

TI Designs: TIDA-01399

TPS92410/411 50-W, 120-V AC Offline, LED Driver With No Magnetics Required for LED General Lighting



Description

The TIDA-01399 TI Design showcases the TPS92410 and TPS92411 with 50-W output power for area lighting with all components on a single printed-circuit board (PCB). This design uses four TPS92411 stages allowing 16 different switch states during the rising and falling rectified-AC waveform, which optimizes the current-regulating MOSFET headroom. The TPS92410 allows monotonic analog dimming down to 3% before shutting off the current regulator. Electromagnetic interference (EMI) filtering without magnetics has been included and designed to meet FCC Title 47 Part 15 class-B conduction requirements.

Resources

TIDA-01399	Design Folder
TPS92410	Product Folder
TPS92411	Product Folder



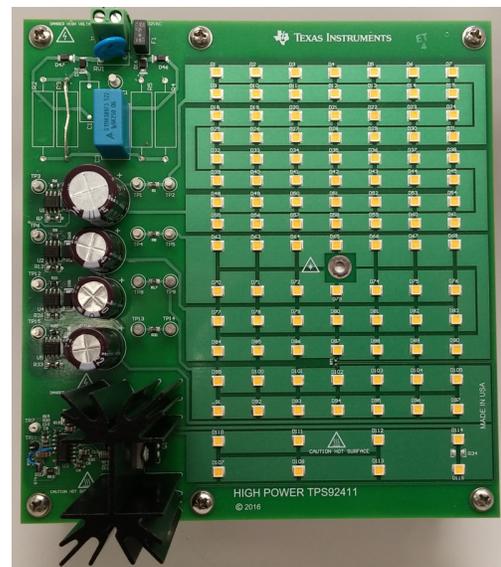
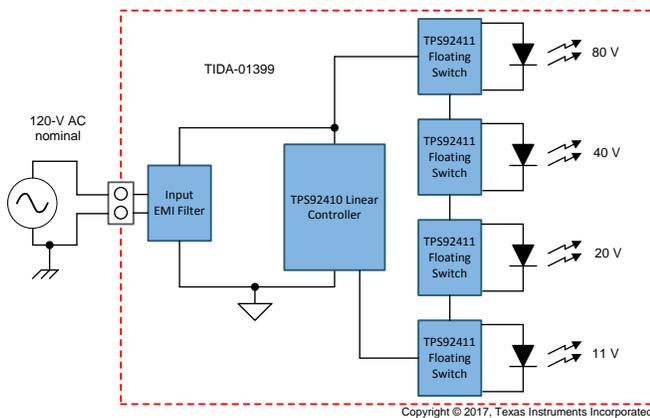
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Features

- Non-Isolated 120-V AC Offline LED Driver With No Magnetics
- Four TPS92411 Channels Provide 16 Switch States
- Efficiency: 86.5%, Power Factor: 0.97, THD: 10.5%
- TPS92411 With Thermal Pad for Higher Current Applications
- TPS92410 Current Regulator for Power Factor Correction With Multiplier for Line Regulation
- TPS92410 Allows Simple NTC Thermal Foldback
- TPS92410 Monotonic Analog Dimming to 3% With Shutdown; Deeper Dimming Using TSNS Input
- FCC Title 47 Part 15 Class-B Tested EMI

Applications

- General Lighting
- Area Lighting
- Security Lighting
- Downlights
- Indoor Lighting



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1 System Description

TIDA-01399 provides a method to drive 50 W of LEDs on a single board without the use of magnetics. By using energy storage capacitors, low light-emitting diode (LED) ripple can be realized. The TPS92410 device provides power factor correction (PFC) and line regulation while allowing monotonic analog dimming. Thermal foldback is easily accomplished with a negative temperature coefficient (NTC) thermistor. The design is ideal for single board solutions requiring low LED current ripple. By using four TPS92411DDA floating switches in the SOP-8 package with thermal heatsink pad, up to 50 W of power can be delivered for general lighting, area lighting, high-power downlights, and security lighting.

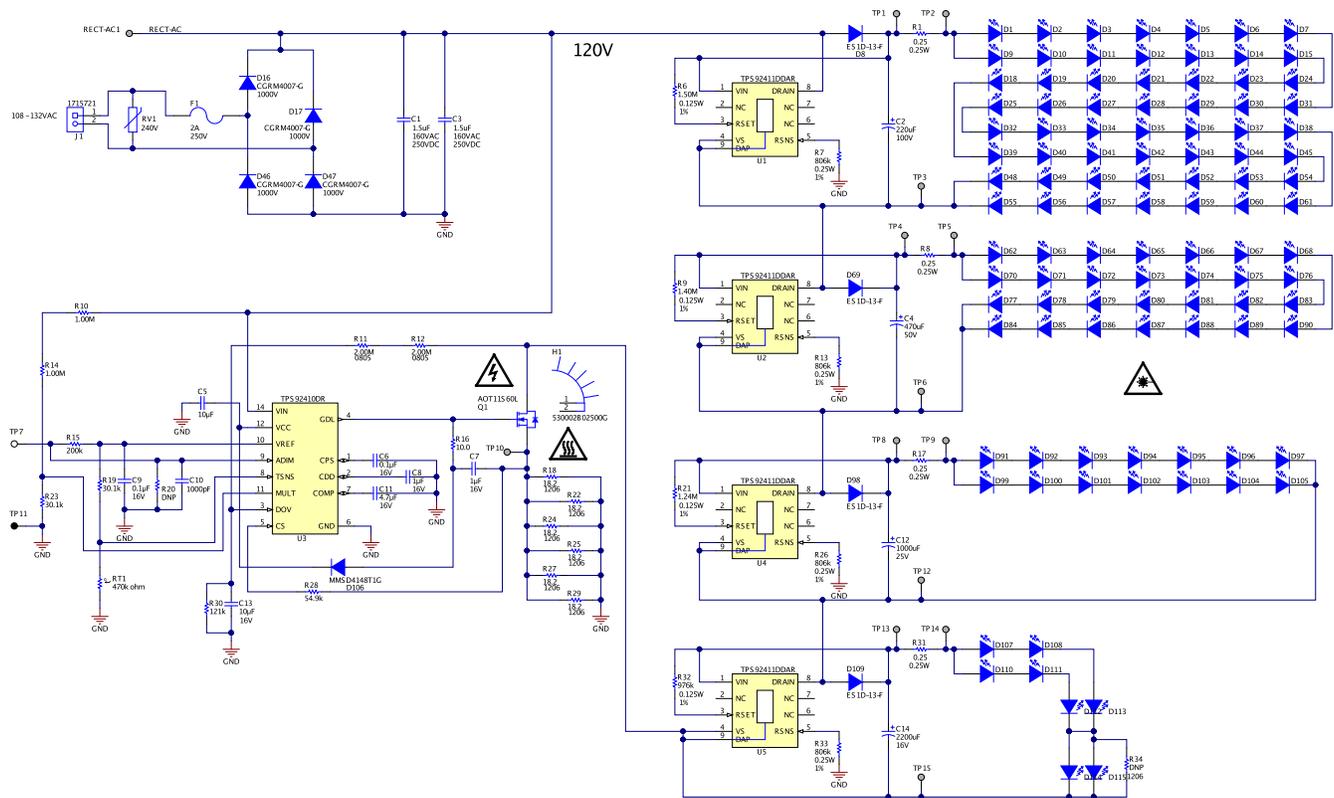
1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT CHARACTERISTICS					
V_{IN} input voltage	—	85	120	135	V AC
OUTPUT CHARACTERISTICS					
1st LED stack	—	—	80	—	V
2nd LED stack	—	—	40	—	V
3rd LED stack	—	—	20	—	V
4th LED stack	—	—	11	—	V
Output power	—	—	50	60	W
Analog dimming range	$V_{ADIM} = 0\text{ V to }1.5\text{ V}$	3	—	100	%
ADIM shutdown threshold	—	18	40	70	mV
SYSTEM CHARACTERISTICS					
Efficiency	$V_{IN} = 120\text{-V AC}$	—	86.5	—	%
EMI (conducted)	—	FCC Part 15 Class B			
BASE BOARD CHARACTERISTICS					
Form factor	—	6 in x 6.4 in (150 mm x 160 mm)			
Number of layers	—	2			
Height	Including heatsinks	4 in (100 mm)			

2 System Overview

2.1 Block Diagram



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Figure 1. TIDA-01399 Schematic

2.2 Highlighted Products

2.2.1 TPS92410 and TPS92411

The TPS92410 is a high-voltage current regulator which is intended to work with multiple TPS92411 devices (see Figure 1). The device is connected directly to rectified AC to generate its bias voltages and reference voltages. The device contains a multiplier for line regulation and creates a sinusoidal current reference for power factor correction (PFC). The device is capable of detecting a leading edge dimmer, latching into DC reference mode to satisfy TRIAC dimmer holding current. The TPS92410 also provides an interface for analog-dimming thermal foldback and MOSFET drain overvoltage protection.

The TPS92411 is a smart switch that is programmed for two set-points: when to open and allow current to an LED string and when to close to bypass an LED string (see Figure 1). The switch slew rate is controlled to reduce conducted electromagnetic interference (EMI) and prevent the current regulator, TPS92410 circuit, to have enough headroom to operate. Multiple TPS92411s are used in a design where the number used depends on the desired efficiency and voltage step size during operation. Two TPS92411s give four switch states, three TPS92411s give eight switch states, and four TPS92411s give 16 switch states.

The TPS92410 and TPS92411s work together as an LED driver. They have separate functions and have no communication between them. The TPS92410 performs the function of regulating current with all of its features. The TPS92411s perform the function of bypassing or allowing current to an LED section. The TPS92411 cannot regulate current.

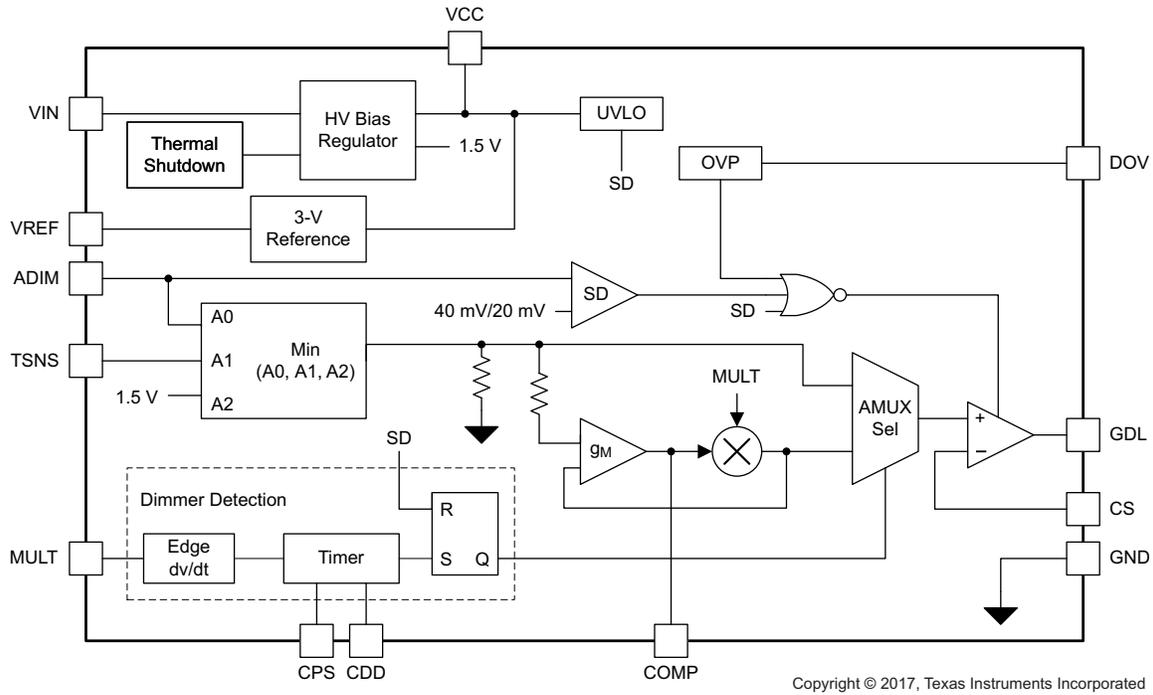


Figure 2. TPS92410 Block Diagram

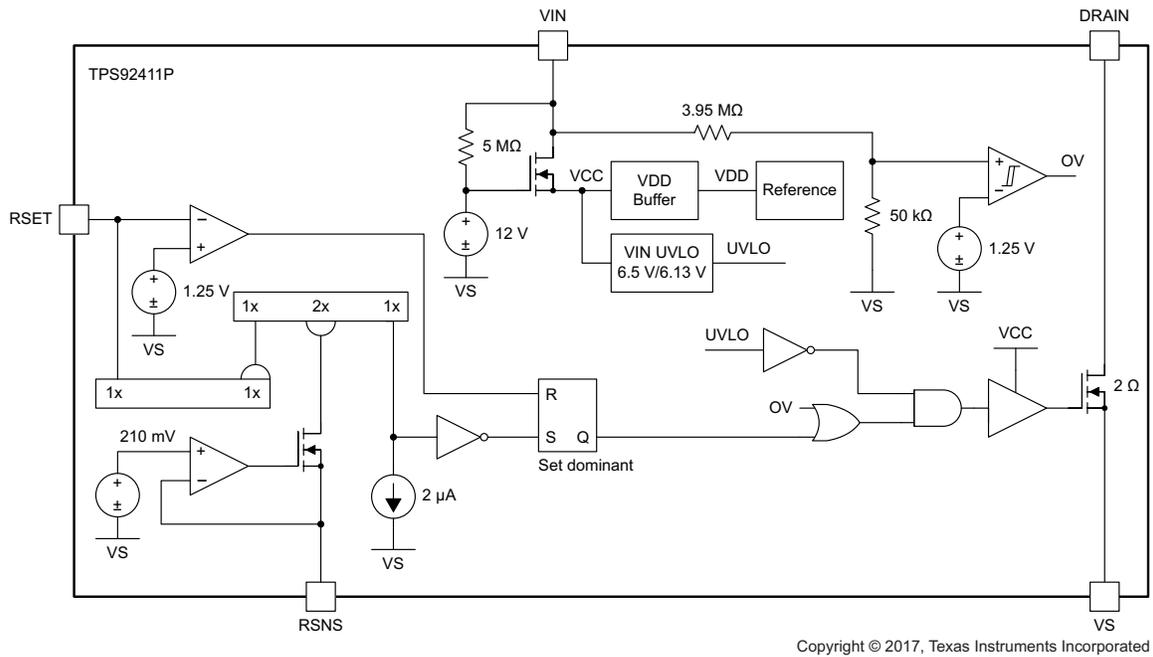


Figure 3. TPS92411 Block Diagram

The TPS92410 device has an operational input range up to 450 V. The TPS92410 is available in a 13-pin high-voltage SOIC package.

TPS92410 features:

- Integrated high-voltage MOSFET
- Input voltage range 9.5 V to 450 V
- Multiplier for good PFC, line regulation, and low total harmonic distortion (THD)
- Compatible with phase dimmers
- Analog dimming input with LED turnoff
- Programmable overvoltage protection
- Precision 3-V reference
- Thermal foldback
- Thermal shutdown
- No inductor required
- 13-pin high-voltage SOIC package
- Integrated thermal protection

The TPS92411P has an operational range up to 94 V with overvoltage protection and the TPS92411 has an operational range to 100 V. The TPS92411 is available in a SOT23-5 package for lower-power applications or a thermally-enhanced PowerPAD™ SO-8 integrated circuit package.

TPS92411 features:

- Integrated 2- Ω MOSFET
- Input voltage range:
 - TPS92411Px: 7.5 V to 94 V
 - TPS92411x: 7.5 V to 100 V
- Controlled open and close slew rates for reduced conducted EMI
- Designed for use with TPS92410 or discrete current regulator
- Input undervoltage protection
- Output overvoltage and open string protection (TPS92411P)
- Low I_Q , 200 μ A
- Close threshold adjusts for variation in LED stack voltage

2.3 System Design Theory

This design utilizes the TPS92410 current regulating controller with four TPS92411DDA, high-power bypass switches (see the preceding [Figure 1](#)). The input voltage range is 85-V AC to 135-V AC, which is optimized for 120-V AC operation. The output power rating is just over 50 W at a 120-V AC input. The design is set up for non-isolated analog dimming using the ADIM pin on the TPS92410 with a 0-V to 1.5-V range for monotonic dimming down to 3% before shutting off. The four stacks consist of two parallel 28-series LED strings, two parallel 14-series LED strings, two parallel 7-series LED strings, and two parallel 4-series LED strings. The forward voltage of the LEDs in this design is approximately 2.85 V, which makes the stack voltages approximately 80 V, 40 V, 20 V, and 11 V for an overall voltage of approximately 151 V excluding four diode drops: D8, D69, D98, and D109.

2.3.1 Analog Adjust Input (ADIM) and Analog Dimming

The analog adjust pin (ADIM) adjusts the current reference for the TPS92410 device. Linear monotonic dimming is set by adjusting the ADIM pin from 0 V to 1.5 V. Shutdown occurs when the ADIM pin is pulled below 40 mV. The output power can be adjusted down to about 3% before shutdown occurs. Deeper dimming is possible using the TPS92410 TSNS pin.

2.3.2 Switching States

The TPS92410 regulates current from rectified AC (in phase with the voltage) to achieve PFC. The TPS92411 internal MOSFET bypasses an LED section when closed or allows current to flow to an LED section when open. This design uses four TPS92411s for a possible 16 switch states. The following [Table 2](#) shows the TPS92411 switch states as a function of input voltage if the LED stack voltages are 80 V, 40 V, 20 V, 11 V, and the TPS92411 headroom for switch closing is 3 V and the switch open headroom is approximately 5 V. Rising voltage headroom is set higher than falling voltage headroom for hysteresis between TPS92411 open and closed states (see [Table 2](#)).

Table 2. TPS92411 Switch States Based on Rectified AC Voltage

RECTIFIED AC VOLTAGE (V) INPUT RISING	TPS92411 SWITCH STATE	DETAILS	
0-16	0000	All TPS92411s bypassing, No LED sections receiving current	
16-25	0001	11 V + 5-V headroom allows stack four to open	
25-36	0010	20 V + 5-V headroom allows stack three to open; four must close	
36-45	0011	—	
45-56	0100	40 V + 5-V headroom allows stack two to open; three and four must close	
56-65	0101	—	
65-76	0110		
76-85	0111		
85-96	1000		80 V + 5-V headroom allows stack one to open; all others must close
96-105	1001	—	
105-116	1010		
116-125	1011		
125-136	1100		
136-145	1101		
145-156	1110		
above 156	1111		All TPS92411 switches are open, all LED strings receive current
RECTIFIED AC VOLTAGE (V) INPUT FALLING	TPS92411 SWITCH STATE		DETAILS
above 154	1111	—	
154-143	1110		
143-134	1101		
134-123	1100		
123-114	1011		
114-103	1010		
103-94	1001		
94-83	1000		
83-74	0111		
74-63	0110		
63-54	0101		
54-43	0100		
43-34	0011		
34-23	0010		
23-14	0001		
14-0	0000		All TPS92411s bypassed when 11 V + 3-V headroom threshold is crossed

2.3.3 Calculating Sense Resistor

The current sense resistors consisting of R18, R22, R24, R25, R27, and R29 in parallel are calculated by (Equation 1).

$$R_{CS} = \frac{V_{IN} \times 1.428}{P_{IN}} \quad (1)$$

Assuming 85% efficiency and 50-W output power, the resulting input power is around 59 W. This result gives R_{CS} a value of 2.9 Ω . Six resistors in parallel would require 17.4 Ω each. 18.2 Ω are the final adjusted values for the current sense resistors based on initial measurements.

2.3.4 Thermal Protection

TIDA-01399 utilizes the thermal foldback function of the TPS92410. A resistor and NTC thermistor divider are placed between the V_{REF} pin and GND of the TPS92410 device. The resistor is tied to V_{REF} . The NTC thermistor is tied to GND with the center of the divider connected to T_{SNS} . As the board heats, the resistance of the NTC thermistor drops eventually causing the divider to cross the 1.5-V T_{SNS} threshold and starting current foldback.

3 Testing and Results

3.1 Designing for Low EMI

3.1.1 EMI Performance

Figure 4 shows the conducted EMI scan for this design at a nominal 120-V AC input voltage, 60 Hz, room temperature, and 50-W output power. The blue trace is the peak scan and the line labeled "QP.LIN" denotes the peak limits for FCC Part 15 class B. The black trace is the average scan with the line labeled "A.LIN" denoting the average limits for FCC Part 15 class B. The scan covers the entire conducted frequency range of 150 kHz to 30 MHz. This image is a pre-compliance test scan used for engineering development and evaluation and is not a certified EMI test result. The end user is responsible for submitting any design based on this TI Design to a certified EMI lab if an official EMI test result is required. Quasi-peak measurements are shown for elevated peak measurements to show actual quasi-peak margin.

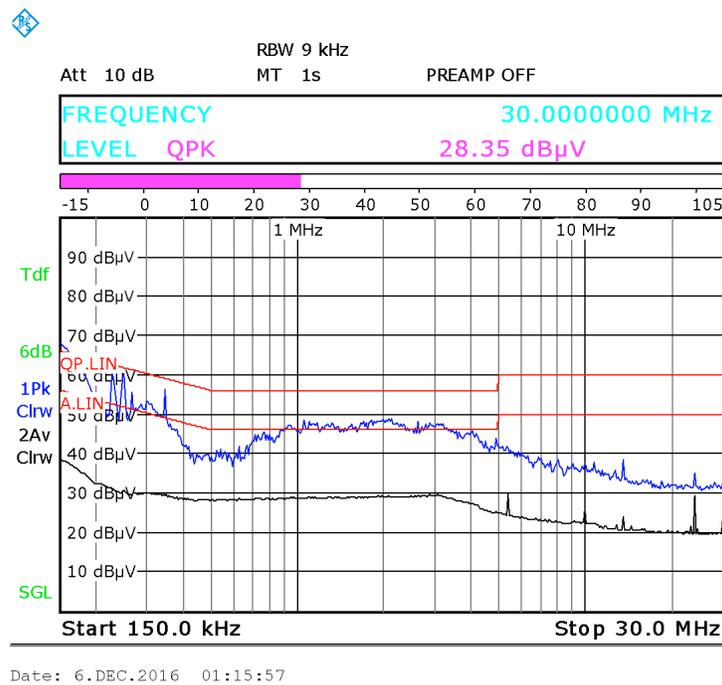


Figure 4. FCC Part 15 Class B Conducted EMI Scan (QP.LIN: Peak Limits, A.LIN: Average Limits)
 $V_{IN} = 120\text{-V AC}$, $P_{OUT} = 50\text{ W}$ (Pre-Compliance Data)

Table 3. Quasi-Peak Measurements of Peak Levels

FREQUENCY (kHz)	QP LEVEL (dB)
150	-4.22
226	-11.39
250	-9.65
266	-10.21
346	-19.54

3.1.2 EMI Filter Design

The input EMI filter consists of a capacitor across the rectified AC. This design uses two such capacitors, C1 and C3; however, a single capacitor of twice the value can be used to replace C1 and C3. Conducted EMI reduction is proportional to the increased value of C1 and C3. A slew control capacitor, C7, across the gate to source of the current regulating MOSFET, Q1, slows the response of the MOSFET drain.

3.2 Test Setup

Figure 5 shows the test setup used. The input voltage was supplied by an AC power source to J1. Four out of the ten digital multimeters (DMMs) shown in the following diagram switch between stacks one through four. Two DMMs were used to measure the input voltage and current and two were used to measure the channel stack voltage and current (through the voltage across the current sense resistors on the board R1, R8, R17, and R31). A power analyzer was used for PFC and THD measurements.

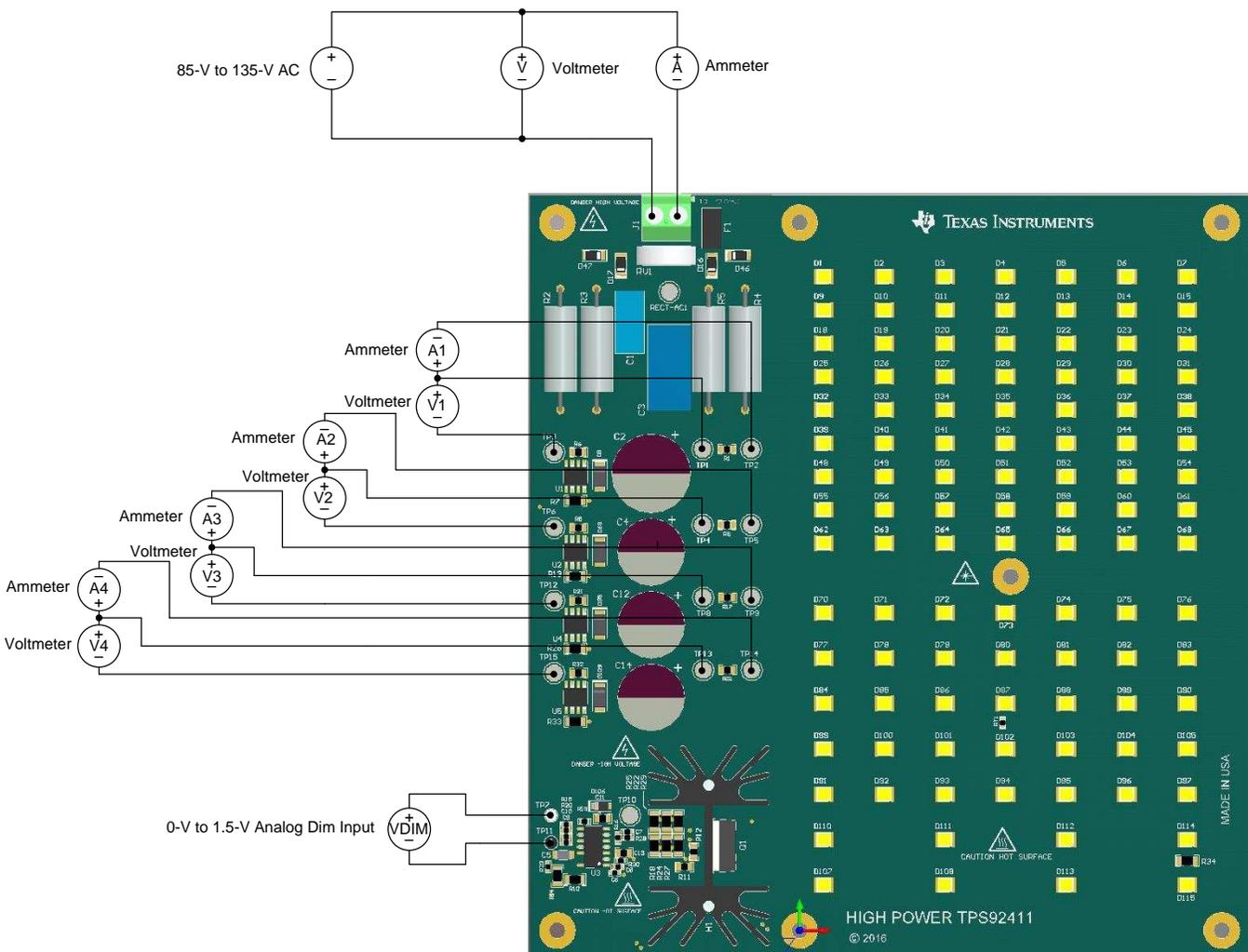


Figure 5. Test Setup Connections

3.3 Test Results

The test setup described in Figure 5 was used to generate the following data for analog measurements. All graphs and oscilloscope shots were taken with an input of 120-V AC and 50-W output power unless analog dimming occurred.

3.3.1 Nominal Operation Waveforms

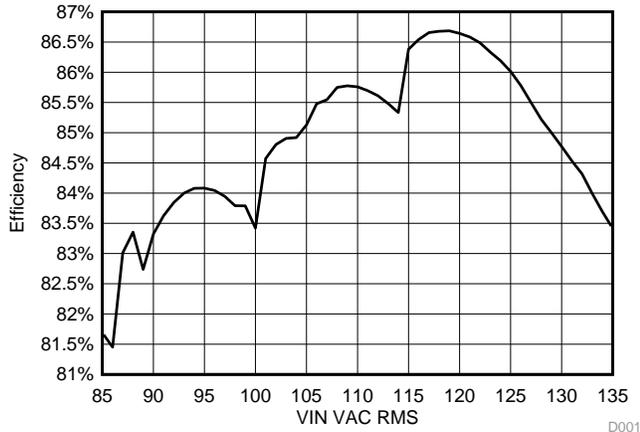


Figure 6. Efficiency versus Input Voltage

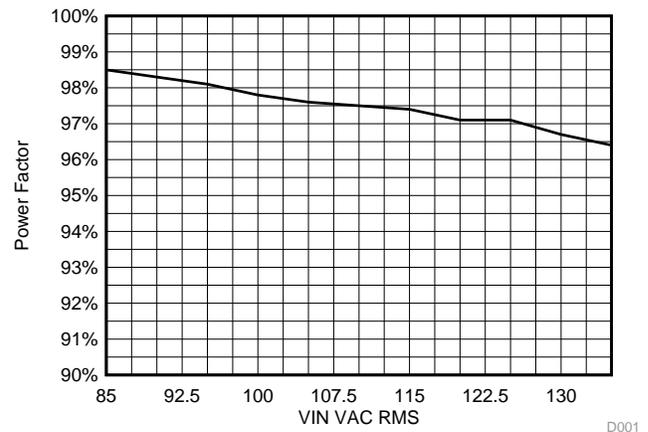


Figure 7. Power Factor versus Input Voltage

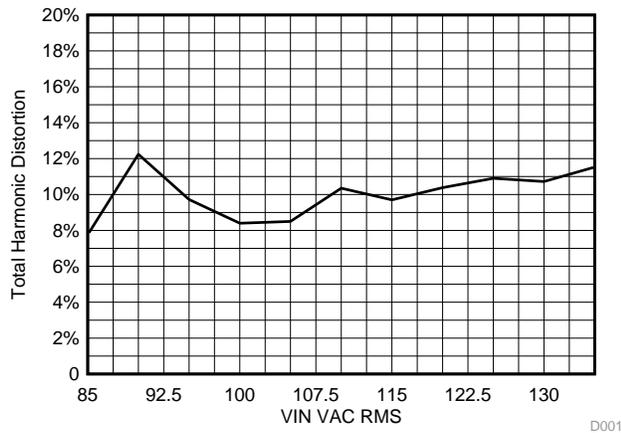


Figure 8. Total Harmonic Distortion versus Input Voltage

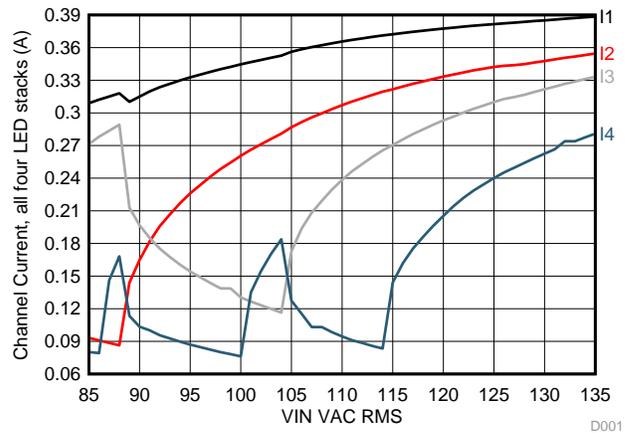


Figure 9. Stack Currents versus Input Voltage

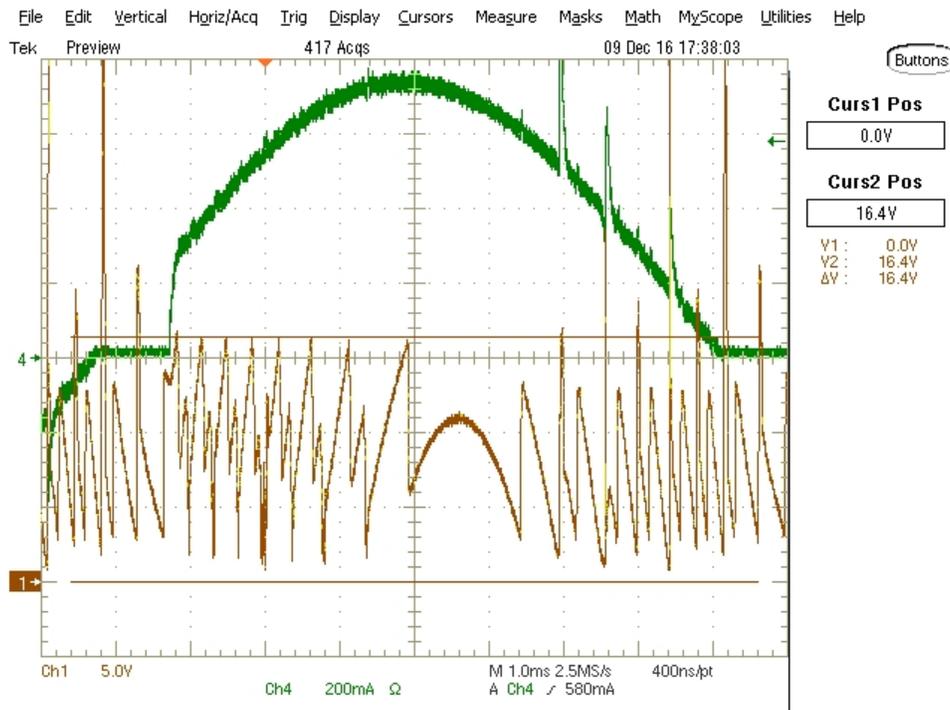


Figure 10. Current-Regulating MOSFET Drain Voltage, Q1, CH1, Input Current, CH4

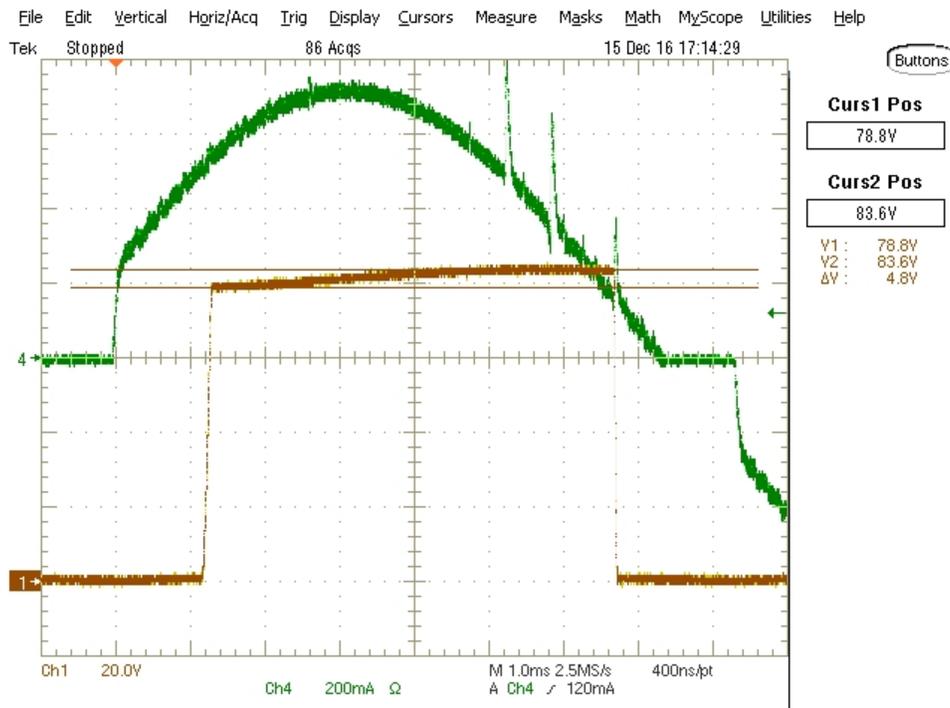


Figure 11. LED Stack One TPS92411 Drain Voltage, CH1, Input Current, CH4

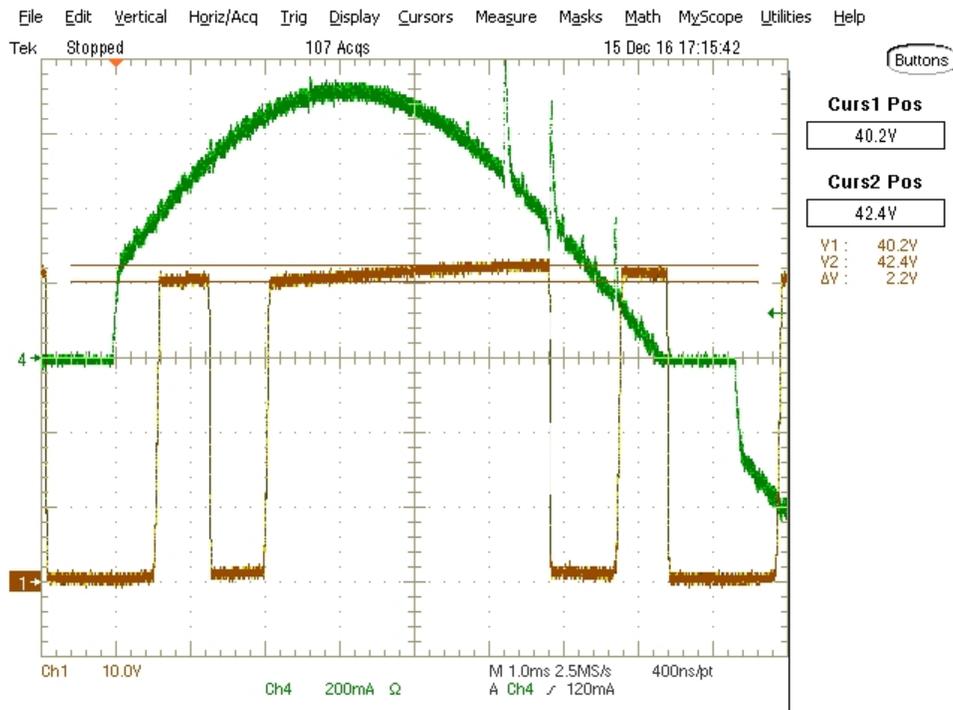


Figure 12. LED Stack Two TPS92411 Drain Voltage, CH1, Input Current, CH4

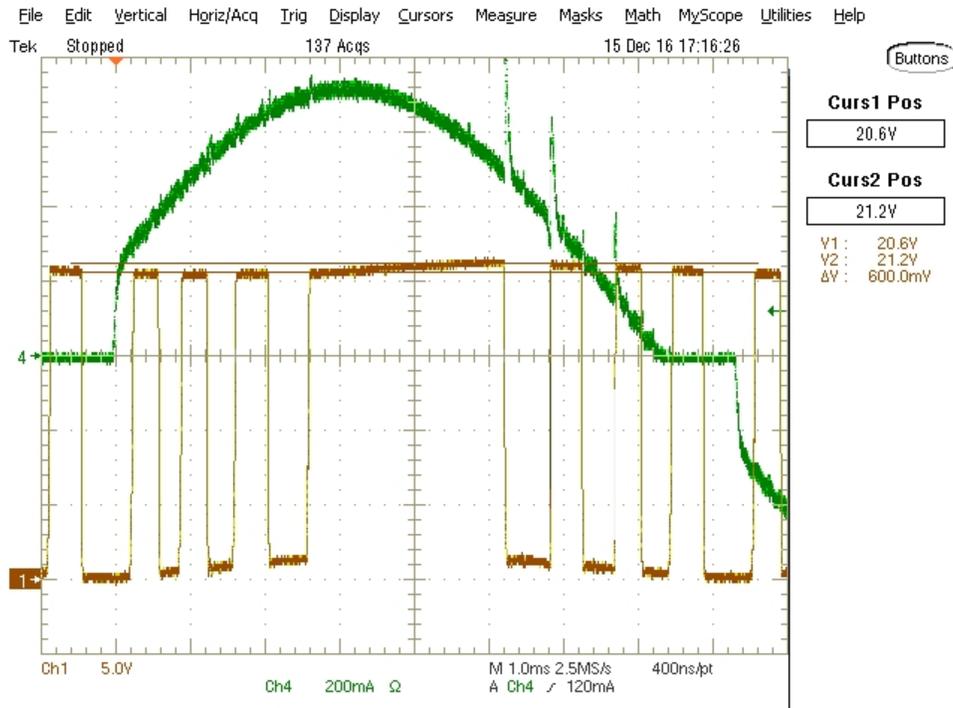


Figure 13. LED Stack Three TPS92411 Drain voltage, CH1, Input Current, CH4

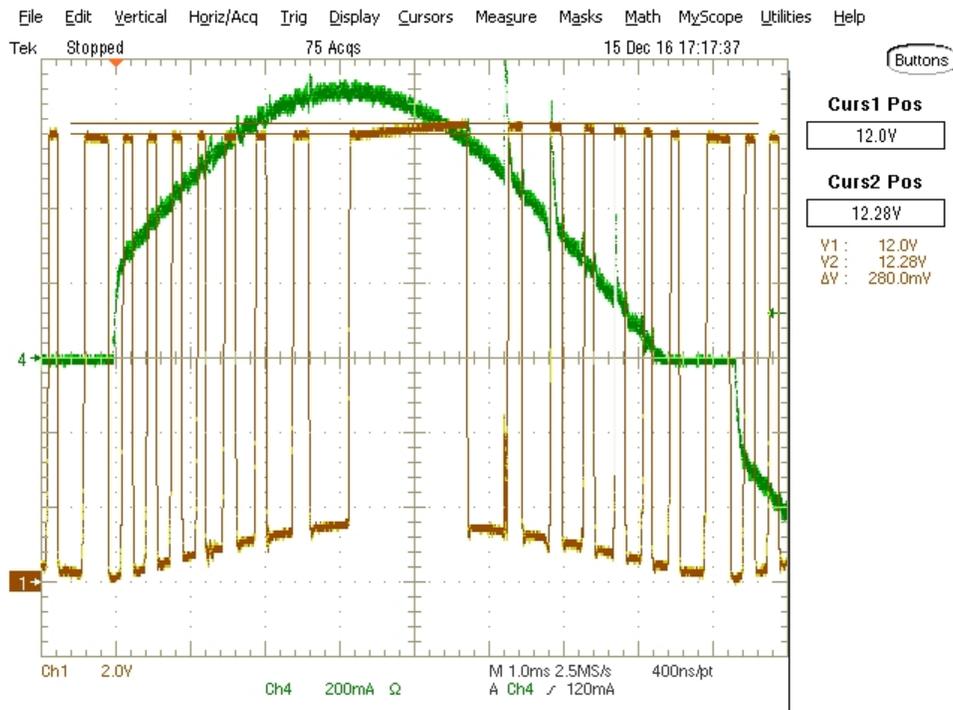


Figure 14. LED Stack Four TPS92411 Drain Voltage, CH1, Input current, CH4

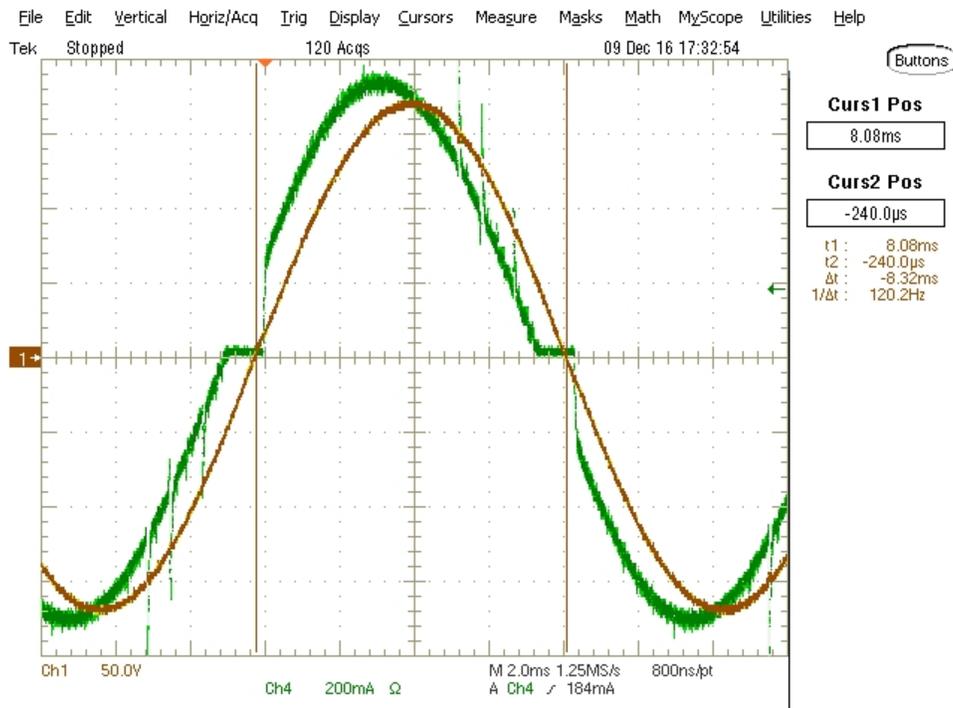


Figure 15. Input Voltage, CH1 and Input Current, CH4

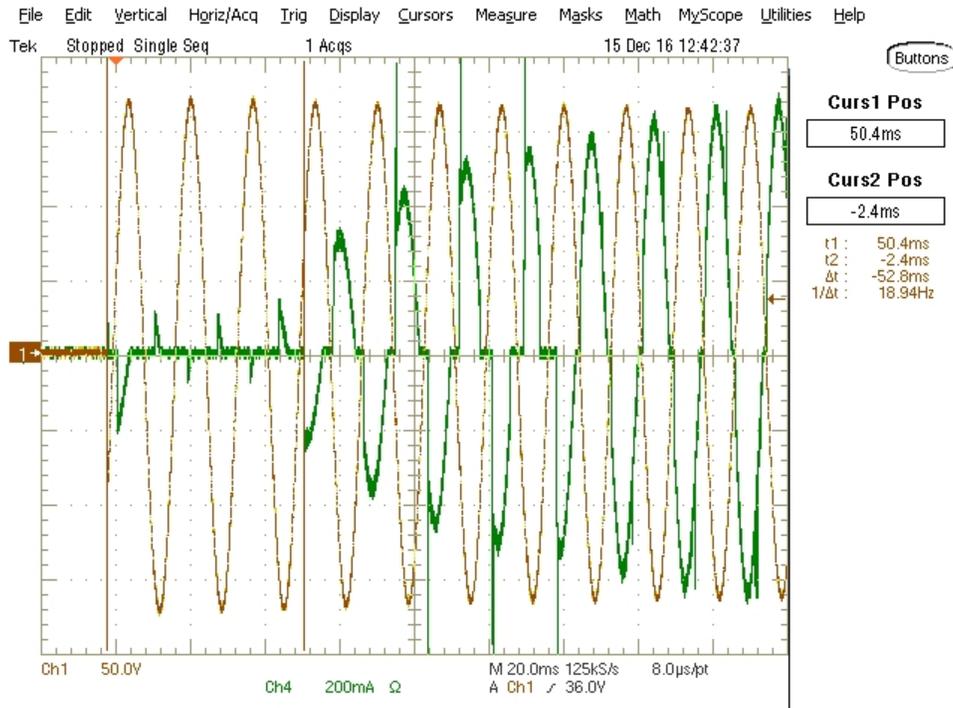


Figure 16. Turnon Delay, Input Voltage, CH1, Input Current, CH4

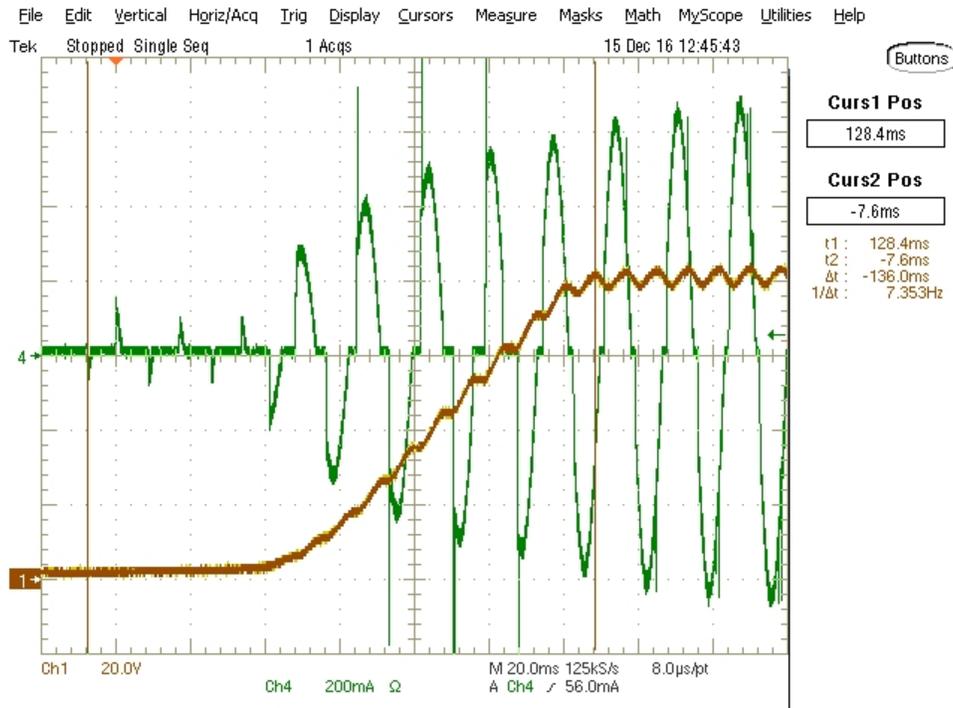


Figure 17. Turnon Delay, Input Current, CH4, LED Stack One Voltage, CH1

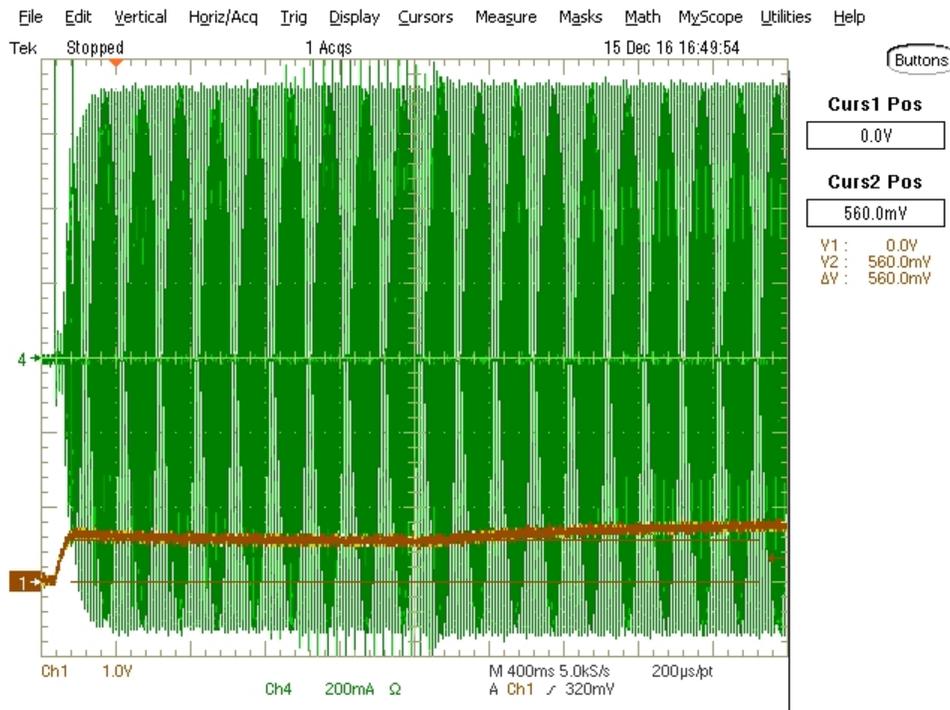


Figure 18. Overvoltage, CH1, Input Current, CH4, Normal Operation, 120-V AC to 135-V AC Step

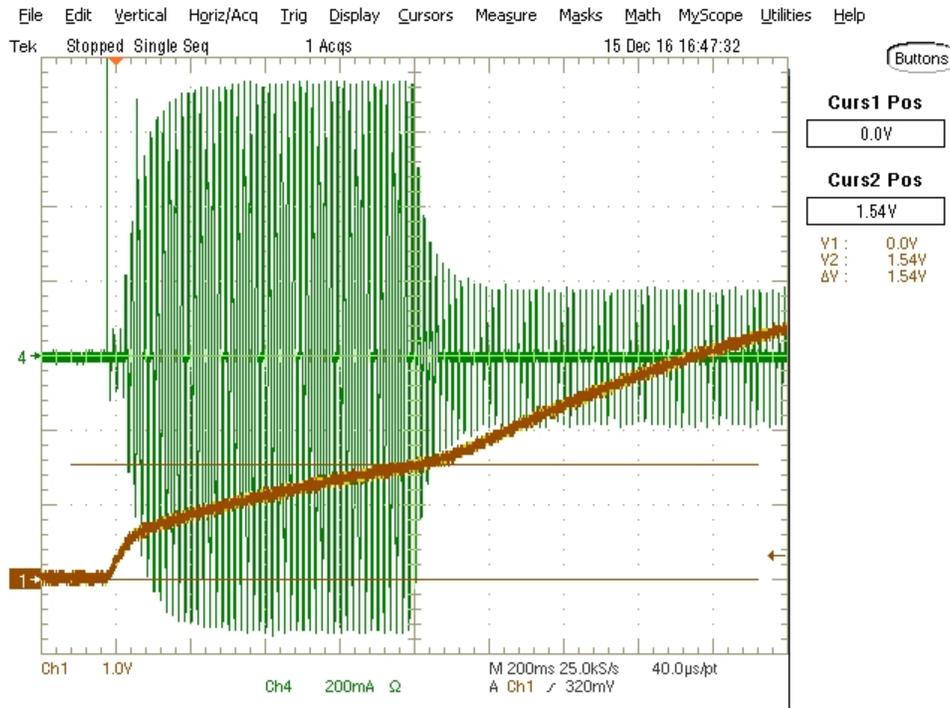


Figure 19. Overvoltage Protection, CH1, Input Current, CH4, LED Stack One Shorted, Power on to Foldback

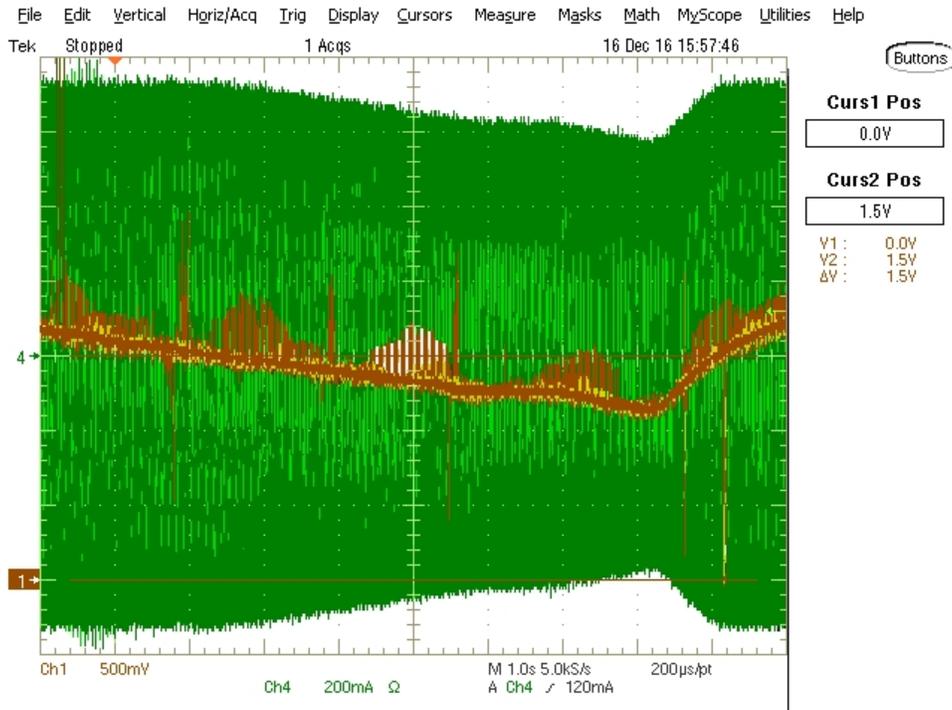


Figure 20. Thermal Foldback, CH1, Input Current, CH4, External Heat Source on NTC Thermistor

3.3.2 Analog Dimming

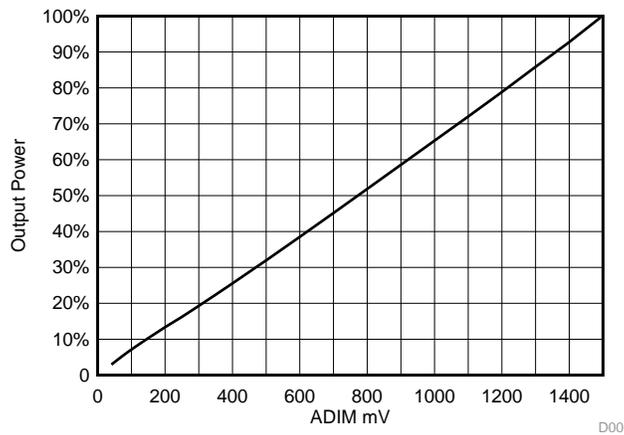


Figure 21. Output Power versus ADIM Voltage (3% to 100%)

3.3.3 LED Current Ripple

The following scope shots show the LED string current ripple for each of the four different strings.

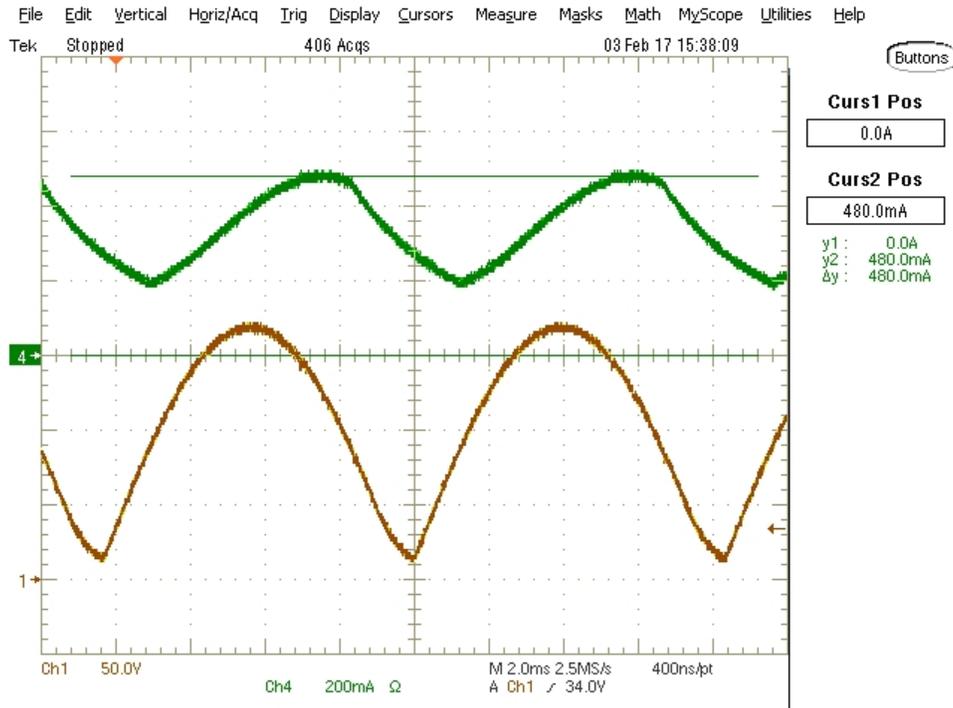


Figure 22. LED Stack One Current, CH4, Rectified AC, CH1

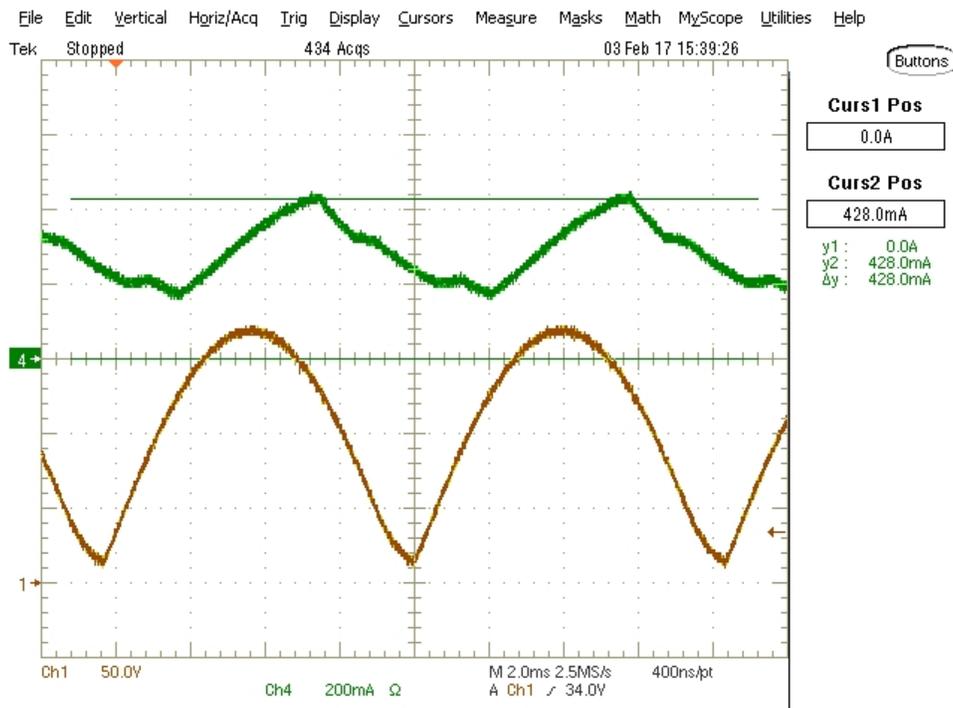


Figure 23. LED Stack Two Current, CH4, Rectified AC, CH1

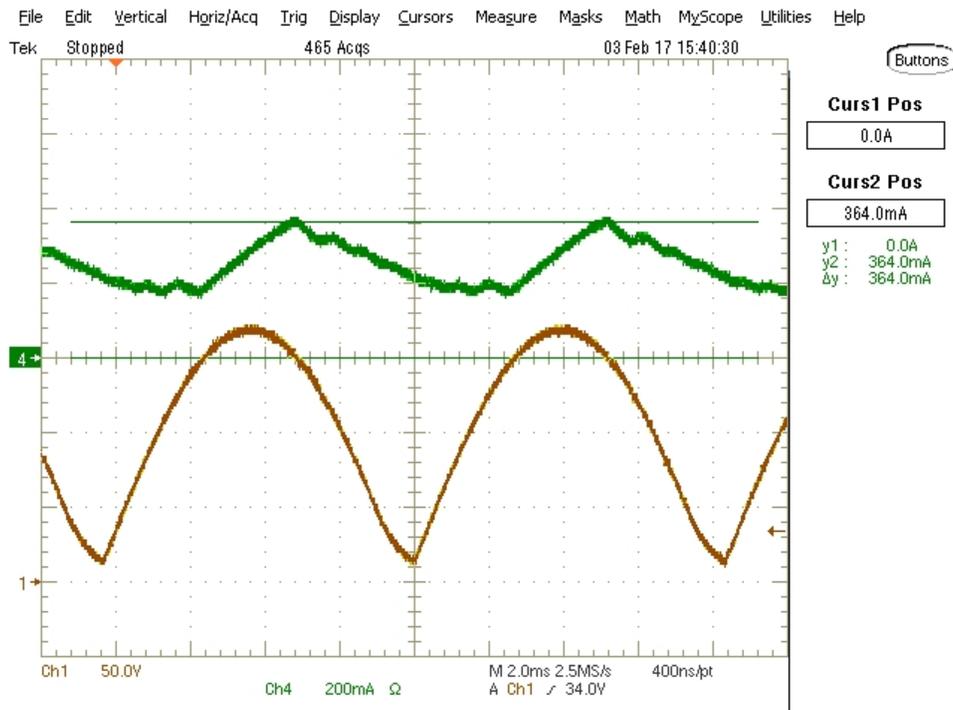


Figure 24. LED Stack Three Current, CH4, Rectified AC, CH1

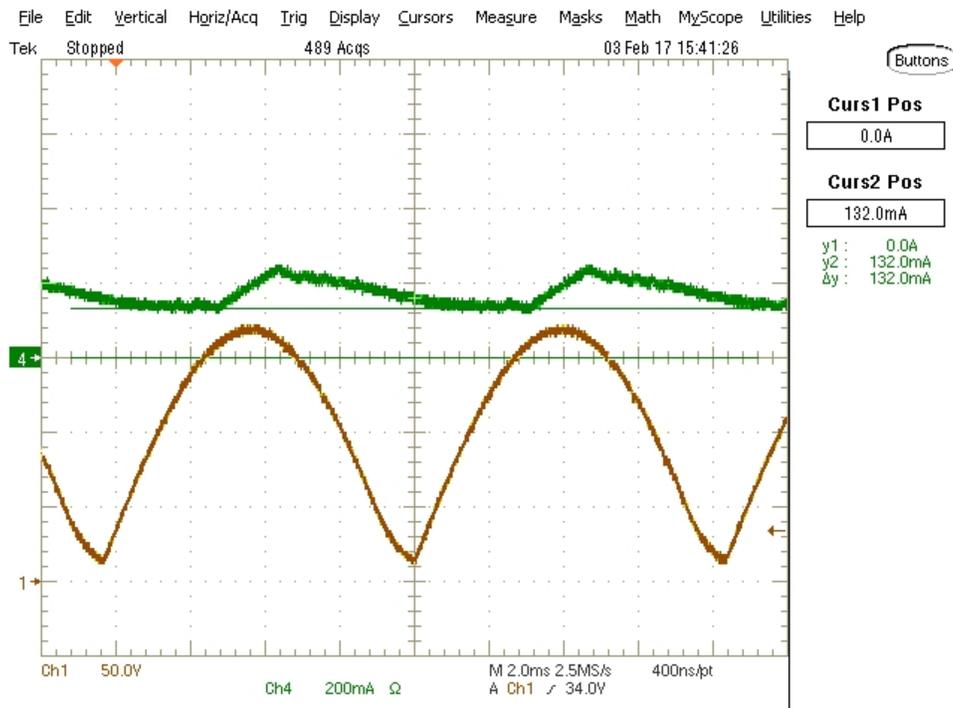


Figure 25. LED Stack Four Current, CH4, Rectified AC, CH1

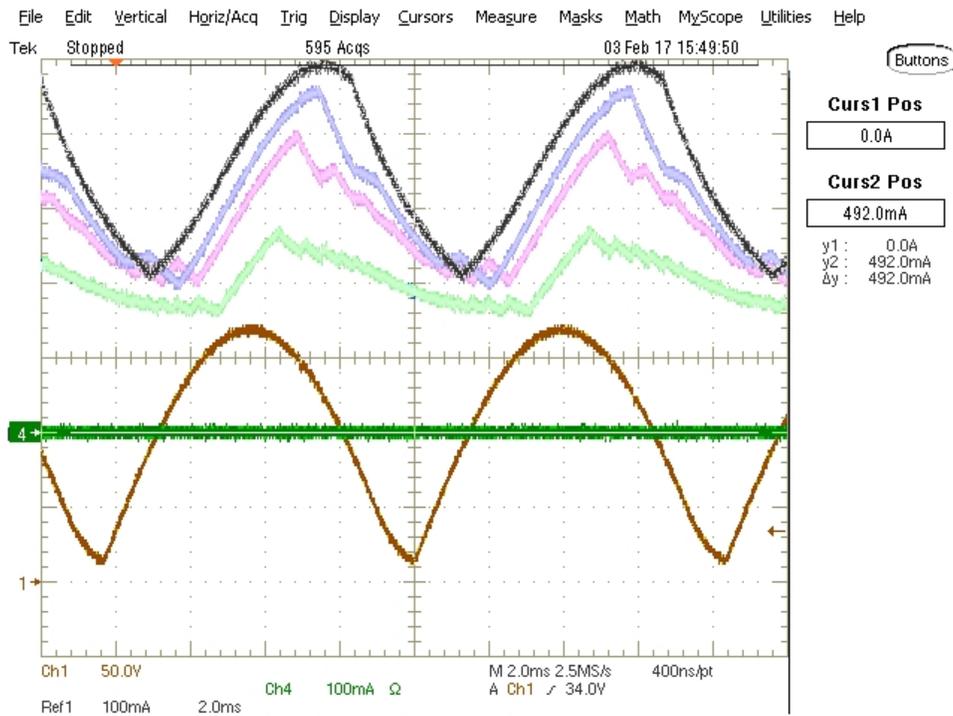


Figure 26. Current All LED Stacks, Rectified AC, CH1

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-01399](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-01399](#).

4.3 PCB Layout Recommendations

The performance of the switch-controlled, direct-drive linear controller can be influenced by layout as well as LED stack voltages. The copper area on the TPS92411 RSNS and RSET pins must be minimized to reduce capacitive coupling (metal core boards are more sensitive to this). The RSNS and RSET resistors should be placed close to the RSNS and RSET pins. Multiple switching events may occur if excess copper area exists on these connections. The sum of any of the LED stacks should not equal another stack. For instance, a fourth stack of 15 V, a third stack of 30 V, and a second stack of 45 V results in two TPS92411s tripping near the same point on the rectified AC ($15\text{ V} + 30\text{ V} = 45\text{ V}$). Tolerances and V_f changes with temperature can cause the switching order to change during operation. Figure 27 shows a generic layout.

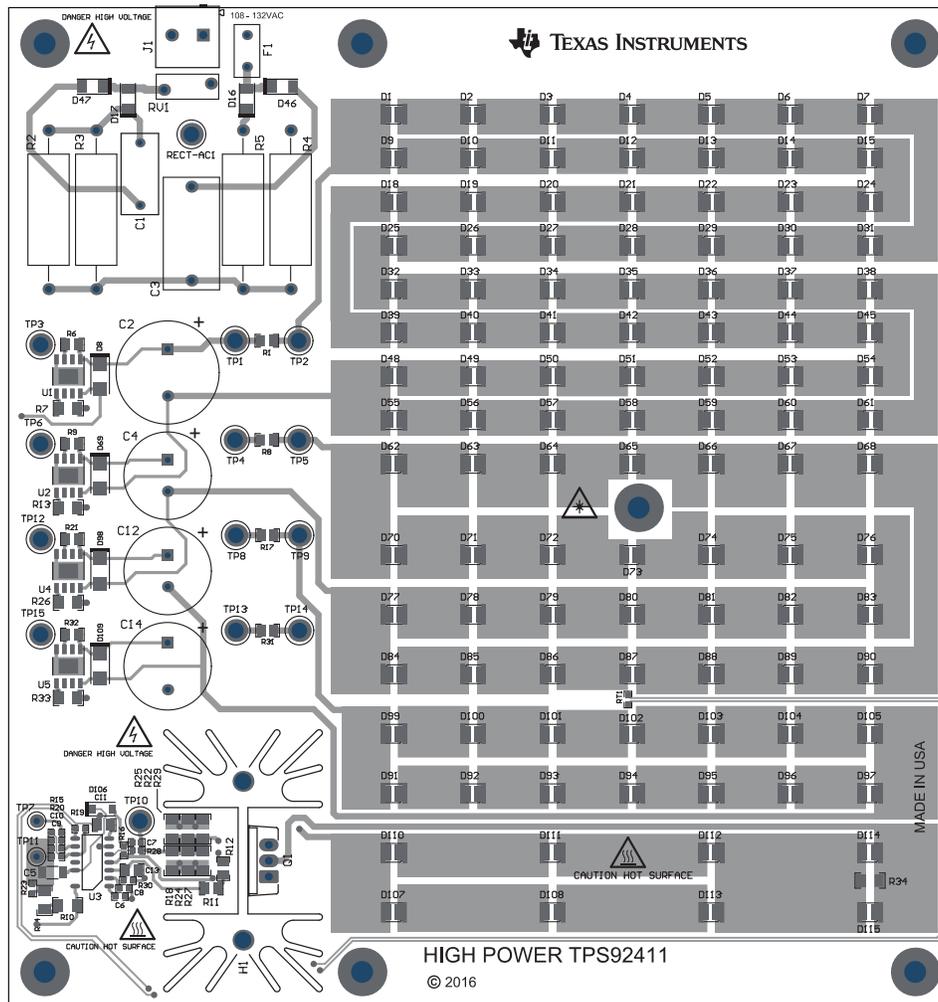


Figure 27. PCB Layout

Three components on this design determine conducted EMI levels (C1, C3, and C7):

- C1 and C3 can be combined into one capacitor and should be film type. C7 is a low-voltage ceramic.
 - A change in power level is proportional to the value of C1 and C3 combined. Halving the power of the design allows the reduction of C1 and C3 to be one half of their values or by removing one of the two capacitors.
 - The C7 value does not change in proportion to the power level, it limits the slew rate of the current-regulating MOSFET, Q1.

4.4 Thermal Scans

Figure 28 shows a thermal scan of the board running at a room temperature ($\approx 25^{\circ}\text{C}$) with no airflow. Table 4 and Table 5 show and list the measured temperatures of key components.

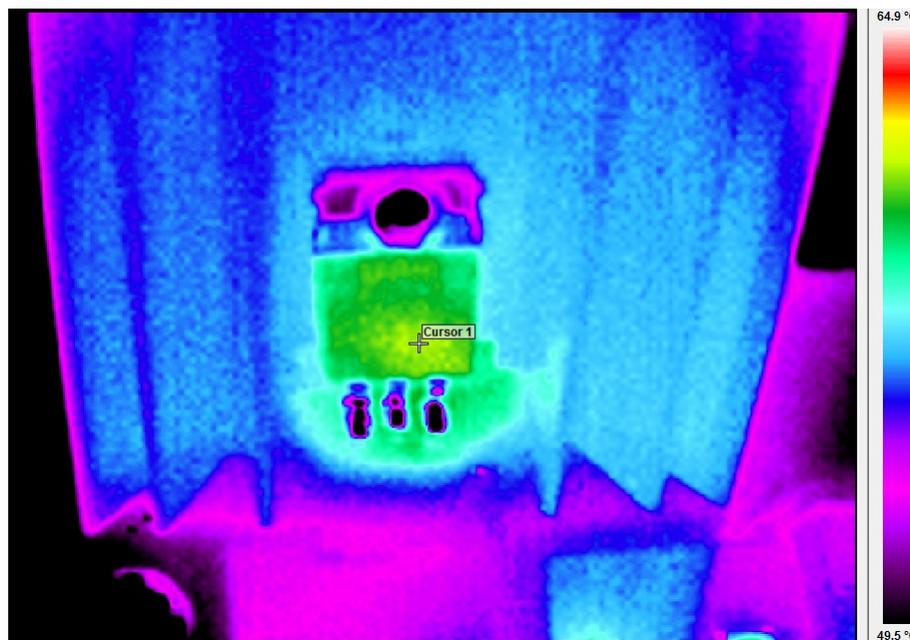


Figure 28. Thermal Scan—Linear Regulator FET, Q1: $V_{IN} = 120\text{-V AC}$, Full Power

Table 4. Component Temperatures

CURSOR	COMPONENT	TEMPERATURE ($^{\circ}\text{C}$)
1	Q1	61.3

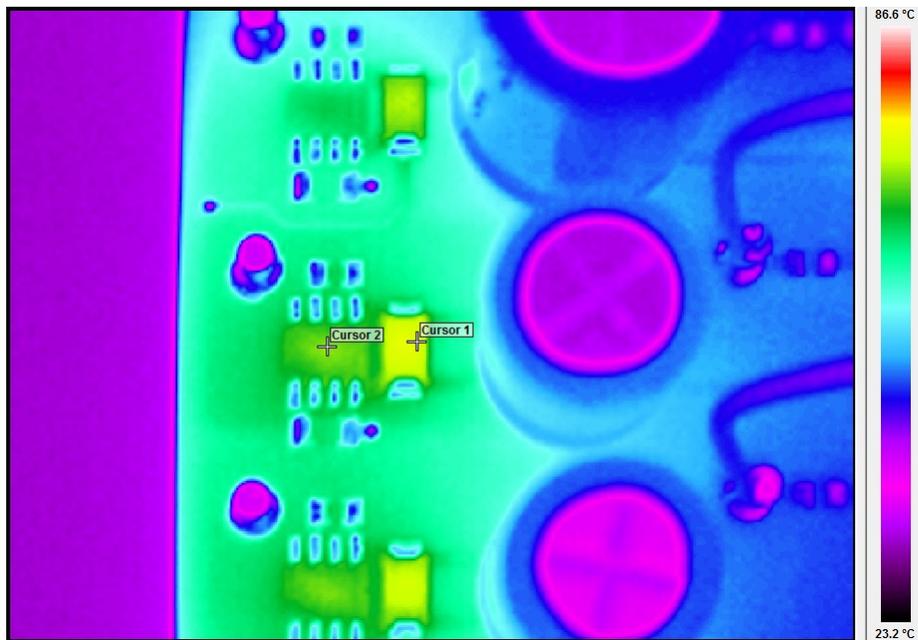


Figure 29. Thermal Scan—TPS92411 and Blocking Diode: $V_{IN} = 120\text{-V AC}$, Full Power

Table 5. Component Temperatures

CURSOR	COMPONENT	TEMPERATURE (°C)
1	D69	73.3
2	U2	70.3

4.5 Layout Prints

To download the layer plots, see the design files at [TIDA-01399](#).

4.6 Altium Project

To download the Altium project files, see the design files at [TIDA-01399](#).

4.7 Gerber Files

To download the Gerber files, see the design files at [TIDA-01399](#).

4.8 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-01399](#).

5 Related Documentation

1. Texas Instruments, [Switch-Controlled, Direct Drive, Linear Controller for Offline LED Drivers](#), TPS92410 Data Sheet (SLUSBW9)
2. Texas Instruments, [Floating Switch for Offline AC Linear Direct Drive of LEDs with Low Ripple Current](#), TPS92411 Data Sheet (SLUSBQ6)

5.1 Trademarks

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (July 2017) to A Revision	Page
• Updated Figure 21 with correct x-axis label.....	17

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