectifier Peak Reverse Voltage at 60 V, 12 A.
Time Division: 5 µs/div.
CH1: HB Voltage, 200 V/div.
CH2: Q_6 V_{DS}, 50 V/div.
CH3: HB Current, 5 A/div.
CH4: Q_9 V_{DS}, 50 V/div.

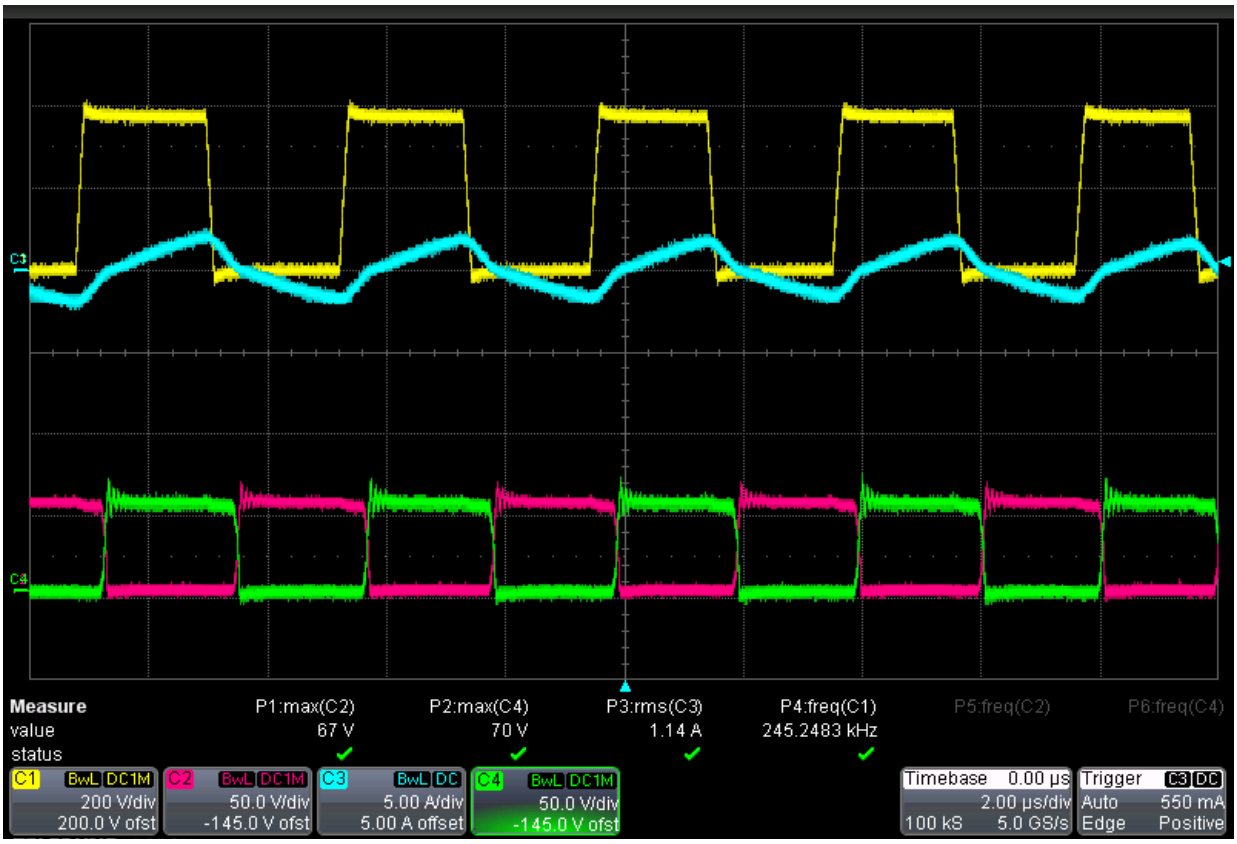


Figure 51 – Output Rectifier Peak Reverse Voltage at 26 V, 4 A.

Time Division: 2 µs/div.
CH1: HB Voltage, 200 V/div.
CH2: Q_6 V_{DS}, 50 V/div.
CH3: HB Current, 5 A/div.
CH4: Q_9 V_{DS}, 50 V/div.

12.6 Dynamic Loading

Figure 51 and Figure 52 show the response of the LLC converter during a dynamic loading at 60 V output in CV mode.

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

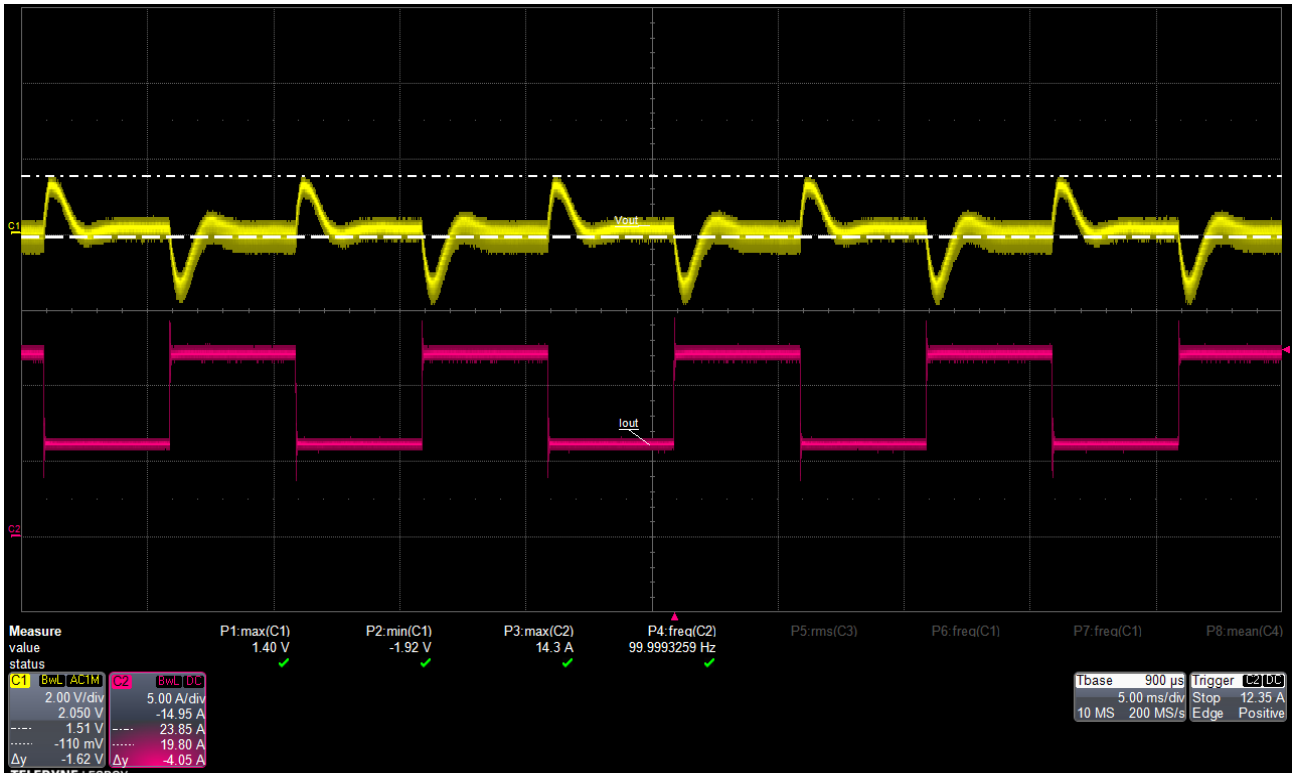


Figure 52 – Dynamic Loading, 230 VAC, 50-100% Load.
Time Division: 200 μs/div.
2.7% Output Regulation Change.
CH1: V_{OUT}, 2 V/div.
CH2: I_{OUT}, 5 A/div.

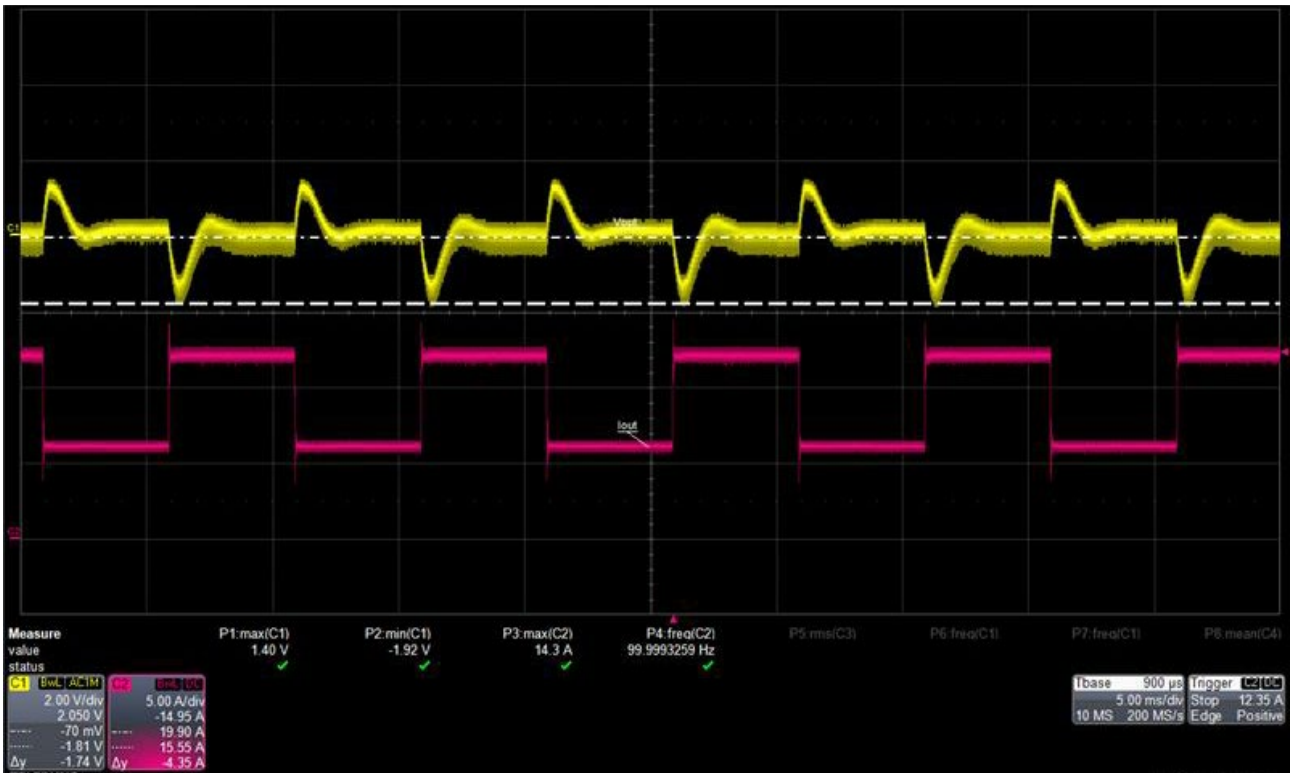


Figure 53 – Dynamic Loading. 230 VAC, 100-50% Load.

Time Division: 200 µs/div.
2.7% Output Regulation Change.
CH1: V_{OUT}, 2 V/div.
CH2: I_{OUT}, 5 A/div.

14 Appendix

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.

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

To enable MCU based control, the changes described below have been incorporated into the design to allow selective population of components.

Please refer to Figure 54 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.

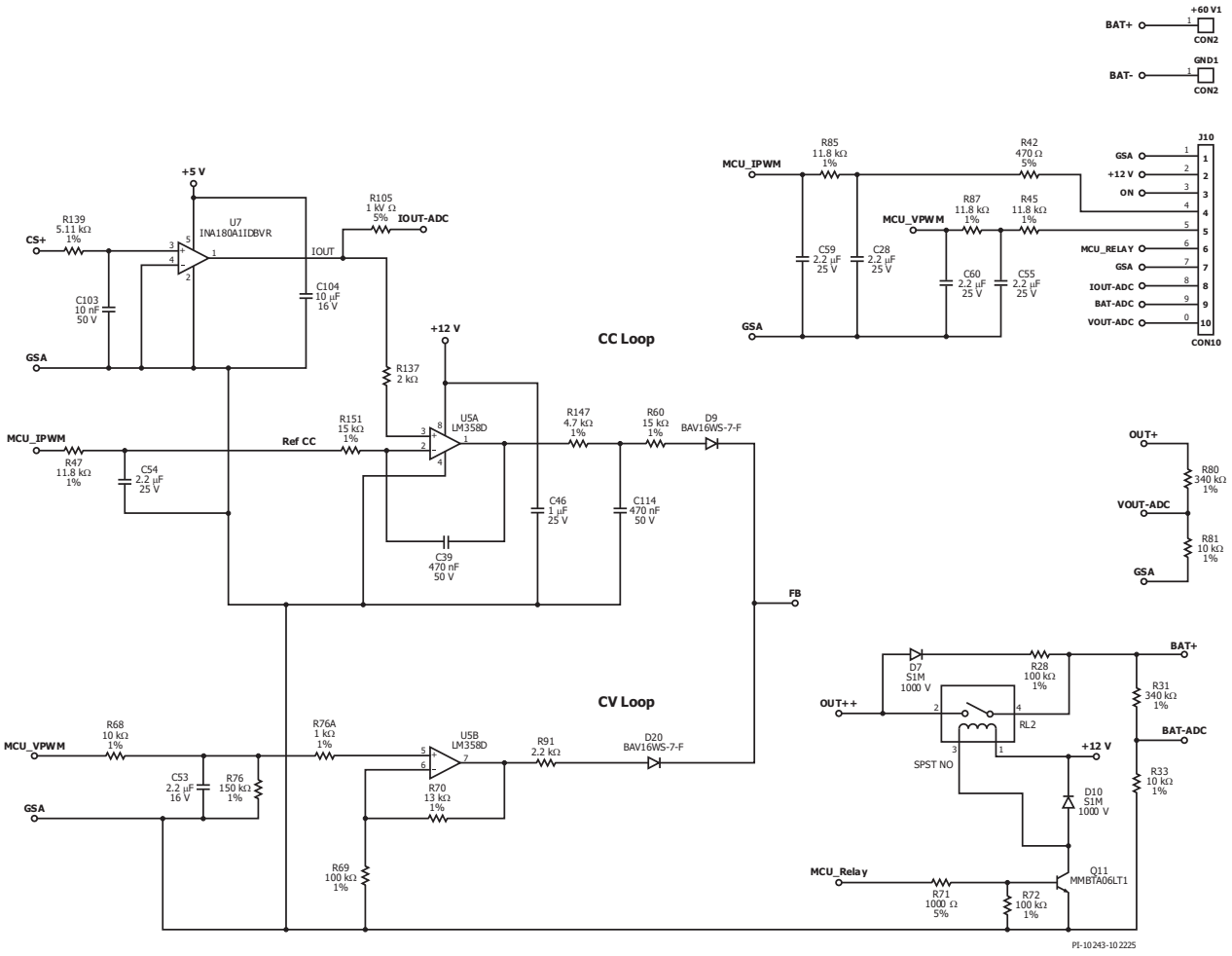


Figure 54 – CV/CC Control via MCU CAN Interface.

15 Revision History

Date	Author	Revision	Description and Changes	Reviewed
17-Sept-2025	CFM/HV	A	Initial Release	Apps & Mktg
22-Oct-2025	CFM	B	Figure 4 and 54 Correction. Corrected spelling errors.	Apps & Mktg

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