Offline 140W PD3.1 Adapter

PFC + Flyback with the MPX2002

Table of Contents

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

1 Overview

1.1 Description

The EVX2002-44018A-00B is a 140W, USB Type-C power delivery (PD) 3.1 reference design board. It features a very small form factor with a high power density. Its electrical specifications are well-suited for cellphone and computer power adapters. The reference design board provides very low no-load power consumption, and its high overall efficiency meets DOE Level VI and CoC Tier 2.

The MP44018A is a critical conduction mode (CrM) / discontinuous conduction mode (DCM), multi-mode power factor correction (PFC) controller that provides simple and high-performance active PFC using minimal external components. The switching frequency (f_{SW}) is reduced by dead time (DT) extension technology under light-load conditions, which improves light-load efficiency. The MP44018A also achieves reduced total harmonic distortion (THD) due to variable on-time control in DCM when compared to conventional constant-on-time (COT) control.

The MPX2002 is an all-in-one flyback controller with an integrated primary driving circuit, secondary controller, synchronous rectification driver, and safety-compliant feedback. The device offers the benefits of both primary-side regulation (PSR) and secondary-side regulation (SSR).The MPX2002 adopts novel quasi-resonant (QR) mode switching when it runs in DCM. Due to this feature, the power supply has improved efficiency. Under very light loads, the controller enters burst mode to achieve very low standby power consumption. The MPX2002 offers frequency jittering to help dissipate the energy generated by conducted noise.

The EVX2002-44018A-00B is a reference design for a universal offline, isolated power supply with a 28V/5A, 20V/5A, 15V/3A, 12V/3A, 9V/3A, or 5V/3A output. This datasheet contains the complete specification of the power supply, a detailed circuit diagram, the entire bill of materials required to build the power supply, a drawing of the transformers, and performance testing.

1.2 Features

- Wide Operating Input Voltage (V_{IN}) Range (from 90V to 265V)
- High Power Density
- Low No-Load Consumption
- Meets DOE VI/CoC Tier 2 Efficiency
- Meets EN55022 Class B Emissions
- Surge Endurance: 2kV
- Short-Circuit Protection (SCP)
- Over-Voltage Protection (OVP)
- Under-Voltage Protection (UVP)
- Over-Temperature Protection (OTP)

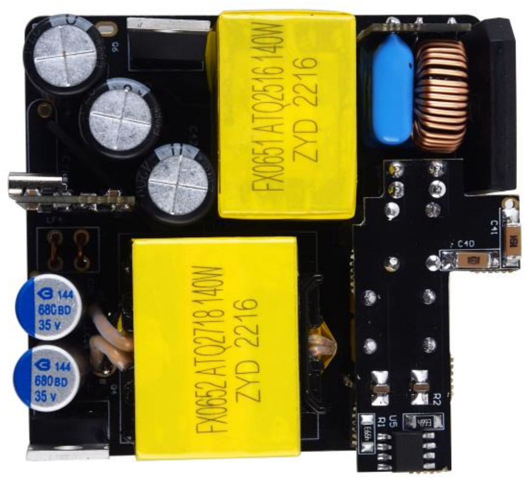


Figure 1: Top View

1.3 Applications

- Laptop Charging
- Mobile Phone Charging

All MPS parts are lead-free and adhere to the RoHS directive. For MPS green status, please visit the MPS website under Quality Assurance. "MPS", the MPS logo, and "Simple, Easy Solutions" are registered trademarks of Monolithic Power Systems, Inc. or its subsidiaries.

High Voltage

Warning: Although this board is designed to satisfy safety requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

© 2023 MPS. All Rights Reserved.

2 Reference Design

2.1 Block Diagram

Figure 2 shows the reference design board's system block.

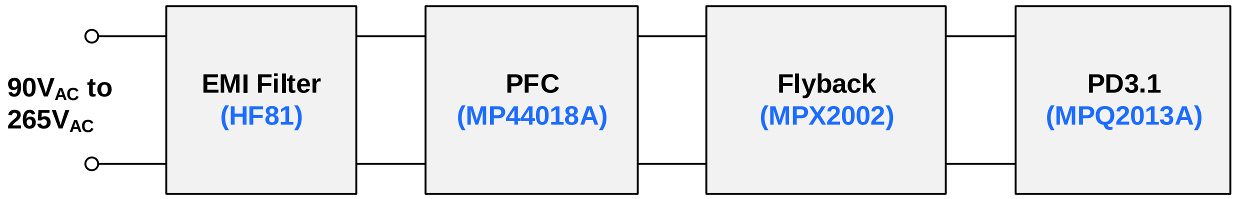


Figure 2: Block Diagram

2.2 Related Solutions

This reference design is based on the following MPS solutions:

Table 1: System Integrated Circuits

MPS Integrated Circuit	Description
MPX2002	All-in-one flyback controller
MP44018A	CrM/DCM multi-mode PFC controller
HF81	X-capacitor bleeder
MPQ2013A	Low quiescent current linear regulator

2.3 System Specifications

Table 2: System Specifications

Parameter	Specifications
Input voltage (V_{IN}) range	$90V_{AC}$ to $265V_{AC}$
Output voltage (V_{OUT})	28/20/15/12/9/5V
Nominal load	28V/5A, 20V/5A, 15V/3A, 12V/3A, 9V/3A, 5V/3A
PF	>0.93 at full load
Efficiency	>92.3% at full load
No Load-Consumption	<100mW
Output Voltage Ripple	<200mV
Line Regulation	<±3%
Load Regulation	<±3%
Short-Circuit Protection	Latch
Board form factor	62mmx59mmx23.5mm

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

3 Design

3.1 MPX2002 (All-in-One Flyback Controller)

The MPX2002 is an all-in-one flyback controller that integrates a primary driving circuit, secondary controller, synchronous rectification driver, and safety-compliance feedback all in one chip. The MPX2002 maintains the benefits of both PSR and SSR.

With the MPX2002, system complexity can be reduced since no feedback circuit is required. This also reduces the total BOM cost. The synchronous rectifier (SR) can be matched perfectly with the driving signal of the primary-side MOSFET. With this feature, the SR can operate safely in continuous conduction mode (CCM). Meanwhile, the SR controller integrated in the MPX2002 regulates the SR FET at very low threshold, which helps increase overall efficiency and provides the design with more flexibility. The SR power supply has an internal, integrated linear regulator, so the MPX2002 can drive the low-side SR FET without auxiliary winding, even when the output is too low.

The MPX2002 can run in CCM at heavy loads, then switches to QR mode when the load decreases. When the load drops further, the MPX2002 works in pulse-frequency modulation (PFM) and f_{SW} is fixed at 20kHz when it enters burst mode, which can prevent audible noise. With this feature, the MPX2002 can achieve high efficiency across all load conditions with excellent electromagnetic interference (EMI) performance.

3.2 MP44018A (CrM/DCM Multi-Mode PFC Controller)

The MP44018A is a CrM/DCM multi-mode PFC controller that provides simple and high-performance active power factor correction (PFC) using minimal external components. The MP44018A features a very low supply current. This allows the device to achieve low standby power loss, and the typical no-load power is below 30mW.

f_{SW} is reduced by dead time extension technology under light-load conditions, which improves light-load efficiency. The MP44018A also achieves a lower THD due to variable-on-time control in DCM when compared to conventional COT control.

3.3 HF81 (X-Capacitor Bleeder)

The HF81 is an innovative two-terminal IC that automatically discharges an X-capacitor while eliminating power losses and allowing power supplies to comply with safety standards.

The HF81 acts as a smart high-voltage switch when placed in series with discharge resistors (alternatively bleed resistors). In the presence of an AC voltage, the HF81 blocks current flow in the safety discharge resistors to reduce the power loss in these components to zero at $230V_{AC}$. When disconnected from the AC voltage, the HF81 automatically and safely discharges the X-capacitor by closing the circuit through the bleed resistors and directing the energy away from the exposed AC plug.

3.4 MP2013A (Low Quiescent Current Linear Regulator)

The MPQ2013A is a low-power linear regulator that supplies power to systems with high-voltage batteries. It features a wide 2.5V to 40V input voltage (V_{IN}) range, low dropout voltage, and low quiescent supply current. The low quiescent current and low dropout voltage allow for operation at extremely low power levels. Therefore, the MPQ2013A is ideal for low-power microcontrollers (MCUs) and the battery-powered equipment.

The MPQ2013A provides a wide variety of fixed output voltage (V_{OUT}) options by request: 1.8V, 1.9V, 2.3V, 2.5V, 3V, 3.3V, 3.45V, and 5V. It also provides an adjustable V_{OUT} option (from 1.215V to 15V). The regulator's output current is internally limited and the device is protected against overload and over-temperature (OT) conditions.

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

3.5 Schematics

Figure 3 shows the PFC stage.

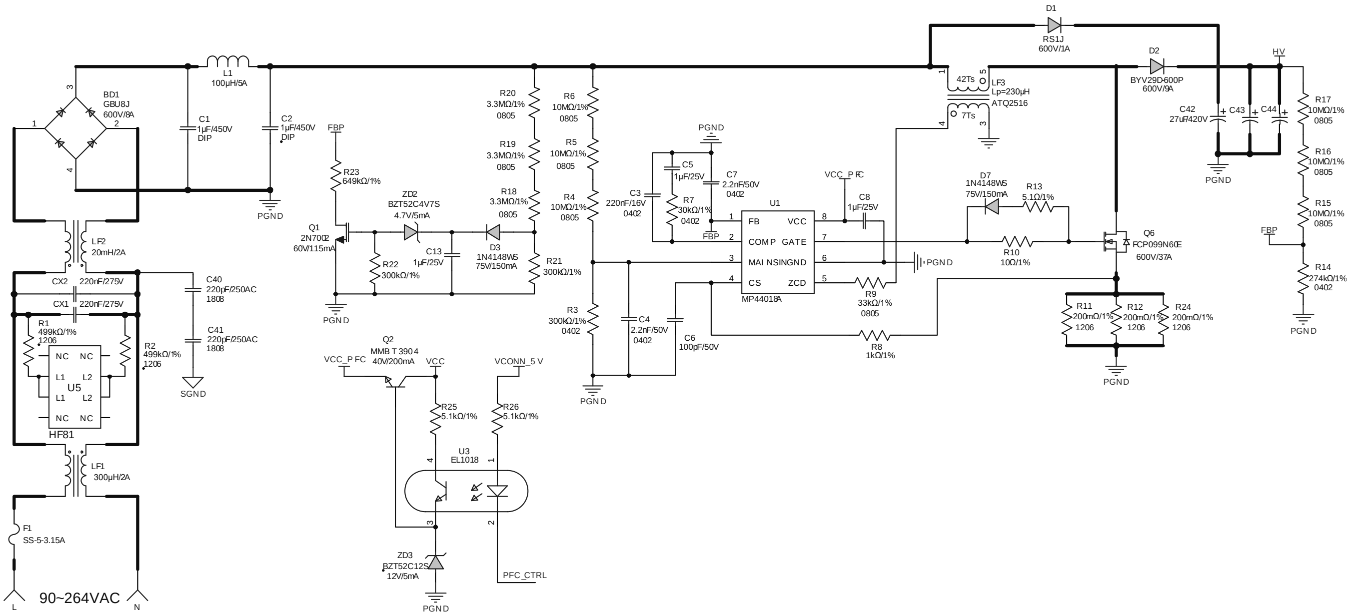


Figure 3: PFC Stage

Figure 4 shows the flyback stage.

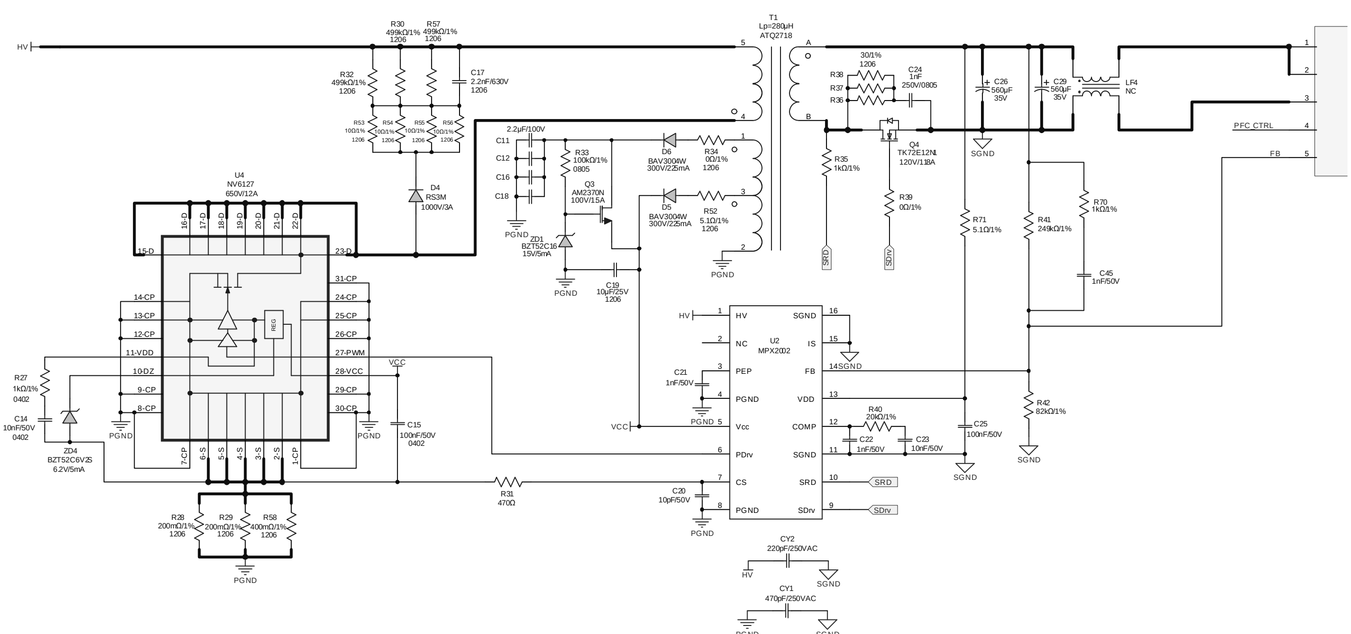


Figure 4: Flyback Stage

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Figure 5 shows the PD output stage.

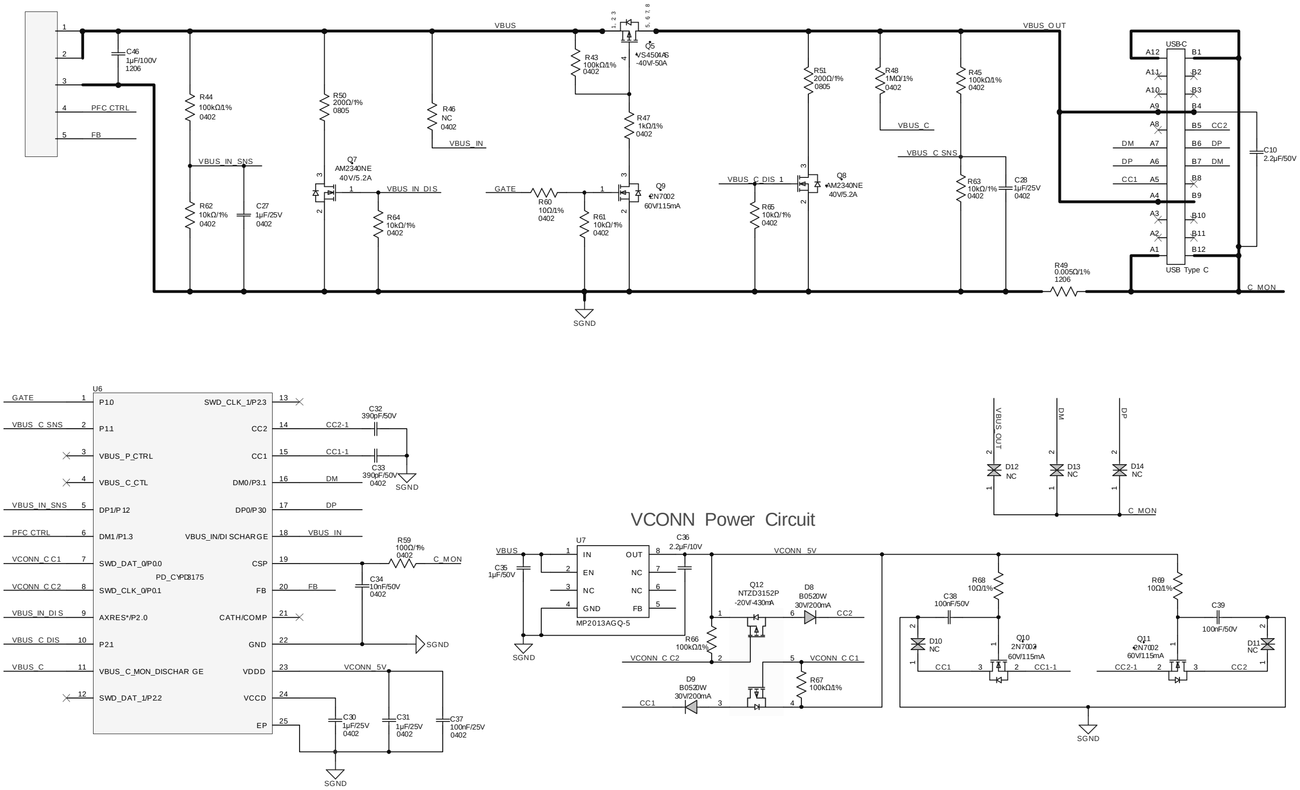


Figure 5: PD Output Stage

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

3.6 BOM

Qty	Ref	Value	Description	Package	Manufacturer	Manufacturer PN
Main Board/Power Stage						
1	BD1	600V	Bridge rectifier, 8A	DIP	Vishay	GBU8J-E3/51
2	C1, C2	1µF	CBB capacitor, 450V	DIP	DGCX	MPP105J450DP10T6
1	C3	220nF	Ceramic capacitor, 16V, X7R	0402	Murata	GRM155R71C224KA12D
2	C4, C7	2.2nF	Ceramic capacitor, 50V, X7R	0402	Murata	GRM155R71H222KA01D
3	C5, C8, C13	1µF	Ceramic capacitor, 25V, X7R	0603	Murata	GCM188R71E105KA64D
1	C6	100pF	Ceramic capacitor, 50V, NP0	0603	Wurth	885012006057
4	C11, C12, C16, C18	2.2µF	Ceramic capacitor, 100V, X7R	1206	Murata	GRM31CR72A225KA73L
1	C14	10nF	Ceramic capacitor, 50V, X7R	0402	Murata	GRM155R71H103KA88D
1	C15	100nF	Ceramic capacitor, 50V, X7R	0402	Murata	GRM155R71H104KE14D
1	C17	2.2nF	Ceramic capacitor, 630V, X7R	1206	Murata	GRM31BR72J222KW01L
1	C19	10µF	Ceramic capacitor, 25V, X7R	1206	Murata	GRM31CR71E106KA12
1	C20	10pF	Ceramic capacitor, 50V, X7R	0603	Murata	GRM1885C1H100JA01
2	C21, C22	1nF	Ceramic capacitor, 50V, C0G	0603	Murata	GRM1885C1H102JA01D
1	C23	10nF	Ceramic capacitor, 50V, X7R	0603	Murata	GRM188R71H103KA01D
1	C24	1nF	Ceramic capacitor, 250V, X7R	0805	TDK	C2012X7R2E102K
1	C25	100nF	Ceramic capacitor, 50V, X7R	0603	Murata	GRM188R71H104KA93D
2	C26, C29	680µF	Electrolytic capacitor, 35V	DIP	Beryl	PBD035M681F180RR1B
2	C40, C41	220pF	Ceramic capacitor, 250V, X7R	1808	Murata	GA342DR7GF221KW02
3	C42, C43, C44	27µF	Electrolytic capacitor, 420V	DIP	Beryl	ME420M270LO10*18TA-1A3ET
1	C45	1nF	Ceramic capacitor, 25V, X7R	0603	Murata	GRM1885C1E102JA01D
2	CX1, CX2	220nF	Capacitor, 275V_{AC}	DIP	DGCX	MPX224K275AP7.5T6Y
1	CY1	220pF	Capacitor, 400V	DIP	Murata	DE1B3KX221KA4BL01
1	CY2	470pF	Capacitor, 400V	SMD	TRX	THY1470J
1	D1	600V	Diode, 1A	SMA	Diodes, Inc.	RS1J-13-F
1	D2	600V	Diode, 9A	DPAK-3	WeEn	BYV29D-600P
2	D3, D7	75V	Diode, 0.15A	SOD-323	Diodes, Inc.	1N4148WS-7-F
1	D4	1000V	Diode, 3A	SMB	Diodes, Inc.	RS3MB
2	D5, D6	300V	Diode, 225mA	SOD-123	Diodes, Inc.	BAV3004W-7-F
1	F1	250V_{AC}	Fuse, 3.15A	DIP	Cooper Bussmann	SS-5-3.15A
1	L1	100µH	Choke, 5A	DIP	CSC	50125

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Qty	Ref	Value	Description	Package	Manufacturer	Manufacturer PN
1	LF1	300µH	Common choke, 2A	DIP	Emei	TP4U300-00
1	LF2	20mH	Common choke, 2A	DIP	Sanci	14*9*5MH
1	LF3	230µH	Inductor, ATQ2516 core	DIP	ARK	FX0651
1	LF4	NC				
1	Q1	60V	N-channel MOSFET, 115mA	SOT-23	On Semiconductor	2N7002LT1G
1	Q2	40V	Transistor, 200mA	SOT-23	On Semiconductor	MMBT3904LT1
1	Q3	100V	N-channel MOSFET, 1.5A	SOT-23	Analog Power	AM2370N-T1-PF
1	Q4	120V	N-channel MOSFET, 179A	TO-220	Toshiba	TK72E12N1
1	Q6	600V	N-channel MOSFET, 37A	TO-220	On Semiconductor	FCP099N60E
5	R1, R2, R30, R32, R57	499kΩ	Film resistor, 1%	1206	Yageo	RC1206FR-07499KL
1	R3	300kΩ	Film resistor, 1%	0402	Yageo	RC0402FR-07300KL
6	R4, R5, R6, R15, R16, R17	10MΩ	Film resistor, 1%	0805	Yageo	RC0805FR-0710ML
1	R7	30kΩ	Film resistor, 1%	0402	Yageo	RC0402FR-0730KL
2	R8, R70	1kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-071KL
1	R9	33kΩ	Film resistor, 1%	0805	Yageo	RC0805FR-0733KL
1	R10	10Ω	Film resistor, 1%	0603	Yageo	RC0603FR-0710RL
5	R11, R12, R24, R28, R29	200mΩ	Film resistor, 1%	1206	Yageo	RL1206FR-070R2L
1	R13	5.1Ω	Film resistor, 1%	0603	Yageo	RC0603FR-075R1L
1	R14	274kΩ	Film resistor, 1%	0402	Yageo	RC0402FR-07274KL
3	R18, R19, R20	3.3MΩ	Film resistor, 1%	0805	Yageo	RC0805FR-073M3L
2	R21, R22	300kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07300KL
1	R23	649kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07649KL
2	R25, R26	5.1kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-075K1L
1	R27	1kΩ	Film resistor, 1%	0402	Yageo	RC0402FR-071KL
1	R31	470Ω	Film resistor, 1%	0603	Yageo	RC0603FR-07470RL
1	R33	100kΩ	Film resistor, 5%	0805	Yageo	RC0805JR-07100KL
1	R34	0Ω	Film resistor, 1%	1206	Yageo	RC1206FR-070RL
1	R35	1kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-071KL
3	R36, R37, R38	30Ω	Film resistor, 1%	1206	Yageo	RC1206FR-0730RL
1	R39	0Ω	Film resistor, 1%	0603	Yageo	RC0603FR-070RL
1	R40	20kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0720KL
1	R41	249kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07249KL
1	R42	82kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-071K82L
1	R52	5.1Ω	Film resistor, 1%	1206	Yageo	RC1206FR-075R1L
4	R53, R54, R55, R56	10Ω	Film resistor, 1%	1206	Yageo	RC1206FR-0710RL
1	R58	400mΩ	Film resistor, 1%	1206	Yageo	RL1206FR-070R4L

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Qty	Ref	Value	Description	Package	Manufacturer	Manufacturer PN
1	T1	280µH	Transformer, ATQ2718 core	DIP	ARK	FX0652
1	U3	5000V_{RMS}	Photocoupler, 1 channel	SOP-4L	Everlight	EL1018(TA)-VG
1	U4	650V	GaN, 260mΩ	QFN-31 (6mmx 8mm)	Navitas	NV6127-RA
1	ZD1	16V	Zener diode, 5mA	SOD-123	Diodes, Inc.	BZT52C16-7-F
1	ZD2	4.7V	Zener diode, 5mA	SOD-323	Diodes, Inc.	BZT52C4V7S
1	ZD3	12V	Zener diode, 5mA	SOD-323	Diodes, Inc.	BZT52C12S
1	ZD4	6.2V	Zener diode, 5mA	SOD-323	Diodes, Inc.	BZT52C6V2S
1	U1	MP44018A	CrM/DCM PFC controller	SOIC-8	MPS	MP44018-AGS-Z
1	U2	MPX2002	All-in-one flyback controller	SOICW-16	MPS	MPX2002GY-Z
1	U5	HF81	X-capacitor bleeder	SOIC-8	MPS	HF81GS-Z
Daughter Board/PD 3.1 Controller						
1	C46	1µF	Ceramic capacitor, 100V, X7R	1206	Murata	GRM31CR72A105KA01L
1	C10	2.2µF	Ceramic capacitor, 50V, X5R	0603	Murata	GRM188R61H225KE11D
4	C27, C28, C30, C31	1µF	Ceramic capacitor, 25V, X5R	0402	Murata	GRM155R61E105KA12
1	C32	390pF	Ceramic capacitor, 50V, C0G	0603	Murata	GRM1885C1H391JA01D
1	C33	390pF	Ceramic capacitor, 50V, X7R	0402	Yageo	CC0402KRX7R9BB391
1	C34	10nF	Ceramic capacitor, 50V, X7R	0402	Murata	GRM155R71H103KA88D
1	C35	1µF	Ceramic capacitor, 50V, X5R	0603	Murata	GRM188R61H105KAAL
1	C36	2.2µF	Ceramic capacitor, 10V, X7R	0603	Murata	GRM188R71A225KE15D
1	C37	100nF	Ceramic capacitor, 25V, X7R	0402	Murata	GRM155R71E104KE14D
2	C38, C39	100nF	Ceramic capacitor, 50V, X7R	0603	Murata	GRM188R71H104KA93D
3	R43, R44, R45	100kΩ	Film resistor, 1%	0402	Yageo	RC0402FR-07100KL
1	R46	NC				
1	R47	1kΩ	Film resistor, 1%	0402	Yageo	RC0402FR-071KL
1	R48	1MΩ	Film resistor, 1%	0402	Yageo	RC0402JR-071ML
1	R49	5mΩ	Film resistor, 1%	1206	Yageo	PA1206FRF070R005L
2	R50, R51	200Ω	Film resistor, 1%	0805	Yageo	RC0805FR-07200RL
1	R59	100Ω	Film resistor, 1%	0402	Yageo	RC0402FR-07100RL
1	R60	10Ω	Film resistor, 1%	0402	Yageo	RC0402FR-0710RL
5	R61, R62, R63, R64, R65	10kΩ	Film resistor, 1%	0402	Yageo	RC0402FR-0710KL
2	R66, R67	100kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07100KL

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Qty	Ref	Value	Description	Package	Manufacturer	Manufacturer PN
2	R68, R69	10Ω	Film resistor, 1%	0603	Yageo	RC0603FR-0710RL
2	D8, D9	30V	Diode, 200mW	SOD-323	Diodes, Inc.	BAT43WS-7-F
5	D10, D11, D12, D13, D14	NC				
1	Q5	-40V	P-channel MOSFET, -50A	PDFN3333	Vanguard	VSE014P04MS
2	Q7, Q8	40V	N-channel MOSFET, 5.2A	SOT-23	Analog Power	AM2340NE
3	Q9, Q10, Q11	60V	N-channel MOSFET, 115mA	SOT-23	On Semiconductor	2N7002LT1G
1	Q12	-20V	Dual P-channel MOSFET, -430mA	SOT563-6	On Semiconductor	NTZD3152PT1G
1	USB-C	30V	USB Type-C connector	DIP	Yalian	93551001
1	U6	5.5V	USB PD controller	QFN-24 (4mmx 4mm)	Cypress	CYPD3175-24LQXQ
1	U7	MPQ2013A	40V, 150mA low-I_Q current linear regulator, AEC-Q100 qualified	QFN-8 (3mmx 3mm)	MPS	MPQ2013AGQ-5-Z

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

3.7 PFC Inductor LF3 Specification

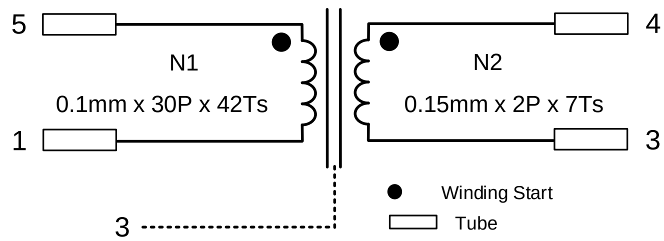


Figure 6: Electrical Diagram

Figure 7: Winding Diagram

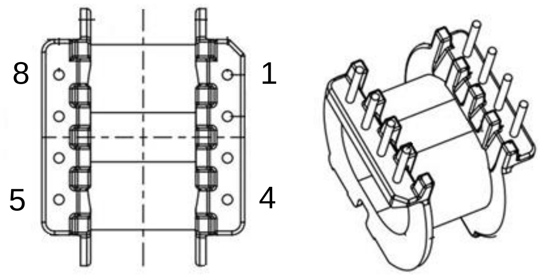


Figure 8: Pin Definition of Bobbin

Table 3: Electrical Characteristic

Parameter	Condition	Value
Primary inductance	L_P (5-1)	230μH ±5%
Core	-	ATQ2516
Bobbin	-	ATQ2516
Core material	-	PC95
Turn ratio	N1:N2	42:7

Table 4: Winding Specification

Tape Turns	Winding No.	Start to End	Wire Diameter (φ)	Turns	Winding	Tube
	N1	5 to 1	0.1mm x 30P	42Ts	5 layers	Yes
2Ts						
	N2	4 to 3	0.15mm x 2P	7Ts	1 layer	Yes
3Ts						
Connect the core to GND (pin 3) via copper. The core center column is fixed with epoxy resin.						

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

3.8 Flyback Transformer T1 Specification

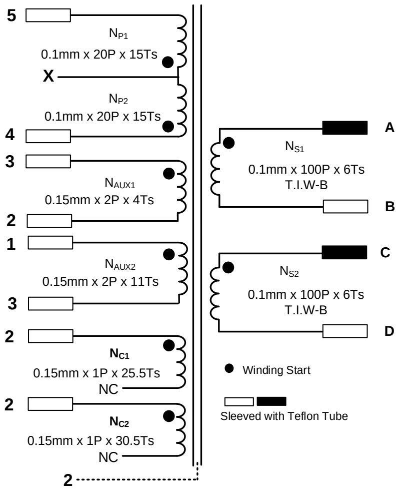


Figure 9: Electrical Diagram

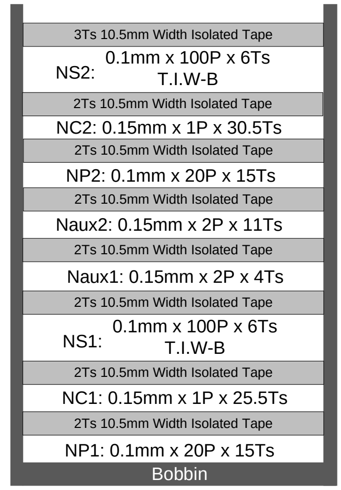


Figure 10: Winding Diagram

Table 5: Electrical Characteristic

Parameter	Condition	Value
Primary inductance	L_P (4-5)	280µH ±5%
Leakage inductance	L_{LK} (4-5)	4µH max
Core	-	ATQ2718
Bobbin	-	ATQ2718
Core Material	-	PC95

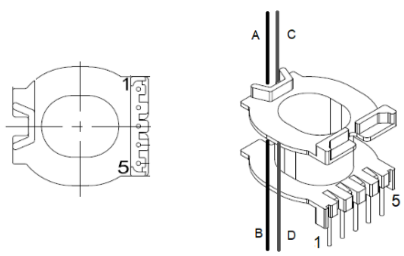


Figure 11: Pin Definition of Bobbin

Table 6: Winding Specification

Tape Turns	Winding No.	Start to End	Wire Diameter (φ)	Turns	Winding	Tube
	N_{P1}	4 to X	0.1mm x 20P	15Ts	1 full layer	Yes
2Ts	N_{C1}	2 to NC	0.15mm x 1P	25.5Ts	1-layer spread	Yes
2Ts	N_{S1}	A to B	0.1mm x 100P (T.I.W-B)	6Ts	1 full layer	Yes
2Ts	N_{AUX1}	3 to 2	0.15mm x 2P	4Ts	1-layer spread	Yes
2Ts	N_{AUX2}	1 to 3	0.15mm x 2P	11Ts	1-layer spread	Yes
2Ts	N_{P2}	X to 5	0.1mm x 20P	15Ts	1 full layer	Yes
2Ts	N_{C2}	2 to NC	0.15mm x 1P	30.5Ts	1-layer spread	Yes
2Ts	N_{S2}	C to D	0.1mm x 100P (T.I.W-B)	6Ts	1 full layer	Yes
3Ts						
Connect A to C, and connect B to D. Connect the core to GND (pin 2) via 1.1Ts copper. The core center column is fixed with epoxy resin.						

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

3.9 PCB Layout

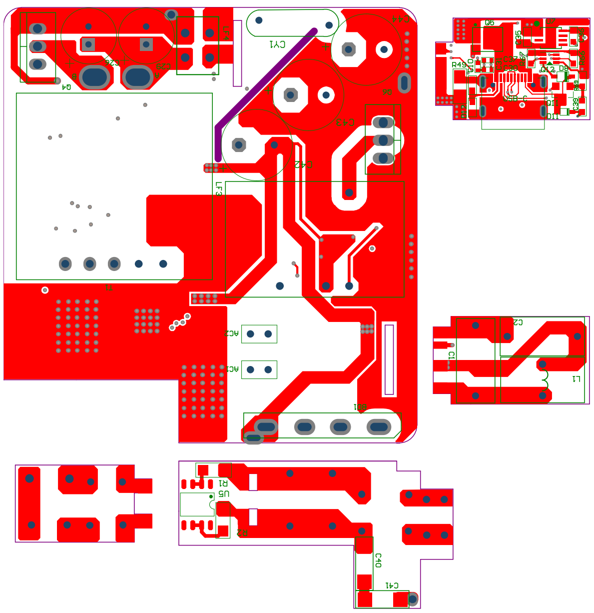


Figure 12: Top Layer

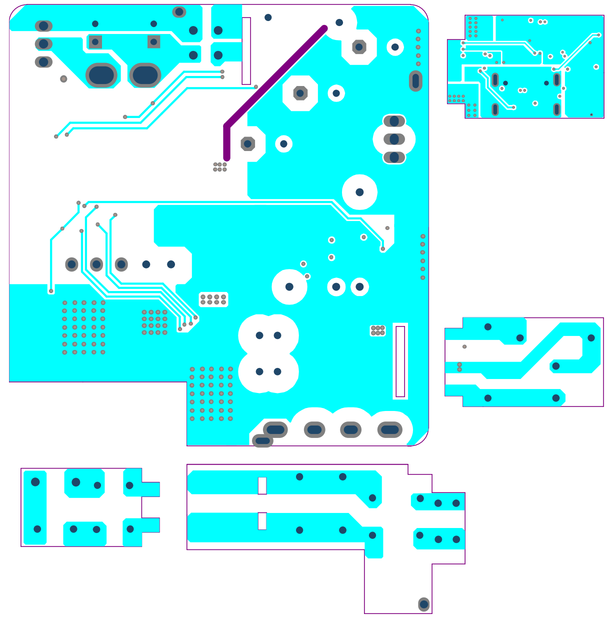


Figure 13: Mid-Layer 1

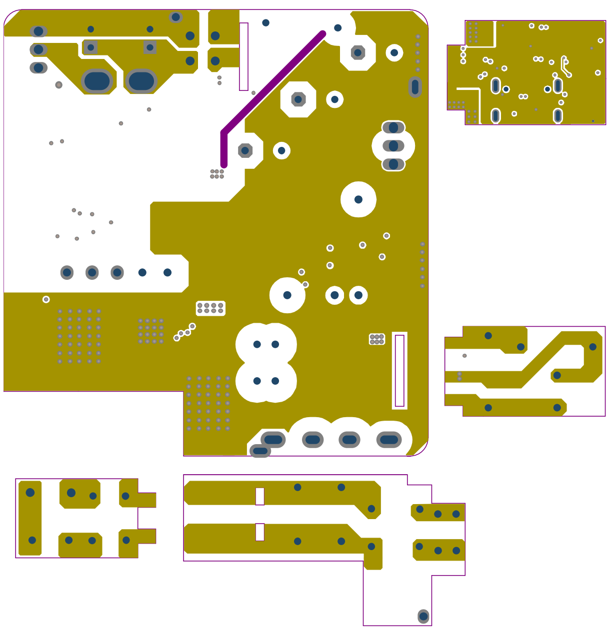


Figure 14: Mid-Layer 2

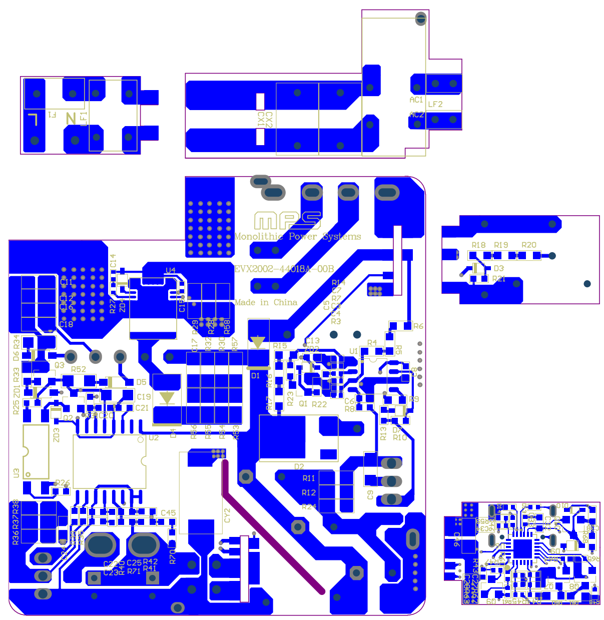


Figure 15: Bottom Layer

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

3.10 PCB Layout Guidelines

Efficient performance in power converter systems depends mainly on the PCB design. In most cases, following generic rules is sufficient. However, the implementation of special components requires additional precautions.

The designer must consider the sensing and driving signals. The designer must also focus on the input PFC current and voltage. For sensing traces, it is recommended to use differential pairs to reduce magnetic coupling and to avoid sharing high dI/dt traces with low-voltage signals. The same principle applies to MOSFET driving signals. Lastly, the designer must ensure that no GND loops are created while using differential pairs.

The flyback controller handles high-to-low voltage conversion in a small space, so it is important to consider the component clearance. This ensures that the system is not at risk of electrical arc damage, and that the system is compliant with dielectric strength standards.

For general AC/DC designs, refer to Figure 12 on page 14, Figure 13 on page 14, Figure 14 on page 14, and Figure 15 on page 14, and follow the guidelines below:

1. Keep a 2.5mm isolation space between the N and L traces to ground.
2. Keep a 6.4mm isolation space between the primary-side and secondary-side traces.
3. Do not place copper planes under the CM or DM filters.
4. If more than one CM filter is used, place the filters 90° from each other to avoid cross-talk and increase effectiveness.
5. Reduce high dV/dt (e.g. PFC and LLC switch nodes) areas.
6. Reduce the dI/dt loops (e.g. output rectification).
7. Place decoupling capacitors (>100nF) near the ICs.
8. Connect the power ground and signal ground at a single point near the bulk capacitor.
9. Use traces with appropriate widths. The AC and high-voltage traces should be narrow, while the DC and low-voltage traces should be wide (about 1A/mm).

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

4 Test Results

4.1 Efficiency

Table 7: Efficiency (V_{OUT} = 5V)

V_{IN} (V_{AC}/Hz)	Load	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Eff. (%)	CoC Tier 2 Requirement
			V_{OUT} = 5V				
115/60	100%	16.420	5.085	3.001	15.260	92.94%	
	75%	12.292	5.078	2.250	11.426	92.95%	
	50%	9.020	5.076	1.500	7.614	84.42%	
	25%	4.628	5.095	0.750	3.821	82.57%	
	Average Efficiency (%)					88.22%	81.84%
	10%	1.889	5.103	0.300	1.531	81.03%	72.48%
230/50	100%	16.573	5.086	3.001	15.263	92.10%	
	75%	12.448	5.081	2.250	11.432	91.84%	
	50%	9.289	5.079	1.500	7.619	82.02%	
	25%	4.744	5.117	0.751	3.843	81.01%	
	Average Efficiency (%)					86.74%	81.84%
	10%	1.946	5.112	0.300	1.533	78.80%	72.48%

Table 8: Efficiency (V_{OUT} = 9V)

V_{IN} (V_{AC}/Hz)	Load	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Eff. (%)	CoC Tier 2 Requirement
			V_{OUT} = 9V				
115/60	100%	29.118	9.040	3.001	27.123	93.15%	
	75%	21.804	9.031	2.250	20.320	93.19%	
	50%	14.510	9.028	1.500	13.542	93.33%	
	25%	7.797	9.028	0.750	6.771	86.85%	
	Average Efficiency (%)					91.63%	87.30%
	10%	3.173	9.038	0.300	2.711	85.46%	77.30%
230/50	100%	28.975	9.037	3.001	27.120	93.60%	
	75%	21.869	9.031	2.250	20.320	92.92%	
	50%	14.756	9.028	1.500	13.542	91.77%	
	25%	7.900	9.031	0.750	6.773	85.73%	
	Average Efficiency (%)					91.01%	87.30%
	10%	3.240	9.045	0.300	2.713	83.75%	77.30%

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Table 9: Efficiency (V_{OUT} = 12V)

V_{OUT} = 12V							CoC Tier 2 Requirement
V_{IN} (V_{AC}/Hz)	Load	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Eff. (%)	
115/60	100%	39.410	12.01	3.001	36.042	91.45%	
	75%	28.930	12.01	2.250	27.022	93.41%	
	50%	19.231	12.00	1.500	18.000	93.60%	
	25%	9.723	12.00	0.751	9.012	92.69%	
	Average Efficiency (%)					92.79%	88.30%
	10%	4.149	12.00	0.300	3.600	86.76%	78.30%
230/50	100%	39.064	12.01	3.001	36.042	92.26%	
	75%	28.907	12.01	2.250	27.023	93.48%	
	50%	19.316	12.00	1.500	18.000	93.19%	
	25%	10.367	12.00	0.751	9.012	86.93%	
	Average Efficiency (%)					91.47%	88.30%
	10%	4.228	12.00	0.300	3.600	85.13%	78.30%

Table 10: Efficiency (V_{OUT} = 15V)

V_{OUT} = 15V							CoC Tier 2 Requirement
V_{IN} (V_{AC}/Hz)	Load	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Eff. (%)	
115/60	100%	48.830	14.98	3.000	44.940	92.03%	
	75%	36.221	14.97	2.250	33.683	92.99%	
	50%	24.049	14.97	1.500	22.455	93.37%	
	25%	12.096	14.97	0.750	11.228	92.82%	
	Average Efficiency (%)					92.80%	88.85%
	10%	5.108	14.98	0.300	4.494	87.97%	78.85%
230/50	100%	48.733	14.98	3.000	44.940	92.22%	
	75%	35.986	14.97	2.250	33.683	93.60%	
	50%	23.991	14.97	1.500	22.455	93.60%	
	25%	12.373	14.97	0.750	11.228	90.74%	
	Average Efficiency (%)					92.54%	88.85%
	10%	5.205	14.98	0.300	4.494	86.33%	78.85%

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Table11: Efficiency (V_{OUT} = 20V)

V_{OUT} = 20V							CoC Tier 2 Requirement
V_{IN} (V_{AC}/Hz)	**Load**	**P_{IN} (W)**	**V_{OUT} (V)**	**I_{OUT} (A)**	**P_{OUT} (W)**	**Eff. (%)**	
115/60	100%	107.51	19.91	5.001	99.570	92.61%	
	75%	80.874	19.90	3.750	74.625	92.27%	
	50%	53.891	19.90	2.500	49.750	92.32%	
	25%	26.730	19.89	1.250	24.863	93.01%	
	Average Efficiency (%)					92.55%	89%
	10%	10.896	19.90	0.500	9.950	91.32%	79%
230/50	100%	107.05	19.91	5.001	99.570	93.01%	
	75%	79.893	19.90	3.750	74.625	93.41%	
	50%	53.982	19.90	2.500	49.750	92.16%	
	25%	26.789	19.89	1.250	24.863	92.81%	
	Average Efficiency (%)					92.85%	89%
	10%	11.032	19.90	0.500	9.950	90.19%	79%

Table 12: Efficiency (V_{OUT} = 28V)

V_{OUT} = 28V							CoC Tier 2 Requirement
V_{IN} (V_{AC}/Hz)	**Load**	**P_{IN} (W)**	**V_{OUT} (V)**	**I_{OUT} (A)**	**P_{OUT} (W)**	**Eff. (%)**	
115/60	100%	149.03	27.80	5.005	139.125	93.35%	
	75%	111.73	27.79	3.750	104.213	93.27%	
	50%	75.075	27.78	2.500	69.450	92.51%	
	25%	37.431	27.77	1.250	34.713	92.74%	
	Average Efficiency (%)					92.97%	89%
	10%	15.233	27.77	0.500	13.885	91.15%	79%
230/50	100%	148.08	27.80	5.005	139.125	93.95%	
	75%	111.21	27.79	3.750	104.213	93.71%	
	50%	74.754	27.78	2.500	69.450	92.90%	
	25%	37.223	27.77	1.250	34.713	93.26%	
	Average Efficiency (%)					93.46%	89%
	10%	15.417	27.77	0.500	13.885	90.06%	79%

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Table 13: Efficiency (V_{OUT} = 28V)

V_{OUT} = 28V (Full Load)						
V_{IN} (V_{AC}/Hz)	Load	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Eff. (%)
90/60	100%	151.11	27.95	5.005	139.876	92.32%
115/60	100%	149.03	27.80	5.005	139.125	93.35%
230/50	100%	148.08	27.80	5.005	139.125	93.95%
264/50	100%	147.39	27.80	5.005	139.125	94.21%

Table 14: No-Load Consumption

V_{IN} (V_{AC})	P_{IN} (mW)
90	44.83
115	47.64
230	66.57
264	74.69

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

4.2 Waveforms

The waveforms below show the correct operation of the reference design board. If not specified, the operation conditions are nominal (see Table 2 on page 4).

Figure 16: PFC Steady State

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 12V, I_{OUT} = 3A

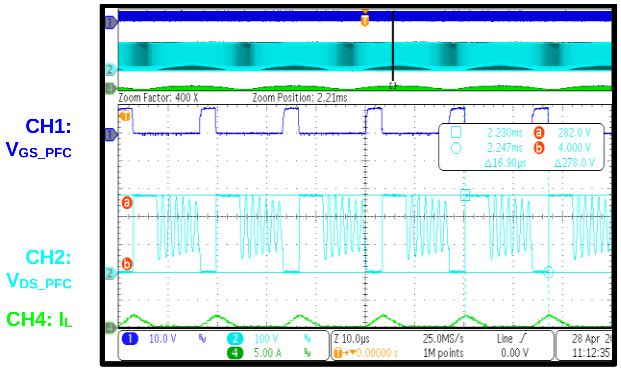


Figure 17: PFC Steady State

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 12V, I_{OUT} = 3A

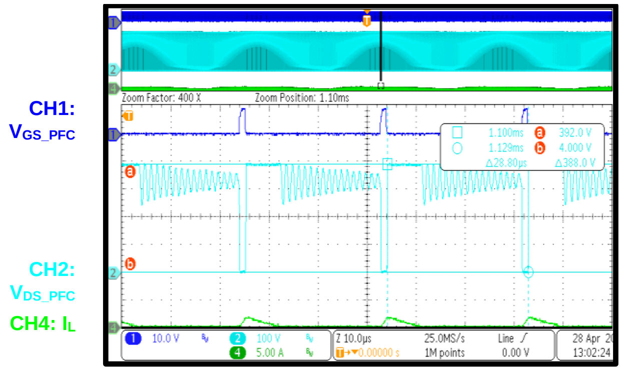


Figure 18: PFC Steady State

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 15V, I_{OUT} = 3A

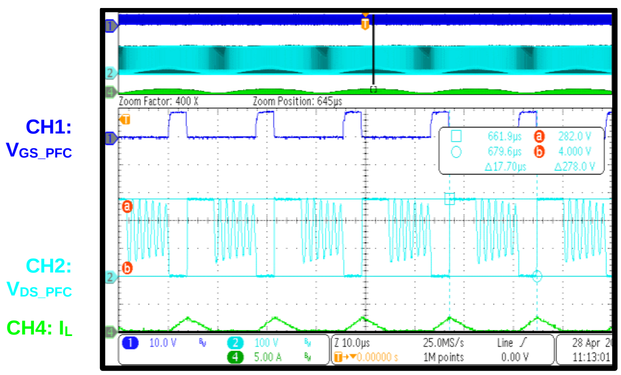


Figure 19: PFC Steady State

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 15V, I_{OUT} = 3A

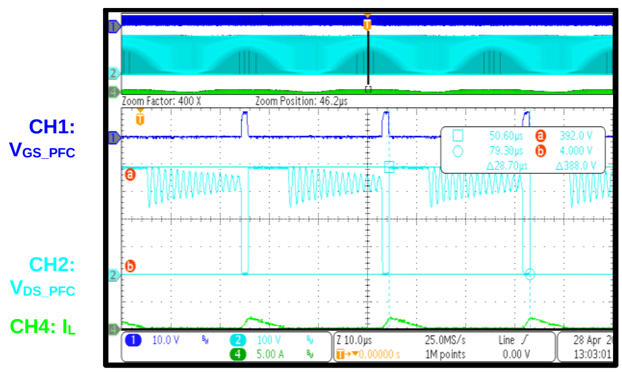


Figure 20: PFC Steady State

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 20V, I_{OUT} = 5A

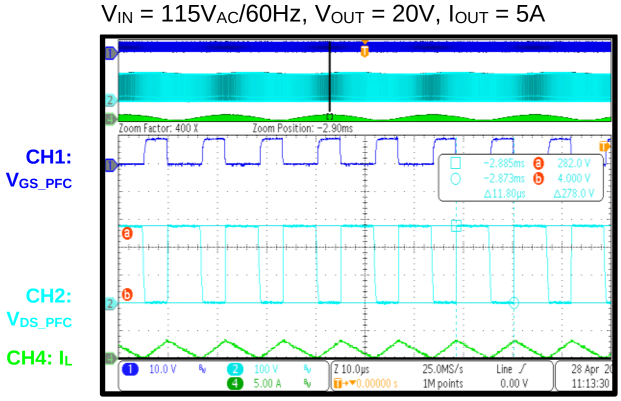
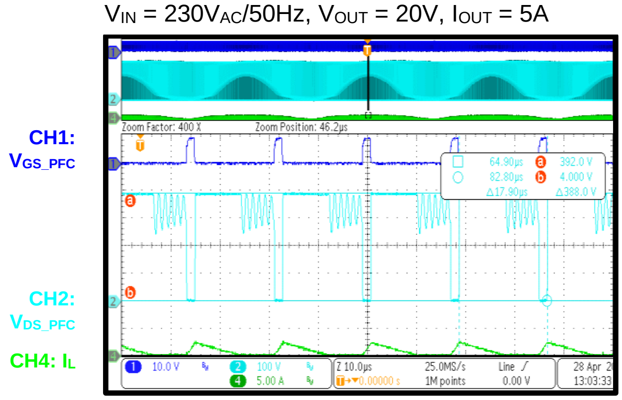


Figure 21: PFC Steady State

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 20V, I_{OUT} = 5A



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Figure 22: PFC Steady State

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A

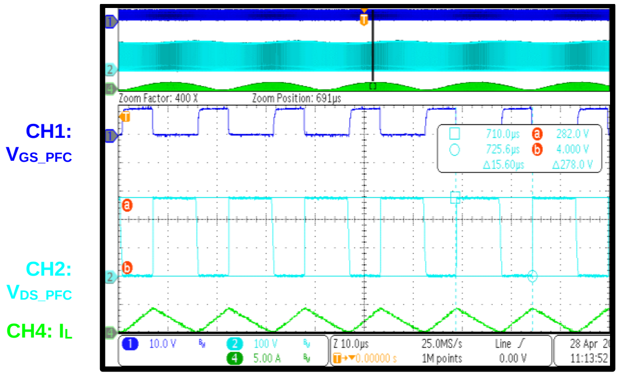


Figure 23: PFC Steady State

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A

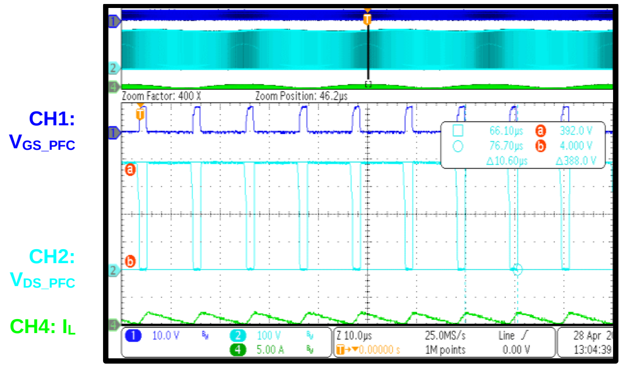


Figure 24: Flyback Steady State

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 5V, I_{OUT} = 3A

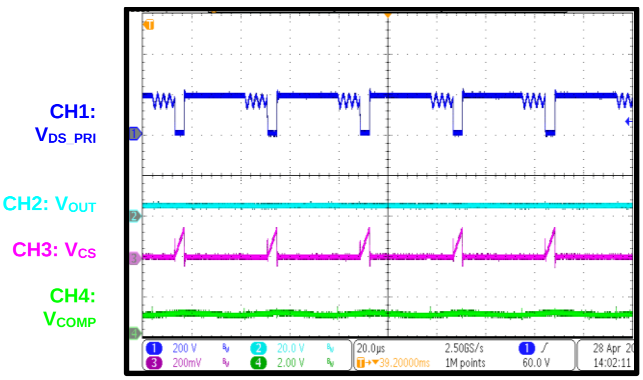


Figure 25: Flyback Steady State

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 5V, I_{OUT} = 3A

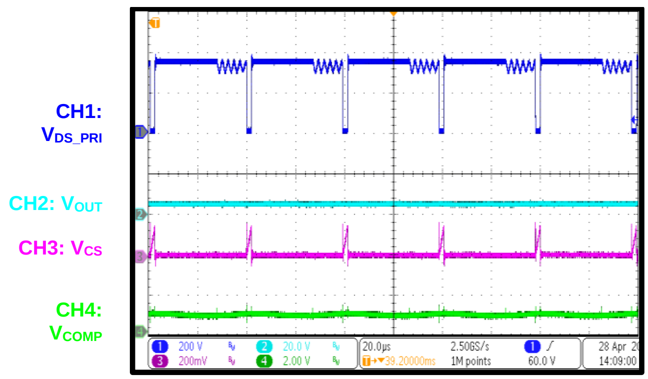


Figure 26: Flyback Steady State

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 9V, I_{OUT} = 3A

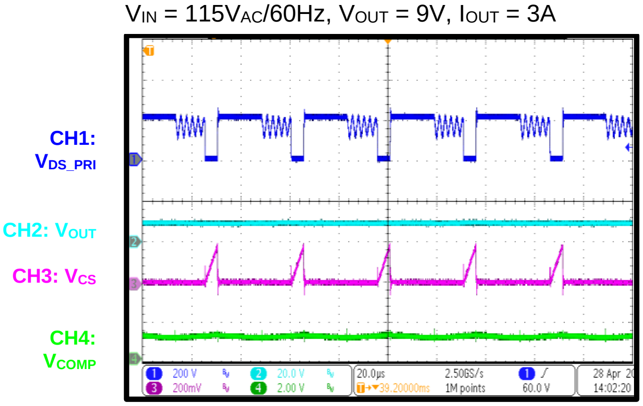
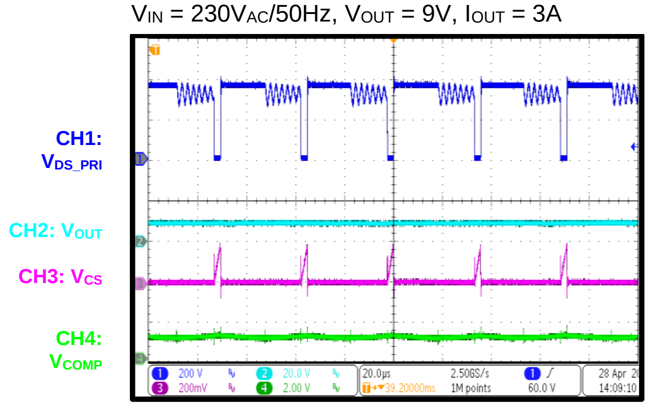


Figure 27: Flyback Steady State

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 9V, I_{OUT} = 3A



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Figure 28: Flyback Steady State
V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 12V, I_{OUT} = 3A

CH1: V_{DS_PRI}
CH2: V_{OUT}
CH3: V_{CS}
CH4: V_{COMP}

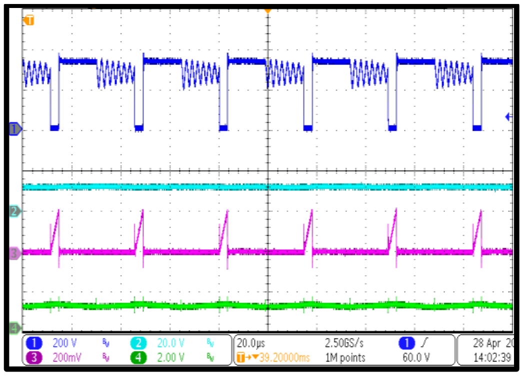


Figure 29: Flyback Steady State
V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 12V, I_{OUT} = 3A

CH1: V_{DS_PRI}
CH2: V_{OUT}
CH3: V_{CS}
CH4: V_{COMP}

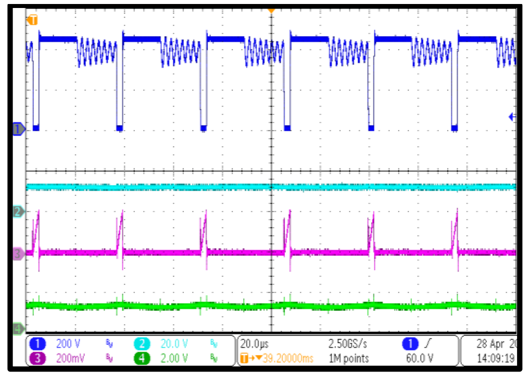


Figure 30: Flyback Steady State
V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 15V, I_{OUT} = 3A

CH1: V_{DS_PRI}
CH2: V_{OUT}
CH3: V_{CS}
CH4: V_{COMP}

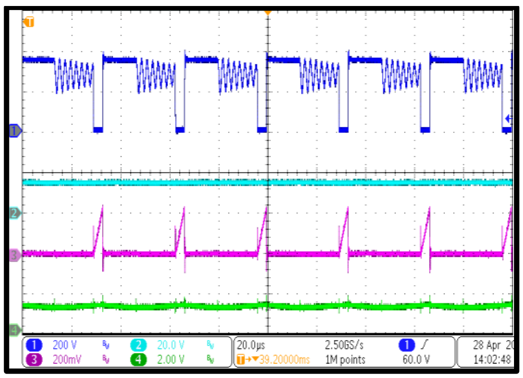


Figure 31: Flyback Steady State
V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 15V, I_{OUT} = 3A

CH1: V_{DS_PRI}
CH2: V_{OUT}
CH3: V_{CS}
CH4: V_{COMP}

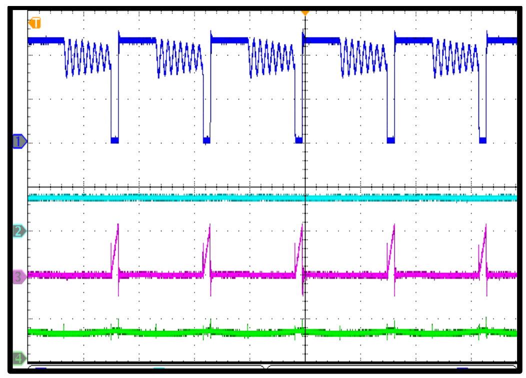


Figure 32: Flyback Steady State
V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 20V, I_{OUT} = 5A

CH1: V_{DS_PRI}
CH2: V_{OUT}
CH3: V_{CS}
CH4: V_{COMP}

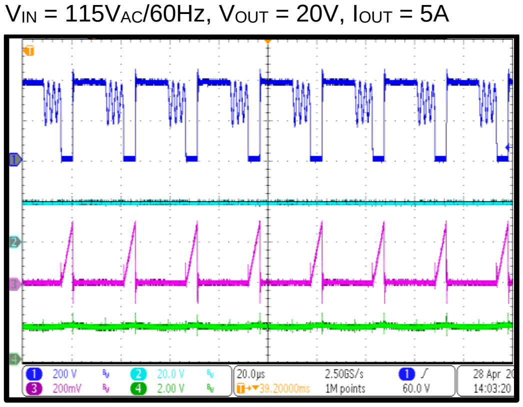
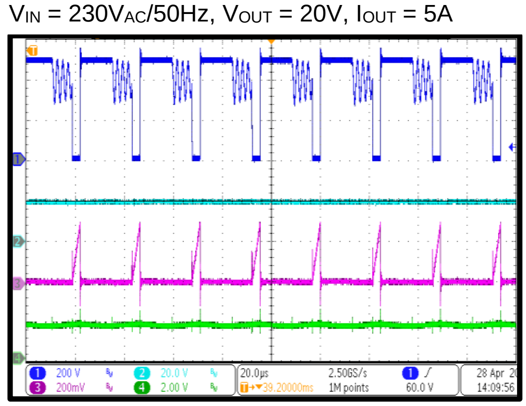


Figure 33: Flyback Steady State
V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 20V, I_{OUT} = 5A

CH1: V_{DS_PRI}
CH2: V_{OUT}
CH3: V_{CS}
CH4: V_{COMP}



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Figure 34: Flyback Steady State

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A

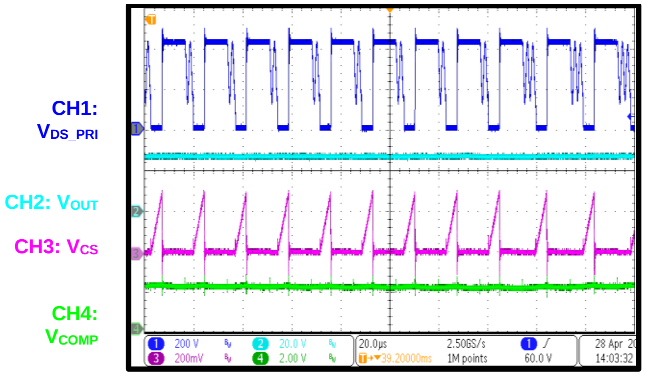


Figure 35: Flyback Steady State

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A

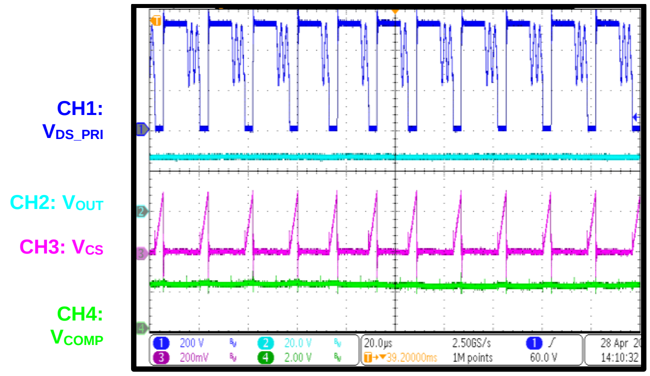


Figure 36: SR Steady State

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 5V, I_{OUT} = 3A

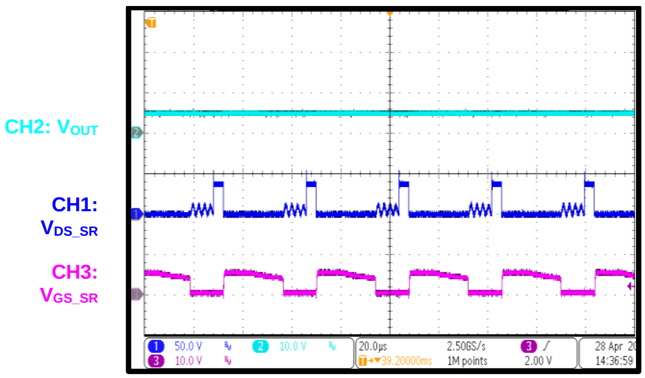


Figure 37: SR Steady State

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 5V, I_{OUT} = 3A

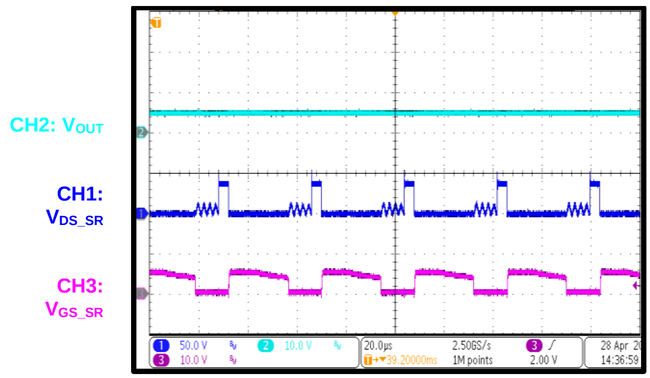


Figure 38: SR Steady State

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 9V, I_{OUT} = 3A

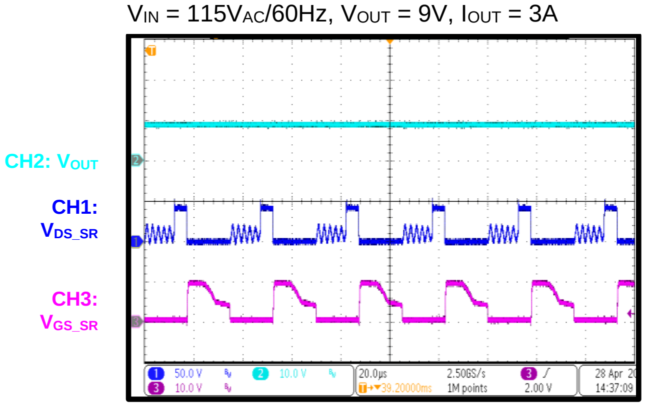
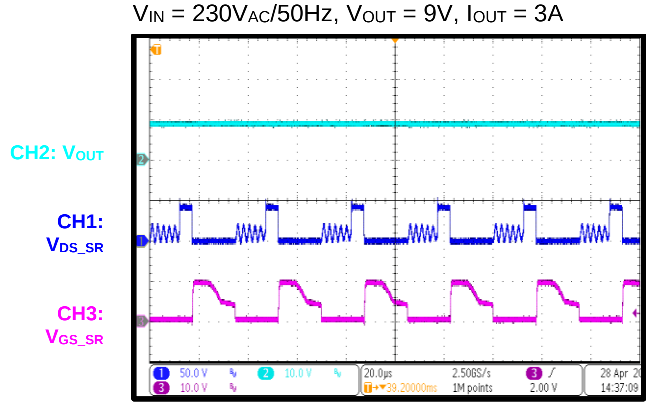


Figure 39: SR Steady State

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 9V, I_{OUT} = 3A



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Figure 40: SR Steady State
V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 12V, I_{OUT} = 3A

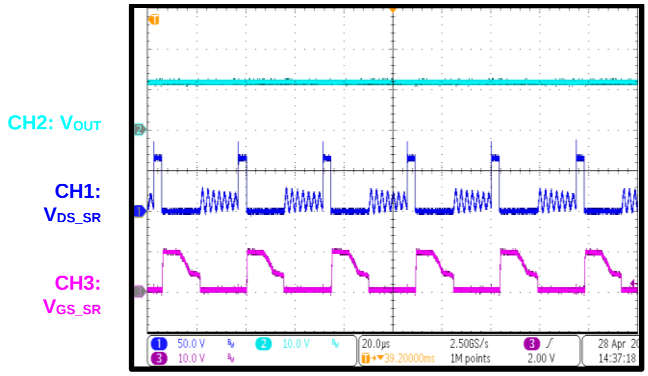


Figure 41: SR Steady State
V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 12V, I_{OUT} = 3A

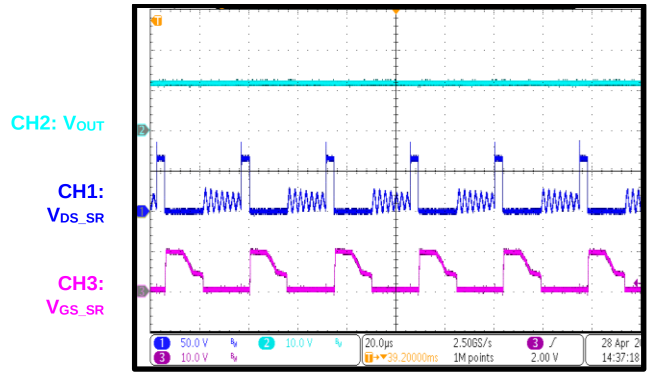


Figure 42: SR Steady State
V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 15V, I_{OUT} = 3A

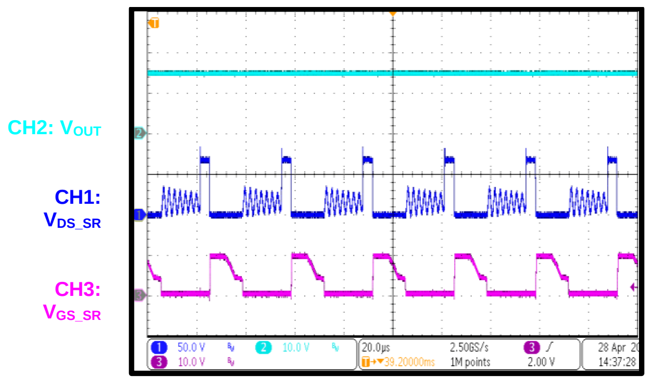


Figure 43: SR Steady State
V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 15V, I_{OUT} = 3A

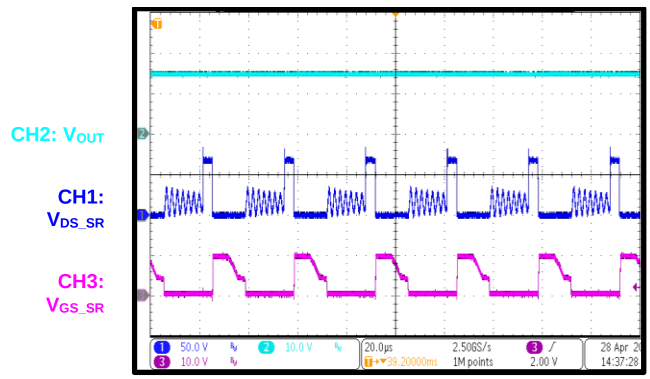


Figure 44: SR Steady State
V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 20V, I_{OUT} = 5A

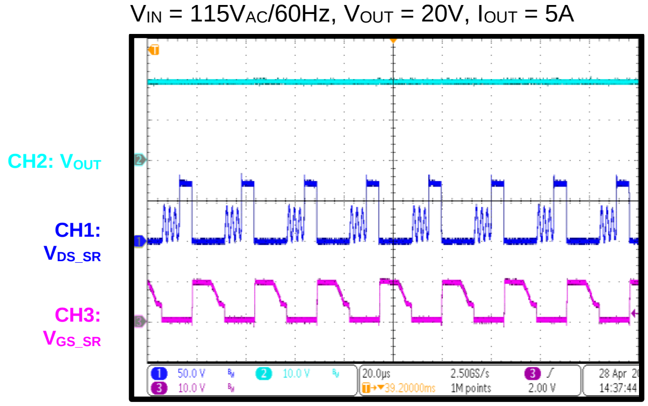
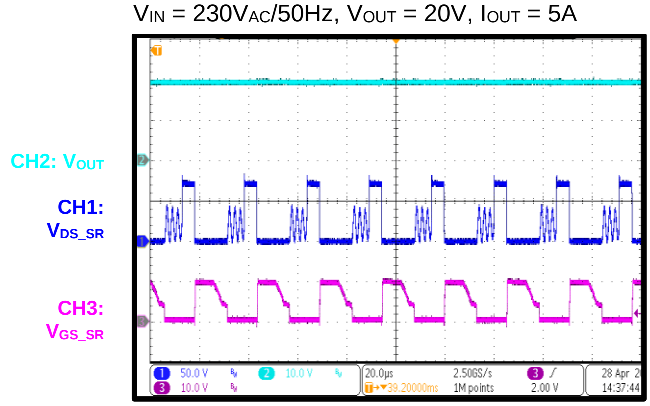


Figure 45: SR Steady State
V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 20V, I_{OUT} = 5A



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Figure 46: SR Steady State

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A

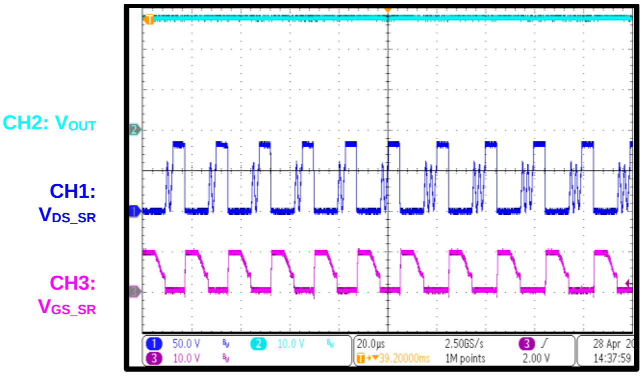


Figure 47: SR Steady State

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A

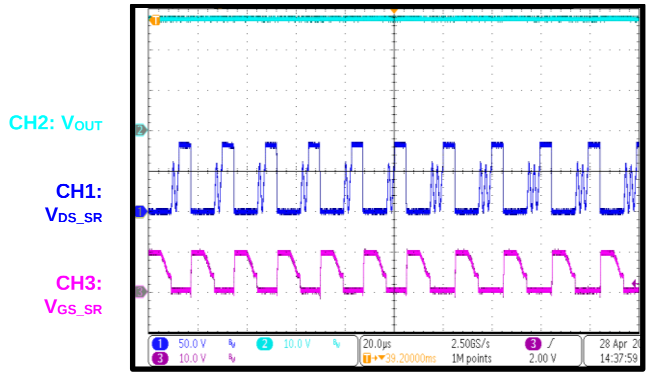


Figure 48: Primary MOSFET Stress

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 15V, I_{OUT} = 3A

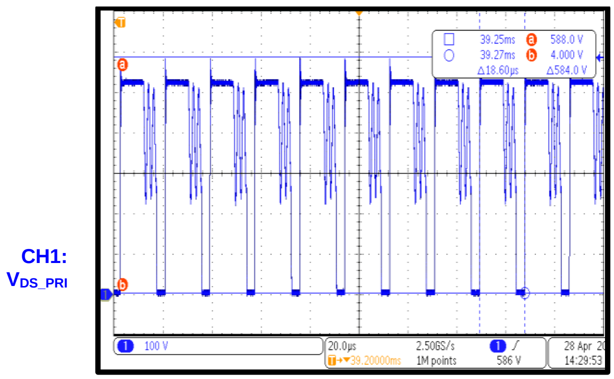


Figure 49: Secondary MOSFET Stress

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 15V, I_{OUT} = 3A

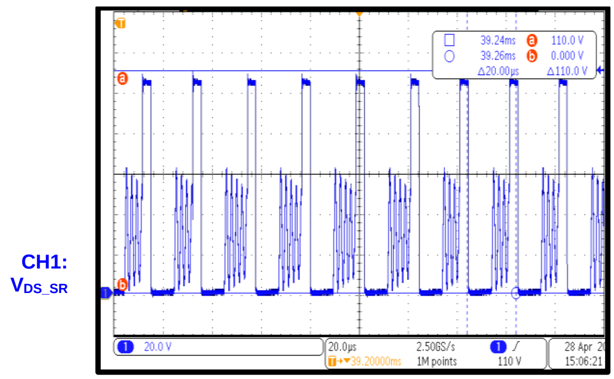


Figure 50: Output Voltage Ripple

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A,
V_{PP} = 172mV

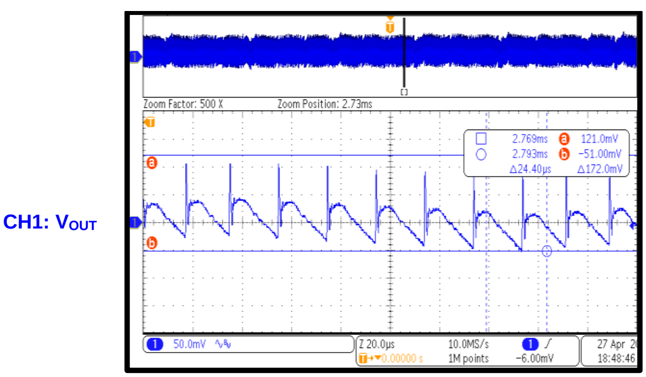
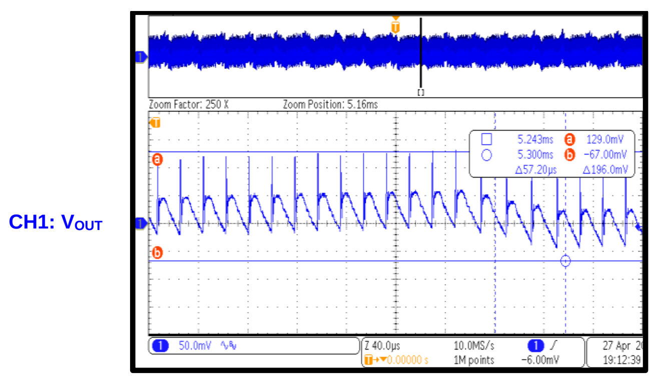


Figure 51: Output Voltage Ripple

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A,
V_{PP} = 196mV



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Figure 52: PFC Start-Up

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A

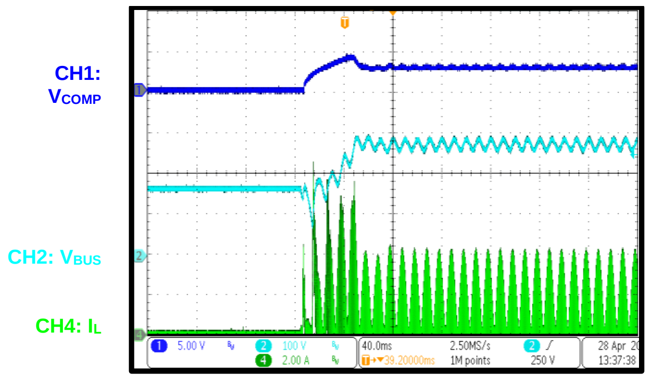


Figure 53: PFC Start-Up

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A

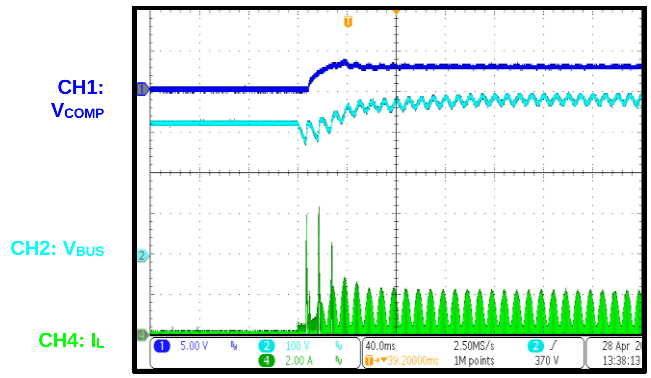


Figure 54: PFC Shutdown

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A

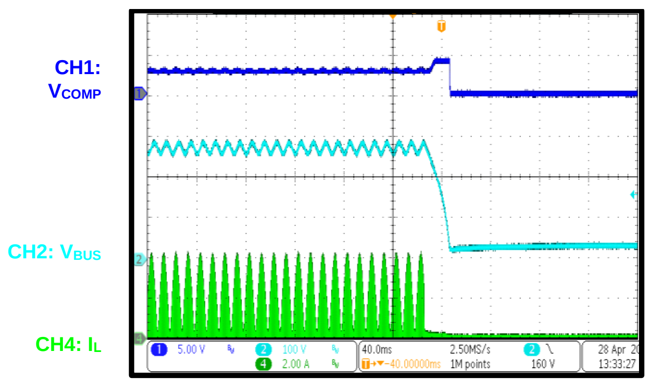


Figure 55: PFC Shutdown

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A

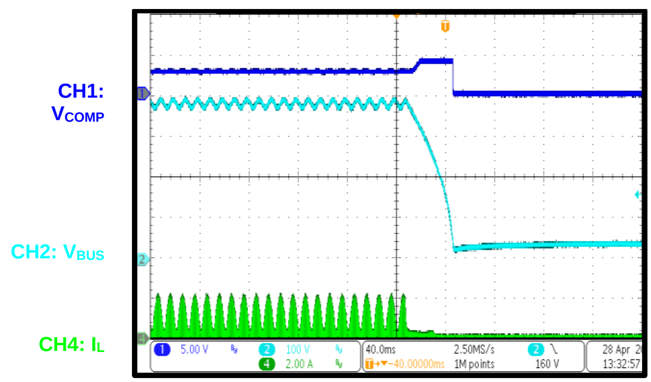


Figure 56: Output OCP

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A

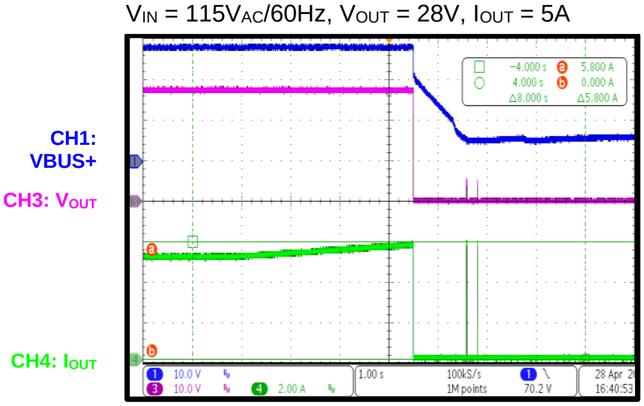
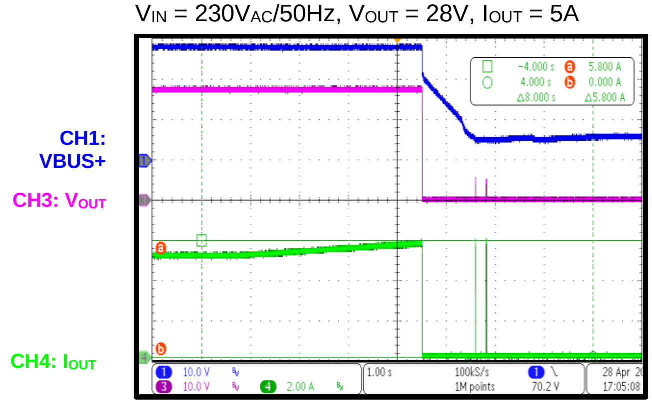


Figure 57: Output OCP

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

4.3 Thermal Measurements

Figure 58: Thermal Measurements

V_{IN} = 90V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A,
bridge diode: 113.2°C

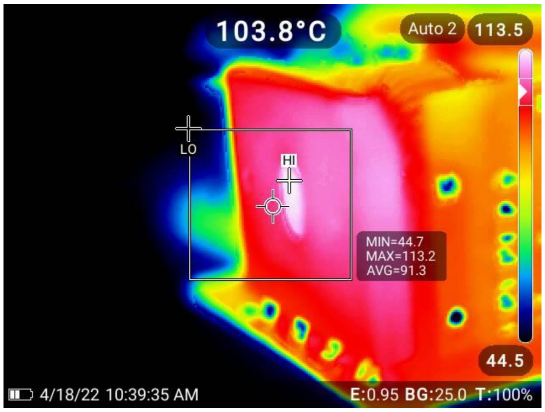


Figure 59: Thermal Measurements

V_{IN} = 90V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A,
PFC MOSFET: 104.5°C

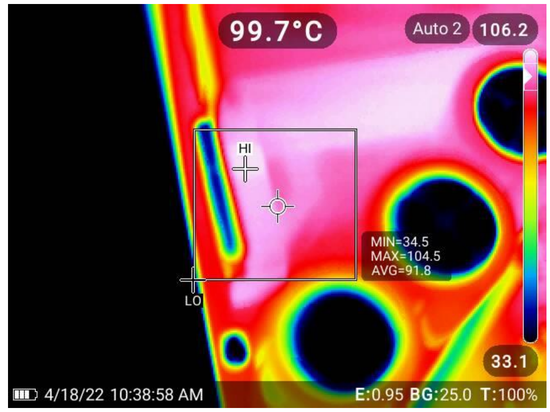


Figure 60: Thermal Measurements

V_{IN} = 90V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A,
PFC freewheeling diode: 100.3°C

Figure 61: Thermal Measurements

V_{IN} = 90V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A,
PFC conductor: 99.9°C

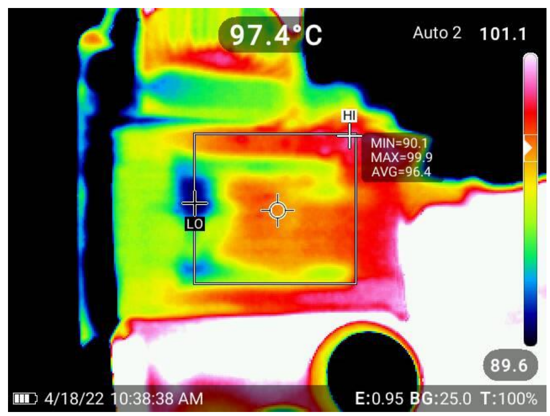
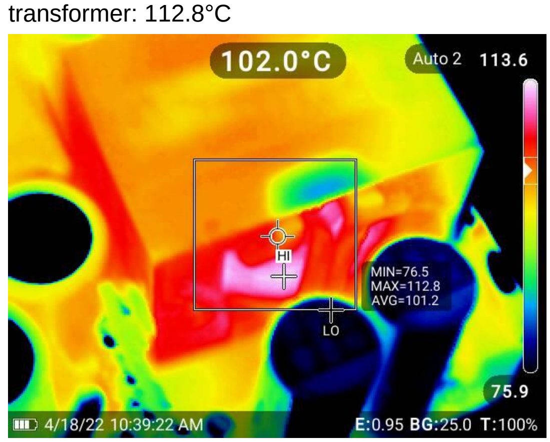


Figure 62: Thermal Measurements

V_{IN} = 90V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A,
flyback MOSFET: 95.8°C

Figure 63: Thermal Measurements

V_{IN} = 90V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A,
transformer: 112.8°C



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Figure 64: Thermal Measurements
V_{IN} = 90V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A,
RCD: 100.5°C

Figure 65: Thermal Measurements
V_{IN} = 90V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A,
SR MOSFET: 99.9°C

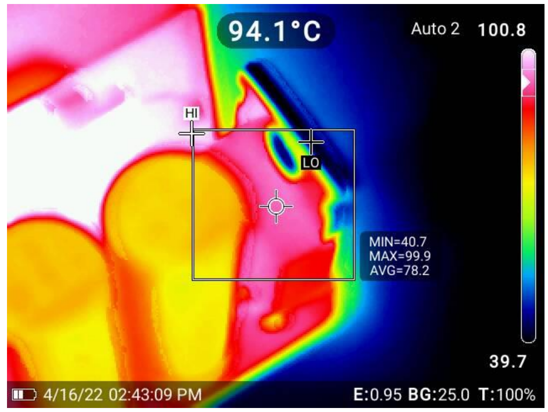


Figure 66: Thermal Measurements
V_{IN} = 264V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A,
bridge diode: 79.2°C

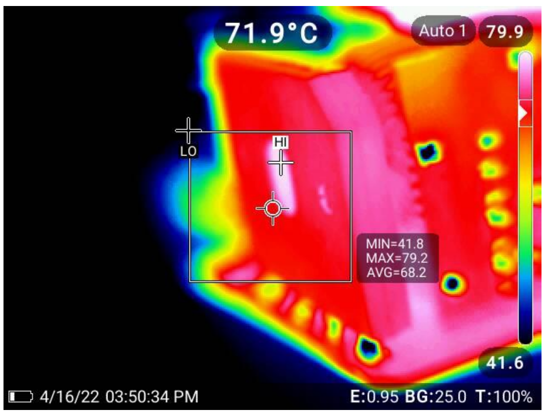


Figure 67: Thermal Measurements
V_{IN} = 264V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A,
PFC MOSFET: 92.9°C

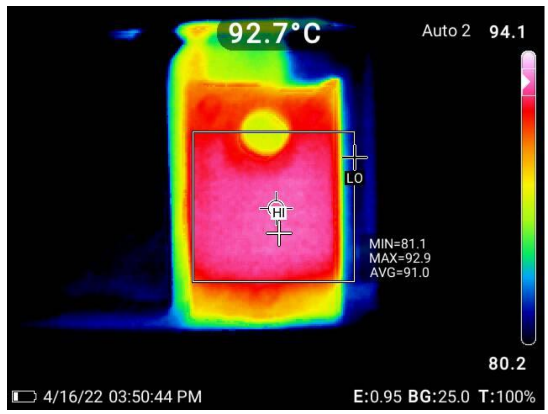


Figure 68: Thermal Measurements
V_{IN} = 264V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A
PFC freewheeling diode: 85°C

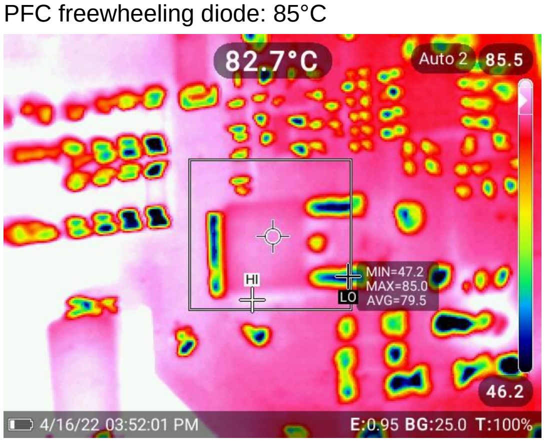
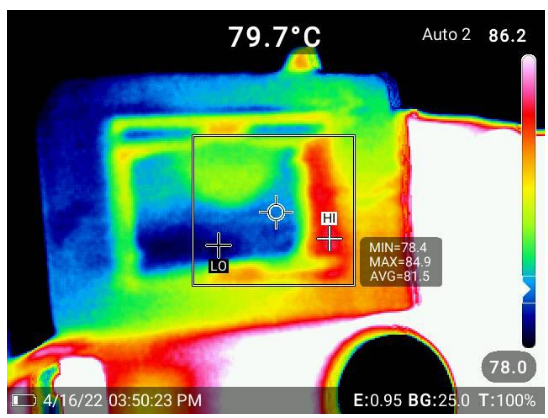


Figure 69: Thermal Measurements
V_{IN} = 264V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A
PFC inductor: 84.9°C



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

Figure 70: Thermal Measurements
V_{IN} = 264V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A,
flyback MOSFET: 89.3°C

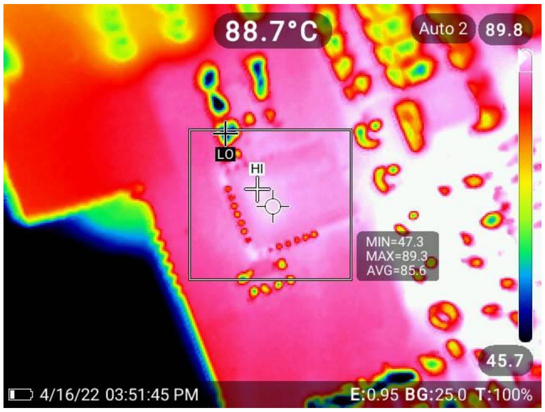


Figure 71: Thermal Measurements
V_{IN} = 264V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A,
transformer: 111.5°C

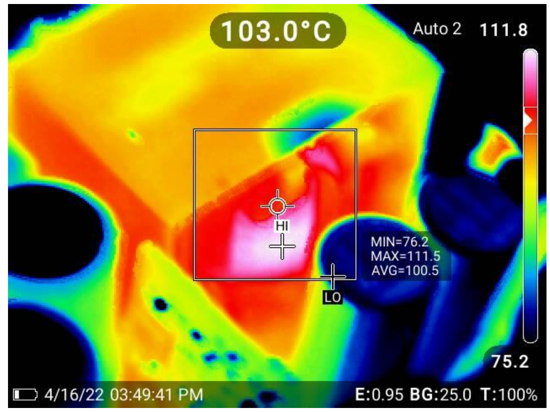


Figure 72: Thermal Measurements
V_{IN} = 264V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A,
RCD: 93.8°C

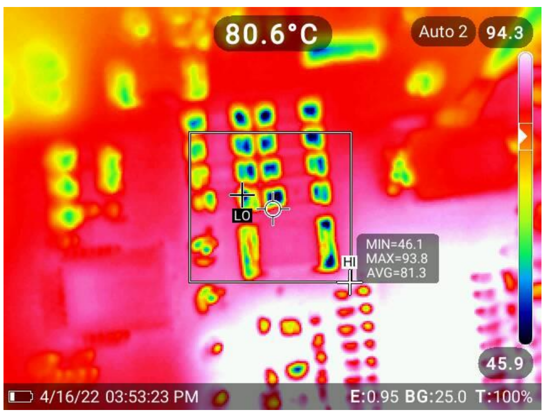
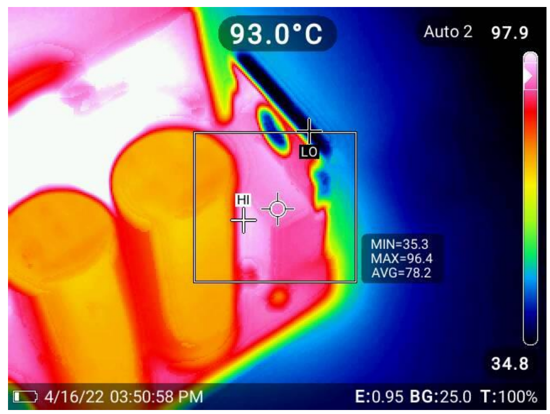


Figure 73: Thermal Measurements
V_{IN} = 264V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A,
SR MOSFET: 96.4°C



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

4.4 EMC Measurements

Figure 74: Conducted EMI

V_{IN} = 115V_{AC}/60Hz, V_{OUT} = 28V, I_{OUT} = 5A, Line L

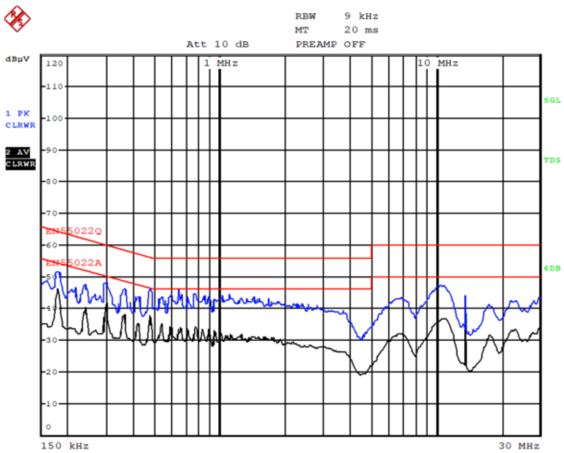


Figure 75: Conducted EMI

V_{IN} = 115VAC/50Hz, V_{OUT} = 28V, I_{OUT} = 5A, Line N

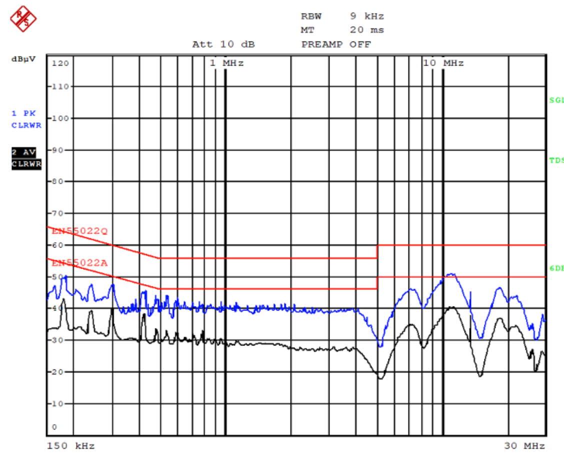


Figure 76: Conducted EMI

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A, Line L

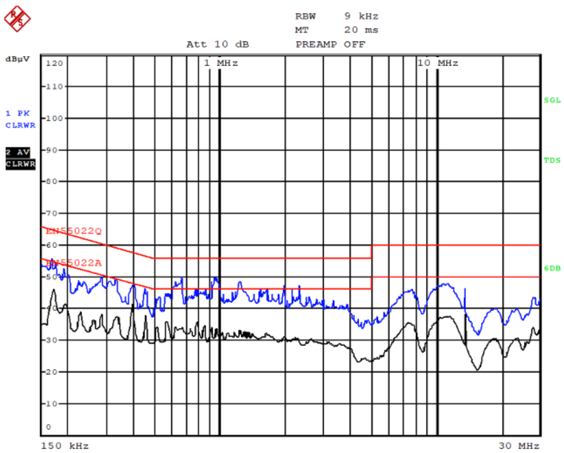
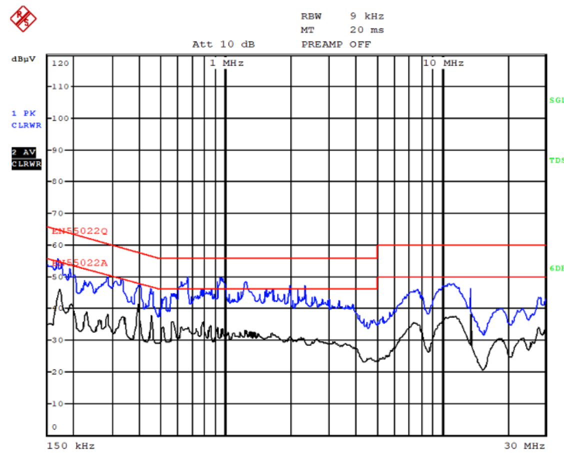


Figure 77: Conducted EMI

V_{IN} = 230V_{AC}/50Hz, V_{OUT} = 28V, I_{OUT} = 5A, Line N



MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

5 Disclaimer

Monolithic Power Systems (MPS) reserves the right to make changes to its products and to discontinue products without notice. The applications information, schematic diagrams, and other reference information included herein is provided as a design aid only and are therefore provided as-is. MPS makes no warranties with respect to this information and disclaims any implied warranties of merchantability or non-infringement of third-party intellectual property rights.

MPS cannot assume responsibility for use of any circuitry other than circuitry entirely embodied in an MPS product. No circuit patent licenses are implied.

Certain applications using semiconductor products may involve potential risks of death, personal injury, or severe property or environmental damage (“Critical Applications”).

MPS PRODUCTS ARE NOT DESIGNED, INTENDED, AUTHORIZED, OR WARRANTED TO BE SUITABLE FOR USE IN LIFE SUPPORT APPLICATIONS, DEVICES OR SYSTEMS, OR OTHER CRITICAL APPLICATIONS.

Inclusion of MPS products in critical applications is understood to be fully at the risk of the customer.

Questions concerning potential risk applications should be directed to MPS.

MPS semiconductors are typically used in power supplies in which high voltages are present during operation. High-voltage safety precautions should be observed in design and operation to minimize the chance of injury.

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.

REVISION HISTORY

Revision #	Revision Date	Description	Pages Updated
1.0	2/21/2023	Initial Release	-

Notice: The information in this document is subject to change without notice. Users should warrant and guarantee that third-party Intellectual Property rights are not infringed upon when integrating MPS products into any application. MPS will not assume any legal responsibility for any said applications.

MPS Proprietary Information. Patent Protected. Unauthorized Photocopy and Duplication Prohibited.
© 2023 MPS. All Rights Reserved.