

Evaluating the **ADP1046A** Digital Controller in Resonant Mode for Isolated Power Supply

FEATURES

Full support evaluation kit for the **ADP1046A** in resonant mode
600 W, half bridge LLC topology
Wide input range
Synchronous rectifier control
98% peak efficiency
Fully integrated resonant inductor
Multiple address selections
6 pulse-width modulation (PWM) control signals
Redundant programmable overvoltage protection (OVP)
Digital trimming
Current, voltage, and temperature sense and calibration via graphical user interface (GUI)

EVALUATION KIT CONTENTS

EVAL-ADP1046A resonant mode evaluation board

ADDITIONAL EQUIPMENT NEEDED

ADP-I2C-USB-Z USB to I²C connector, with driver CD
(order separately from Analog Devices, Inc.)

GENERAL DESCRIPTION

The **EVAL-ADP1046A** evaluation board, together with a daughter card, allows the user to evaluate the **ADP1046A** in a power supply application. With the USB to I²C connector and the GUI, the **ADP1046A** located on the evaluation board can be interfaced with a PC via a USB port.

The evaluation board is set up to act as an isolated power supply unit (PSU) with a rated load of 48 V, 600 W from a 385 V dc source.

Connectors on the evaluation board provide synchronization and share bus and PMBus™ interfaces, allowing direct paralleling evaluation when multiple evaluation boards are connected in parallel to a common bus.

Multiple test points allow easy access to all critical points and pins.

Full specifications on the **ADP1046A** are available in the product data sheet, which should be consulted in conjunction with this user guide when using the evaluation board.

EVAL-ADP1046A RESONANT MODE EVALUATION BOARD PHOTOGRAPH

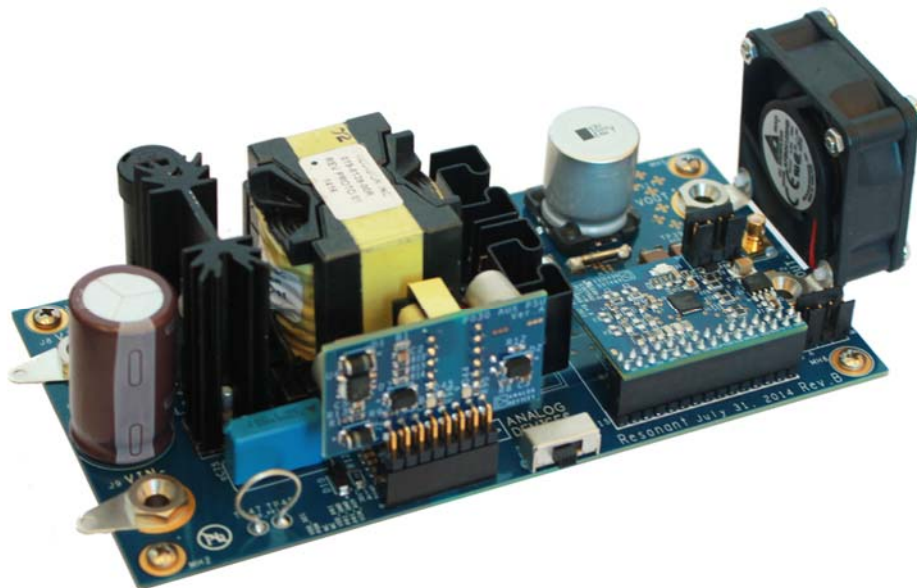


Figure 1.

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REVISION HISTORY

10/14—Revision 0: Initial Version

EVALUATION BOARD OVERVIEW

This evaluation board features the [ADP1046A](#) in a dc-to-dc switching power supply in a half bridge LLC topology with synchronous rectification.

Figure 4 shows the block diagram of the evaluation board. The circuit provides a rated load of 48 V, 12.5 A from a dc input voltage source of 385 V dc. The [ADP1046A](#) provides functions including output voltage regulation, synchronous rectification, pre-bias startup, and comprehensive protection functions.

The evaluation kit consists of a power board, a daughter card board, and the auxiliary circuit board.

POWER BOARD AND POWER TRAIN OVERVIEW

Figure 1 shows the power board. Refer to the Evaluation Board Schematics and Artwork section for more information on the circuit components.

The main power stage consists of the following components. The primary half bridge is formed with the QA and QB MOSFETs, while the Q8 and Q22 MOSFETs form the secondary side rectification. Transformer T12 provides the isolation. The resonant inductor of the power stage is fully integrated in the transformer. Capacitor C75 acts as the resonant capacitor. The output filter consists of a capacitor bank (C41, C79, C80, C84, C68, C73, C77, C78, and C76).

Additional circuitry around the power train are as follows. The input consists of a fuse (F2) and bypass capacitors (C71 and C72). Component U17 is a half bridge, 4 A driver based on the Analog Devices *iCoupler*® technology that provides gate drive for driving the primary half bridge.

The primary current is sensed using a current transformer (T5) that provides primary fast and accurate overcurrent protection (OCP), whereas the secondary side current (the load current) is sensed using a sense resistor (R2). Jumper J29 and Jumper J30 are placeholders to sense the primary and secondary currents.

AUXILIARY POWER BOARD CIRCUIT

Figure 2 shows the auxiliary power board. The auxiliary power circuit provides 12 V on the primary side and approximately 13 V on the secondary side. The minimum operating voltage of the auxiliary power board is approximately 50 V dc.

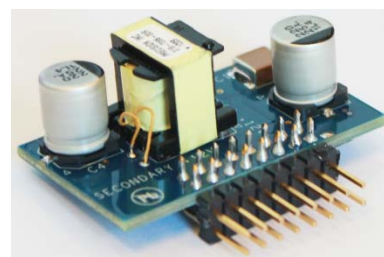


Figure 2. Auxiliary Power Board

DAUGHTER CARD BOARD

Figure 3 shows the [ADP1046ADC1-EVALZ](#) daughter card board. This board contains the [ADP1046A](#) digital controller that provides the control signals for driving the power stage. The daughter card board contains an on-board linear regulator that provides 3.3 V for the operation of the [ADP1046A](#).

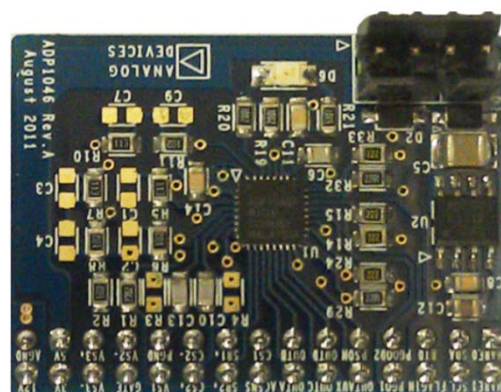


Figure 3. Daughter Card Board with [ADP1046A](#)



Figure 4. **EVAL-ADP1046A** Evaluation Board Block Diagram

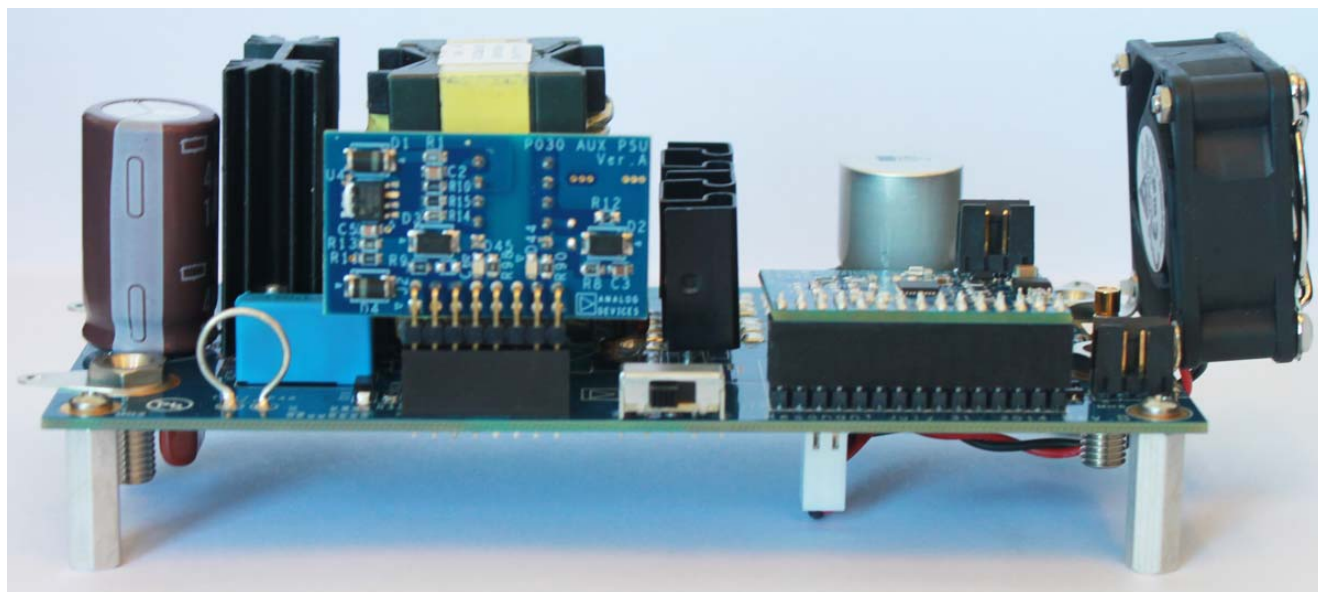


Figure 5. Front View of the EVAL-ADP1046A Resonant Mode Evaluation Board

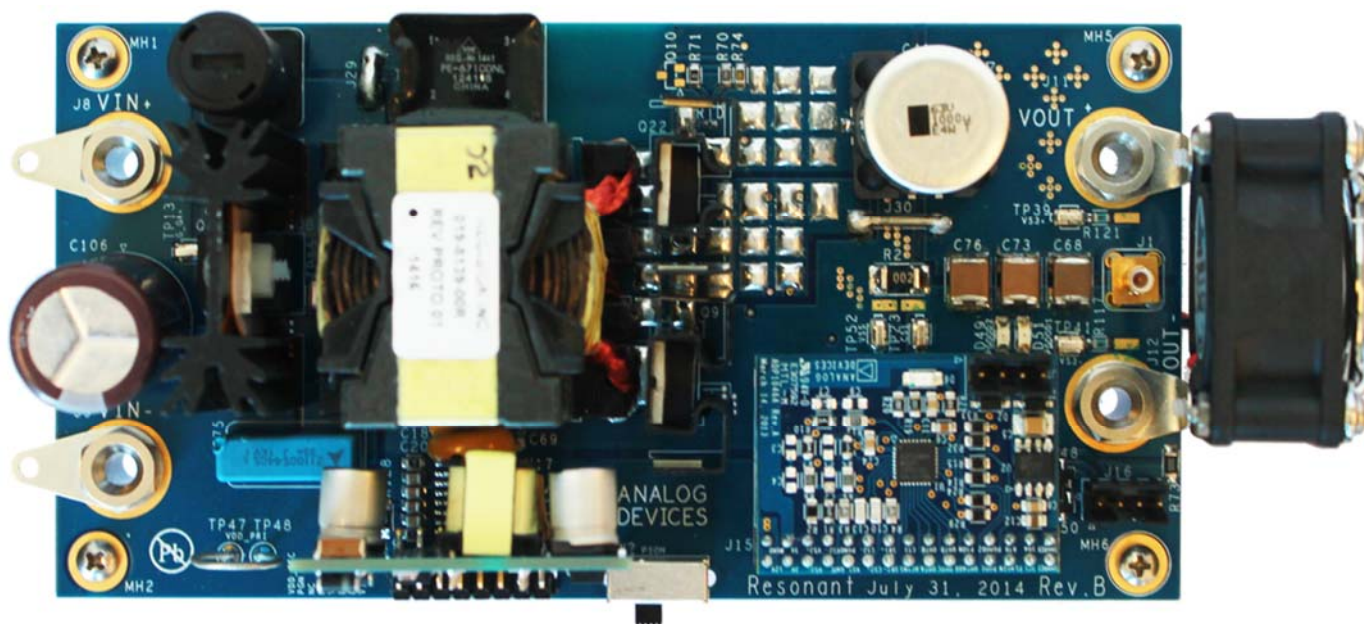


Figure 6. Top View of the [EVAL-ADP1046A](#) Resonant Mode Evaluation Board

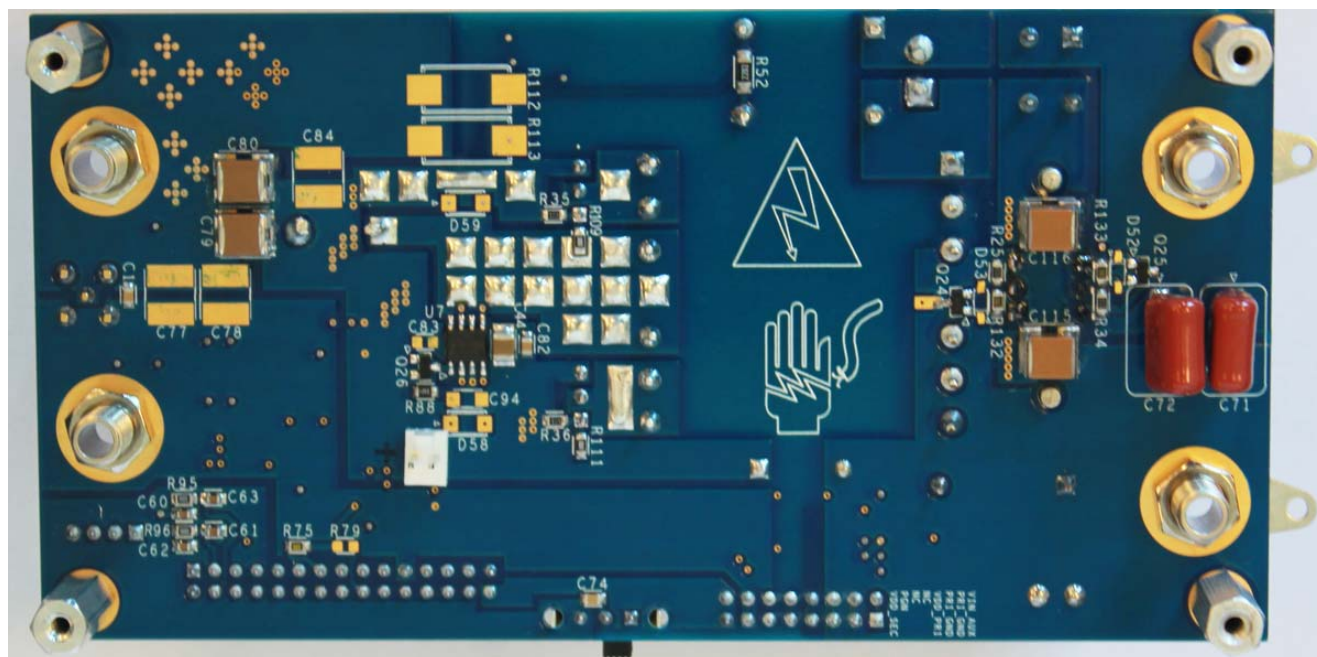


Figure 7. Bottom View the [EVAL-ADP1046A](#) Resonant Mode Evaluation Board

APPLICATIONS

Applications of the [ADP1046A](#) for high power density, isolated dc-to-dc power supplies include

- Intermediate bus converters
- Paralleled power supply systems
- Server, storage, industrial, networking, and infrastructure

CONNECTORS

Table 1 shows the connections to the [EVAL-ADP1046A](#) evaluation board. Table 2 shows the details of the I²C connector.

Table 1. Evaluation Board Connections

Connector	Function
J8	VIN+, dc input
J9	VIN–, ground return for dc input
J11	VOU+, dc output
J12	VOU–, return for dc output
J15	Daughter card connector
J16	I ² C connector
J18	Auxiliary power board connector
J1	BNC connector for measuring output ripple

I²C/PMBus Connector on [ADP1046ADC1-EVALZ](#) Daughter Card

Table 2. J16 Connections (Left to Right)

Pin No.	Function
1	5 V
2	SCL
3	SDA
4	AGND

SPECIFICATIONS

Table 3. Evaluation Board Connection Specifications

Parameter	Symbol	Min	Typ	Max	Unit	Test conditions/comment
Input Voltage	V _{IN}	350	385	410	V	At 600 W for brownout conditions only (see Figure 38)
Output Voltage	V _{OUT}		48		V	
Output Current	I _{OUT}		12.5		A	
Operation Temperature	T _A		25		°C	Natural convection
			25	60	°C	Airflow = 200 LFM or greater
Efficiency	η		98		%	V _{IN} = 385 V, V _{OUT} = 48 V, I _{OUT} = 7.5 A
Switching Frequency	f _{sw}		110		kHz	V _{IN} = 385 V, V _{OUT} = 48 V, 600 W
Output Voltage Ripple			350		mV	V _{IN} = 385 V, V _{OUT} = 48 V, I _{OUT} = 12.5 A
Dimension						Excluding standoff
Length			5.75		in	
Width			2.9		in	
Component Height			1.5		in	Excluding mounted fan

GETTING STARTED

CAUTION

This evaluation board uses high voltages and currents. Extreme caution should be taken, especially on the primary side, to ensure user safety. It is strongly advised to switch off the evaluation board when not in use. It is recommended to use a current-limited, isolated dc source at the input.

HARDWARE

Evaluation Equipment

The following equipment is required, unless otherwise noted:

- A dc power supply capable of 300 V dc to 400 V dc, 3 A.
- An electronic load capable of 60 V, 700 W.
- An oscilloscope capable of 500 MHz bandwidth or greater, 2-channel to 4-channel.
- A PC running Windows® XP (32-bit), Windows Vista (32-bit), Windows 7 (32-bit or 64-bit), or Windows 8 (32-bit).
- Precision digital multimeters (HP34401 or equivalent).

- The **ADP-I2C-USB-Z** USB to I²C connector, as shown in Figure 8. This connector must be ordered separately from Analog Devices.
- A portable digital multimeter (Fluke) for measuring up to 15 A of dc current (optional).

Evaluation Board Configurations

The evaluation board is preconfigured with the default settings to operate the power supply at the rated load. No additional configuration is necessary except for turning on the hardware PSON switch, which is described in the Powering Up section. Additional software configuration may be necessary to change the thresholds and parameters.

Hardware Connection

Figure 9 shows an example of the test configuration of the hardware with a mounted fan.



Figure 8. **ADP-I2C-USB-Z** USB to I²C Interface Connector

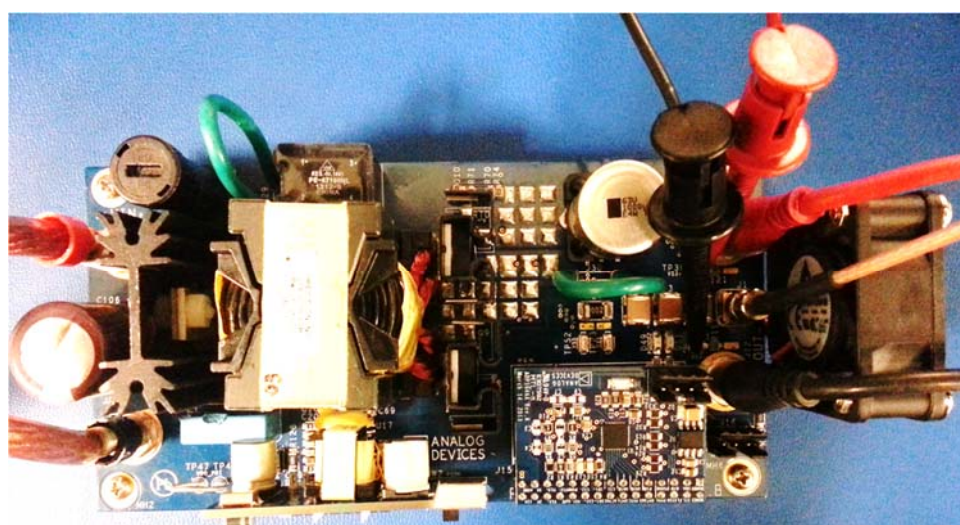


Figure 9. Test Configuration for the Evaluation Board with Mounted Fan

SOFTWARE GUI

Overview

The [ADP1046A](#) GUI is a free software tool for programming and configuring the [ADP1046A](#). The software can be downloaded from the [ADP1046A](#) product page.

GUI Installation

Connect the USB cable to the evaluation board only after the software has been installed.

1. Install the [ADP1046A](#) software GUI. Double-click the **ADP1046A Setup.msi** installation file to start the installation. Click **Next** to proceed.

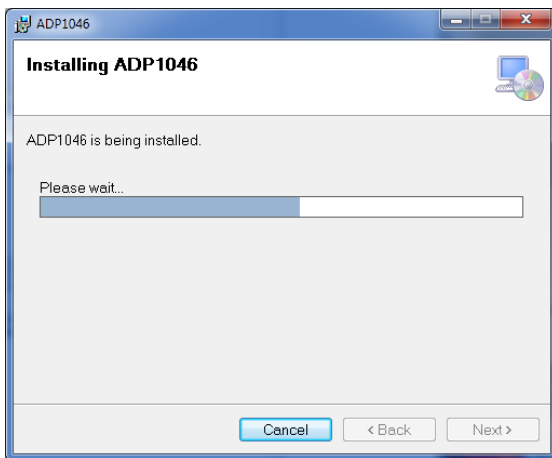


Figure 10. GUI Installation

2. When the **Total Phase USB Driver Setup** window appears, click **Next**. Read the license agreement, select **I accept the terms in the License Agreement**, and click **Next**.

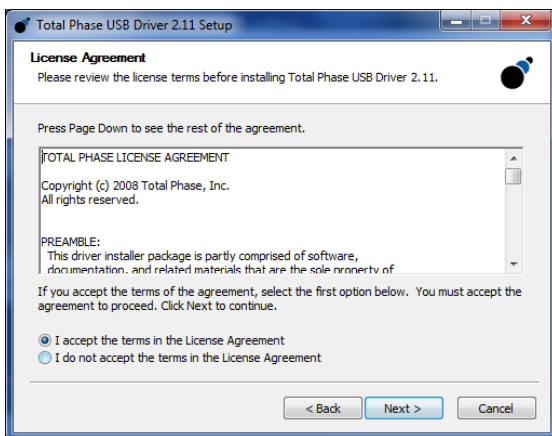


Figure 11. PC Driver Installation

3. Select the **Install USB driver** option if the driver is not installed. If the driver is installed, clear the **Install USB driver** option. Click **Install**. After the installation, click **Close** to complete the driver installation.
4. When the **Adobe Flash Player Installer** window appears, read the license agreement and select **I have read and agree to the terms of the Flash Player License Agreement**. Click **Install**, and then click **Done** to exit setup.

5. A dialog box appears to indicate that installation is complete.

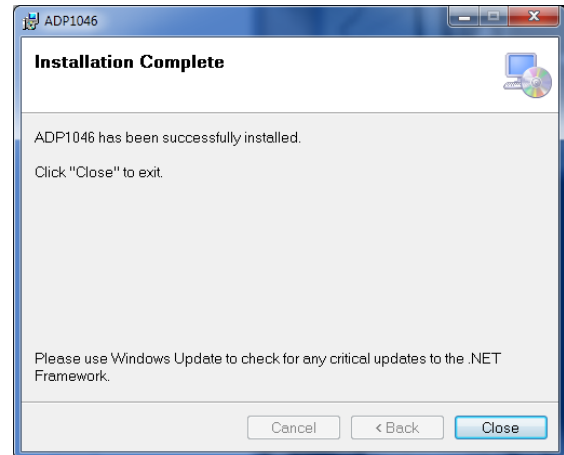


Figure 12. GUI Installation Complete

Launching the GUI

Take the following steps to launch the GUI:

1. Ensure that the evaluation board, the auxiliary power board, and the daughter card are plugged into the main power board. Ensure that the boards are properly attached, as shown in Figure 1.
2. Connect one end of the USB to I²C adapter or connector to the daughter card, and connect the other end to the USB port of the PC.
3. Launch the [ADP1046A](#) GUI. The software GUI reports that the [ADP1046A](#) has been located with the address (see Figure 13). Click **Finish** to proceed.



Figure 13. Address Detection of [ADP1046A](#)

4. The following step is optional; the [ADP1046A](#) in the evaluation kit comes preprogrammed with the board and command settings. To load the default command and board settings file from a local folder, click the **Load register settings** icon and the **Load board settings** icon (see Figure 14).

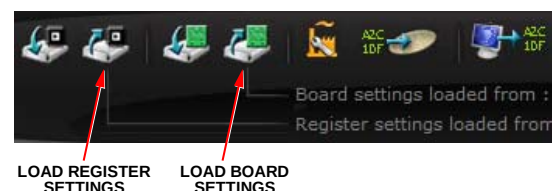


Figure 14. Icons Show Loading of **.46r** and **.46b** Files

Copy the contents from the Register Settings File (.46r) for GUI section and Board Settings File (.46b) for GUI section and store them in **.46r** and **.46b** files, respectively. For more information about the [ADP1046A](#) GUI, click the **GUI Reference Guide** icon (see Figure 15).



Figure 15. GUI Reference Guide

POWERING UP

Take the following steps to power up the evaluation board:

1. Ensure that the CTRL switch or hardware PSON (SW2) is turned to the off position (switch position is to the right).

2. Connect a dc source voltage range of 385 V dc at the input terminals and an electronic load at the output terminals.
3. Connect voltmeters on the input terminals (optional).
4. Connect the voltage probes at different test pins. Ensure that differential probes are used and that the ground of the probes are isolated if measurements are made on the primary and secondary sides of the transformer simultaneously.
5. Set the electronic load to a suitable load less than or equal to 12.5 A.
6. Turn the CTRL switch (SW2) to the on position (switch position is to the left).

The evaluation board is now running and ready for evaluation.
The output should read 48 V dc.

For more information on the board settings, refer to the GUI reference guide (see Figure 15).

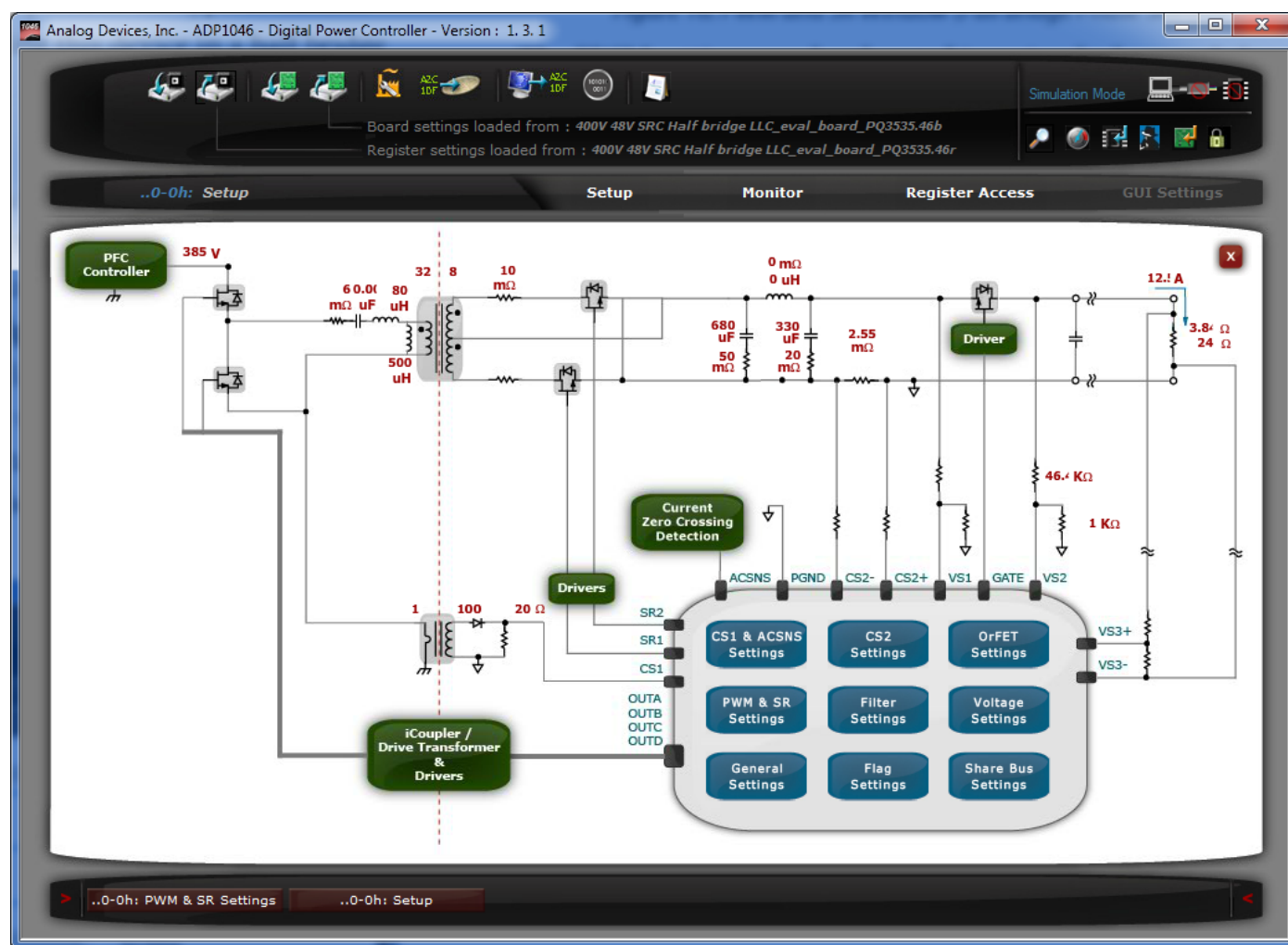


Figure 16. Main Setup Window of the ADP1046A GUI



Figure 17. Monitor Window in the GUI

POWER BOARD SETTINGS AND PERFORMANCE

This user guide describes the [ADP1046A](#) GUI and the flexibility available with the extensive programming options provided by the [ADP1046A](#). Test points on the evaluation board allow easy monitoring of the various signals. The user can use the GUI software to program multiple responses for the various fault conditions. The following sections provide a description of the typical features and results when evaluating the [ADP1046A](#) in a half bridge resonant mode topology.

PWM AND SR WINDOW

The PWM and synchronous rectifier (SR) window shows the PWM settings for the switches on the primary side and the synchronous rectifiers. This window also allows the user to program the maximum and minimum switching frequency.

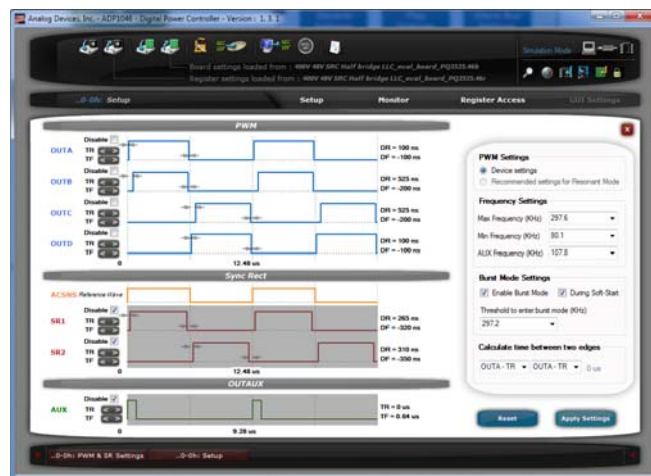


Figure 18. PWM and SR Window (Half Bridge LLC Resonant Topology)

Note the following:

- All the signals shown in Figure 18 represent the signals at the output pins of the IC.
- The software does not account for the dead times; dead times must be programmed manually by measuring the propagation delays between the output of the [ADP1046A](#) and the gate of the MOSFET. A 200 ns delay is conservative for the evaluation board.

Figure 18 shows a typical PWM configuration for a half bridge LLC resonant topology. OUTA and OUTD form the PWMs of the half bridge on the primary side, while OUTB and OUTC form the drive signals for the two synchronous rectifiers.

The PWM settings can be changed in a drag-and-drop fashion or by selecting the respective function. The **Apply Settings** button is highlighted in red whenever a change is made. Changes take place after **Apply Settings** is clicked; the changes are stored in the RAM of the IC, but need to be saved to the EEPROM for permanent storage.

SOFT START

Figure 19 shows the configuration of the soft start, which is set to hardware AND software PSON AND, is used in the logical sense here.

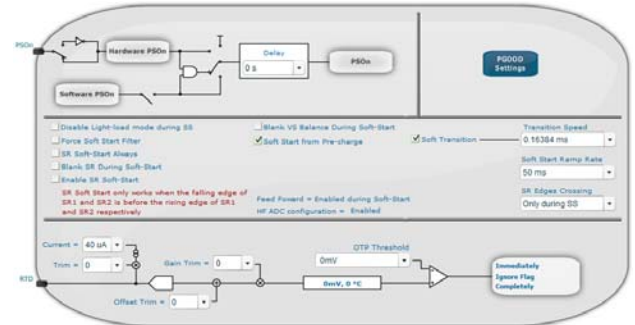


Figure 19. General Settings Window in the GUI

To change the soft start ramp rate, select a value from the **Soft Start Ramp Rate** drop-down box. Change the configurations of the hardware and software PSON by clicking the desired logical path.

Figure 20 to Figure 22 show the operation of the soft start.

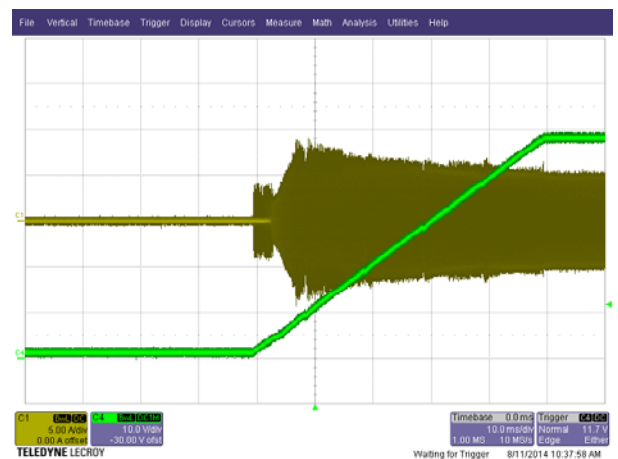


Figure 20. Soft Start at 600 W, 385 V dc Input; Green Trace = Output Voltage, 10 V/div; Yellow Trace = Primary Current, 5 A/div

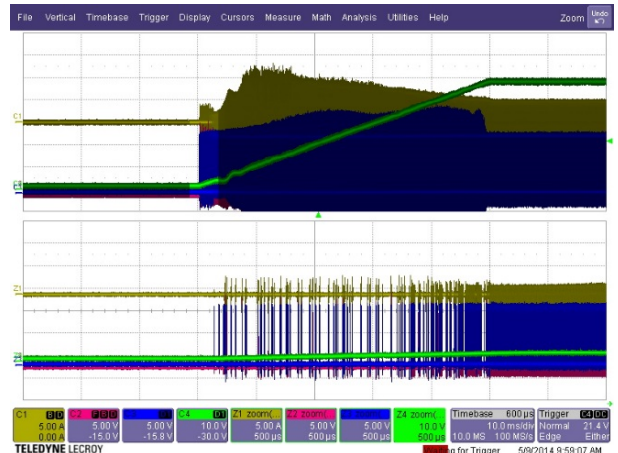


Figure 21. Soft Start at 600 W (Zoomed in to Show Operation of Burst Mode), 385 V dc input; Green Trace = Output Voltage, 10 V/div; Yellow Trace = Primary Current, 5 A/div; Blue Trace = SR Drive, 5 V/div

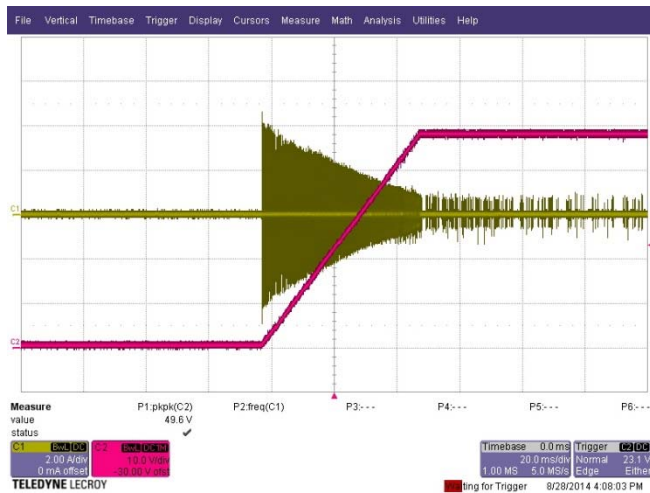


Figure 22. Soft Start at 0 W, 385 V dc Input; Red Trace = Output Voltage, 10V/div; Yellow Trace = Primary Current, 5A/div

OUTPUT VOLTAGE SETTINGS

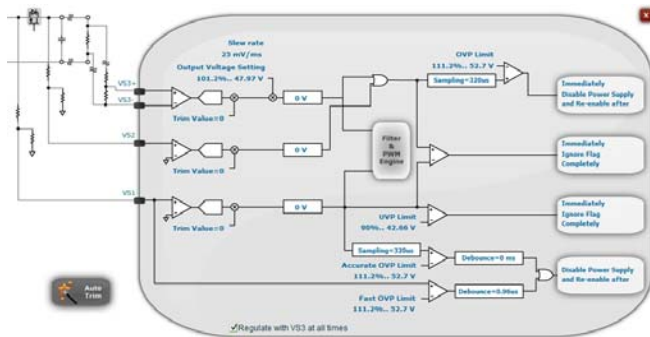


Figure 23. Output Voltage Settings in the GUI

Figure 23 shows the output voltage settings. Output voltage regulation is performed by the VS3± pins. Accurate OVP (ADC based) is present on the VS3± and VS1 pins. Fast OVP (comparator based) is present on the VS1 pin, which acts as the redundant OVP path.

Additional controls include setting the output voltage by selecting the value from a drop-down box. Undervoltage protection (UVP) is also done in a similar fashion.

When the output voltage crosses any of the thresholds mentioned previously, the corresponding flag is set, and a user defined action can be performed, such as shut down power supply or disable PWMs. These actions can be programmed individually.

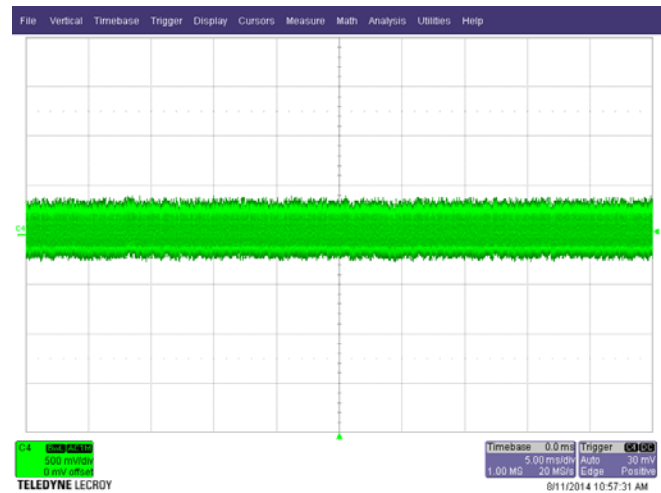


Figure 24. Output Voltage Ripple at 600 W, 385 V dc Input; Green Trace = AC-Coupled Output Voltage, 500 mV/div, 5 ms/div

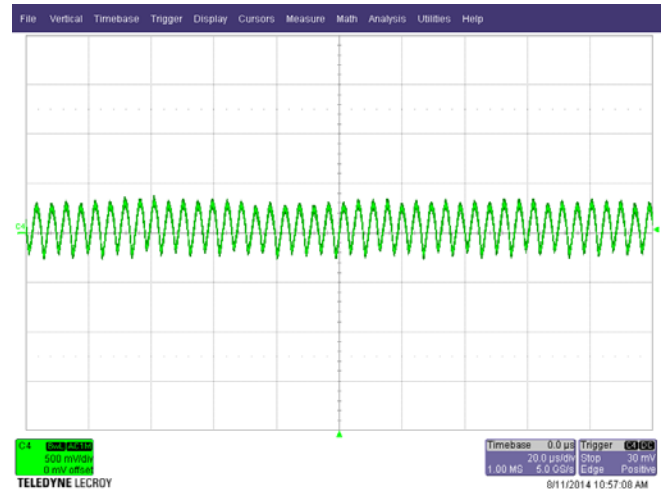


Figure 25. Output Voltage Ripple at 600 W, 385 V dc Input; Green Trace = AC-Coupled Output Voltage, 500 mV/div, 20 μs/div

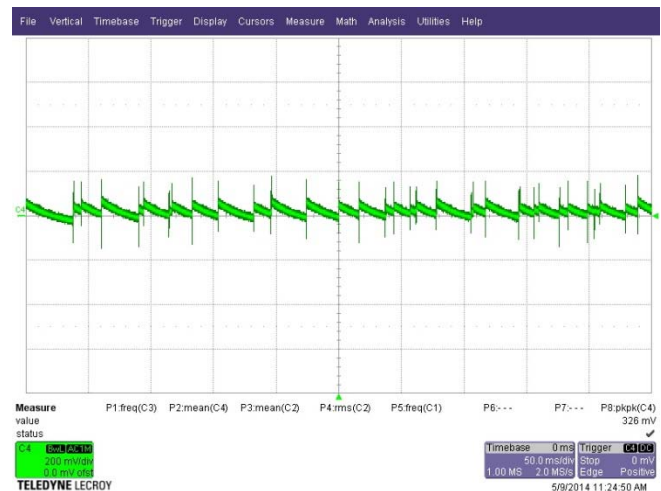


Figure 26. Output Voltage Ripple at Light Load, 385 V dc Input; Green Trace = AC-Coupled Output Voltage, 200 mV/div, 50 μs/div

PRIMARY CURRENT SETTINGS

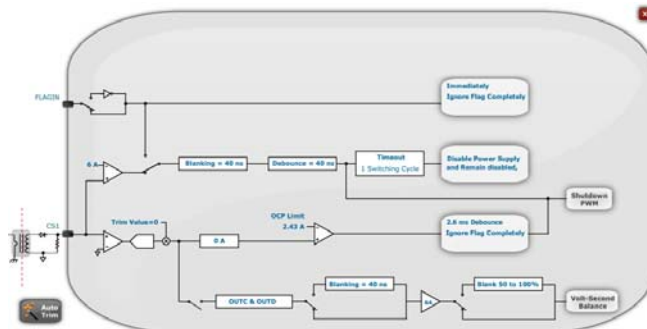


Figure 27. CS1 (Input Current) Settings Window

Figure 27 shows the CS1 settings window, which sets the accurate OCP threshold for the primary current and the response to a fast OCP fault.

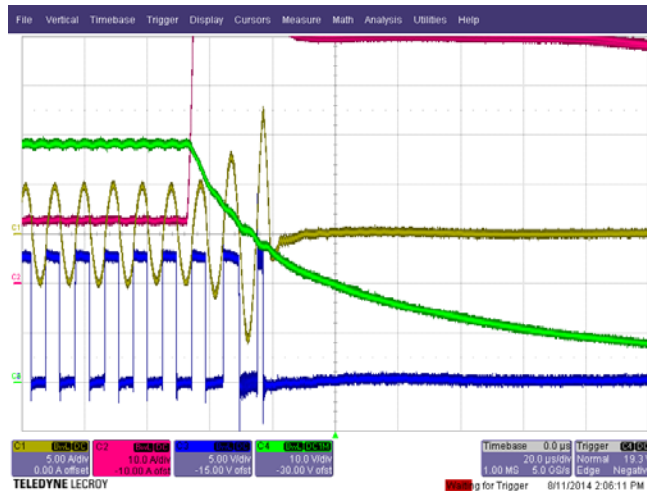


Figure 28. Primary Overcurrent Shutdown Under Shorted Load, 385 V dc Input; Green Trace = Output Voltage, 10 V/div, 20 μs/div; Yellow Trace = Secondary Current, 5 A/div; Blue Trace = Primary PWM, 5 V/div

SECONDARY CURRENT SETTINGS

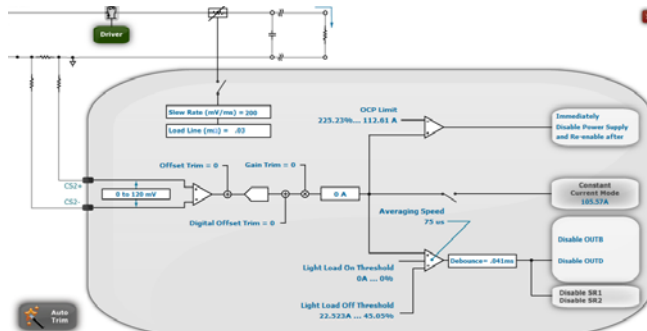


Figure 29. CS2 (Output Current) Settings Window

Figure 29 shows the CS2 settings window, which sets the limit for the accurate OCP threshold for the secondary current and its fault response in the flag settings window.

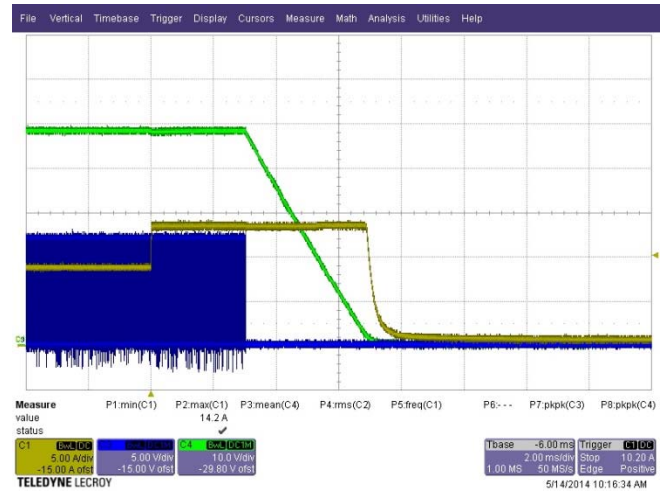


Figure 30. Secondary Overcurrent Shutdown Under Overload Condition; Green Trace = Output Voltage, 10 V/div, 20 μs/div; Yellow Trace = Secondary Current, 5 A/div; Blue Trace = Primary PWM, 5 V/div



Figure 31. Overvoltage Shutdown and Retry; Red Trace = Output Voltage, 10 V/div, 200 ms/div; Yellow Trace = Secondary Current, 2 A/div

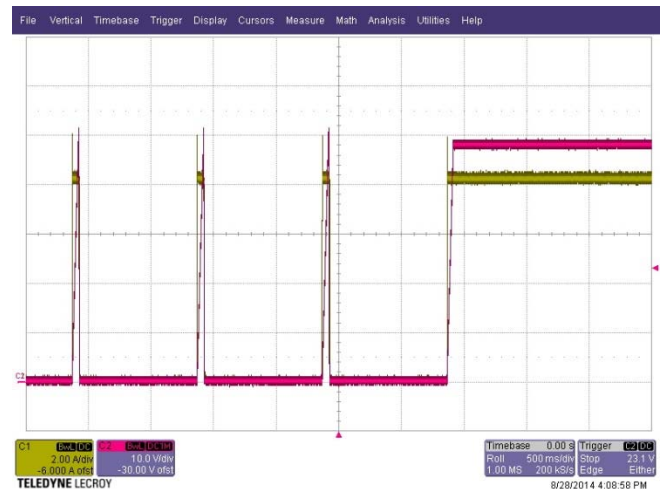


Figure 32. Recovery from Overvoltage Shutdown and Retry; Red Trace = Output Voltage, 10 V/div, 200 ms/div; Yellow Trace = Secondary Current, 2 A/div

FLAG SETTINGS WINDOW

The flag settings window programs the fault response for all fault conditions, including voltage, current, and temperature.

Each fault has a configuration with a programmable debounce time, and the response to the fault followed by the delay time between consecutive soft starts if the PSU is shut down as a result of the fault action. Some faults can also be blanked during soft start.

	Timing	Action	Blank flag during Soft-Start
CS1 Fast OCP	Immediately	Disable Power Supply and Remain disabled, PSON needed	☐
CS1 Accurate OCP	2.6 ms Debounce	Ignore Flag Completely	☒
CS2 Accurate OCP	Immediately	Disable Power Supply and Re-enable after 1 s	☐
Load OVP (VS2 or VS3)	Immediately	Disable Power Supply and Re-enable after 1 s	☒
External Flag	Immediately	Ignore Flag Completely	☒
OTP	Immediately	Ignore Flag Completely	☒
UVP	Immediately	Ignore Flag Completely	☐
CS2 Reverse Voltage	After 10 ms Debounce	Ignore Flag Completely	☐
Voltage Continuity	Immediately	Ignore Flag Completely	☐
Share Bus	After 100 ms Debounce	Ignore Flag Completely	☐
ACSNS	After 10 ms Debounce	Ignore Flag Completely	☐
VDD/VCORE OVP	After 500 μ s Debounce	Shutdown and Restart	Restart without EEPROM download
Accurate Local OVP (VS1)	Immediately	Disable Power Supply and Re-enable after 1 s	☐
Fast Local OVP (VS1)	After 0.95 μ s Debounce		

Additional Flag Settings: Power Supply re-enable time: 1 s ☐ OUTAUX PWM Immediate Shutdown ☐ Apply Settings

Figure 33. Flag Settings Window in the GUI

The first fault ID (FFID) that caused the PSU to shut down is displayed in a monitoring window.

A complete description of the fault response can be found in the [ADP1046A](#) data sheet.

DIGITAL CONTROL LOOP

Control Loop Configuration

The control loop configuration procedure is as follows:

1. Set the board parameters, including topology, turn ratio of main transformer, output LC filter, and output voltage feedback network. Using this information, the [ADP1046A](#) generates the Bode plots of the LC filter and feedback network.
2. For resonant mode, enter the nominal switching frequency in the PWM settings window. Changing the switching frequency changes the low frequency gain and the third pole position.
3. Place the zeros and poles, and set the low frequency gain and high frequency gain of the Type III compensator based on the stability rules.

Measure the loop gain of the system using the loop analyzer.

The perturbation signal from the loop analyzer can be injected in J11 and TP39, as shown in the schematic.

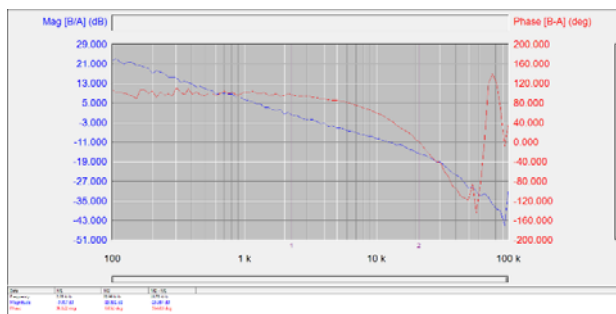


Figure 34. Control Loop Test by AP300 Loop Analyzer, 385 V dc Input, 600 W Load, 2.28 kHz Crossover Frequency, 96° Phase Margin, 15.5 dB Gain Margin

Transient Response for the Load Step

A dynamic electronic load can be connected to the output of the evaluation board to evaluate the transient response. Set up an oscilloscope to capture the transient waveform of the power supply output. Figure 35 and Figure 36 show an example of the load transient response.

The user can vary the digital filter via the GUI to change the transient response. This evaluation shows how the digital filter can be programmed to optimize the transient response of the PSU.



Figure 35. Dynamic Performance 600 W to 300 W, 385 V dc Input;
Green Trace = AC-Coupled Output Voltage, 500 mV/div, 500 μ s/div;
Red Trace = Load Current 2 A/div

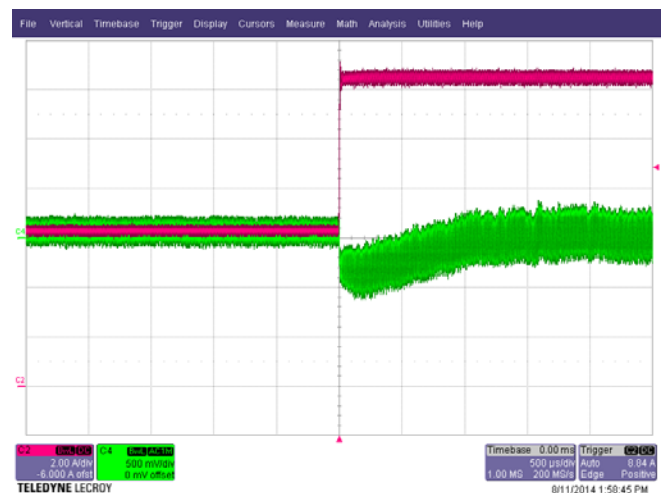


Figure 36. Dynamic Performance 300 W to 600 W, 385 V dc Input;
Green Trace = AC-Coupled Output Voltage, 500 mV/div, 500 μ s/div;
Red Trace = Load Current, 2 A/div

MISCELLANEOUS WAVEFORMS AND DATA

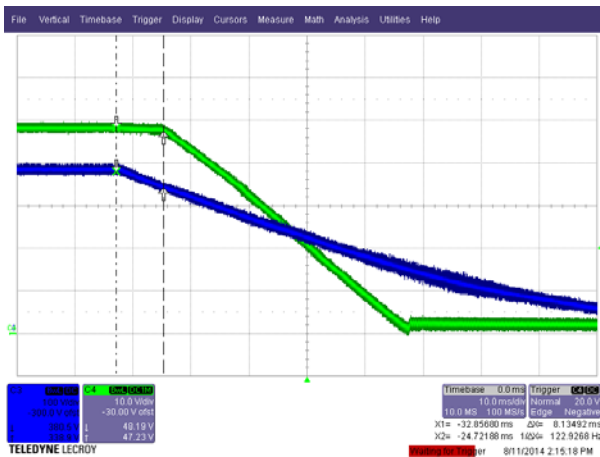


Figure 37. Hold Up Time of 8.13 ms at 300 W Load During Brownout Condition;
Green Trace = Output Voltage, 10 V/div, 10 ms/div;
Blue Trace = Input Voltage, 100 V/div

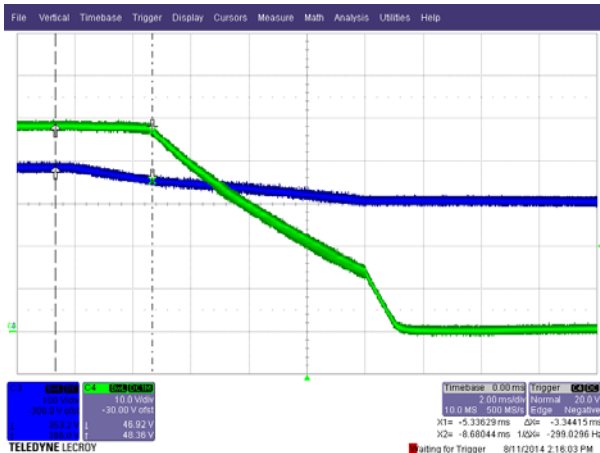


Figure 38. Hold Up Time of 3.34 ms at 600 W Load During Brownout Condition;
Green Trace = Output Voltage, 10 V/div, 10 ms/div;
Blue Trace = Input Voltage, 100 V/div

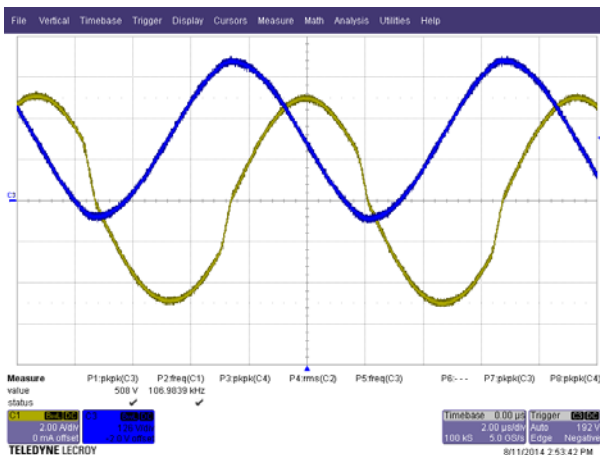


Figure 39. State Variables at 600 W, 385 V dc Input;
Blue Trace = Resonant Capacitor Voltage, 126 V/div, 2 μs/div;
Yellow Trace = Resonant Inductor Current, 2 A/div

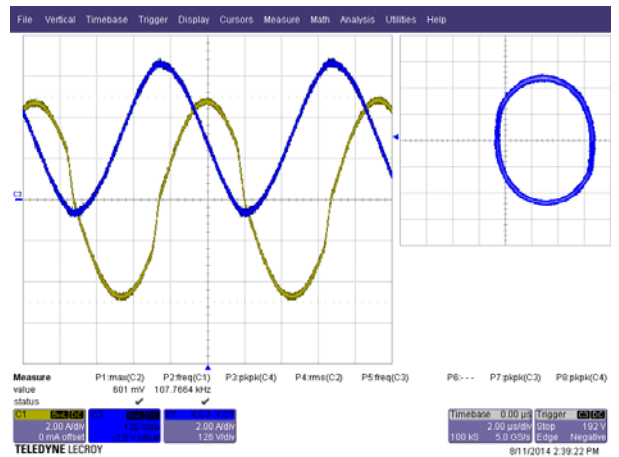


Figure 40. State Plane Diagram at 600 W, 385 V dc Input;
Blue Trace = Resonant Capacitor Voltage, 126 V/div, 2 μs/div;
Yellow Trace = Resonant Inductor Current, 2 A/div;
X-Axis = Resonant Capacitor Voltage; Y-Axis = Resonant Inductor Current

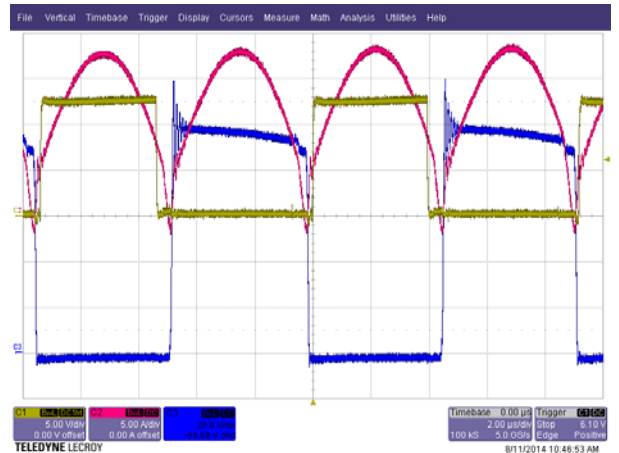


Figure 41. Secondary Side Waveforms, 600 W, 385 V dc Input, 2 μs/div;
Red Trace = Secondary Side Current Through Jumper J30, 5 A/div;
Blue Trace = SR Drain, 20 V/div; Yellow Trace = SR Drive Signal, 5 V/div

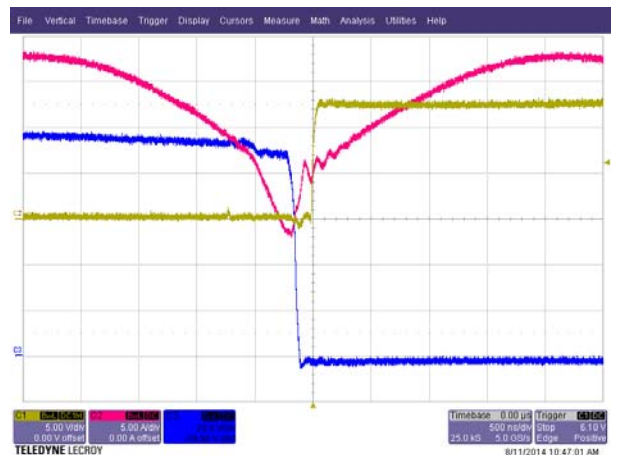


Figure 42. Secondary Side Waveforms Showing Turn On of SR after Reverse Recovery, 600 W, 385 V dc Input, 2 μs/div; Red Trace = Secondary Side Current Through Jumper J30, 5 A/div; Blue Trace = SR Drain, 20 V/div; Yellow Trace = SR Drive Signal, 5 V/div

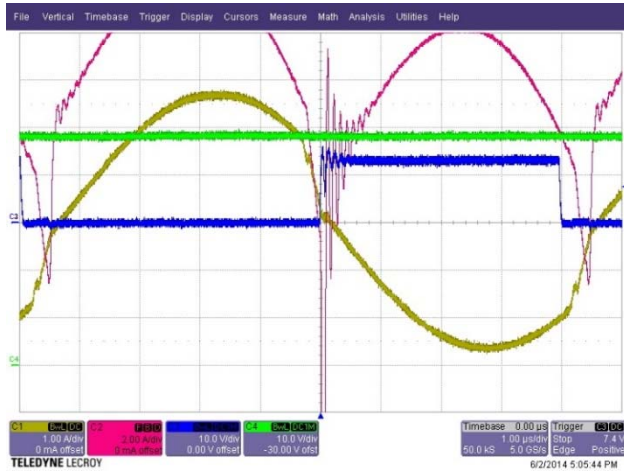


Figure 43. Example Showing Improper Dead Time for SR1 and Correct Dead Time for SR2, 600 W, 385 V dc Input, 2 μ s/div; Red Trace = Secondary Side Current Through Jumper J30, 5 A/div; Blue Trace = SR Drive Signal, 10 V/div; Yellow Trace = Input Current, 2 A/div

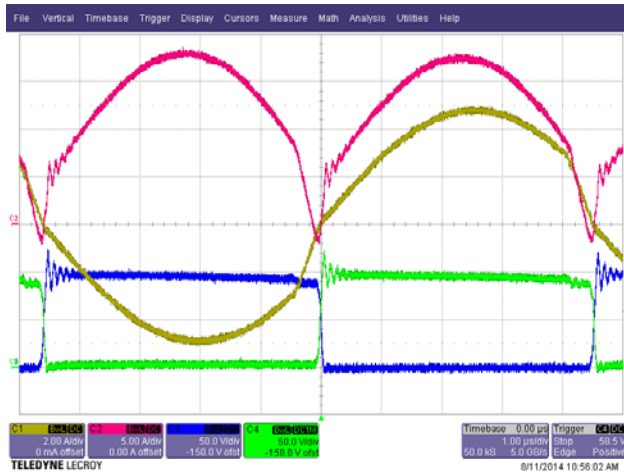


Figure 44. Secondary Side Waveforms Showing Turn On of SR after Reverse Recovery, 600 W, 385 V dc Input, 2 μ s/div; Red Trace = Secondary Side Current Through Jumper J30, 5 A/div; Blue Trace = Synchronous Rectifier 1 Drain, 20 V/div; Green Trace = Synchronous Rectifier 2 Drain, 20 V/div; Yellow Trace = SR Drive Signal, 5 V/div

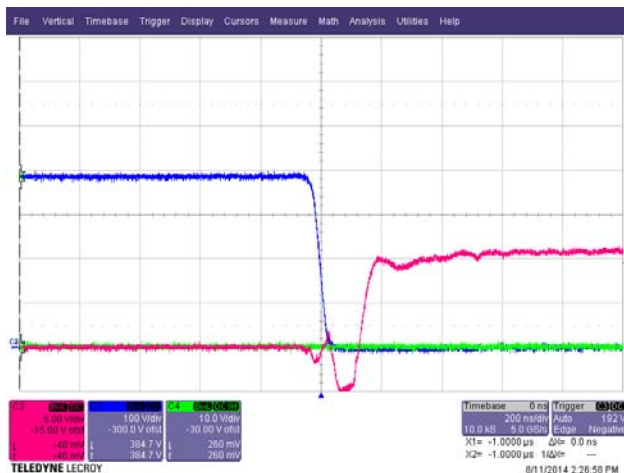


Figure 45. ZVS Waveform for QA, 600 W Load, 385 V dc Input, 2 μ s/div; Red Trace = Gate Drive, 5 V/div

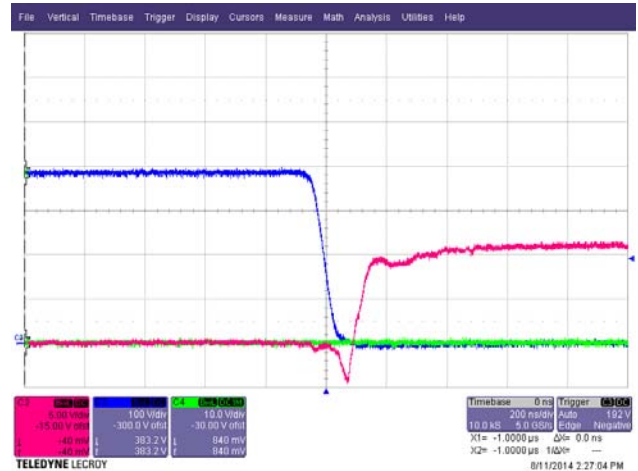


Figure 46. ZVS Waveform for QA, 300 W Load, 385 V dc Input, 2 μ s/div; Red Trace = Gate Drive, 5 V/div

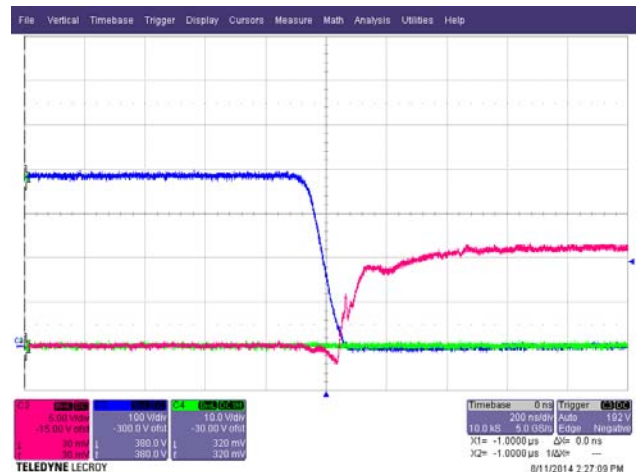


Figure 47. ZVS Waveform for QA, 192 W Load, 385 V dc Input, 2 μ s/div; Red Trace = Gate Drive, 5 V/div

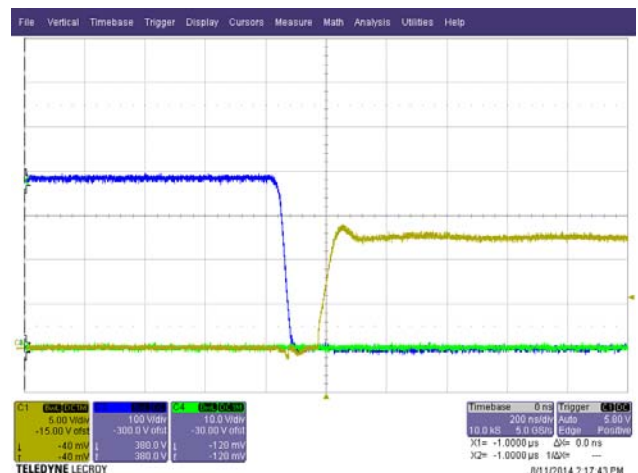


Figure 48. ZVS Waveform for QB, 600 W Load, 385 V dc Input, 2 μ s/div; Yellow Trace = Gate Drive, 5 V/div

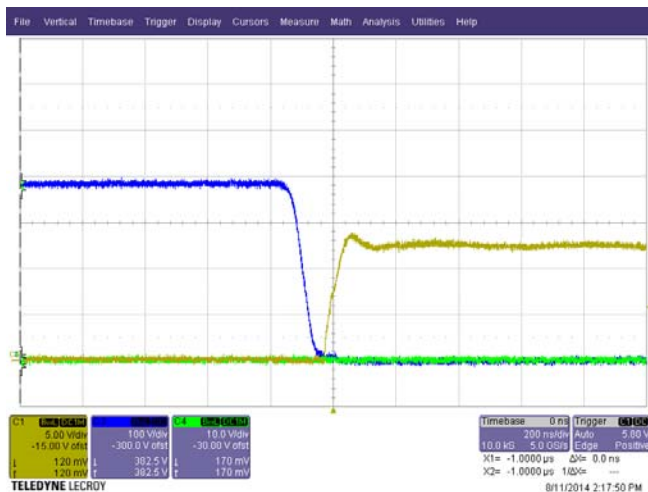


Figure 49. ZVS Waveform for QB, 300 W Load, 385 V dc Input, 2 μ s/div;
Yellow Trace = Gate Drive, 5 V/div

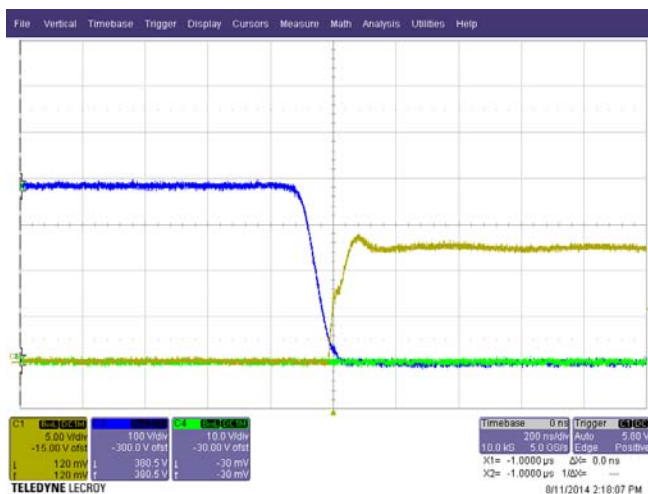


Figure 50. ZVS Waveform for QB, 192 W Load, 385 V dc Input, 2 μ s/div;
Yellow Trace = Gate Drive, 5 V/div

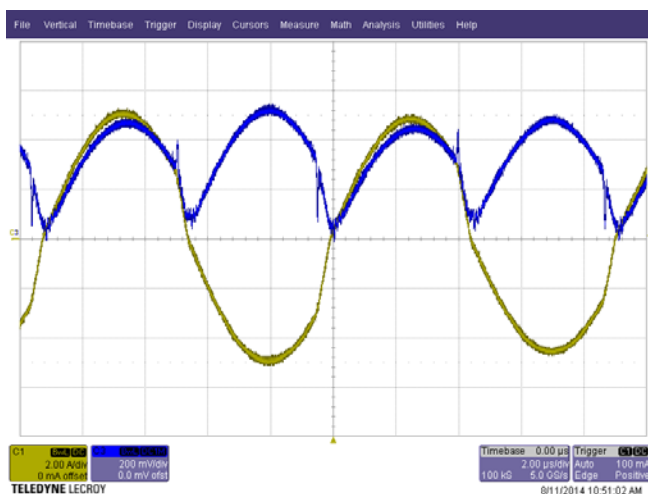


Figure 51. Primary Currents (Actual and Measured), 600 W Load, 385 V dc Input, 2 μ s/div; Yellow Trace = Primary Current, 5 A/div;
Blue Trace = CS1 Pin Voltage, 200 mV/div

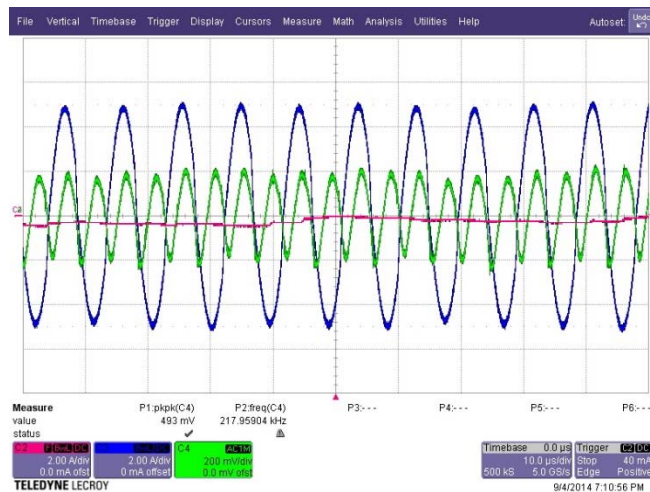


Figure 52. Output Voltage Ripple at 600 W with PFC Nominal Input of 385 V dc, 10 μ s/div; Green Trace = AC-Coupled Output Voltage, 500 mV/div; Blue Trace = LLC Primary Current, 2 A/div; Red Trace = Input Line Current into PFC

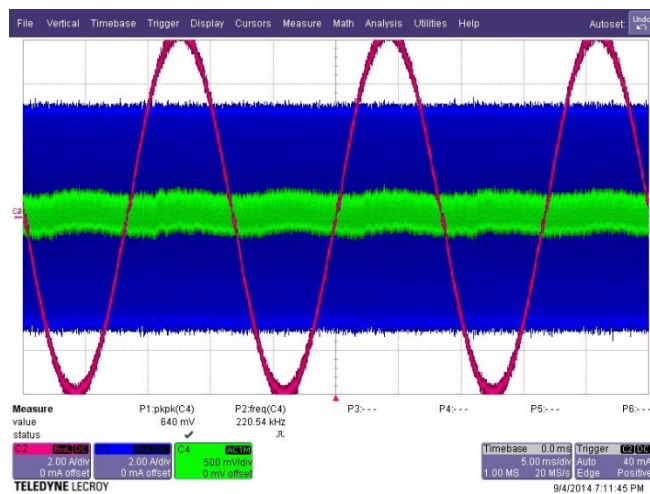


Figure 53. Output Voltage Ripple at 600 W with PFC Nominal Input of 385 V dc, 5 ms/div; Green Trace = AC-Coupled Output Voltage, 500 mV/div; Blue Trace = LLC Primary Current, 2 A/div; Red Trace = Input Line Current into PFC

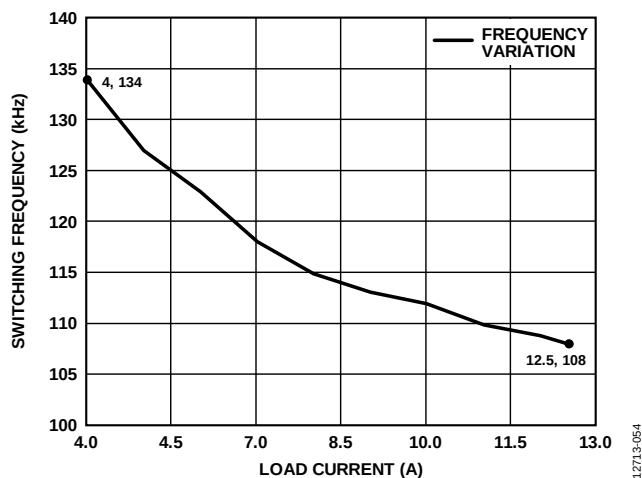


Figure 54. Variation of Switching Frequency Based on Load, 385 V dc Input

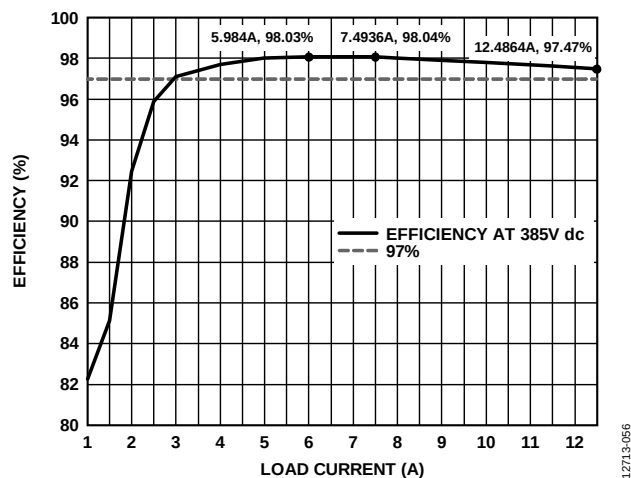


Figure 56. Efficiency Curve at 385 V dc Input for Configuration in Figure 9 Without Fan

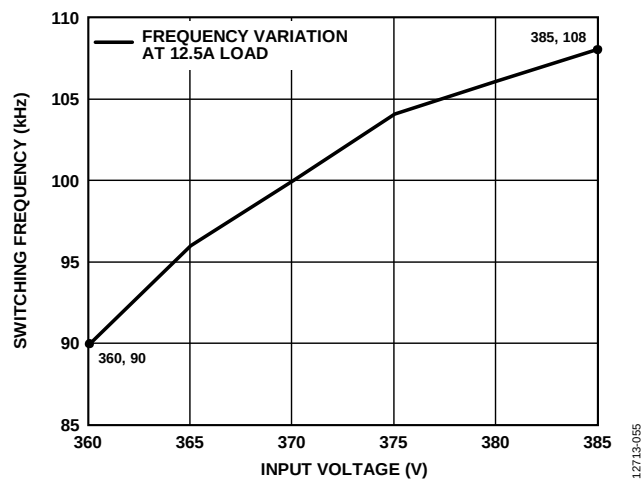


Figure 55. Variation of Switching Frequency Based on Input Voltage, 600 W Load

THERMAL PERFORMANCE

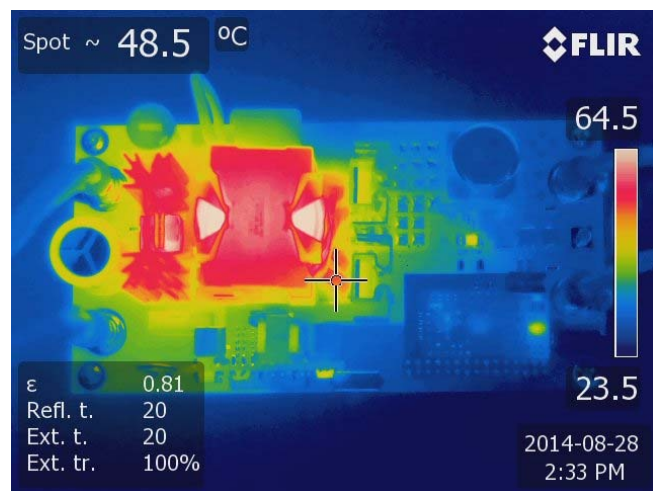


Figure 57. Thermal Image at 385 V dc Input, 600 W Load, 1 Hour Soaking Time with Setup Shown in Figure 9

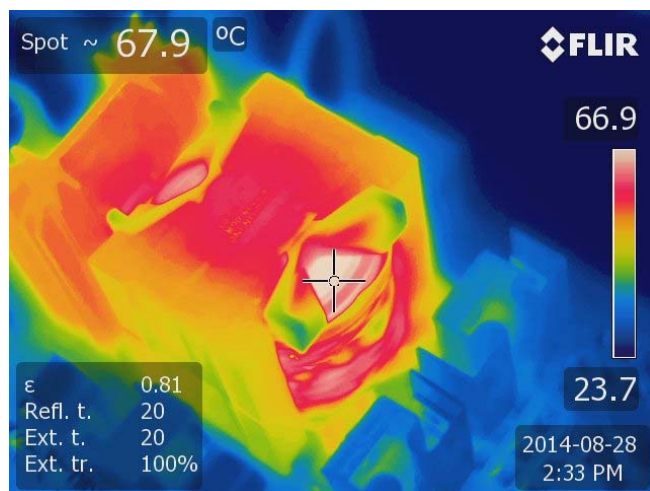


Figure 59. Thermal Image of Transformer at 385 V dc Input, 600 W Load, 1 Hour Soaking Time with Setup Shown in Figure 9

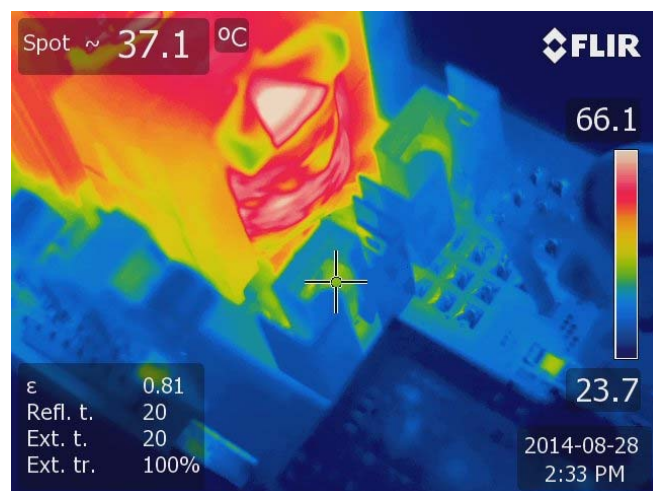


Figure 58. Thermal Image of Secondary Rectifier at 385 V dc Input, 600 W Load, 1 Hour Soaking Time with Setup Shown in Figure 9

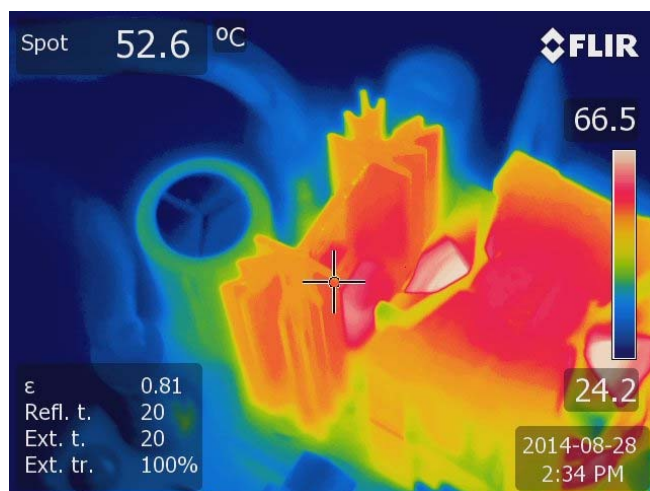


Figure 60. Thermal Image of Primary MOSFET at 385 V dc Input, 600 W Load, 1 Hour Soaking Time with Setup Shown in Figure 9

REGISTER SETTINGS FILE (.46r) FOR GUI

Copy the following content into a text file and rename it with a **.46r** file extension. Load this file in the GUI using the **Load register settings** option. Ensure that the last line of the **.46r** file does not have a carriage return.

Reg(8h) = F0h - Fault Configuration Register 1	Reg(4Ch) = 0h - PWM 3 Negative Edge Setting
Reg(9h) = BBh - Fault Configuration Register 2	Reg(4Dh) = 14h - PWM 4 Positive Edge Timing
Reg(Ah) = B8h - Fault Configuration Register 3	Reg(4Eh) = 1h - PWM 4 Positive Edge Setting
Reg(Bh) = 88h - Fault Configuration Register 4	Reg(4Fh) = 14h - PWM 4 Negative Edge Timing
Reg(Ch) = 8h - Fault Configuration Register 5	Reg(50h) = 0h - PWM 4 Negative Edge Setting
Reg(Dh) = 0h - Fault Configuration Register 6	Reg(51h) = 15h - SR 1 Positive Edge Timing
Reg(Eh) = 21h - Flag Configuration	Reg(52h) = 9h - SR 1 Positive Edge Setting
Reg(Fh) = 6Ah - Soft-Start Blank Fault Flags	Reg(53h) = 60h - SR 1 Negative Edge Timing
Reg(11h) = E6h - RTD Current Settings	Reg(54h) = A0h - SR 1 Negative Edge Setting
Reg(22h) = 2Bh - CS1 Accurate OCP Limit	Reg(55h) = 1Eh - SR 2 Positive Edge Timing
Reg(26h) = 4Fh - CS2 Accurate OCP Limit	Reg(56h) = 8h - SR 2 Positive Edge Setting
Reg(27h) = 60h - CS1 / CS2 Settings	Reg(57h) = 66h - SR 2 Negative Edge Timing
Reg(28h) = 3h - VS Balance Settings	Reg(58h) = D0h - SR 2 Negative Edge Setting
Reg(29h) = 1Fh - Share Bus Bandwidth	Reg(59h) = 0h - PWM AUX Positive Edge Timing
Reg(2Ah) = 6h - Share Bus Setting	Reg(5Ah) = 0h - PWM AUX Positive Edge Setting
Reg(2Ch) = E0h - PSON/Soft Stop Settings	Reg(5Bh) = 8h - PWM AUX Negative Edge Timing
Reg(2Dh) = 48h - PG00D Debounce and Pin Polarity Setting	Reg(5Ch) = 0h - PWM AUX Negative Edge Setting
Reg(2Eh) = B4h - Modulation Limit	Reg(5Dh) = E0h - PWM and SR Pin Disable Setting
Reg(2Fh) = 0h - OTP Threshold	Reg(5Fh) = B3h - Soft Start and Slew Rate Setting
Reg(30h) = C7h - OrFET	Reg(60h) = 16h - Normal Mode Digital Filter LF Gain Setting
Reg(31h) = A2h - VS3 Voltage Setting	Reg(61h) = D0h - Normal Mode Digital Filter Zero Setting
Reg(32h) = 1Bh - VS1 Overvoltage Limit	Reg(62h) = C5h - Normal Mode Digital Filter Pole Setting
Reg(33h) = 17h - VS2 / VS3 Overvoltage Limit	Reg(63h) = 12h - Normal Mode Digital Filter HF Gain Setting
Reg(34h) = 48h - VS1 Undervoltage Limit	Reg(64h) = 16h - Light Load Digital Filter LF Gain Setting
Reg(35h) = FFh - Line Impedance Limit	Reg(65h) = D0h - Light Load Digital Filter Zero Setting
Reg(36h) = 7h - Load Line Impedance	Reg(66h) = C5h - Light Load Digital Filter Pole Setting
Reg(37h) = 56h - Fast OVP Comparator Settings	Reg(67h) = 12h - Light Load Digital Filter HF Gain Setting
Reg(3Bh) = 0h - Light Load Disable Setting	Reg(68h) = 0h - Reserved
Reg(3Fh) = 13h - OUTAUX Switching Frequency Setting	Reg(69h) = Bh - Reserved
Reg(40h) = 3Fh - PWM Switching Frequency Setting	Reg(6Ah) = Dh - Reserved
Reg(41h) = 14h - PWM 1 Positive Edge Timing	Reg(6Bh) = Fh - Reserved
Reg(42h) = 9Ch - PWM 1 Positive Edge Setting	Reg(6Ch) = 0h - Reserved
Reg(43h) = ECh - PWM 1 Negative Edge Timing	Reg(6Dh) = 0h - Reserved
Reg(44h) = 0h - PWM 1 Negative Edge Setting	Reg(6Eh) = 0h - Reserved
Reg(45h) = 69h - PWM 2 Positive Edge Timing	Reg(6Fh) = 0h - Reserved
Reg(46h) = 2Ah - PWM 2 Positive Edge Setting	Reg(70h) = 11h - Reserved
Reg(47h) = D8h - PWM 2 Negative Edge Timing	
Reg(48h) = 0h - PWM 2 Negative Edge Setting	
Reg(49h) = 69h - PWM 3 Positive Edge Timing	
Reg(4Ah) = C1h - PWM 3 Positive Edge Setting	
Reg(4Bh) = 28h - PWM 3 Negative Edge Timing	

Reg(71h) = 16h - Soft Start Digital Filter LF Gain Setting

Reg(72h) = D0h - Soft Start Digital Filter Zero Setting

Reg(73h) = C5h - Soft Start Digital Filter Pole Setting

Reg(74h) = 12h - Soft Start Digital Filter HF Gain Setting

Reg(75h) = F3h - Voltage Feed Forward Settings

Reg(76h) = FFh - Volt Second Balance OUTA/OUTB Settings

Reg(77h) = 0h - Volt Second Balance OUTC/OUTD Settings

Reg(78h) = 0h - Volt Second Balance SR1/SR2 Settings

Reg(79h) = 23h - SR Delay Offset

Reg(7Ah) = Ch - Filter Transitions

Reg(7Bh) = 7Fh - PG00D1 Masking

Reg(7Ch) = 1h - PG00D2 Masking

Reg(7Dh) = 35h - Light Load Mode Threshold Settings

BOARD SETTINGS FILE (.46b) FOR GUI

Copy the following content into a text file and rename it with a **.46b** file extension. Load this file in the GUI using the **Load board settings** option. Ensure that the last line of the **.46b** file does not have a carriage return.

```

Input Voltage = 385 V
N1 = 32
N2 = 8
R (CS2) = 2.2 mOhm
I (load) = 12.5 A
R1 = 46.4 KOhm
R2 = 1 KOhm
C3 = 1 uF
C4 = 1 uF
N1 (CS1) = 1
N2 (CS1) = 100
R (CS1) = 20 Ohm
ESR (L1) = 6 mOhm
L1 = 6 uH
C1 = 680 uF
ESR (C1) = 50 mOhm
ESR (L2) = 0 mOhm
L2 = 0 uH
C2 = 330 uF
ESR (C2) = 20 mOhm
R (Normal-Mode) (Load) = 3.84 Ohm
R (Light-Load-Mode) (Load) = 24 Ohm
Cap Across R1 & R2 = 0 "(1 = Yes: 0 = No)"

Topology = 7 (0 = Full Bridge: 1 = Half
Bridge: 2 = Two Switch Forward: 3 =
Interleaved Two Switch Forward: 4 = Active
Clamp Forward: 5 = Resonant Mode: 6 =
Custom)
Switches / Diodes = 0 (0 = Switches: 1 =
Diodes)
High Side / Low Side Sense (CS2) = 0 (1 =
High-Side: 0 = Low-Side Sense)
Second LC Stage = 1 (1 = Yes: 0 = No)
CS1 Input Type = 0 (1 = AC: 0 = DC)
R3 = 0 KOhm
R4 = 0 KOhm
PWM Main = 0 (0 = OUTA: 1 = OUTB: 2 = OUTC:
3 = OUTD: 4 = SR1: 5 = SR2: 6 = OUTAUX)
C5 = 0 uF
C6 = 0 uF
R6 = 27 KOhm
R7 = 1 KOhm
C7 = 0.009 uF
L3 = 80 uH
Lm = 500 uH
ResF = 110 kHz
R8 = 6 mOhm
R9 = 10 mOhm

```

TRANSFORMER SPECIFICATION

Table 4. Transformer Specifications

Parameter	Min	Typ	Max	Unit	Notes
Core and Bobbin					PQ3535
Primary Inductance	450	502	550	μH	Pin 1 to Pin 6
Leakage Inductance	73	80	90	μH	Pin 1 to Pin 6 with all other windings shorted
Turns Ratio		4:1:1			

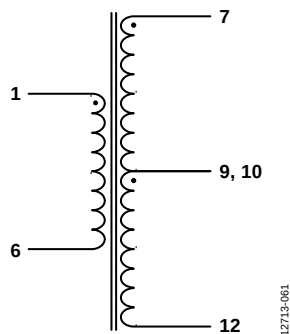


Figure 61. Transformer Electrical Diagram

EVALUATION BOARD SCHEMATICS AND ARTWORK

EVALUATION BOARD SCHEMATICS

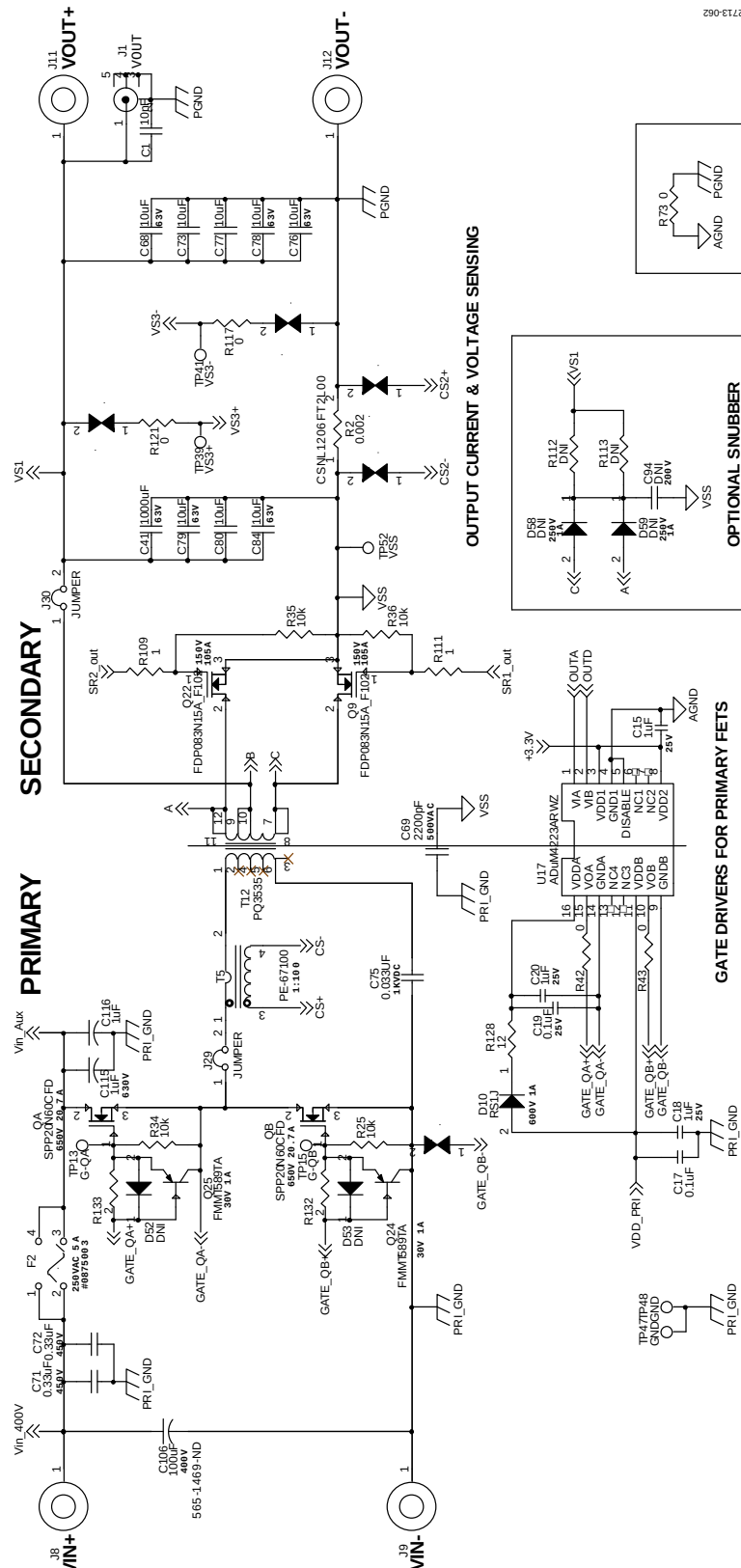
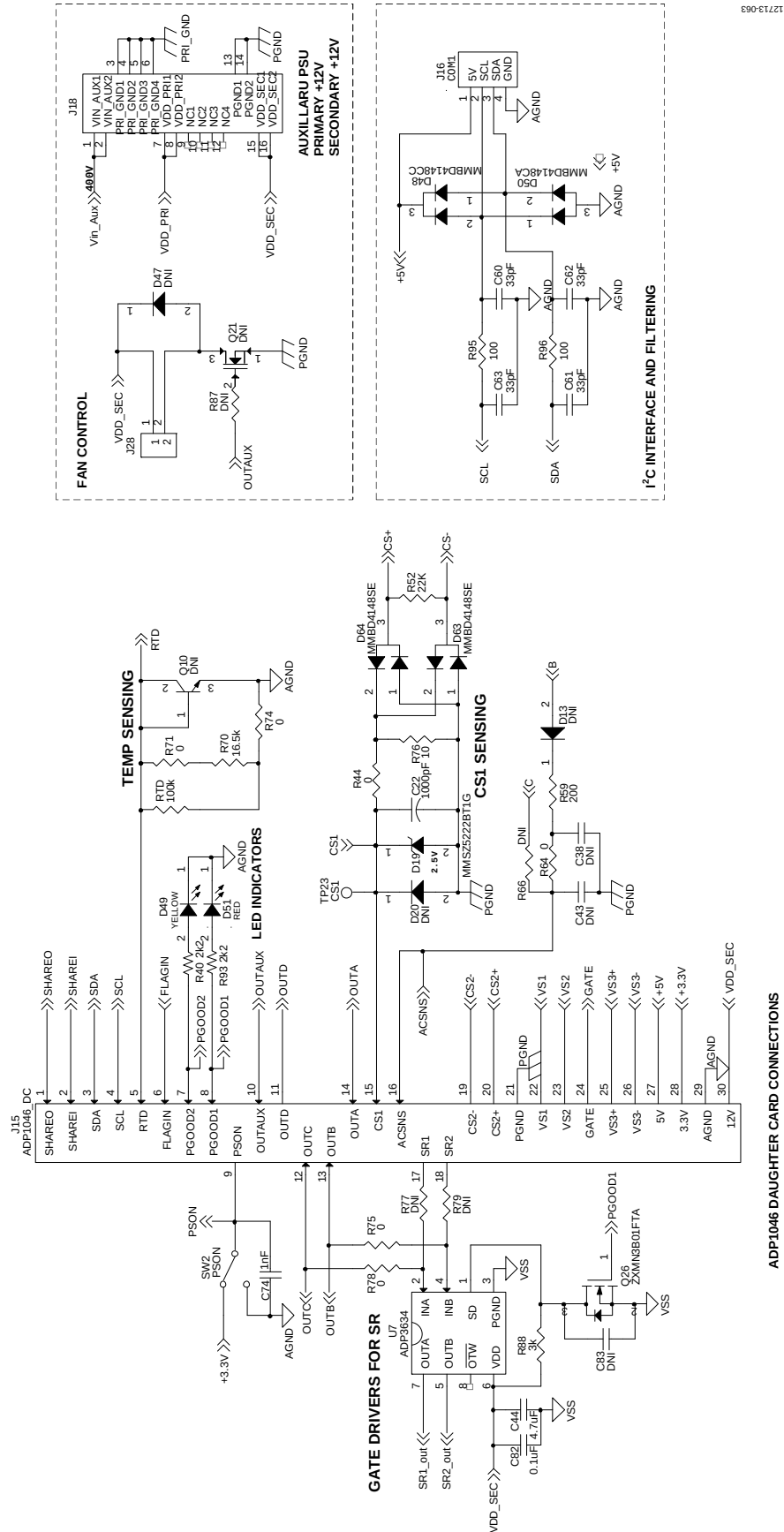


Figure 62. EVAL-ADP1046A Evaluation Board Schematic, Part 1



ADP1046 DAUGHTER CARD CONNECTIONS

Figure 63. EVAL-ADP1046A Evaluation Board Schematic, Part 2

Figure 64. PCB Assembly, Top

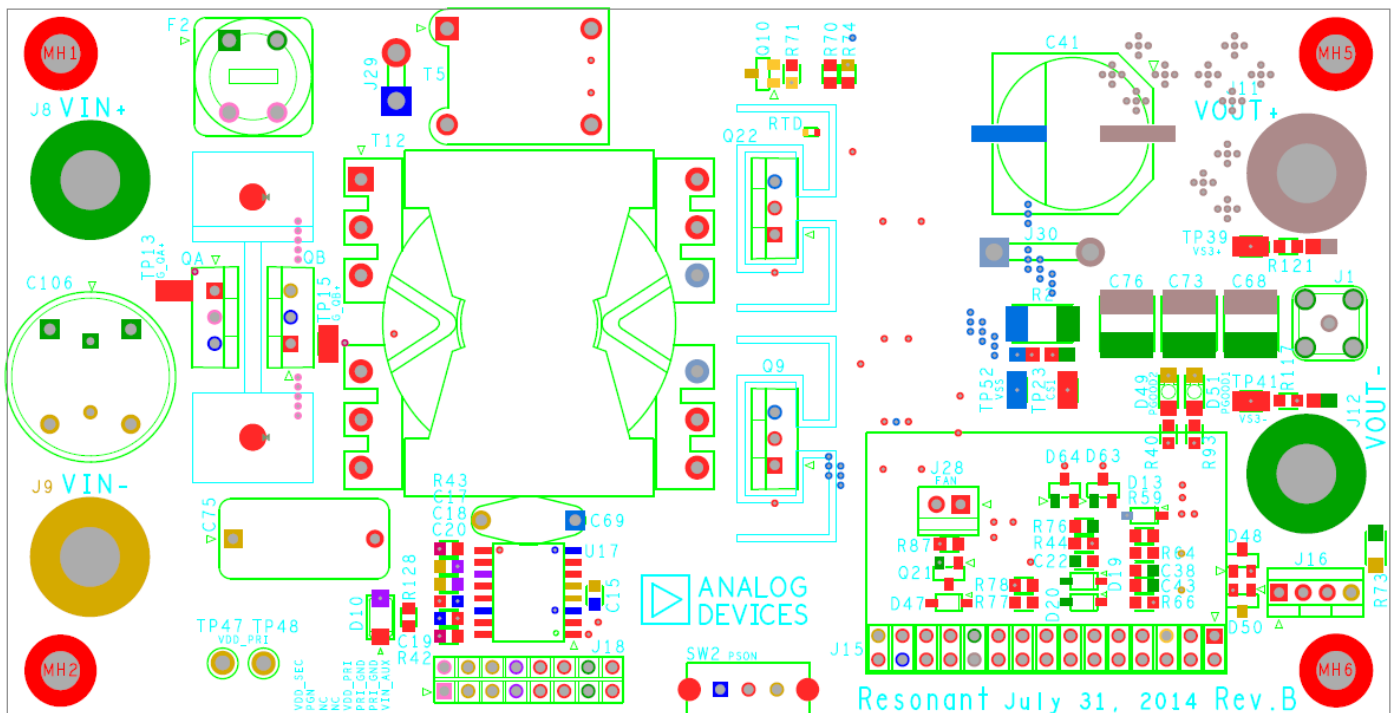


Figure 65. PCB Layout, Silkscreen Layer

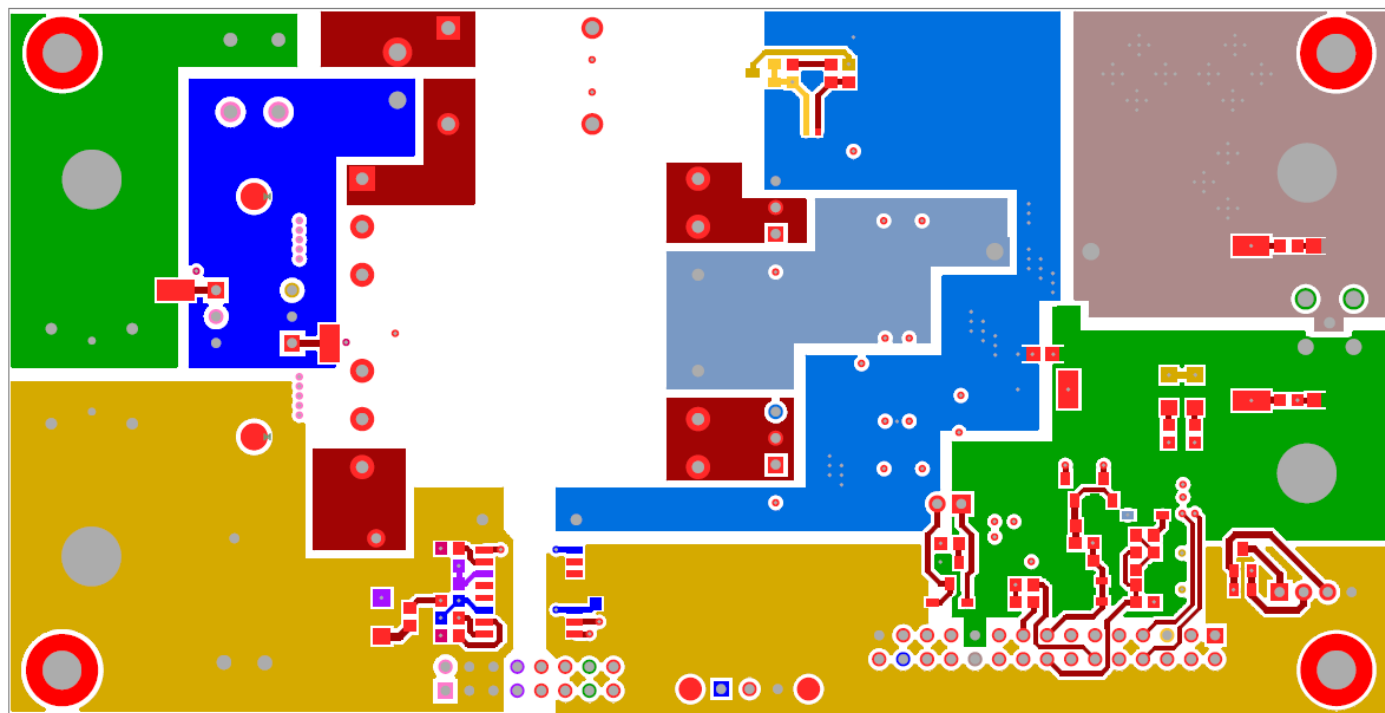


Figure 66. PCB Layout, Top Layer

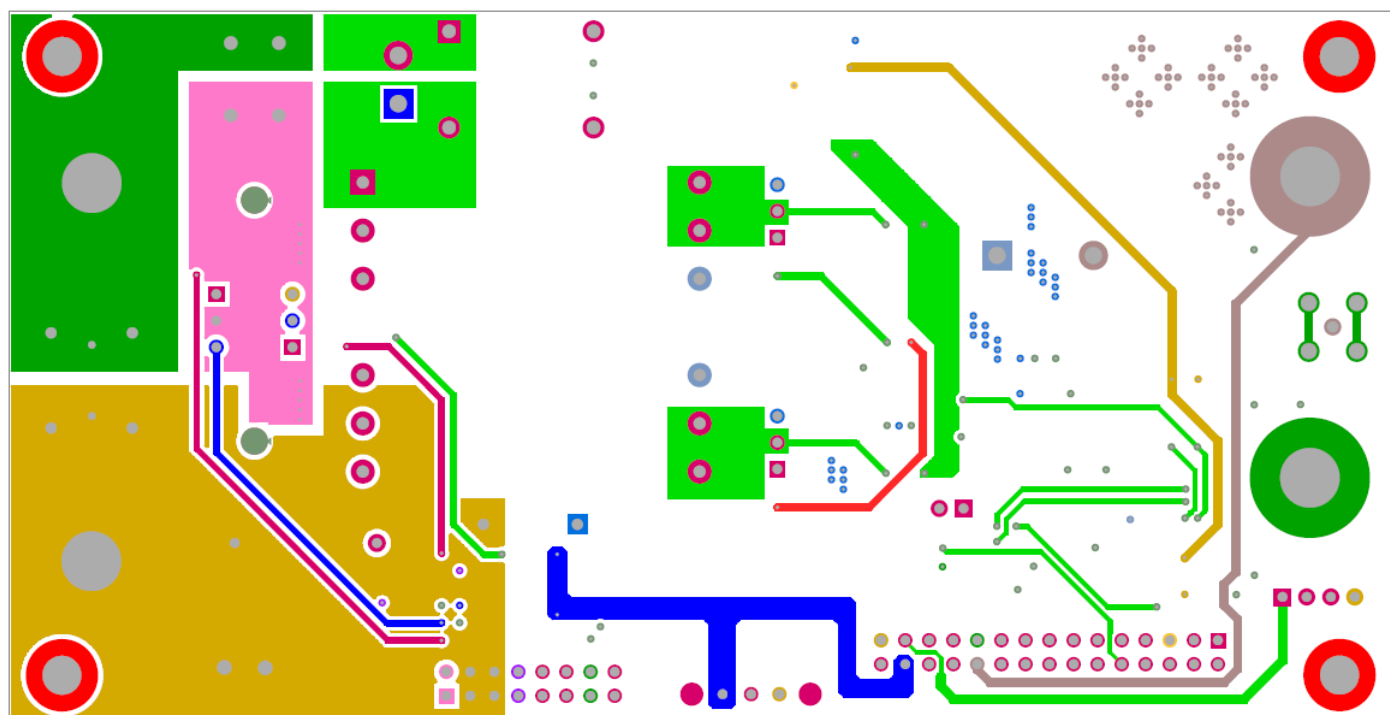


Figure 67. PCB Layout, Layer 2

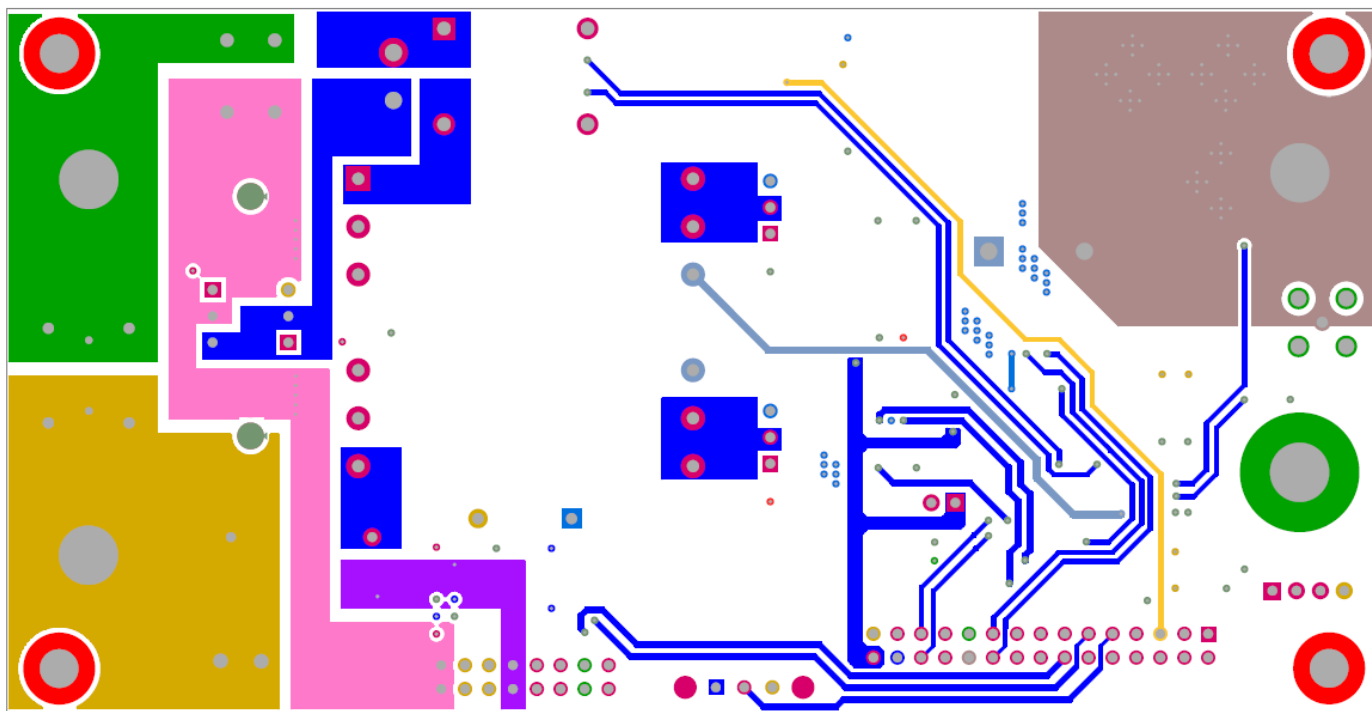


Figure 68. PCB Layout, Layer 3

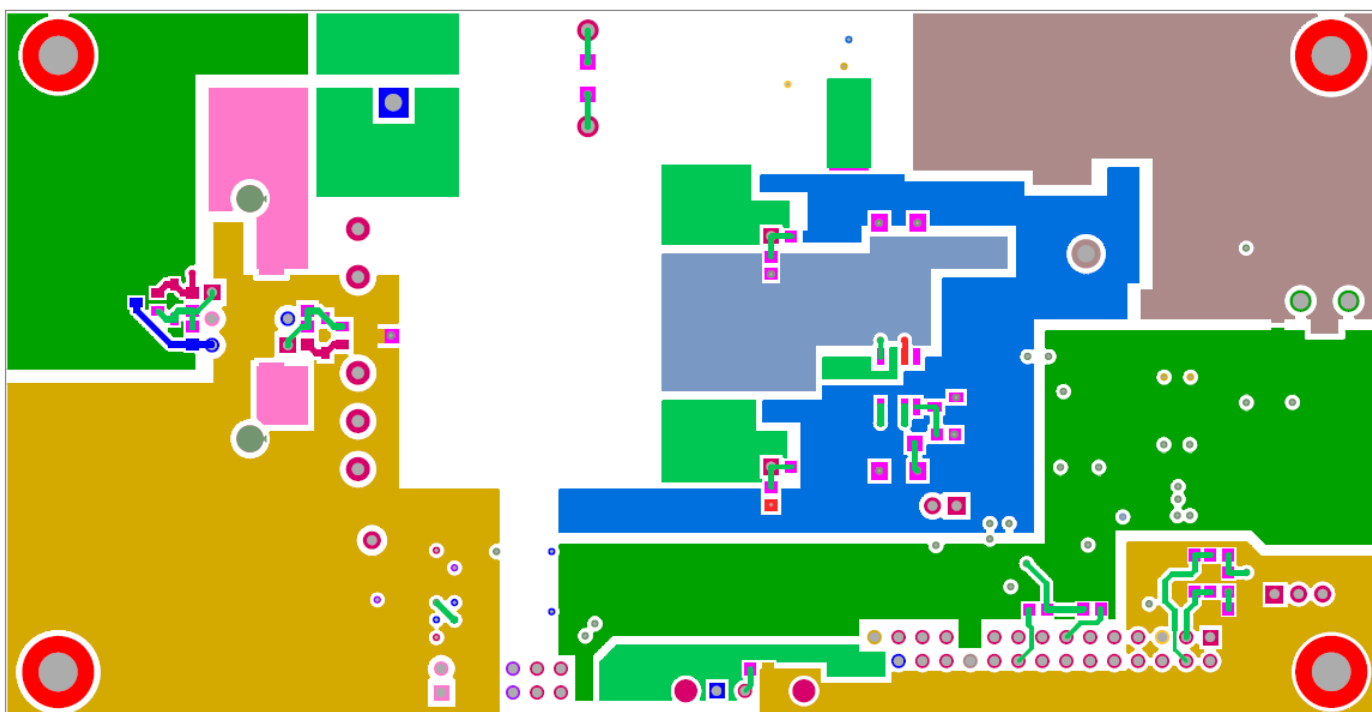


Figure 69. PCB Layout, Layer 4

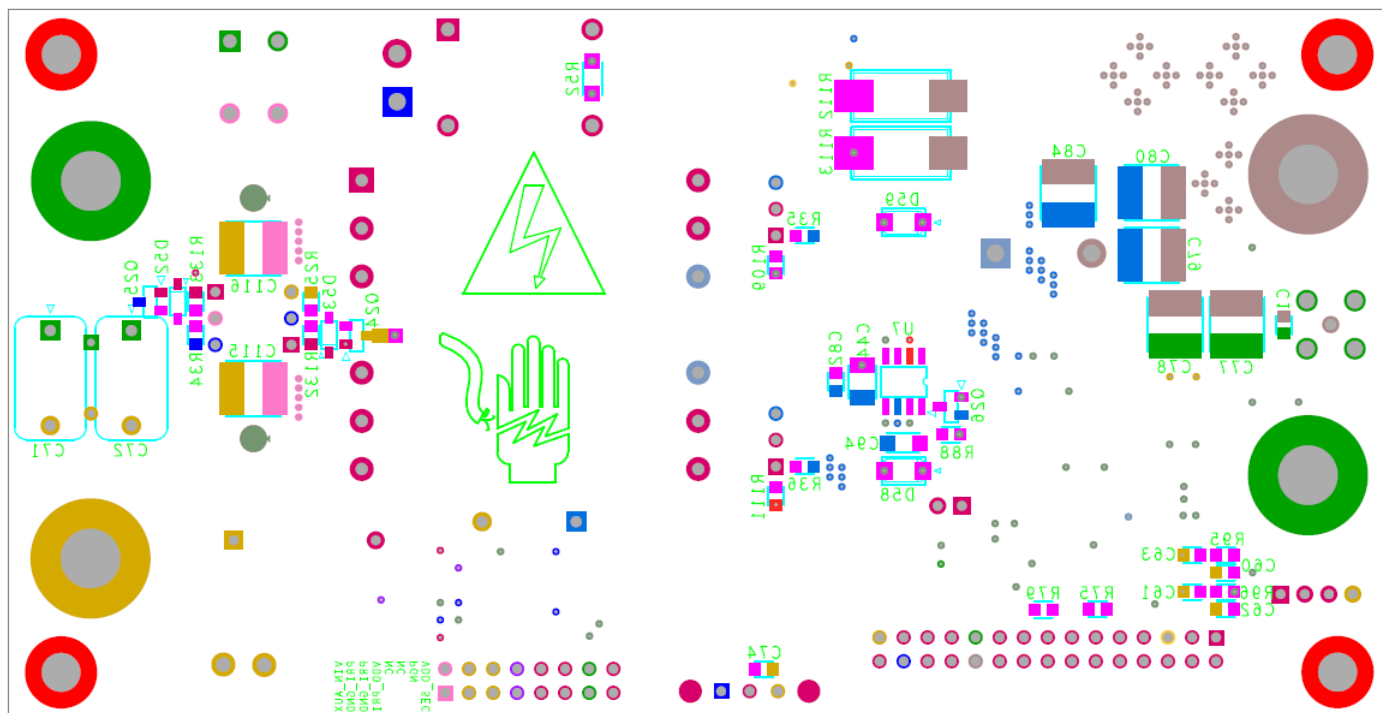


Figure 70. PCB Layout, Bottom Layer

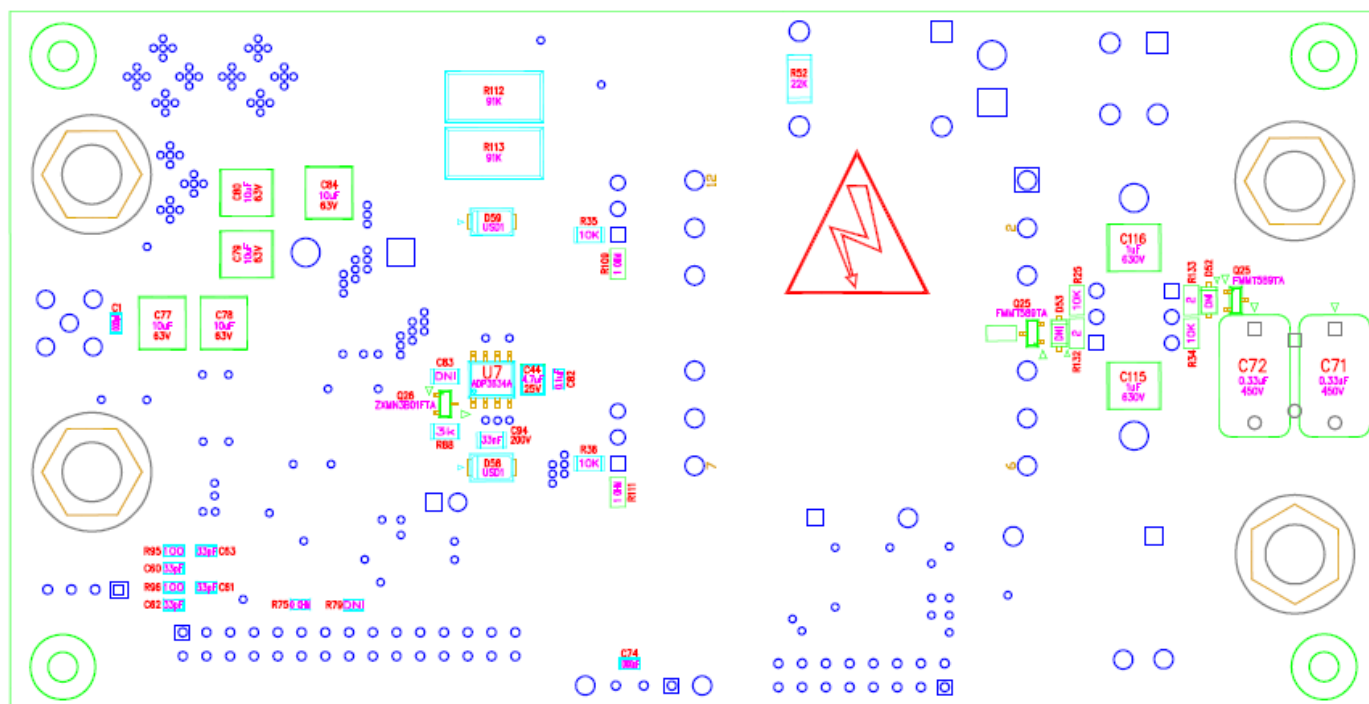


Figure 71. PCB Assembly, Bottom

DAUGHTER CARD SCHEMATIC

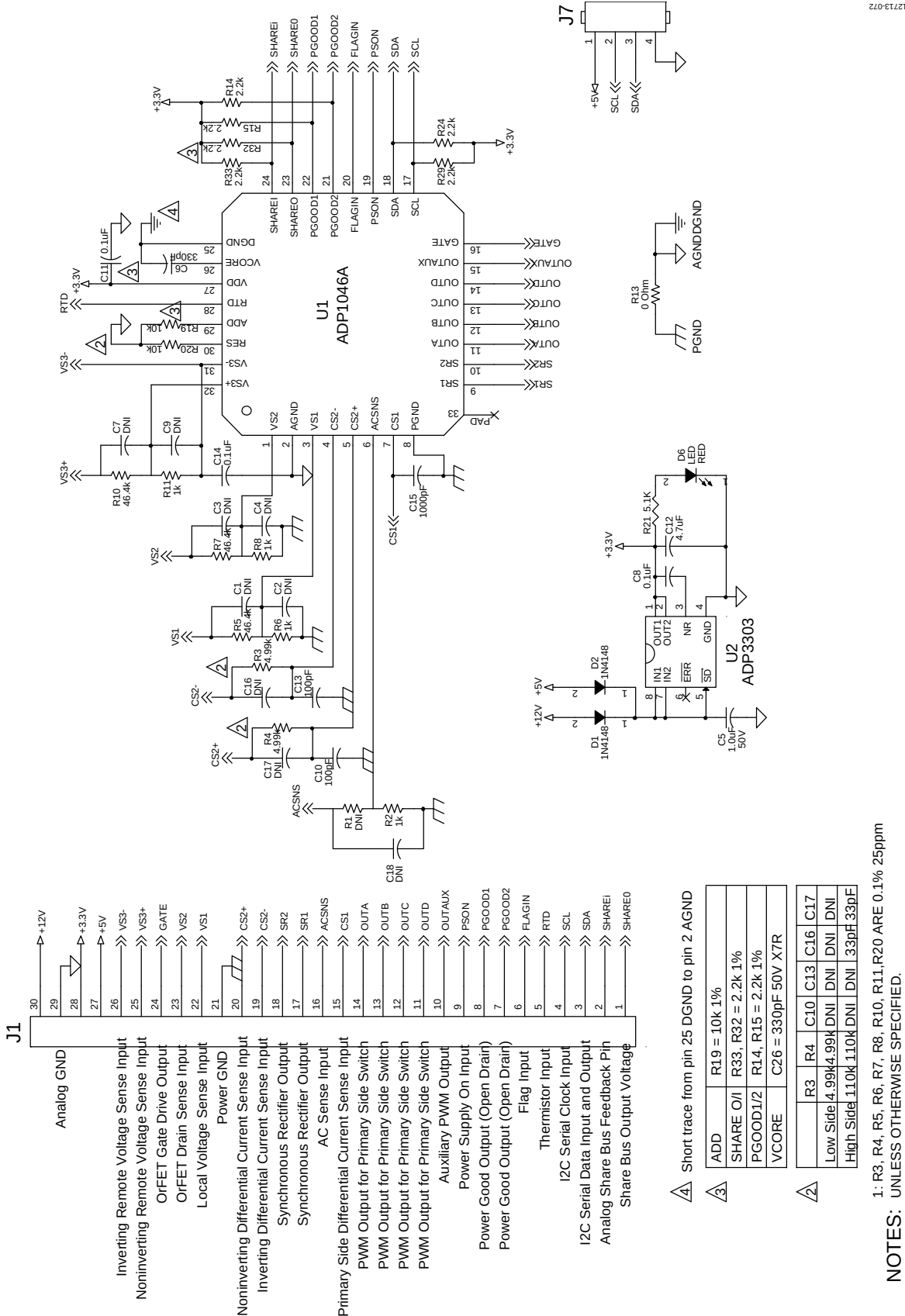


Figure 72. ADP1046ADC1-EVALZ Daughter Card Schematic

DAUGHTER CARD PCB LAYOUT

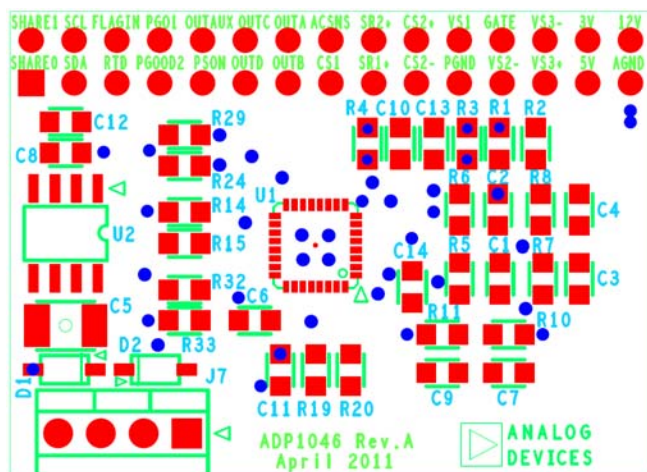


Figure 73. PCB Assembly, Top

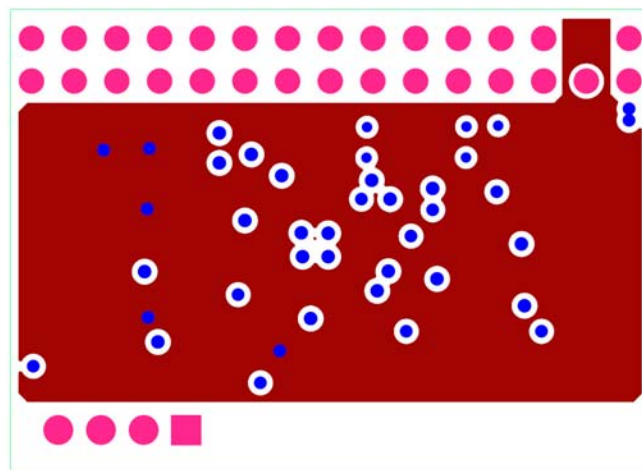


Figure 76. PCB Layout, Layer 3

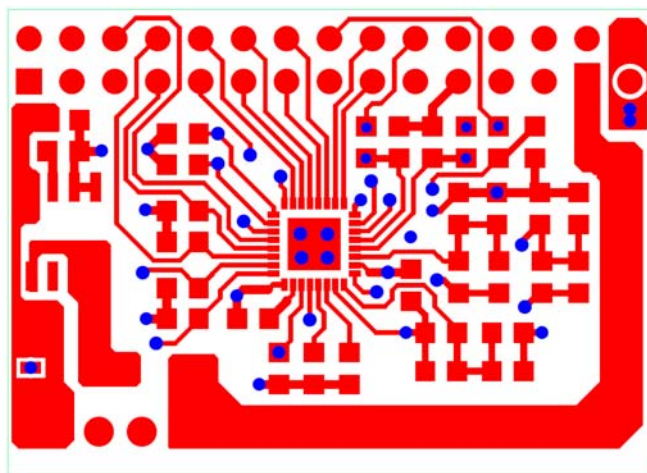


Figure 74. PCB Layout, Top Layer

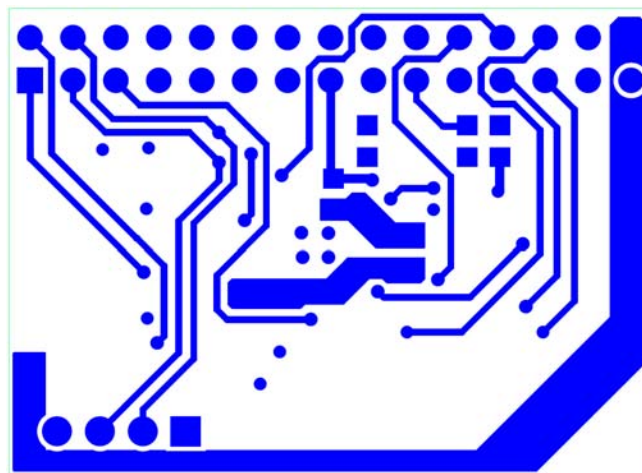


Figure 77. PCB Layout, Bottom Layer

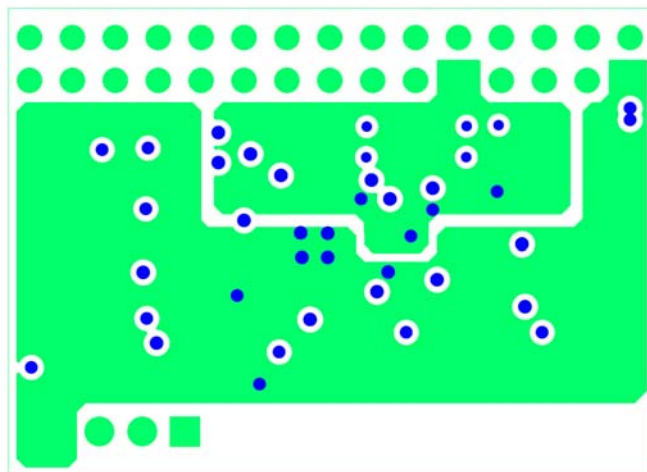


Figure 75. PCB Layout, Layer 2

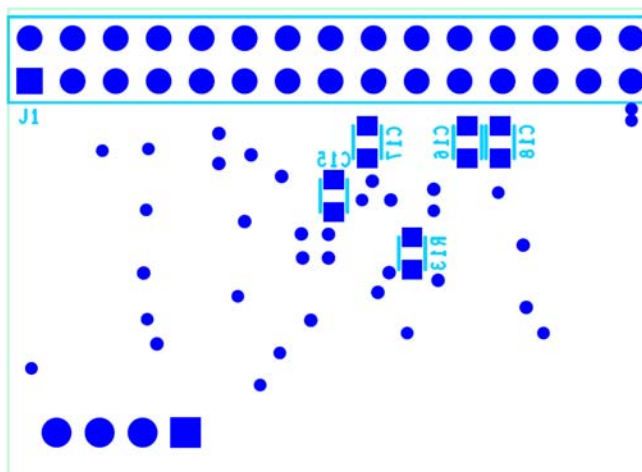


Figure 78. PCB Layout, Silkscreen Bottom

ORDERING INFORMATION

BILLS OF MATERIALS

Table 5. EVAL-ADP1046A Evaluation Board Bill of Materials

Qty.	Reference	Value	Description	Manufacturer	Part Number
3	C1, C22, C74,	1000 pF	Capacitor, ceramic, 1000 pF, 50 V, 10%, X7R, SMD	AVX Corp	08055C102KAT2A
3	C15, C18, C20	1 µF	Capacitor, ceramic, 1.0 µF, 25 V, 10%, X7R, SMD	TDK Corp	C2012X7R1E105K085AB
2	C17, C19	0.1 µF	Capacitor, ceramic, 0.1 µF, 25 V, 10%, X7R, SMD	Vishay	VJ0805Y104KXXAC
1	C38	DNI	Do not insert		
1	C41	1000 µF	Capacitor, aluminum, 1000 µF, 63 V, 20%, SMD	Vishay	MAL214699814E3
1	C43	DNI	Do not insert		
1	C44	4.7 µF	Capacitor, ceramic, 4.7 µF, 25 V, 10%, X7R, SMD	TDK Corp	C3225X7R1E475K
1	C47	1 µF	Capacitor, ceramic, 1 µF, 25V, ±10%, X7R	Digi-Key	490-4785-1-ND
4	C60 to C63	33 pF	Capacitor, ceramic, 33 pF, 50 V, ±5%, NPO, SMD	AVX Corp	08055A330JAT2A
8	C68, C73, C76 to C80, C84	10 µF	Capacitor, ceramic, 10 µF, 63 V, ±10%, X7R, SMD	Murata	KCM55QR71J106KH01K
1	C69	2200 pF	Capacitor, ceramic, 2200 pF, 500 V ac, 20%, radial	Vishay/BC	VY1222M47Y5UQ63V0
2	C71, C72	0.33 µF	Capacitor, film, 0.33 µF, 450 V dc, radial	Panasonic-ECG	ECW-F2W334JAQ
1	C75	0.033 µF	Capacitor, film, 0.033 µF, 1 kV dc, radial	EPCOS, Inc.	B32652A0333J
1	C82	0.1 µF	Capacitor, ceramic, 0.1 µF, 50 V, 10%, X7R SMD	Murata	GRM21BR71H104KA01L
1	C83	DNI	Do not insert		GRM21BR71H104KA01L
1	C94	DNI	Capacitor, ceramic, 0.33 µF, 200 V, 10%, X7R, SMD	AVX Corp	12062C333KAT2A
1	C106	100 µF	Capacitor, aluminum, 100 µF, 400 V, 20%, radial	United Chemi-Con	EKXG401ELL101MMN3S
2	C115, C116	1 µF	Capacitor, 0.33 µF, 630 V dc, metal, poly	TDK Corp	CKG57NX7T2J105M
1	D10	RS1J	SMD diode, super fast, 200 V, 1 A	Vishay	RS1J-E3/61T
1	D13	DNI	Do not insert		
1	D19	MMSZ5222BT1G	SMD diode Zener, 2.5 V, 500 mW	Diodes, Inc.	1N4148W-13-F
1	D20	DNI	Do not insert	ON Semi	SMAZ16-FDICT-ND
1	D47	DNI	Diode, SML, SIG, 100 V, 0.15 A, SMD	Diodes, Inc.	1N4148W-13-F
1	D48	MMBD4148CC	Diode array, 100 V, 200 mA	Fairchild	MMBD4148CC
1	D49	Red	LED, yellow, clear, SMD	Visual	CMD15-21VYC/TR8
1	D50	MMBD4148CA	Diode array, 100 V, 200 mA	Fairchild	MMBD4148CA
1	D51	Red	LED, high efficiency, red, clear, SMD	Visual	CMD15-21VRC/TR8
2	D52, D53	DNI	Do not insert	Diodes, Inc.	1N4148W-7-F
2	D54, R73	0 Ω	SMD, resistor, 0 Ω, 3/4 W, 5%	Vishay/Dale	311-1.00CRCT-ND
2	D58, D59	DNI	Diode fast SW, 300 V, 1 A, SMA	Fairchild	ES1F
2	D63, D64	MMBD4148SE	Diode array, 100 V, 200 mA	Fairchild	MMBD4148SE
1	F2	5A	Fuseholder cartridge, 400 V, 16 A, PCB	Schurter, Inc.	3101.004
1	J1	BNC/R	Connector, jack, vertical, PC mount, gold	Emerson	131-3701-261
1	J8	VIN+	Connector, banana jack, uninsulated, panel mount	Emerson	108-0740-001
1	J9	VIN-	Connector, banana jack, uninsulated, panel mount	Emerson	108-0740-001
1	J11	VOU+	Connector, banana jack, uninsulated, panel mount	Emerson	108-0740-001
1	J12	VOU-	Connector, banana jack, uninsulated, panel mount	Emerson	108-0740-001
1	J15	ADP1046_DC	Connector, header, 30POS, 0.100, vertical, dual	TE Connectivity	4-102973-0-15
1	J16	HDR1X4	Connector, header, 4POS, SGL, PCB, 30, gold	FCI	69167-104HLF
1	J18	HDR1X4	Connector, header, female, 16PS, 0.1" DL, tin	Sullins Connector	PPTC082LFBN-RC
1	J28	HDR1X2	Connector, header, 2POS, 0.100, vertical, tin	Molex, Inc.	22232021
2	J29, J30	Jumper	Jumper		
2	QA, QB	SPP20N60CFD	MOSFET, N-channel, 650 V, 20.7 A	Infineon	SPP20N60CFD
2	Q9, Q22	FDP083N15A_F102	MOSFET, N-channel, 150 V, 105 A	Fairchild	FDP083N15A_F102
1	Q10	DNI	Transistor, GP, NPN, 200 mA, 40 V	Fairchild	MMBT3904
1	Q21	DNI	MOSFET, N-channel, 100 V, 170 mA, SMD	Diodes, Inc.	BSS123-7-F

Qty.	Reference	Value	Description	Manufacturer	Part Number
2	Q24, Q25	FMMT589TA	Transistor, PNP, 30 V, 1 A, medium power	Diodes, Inc.	FMMT589TA
1	Q26	ZXMN3B01FTA	MOSFET, N-channel, 30 V, 2 A	Diodes, Inc.	ZXMN3B01FTA
1	RTD	100 k Ω	Thermistor, NTC, 100 k Ω , $\pm 1\%$, SMD	Murata	NCP15WF104F03RC
1	R2	0.002 Ω	Resistor, 0.002 Ω , 2 W, 1%, SMD	Stackpole Electronics	CSNL2512FT2L00
4	R25, R34 to R36	10 k Ω	Resistor, 10.0 k Ω , 1/2 W, SMD	Vishay	CRCW120610K0FKEAHP
2	R40, R93	2.2 k Ω	Resistor, 2.20 k Ω , 1/8 W, 1%, SMD	Yageo	RC0805FR-072K2L
2	R42, R43	0	Resistor, 0 Ω , 1/8 W, 1%, SMD	Vishay Dale	CRCW08050000Z0EA
6	R44, R64, R71, R74, R75, R78	0	Resistor, 0.0 Ω , 1/8 W, 5%, SMD	Yageo	RC0805JR-070RL
5	R51, R118 to R120, R123	Short pin	Short pin		
1	R52	22 k Ω	Resistor, 22.0 k Ω , 3/4 W, 5%, SMD	Vishay/Dale	CRCW201022K0JNEF
1	R59	200 Ω	Resistor, 200 Ω , 1/8 W, 5%, SMD	Yageo	RC0805JR-07200RL
1	R66	DNI	Do not insert		
1	R70	16.5 Ω	Resistor, 16.5 Ω , 1/8 W, 1%, SMD	Yageo	RC0805FR-0716K5L
1	R76	10 Ω	Resistor, 10.0 Ω , 1/8 W, 5%, SMD	Yageo	RC0805JR-0710RL
1	R77	DNI	Do not insert		
1	R79	DNI	Do not insert		
4	R87, R88, R95, R96	DNI	Resistor, 100 Ω , 1/8 W, 1%, SMD	Yageo	311-100CRCT-ND
2	R109, R111	1 Ω	Resistor, 1.0 Ω , 3/4 W, 5%, SMD	Vishay/Dale	CRCW20101R00JNEF
2	R112, R113	DNI	Resistor, 91.0 k Ω , 2 W, 1%, SMD	TE Connectivity	352191KFT
2	R117, R121	0 Ω	SMD, resistor, 0.0 Ω , 1/8 W, 5%	Digi-Key	311-0.0ARCT-ND
1	R128	12 Ω	Resistor, 12.0 Ω , 1/4 W, 1%, SMD	Yageo	RC1206FR-0712RL
2	R132, R133	2 Ω	Resistor, 2.0 Ω , 1/2 W, 1%, SMD	Susumu	RL1632R-2R00-F
1	SW2	PSON	Switch, slide, SPDT, R/A, L = 3 mm, 30 V, 0.2 A, PC mount	E Switch	EG1206
1	TP13	G-QA	SMD, PC test point, mini	Keystone Electronics	5019
1	TP15	G-QB	SMD, PC test point, mini	Keystone Electronics	5019
1	TP23	CS1	SMD, PC test point, mini	Keystone Electronics	5019
1	TP39	VS3+	SMD, PC test point, mini	Keystone Electronics	5019
1	TP41	VS3-	SMD, PC test point, mini	Keystone Electronics	5019
2	TP47, TP48	GND	Test point, PC, mini, 0.040"D, red	Digi-Key	5010K-ND
1	TP52	VSS	SMD, PC test point, mini	Keystone Electronics	5019
1	T5	PE-67100	Transformer, current sense, 37 A, 20 mH, T/H	Pulse	PE-67100NL
1	T12	PQ3535	Transformer, full bridge, 600 W	Precision, Inc.	019-8139-00R
1	U7	ADP3634	IC, driver, dual, noninverting, 4 A	Analog Devices	ADP3634ARDZ-R7
1	U17	ADuM4223	IC, digital isolated precision half bridge driver	Analog Devices	ADuM4223ARWZ

Table 6. ADP1046ADC1-EVALZ Daughter Card Bill of Materials

Qty.	Reference	Value	Description	Manufacturer	Part Number
1	C5	1.0 μ F	Capacitor, ceramic, 1.0 μ F, 50 V, 10%, X7R	Murata	GRM32RR71H105KA01L
1	C6	330 pF	Capacitor, ceramic, 330 pF, 10%, 100 V, X7R	AVX Corp	08051C331KAT2A
3	C8, C11, C14	0.1 μ F	Capacitor, ceramic, 0.1 μ F, 10%, 50 V, X7R	AVX Corp	08055C104KAT2A
2	C10, C13	100 pF	Capacitor, ceramic, 0.00 μ F, 10%, 100 V, X7R	United Chemi-Con	EKXG401ELL101MMN3S
1	C12	4.7 μ F	Capacitor, ceramic, 4.7 μ F, $\pm$ 10%, 10 V, X7R	TY	LMK212B7475KG-T
1	C15	1000 pF	Capacitor, ceramic, 1000 pF, 10%, 100 V, X7R	TDK Corp	C2012X7R1A475M
2	D1, D2	1N4148	Diode, switch, 150 mA, 100 V	Micro Commercial	1N4448W-TP
1	D6	LED	LED, super, red, clear, 75 mA, 1.7 V, SMD	Chicago Lighting	CMD15-21SRC/TR8
1	J1	CON30	Connector, header, female, 30PS, 0.1" DL, tin	Sullins Connector	PPTC152LFBN-RC
1	J7	HEADER4X1	Connector, header, 4POS, SGL, PCB, 30, gold	FCI	69167-104HLF
1	R1	65 k Ω	Resistor, 65 k Ω , 1/8 W, 1%, SMD	Any	Any
1	R2	1 k Ω	Resistor, 1.00 k Ω , 1/8 W, 1%, SMD	Any	Any
2	R3,R4	4.99 k Ω	Resistor, 4.99 k Ω , 1/10 W, 0.1%, $\pm$ 25 ppm, SMD	Any	Any
3	R5, R7, R10	46.4 k Ω	Resistor, 11.0 k Ω , 1/10 W, 1%, $\pm$ 25 ppm, SMD	Any	Any
3	R6, R8, R11	1 k Ω	Resistor, 1.00 k Ω , 1/10 W, 1%, $\pm$ 25 ppm, SMD	Any	Any
1	R13	0 Ω	Resistor, 0.0 Ω , 1/8 W, 5%, SMD	Any	Any
6	R14, R15, R24, R29, R32, R33	2.2 k Ω	Resistor, 2.20 k Ω , 1/8 W, SMD	Any	Any
2	R19,R20	10 k Ω	Resistor, 10 k Ω , 1/8 W, 0.1%, SMD	Any	Any
1	R21	5.1 k Ω	Resistor, 5.10 k Ω , 1/8 W, SMD	Any	Any
1	U1	ADP1046A	Secondary side power supply controller	Analog Devices	ADP1046A
1	U2	ADP3303	IC, LDO linear regulator, 200 mA, 3.3 V	Analog Devices	ADP3303AR-3.3-ND
9	C1, C2, C3, C4, C7, C9, C16, C17, C18	DNI	Do not insert		

I²C refers to a communications protocol originally developed by Philips Semiconductors (now NXP Semiconductors).

**ESD Caution**

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

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