TI 设计：TIDA-01399
TPS92410/411 50W、120V 交流离线、LED 驱动器（采用 LED 通用照明所需的无磁性器件）

说明

TIDA-01399 TI 设计展示了适用于区域照明的 50W 输出功率 TPS92410 和 TPS92411，该设计的所有组件均安装在单个印刷电路板 (PCB) 上。此设计使用四个 TPS92411 级，以在上升和下降交流整流波形过程中支持 16 种不同的开关状态，从而优化电流调节 MOSFET 余量。TPS92410 允许单调模拟调光在关闭电流调节器之前下降至 3%。此设计包含电磁干扰 (EMI) 滤波（无磁性器件），旨在满足 FCC 第 47 篇第 15 部分的 B 类传导要求。

资源

TIDA-01399	设计文件夹
TPS92410	产品文件夹
TPS92411	产品文件夹

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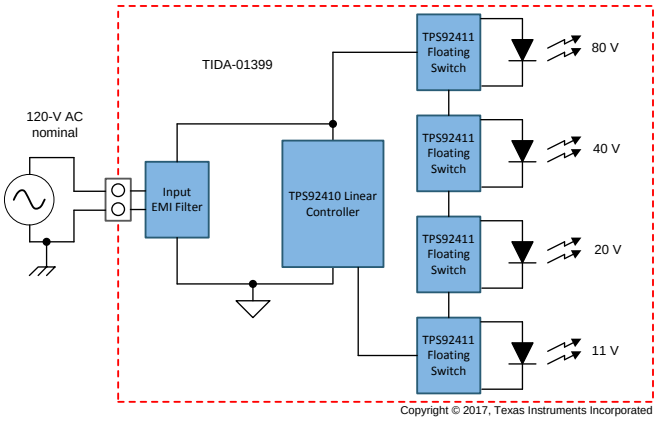
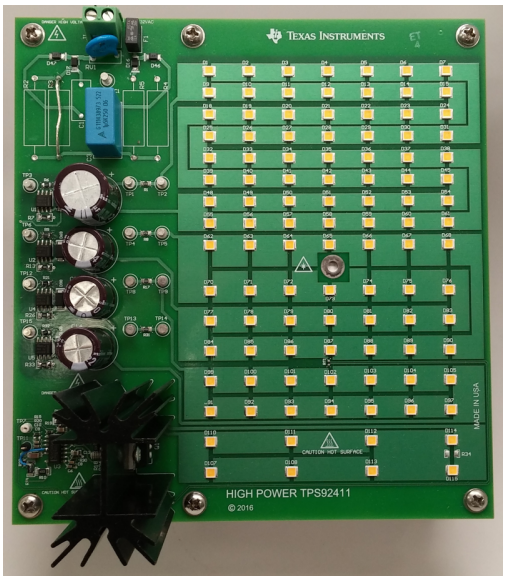
特性

- 采用无磁性器件的非隔离式 120V 交流离线 LED 驱动器
- 4 通道 TPS92411 可提供 16 种开关状态
- 效率：86.5%，功率因数：0.97，THD：10.5%
- TPS92411 带散热垫，适用于较高电流 应用
- 用于功率因数校正的 TPS92410 电流调节器以及用于线路调节的倍增器
- TPS92410 支持简单的 NTC 热折返
- TPS92410 使用关断功能将单调模拟调光降至 3%；使用 TSNS 输入进行更深层次的调光
- 经过 FCC 第 47 篇第 15 部分的 B 类测试的 EMI

应用

- 通用照明
- 区域照明
- 安全照明
- 射灯
- 室内照明





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

表 **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 V to 1.5 V	3	—	100	%
ADIM shutdown threshold	—	18	40	70	mV
SYSTEM CHARACTERISTICS					
Efficiency	V_{IN} = 120-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

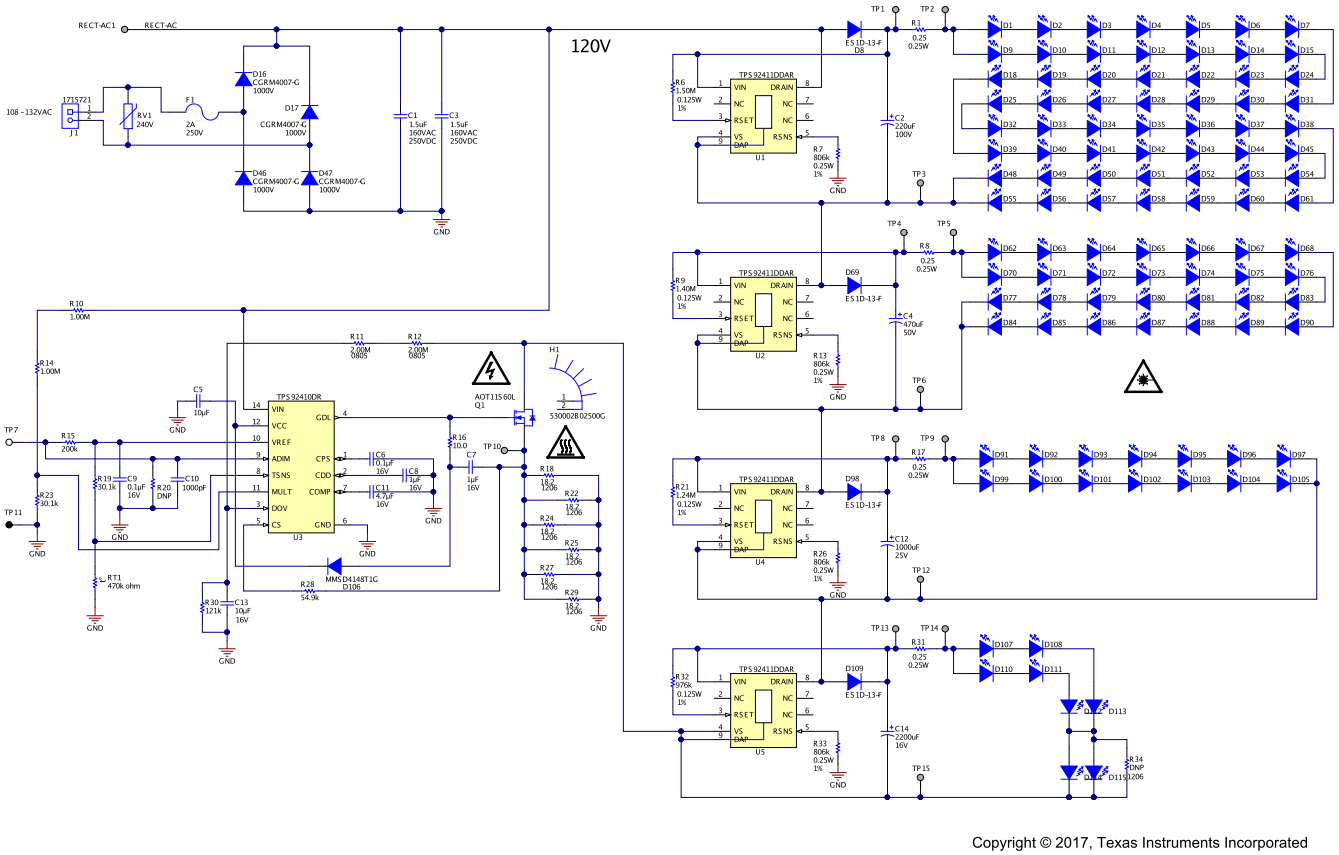


图 1. TIDA-01399 Schematic

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 图 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 图 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.

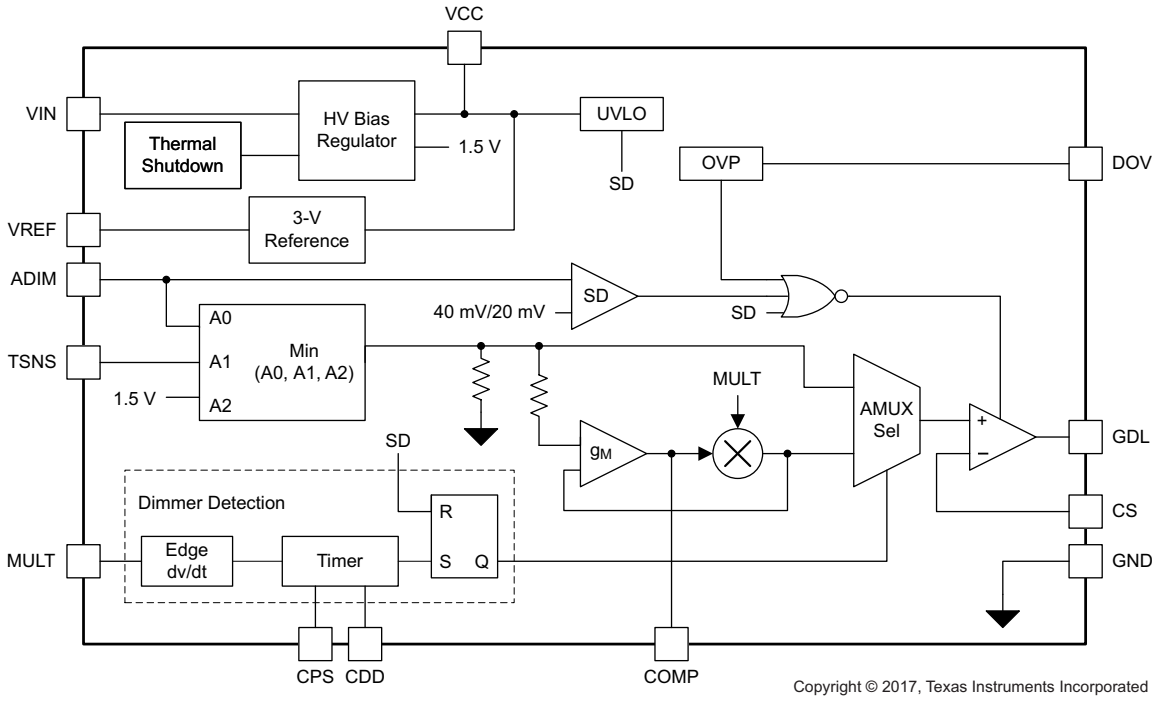


图 2. TPS92410 Block Diagram

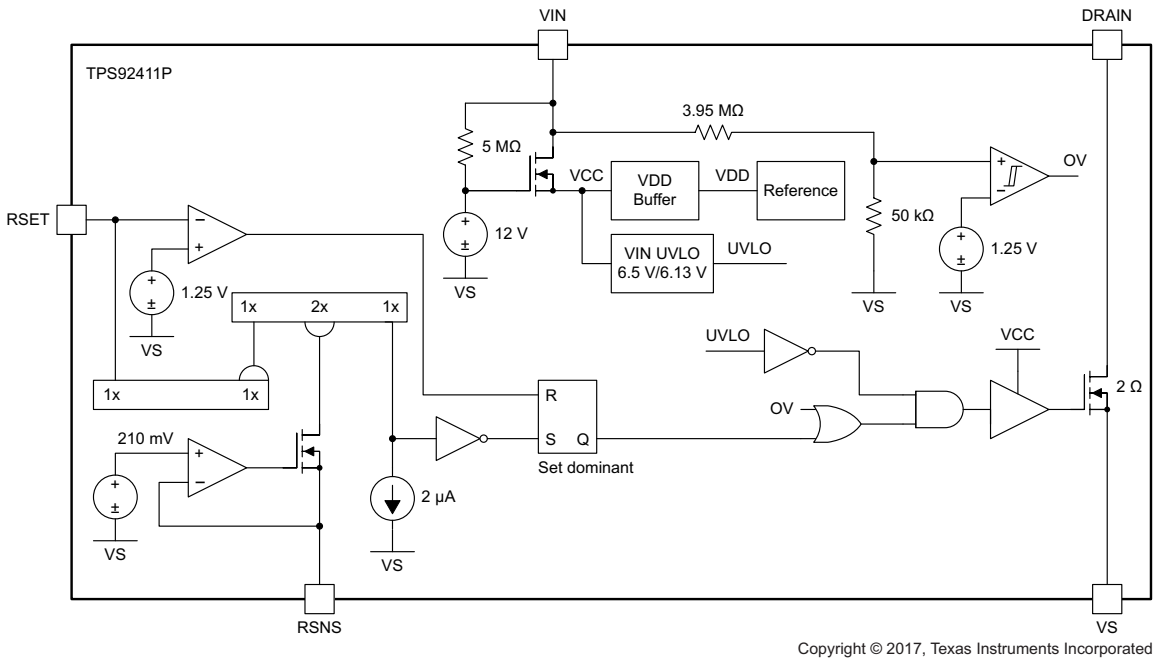


图 3. TPS92411 Block Diagram

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 µA
- 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 图 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 表 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 表 2).

表 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 (公式 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

图 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.

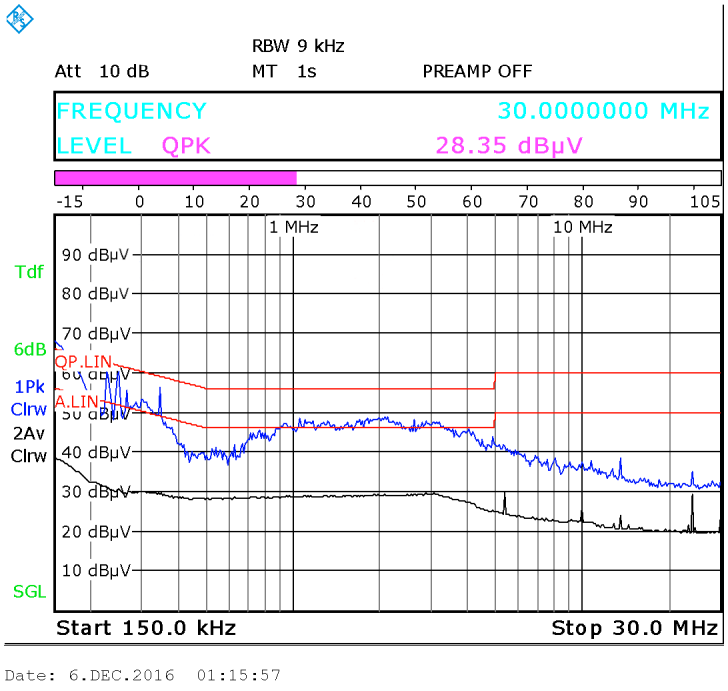


图 4. FCC Part 15 Class B Conducted EMI Scan (QP.LIN: Peak Limits, A.LIN: Average Limits) V_{IN} = 120-V AC, P_{OUT} = 50 W (Pre-Compliance Data)

表 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

图 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.

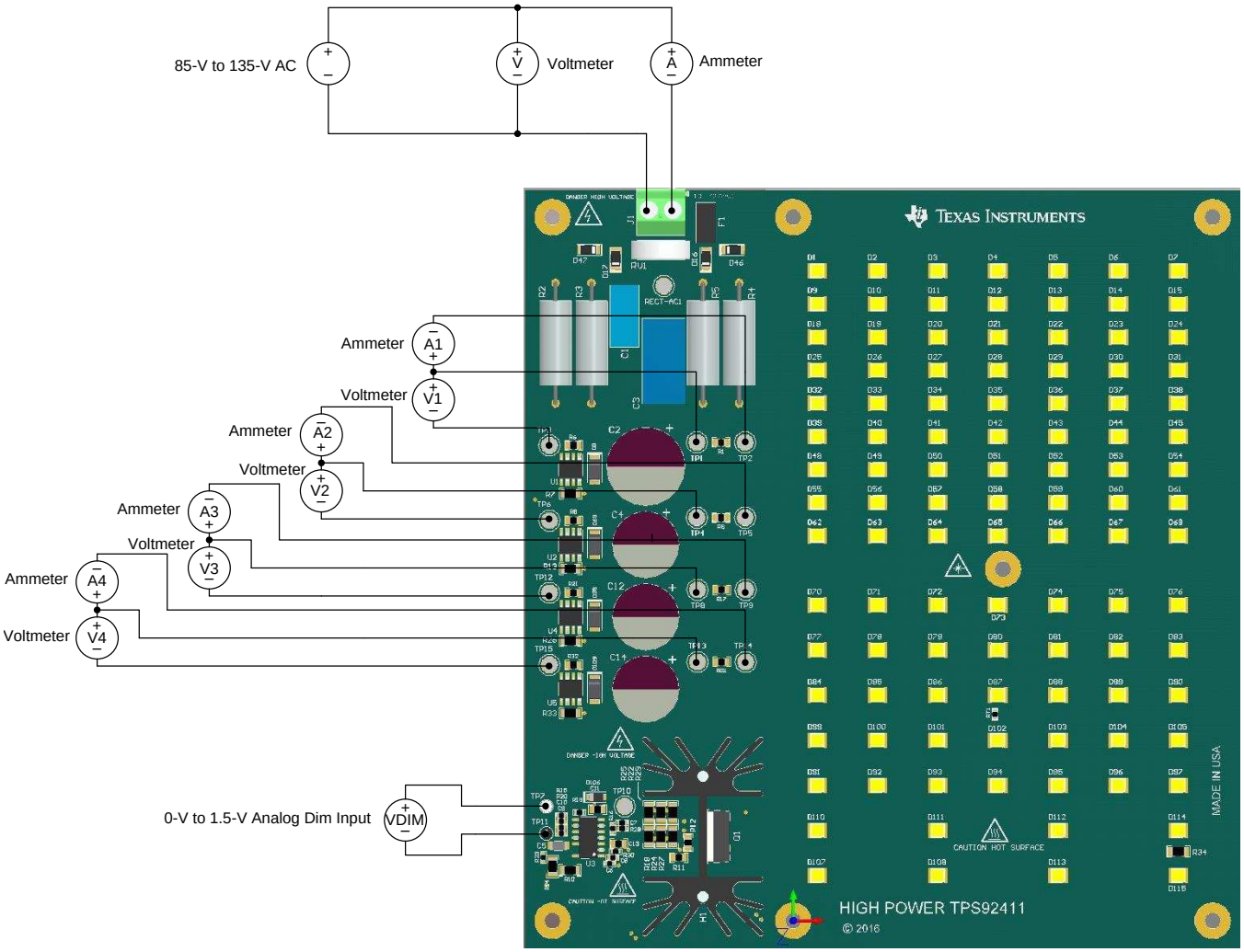


图 5. Test Setup Connections

3.3 Test Results

The test setup described in 图 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

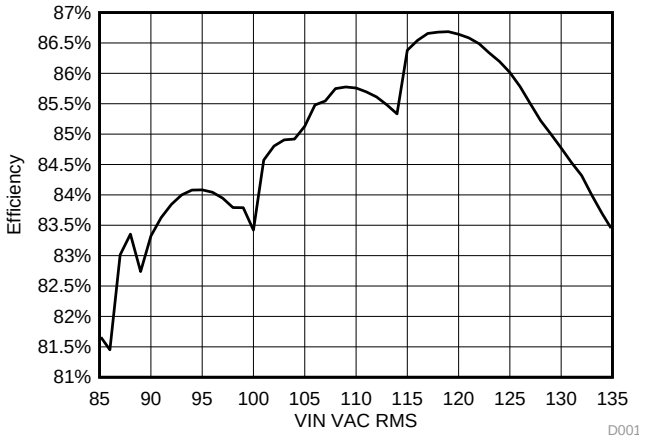


图 6. Efficiency versus Input Voltage

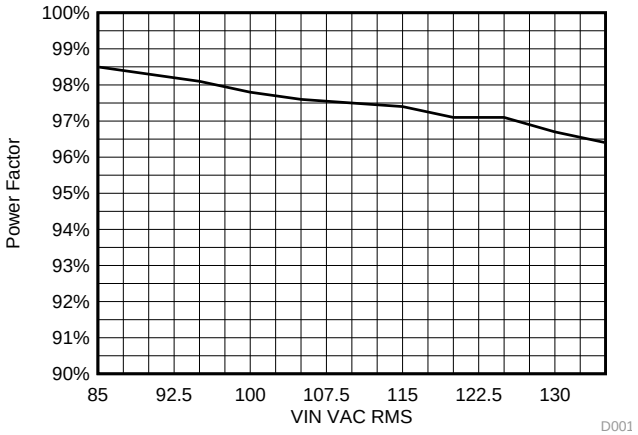


图 7. Power Factor versus Input Voltage

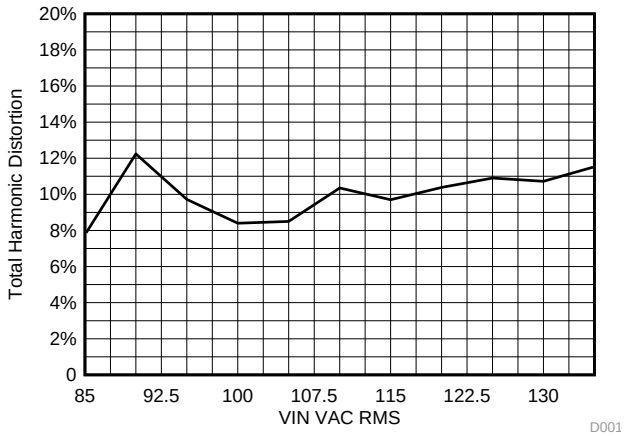


图 8. Total Harmonic Distortion versus Input Voltage

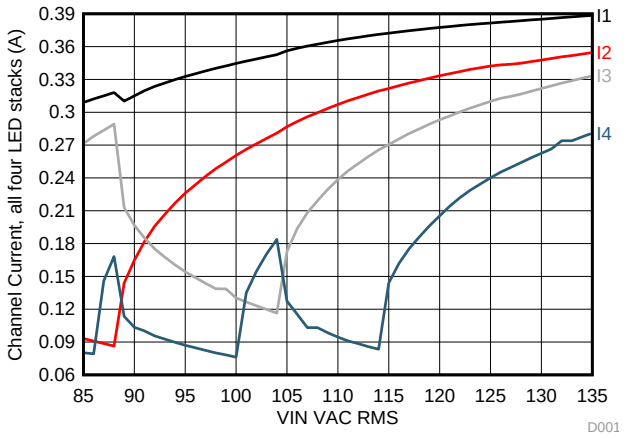


图 9. Stack Currents versus Input Voltage

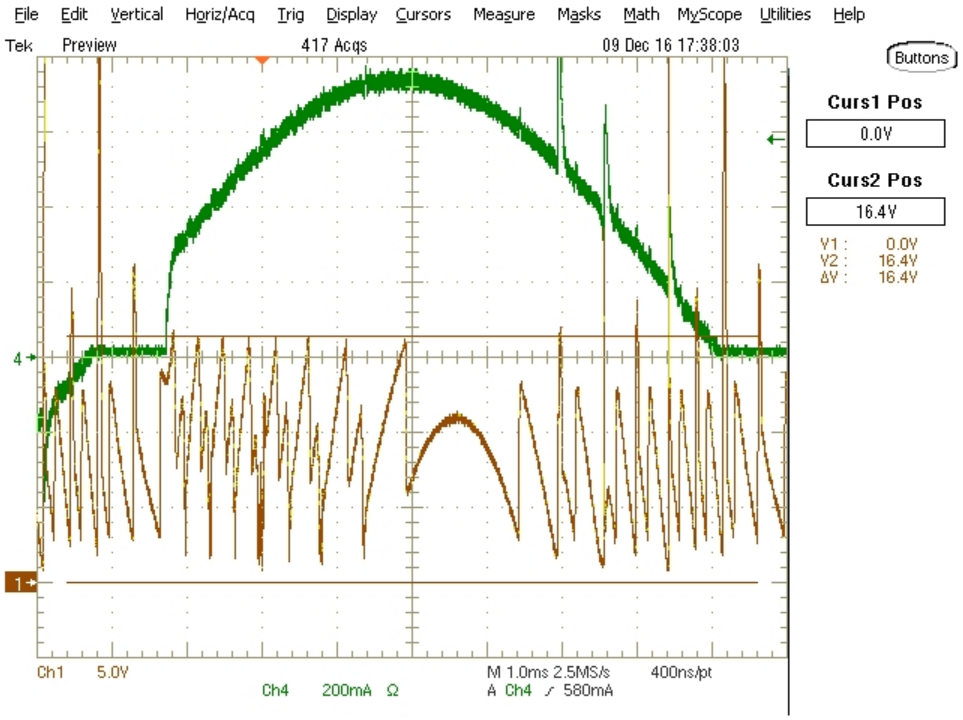


图 10. Current-Regulating MOSFET Drain Voltage, Q1, CH1, Input Current, CH4

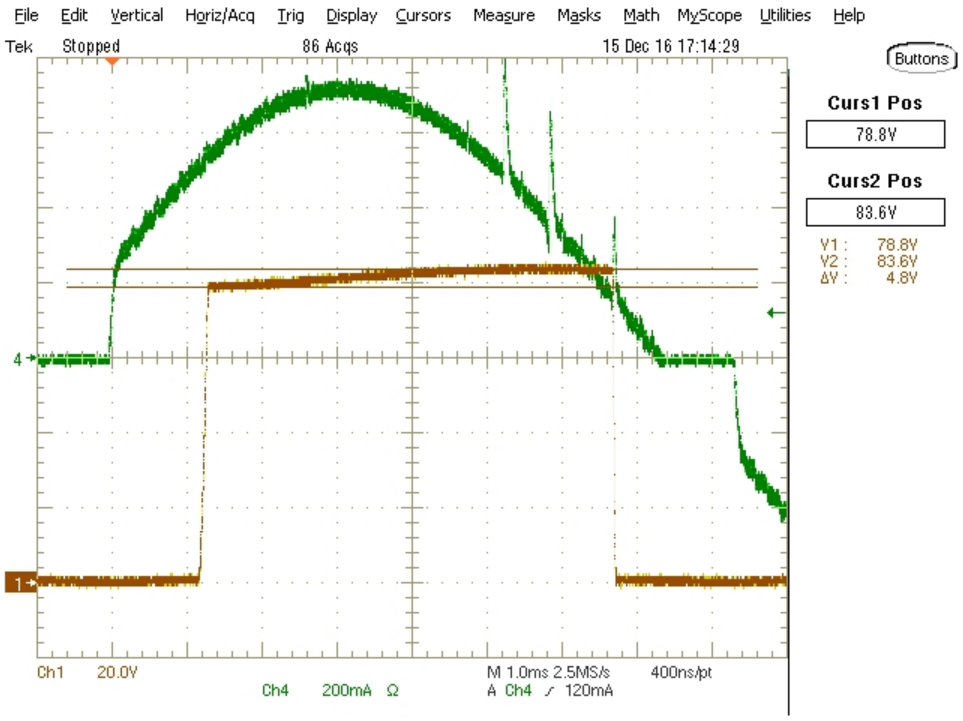


图 11. LED Stack One TPS92411 Drain Voltage, CH1, Input Current, CH4

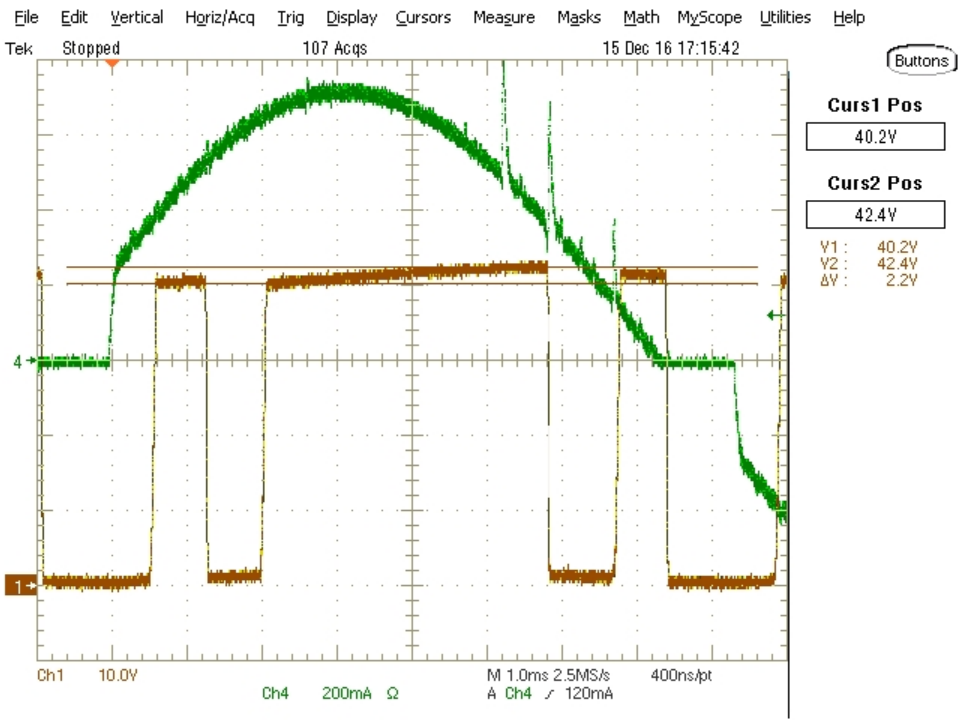


图 12. LED Stack Two TPS92411 Drain Voltage, CH1, Input Current, CH4

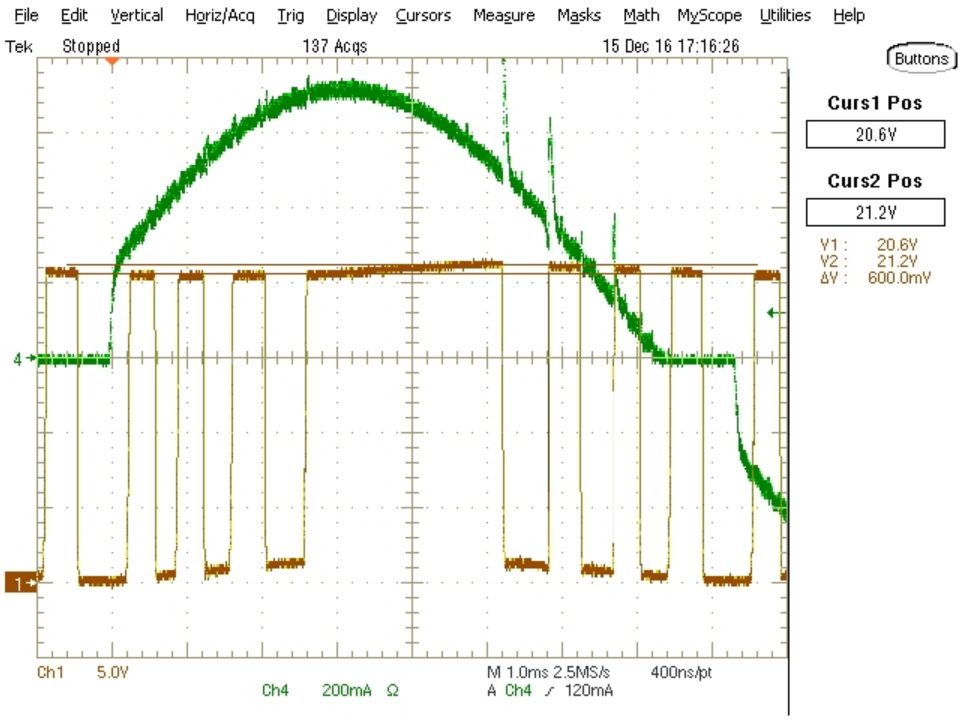


图 13. LED Stack Three TPS92411 Drain voltage, CH1, Input Current, CH4

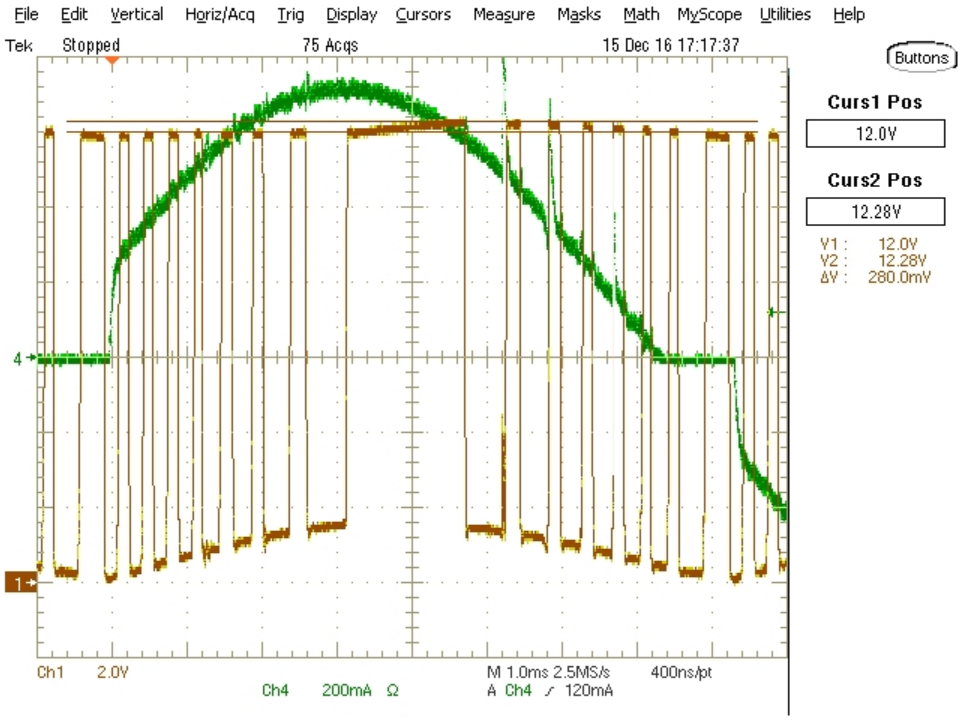


图 14. LED Stack Four TPS92411 Drain Voltage, CH1, Input current, CH4

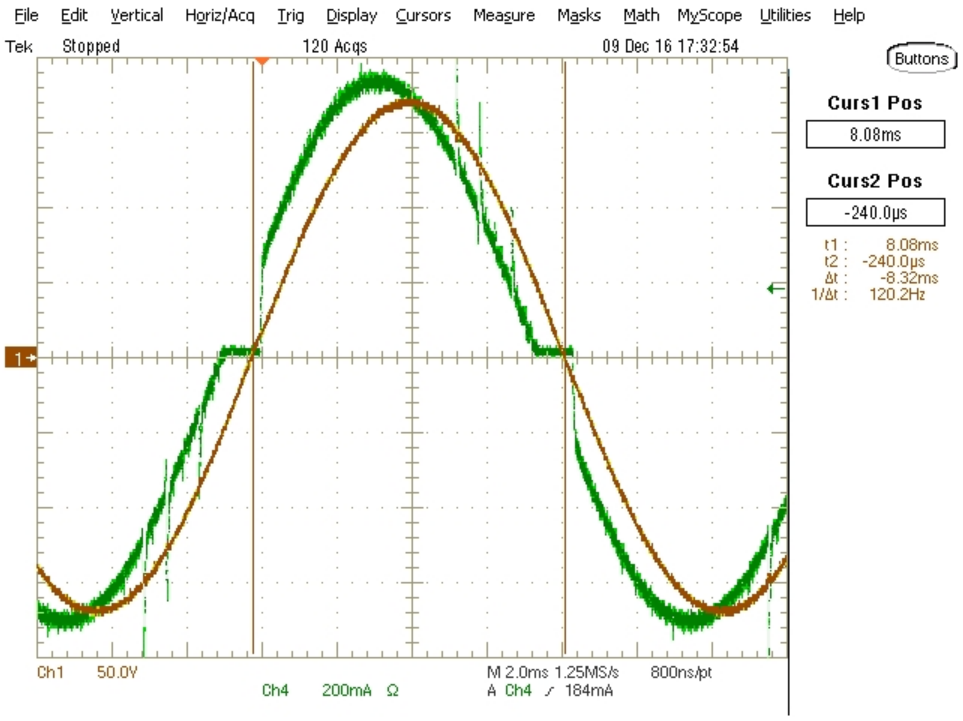


图 15. Input Voltage, CH1 and Input Current, CH4

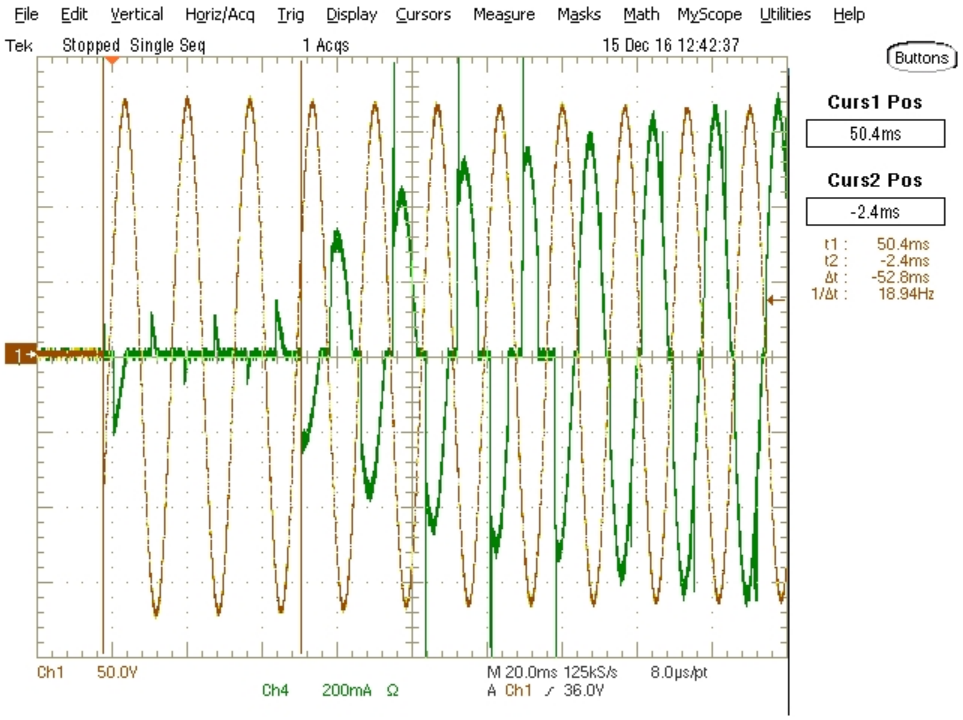


图 16. Turnon Delay, Input Voltage, CH1, Input Current, CH4

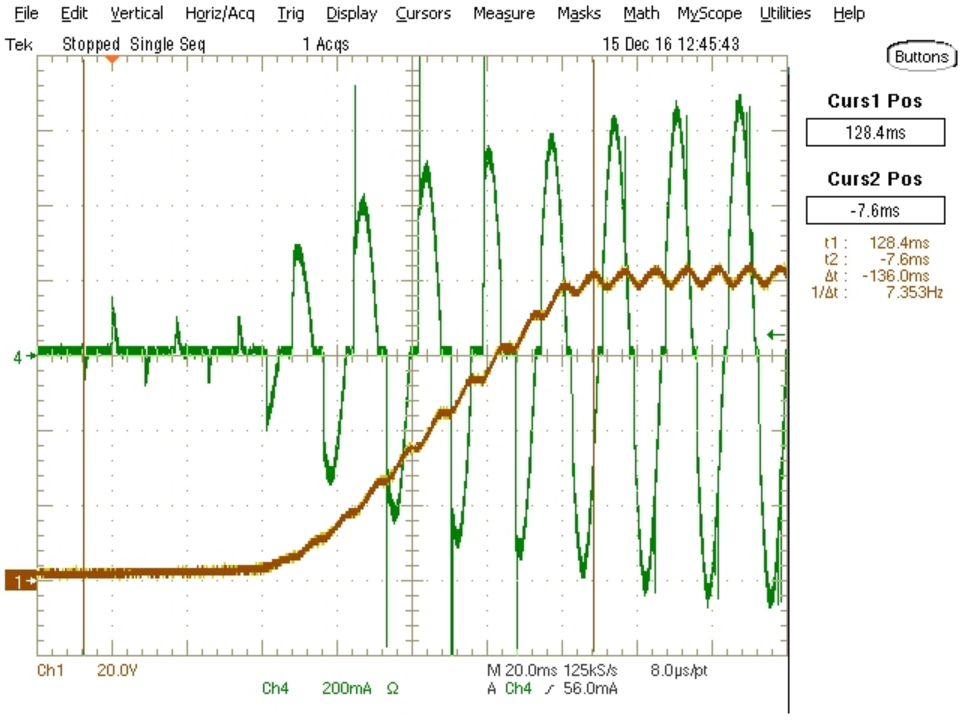


图 17. Turnon Delay, Input Current, CH4, LED Stack One Voltage, CH1

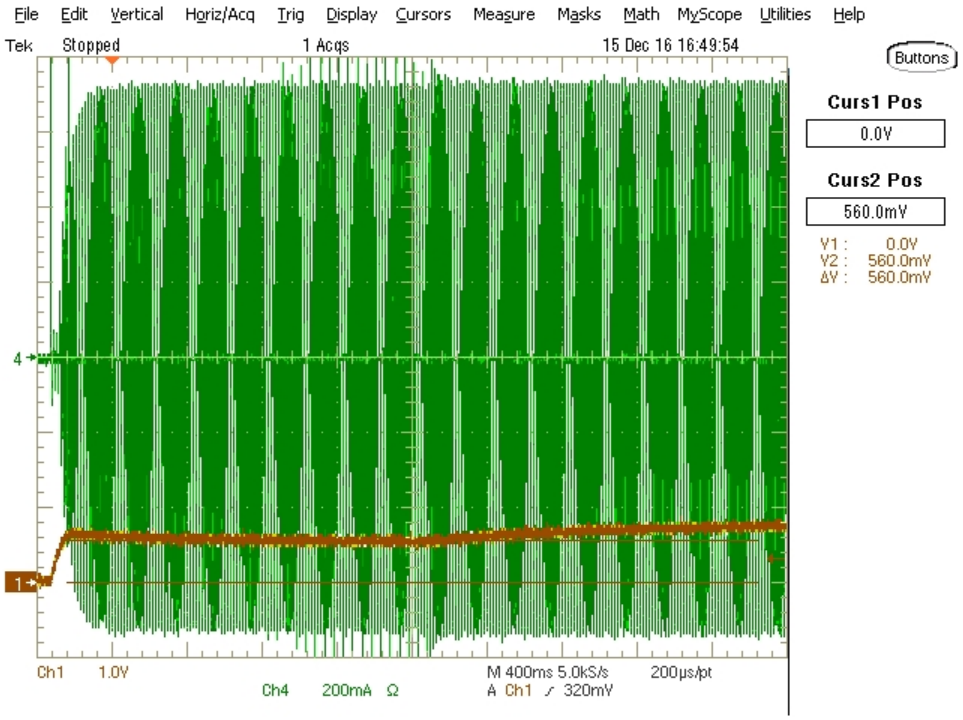


图 18. Overvoltage, CH1, Input Current, CH4, Normal Operation, 120-V AC to 135-V AC Step

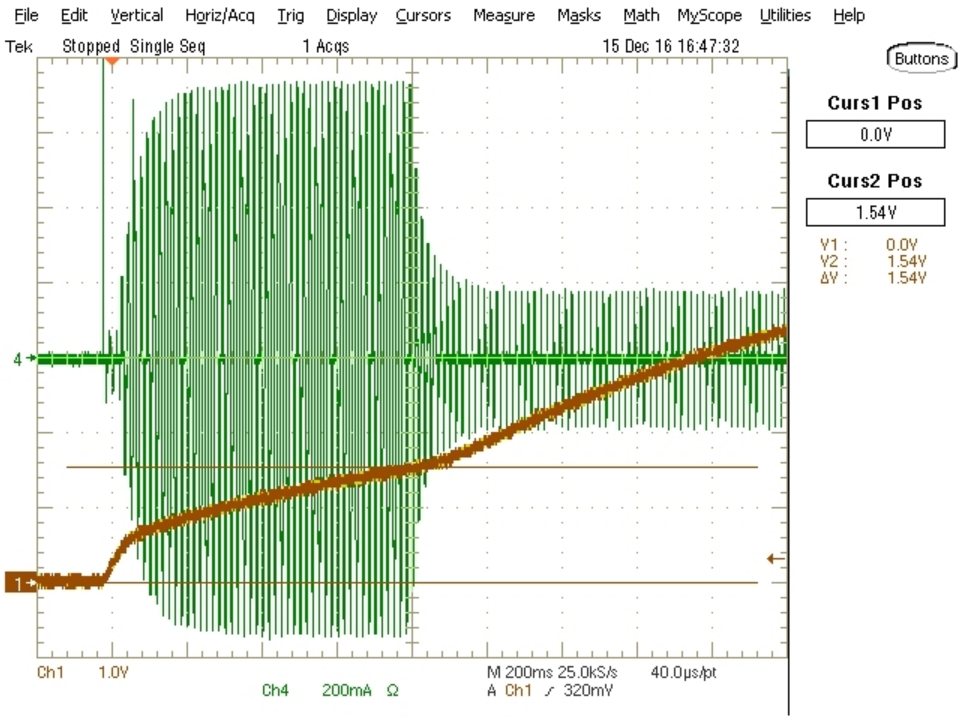


图 19. Overvoltage Protection, CH1, Input Current, CH4, LED Stack One Shorted, Power on to Foldback

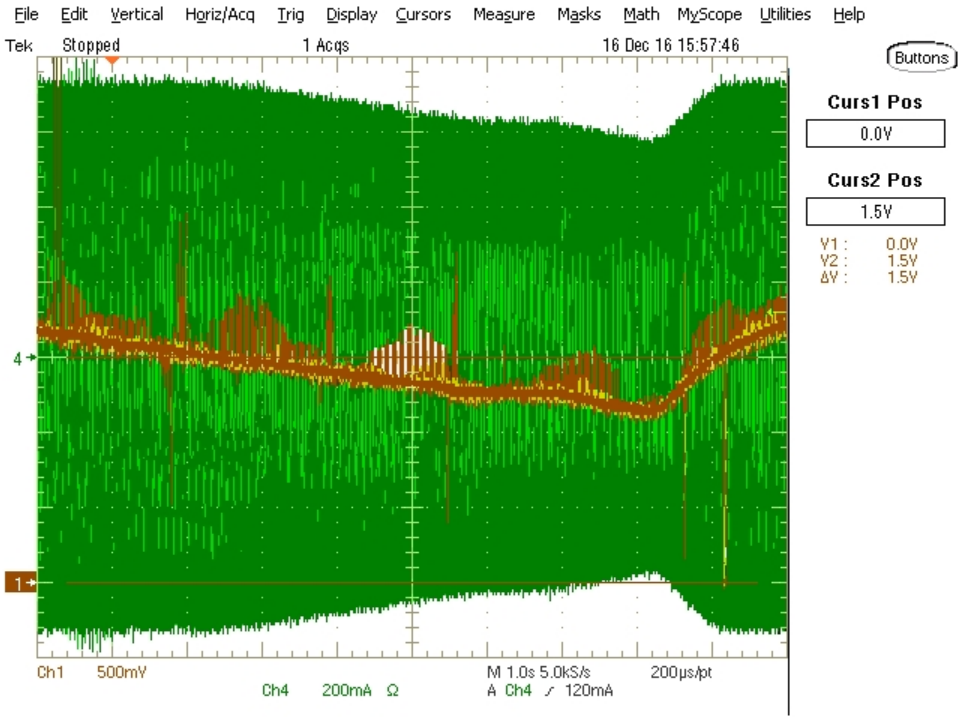


图 20. Thermal Foldback, CH1, Input Current, CH4, External Heat Source on NTC Thermistor

3.3.2 Analog Dimming

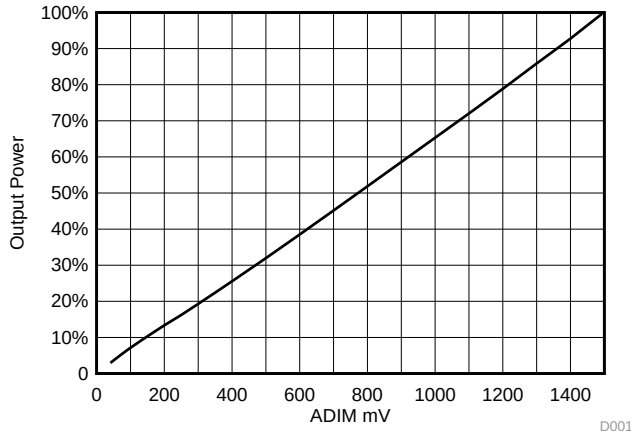


图 21. Output Power versus ADIM Voltage (3% to 100%)

3.3.3 LED Current Ripple

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

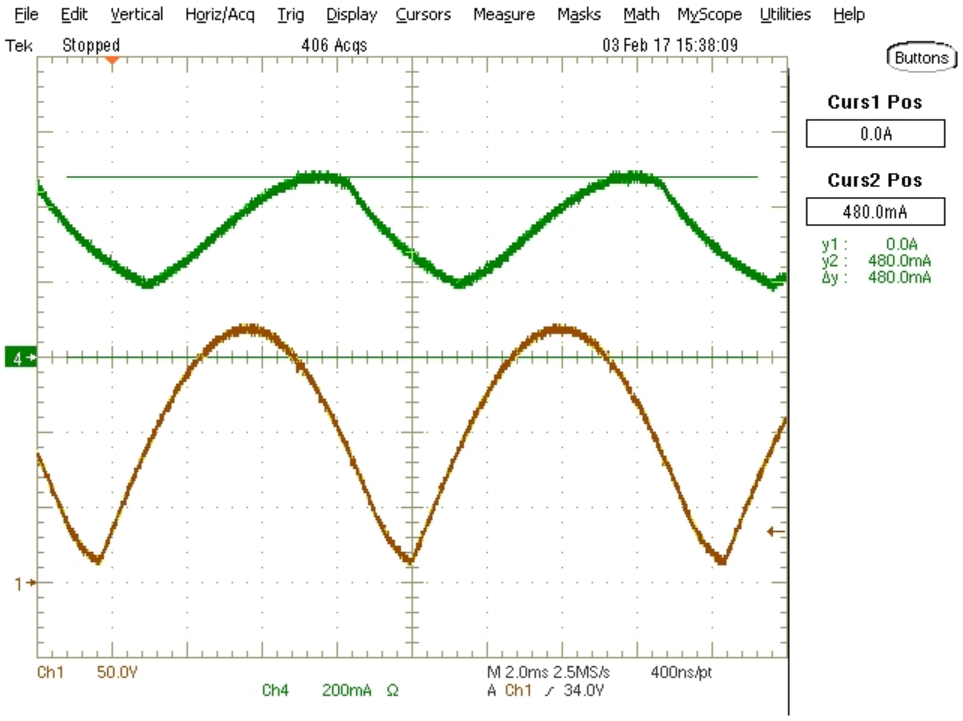


图 22. LED Stack One Current, CH4, Rectified AC, CH1

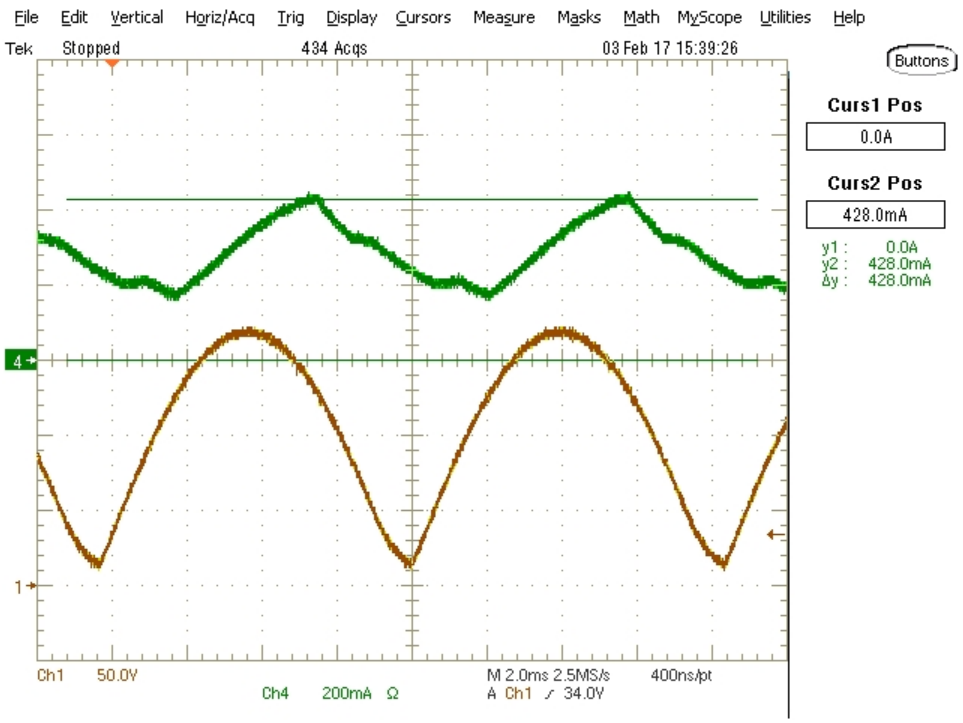


图 23. LED Stack Two Current, CH4, Rectified AC, CH1

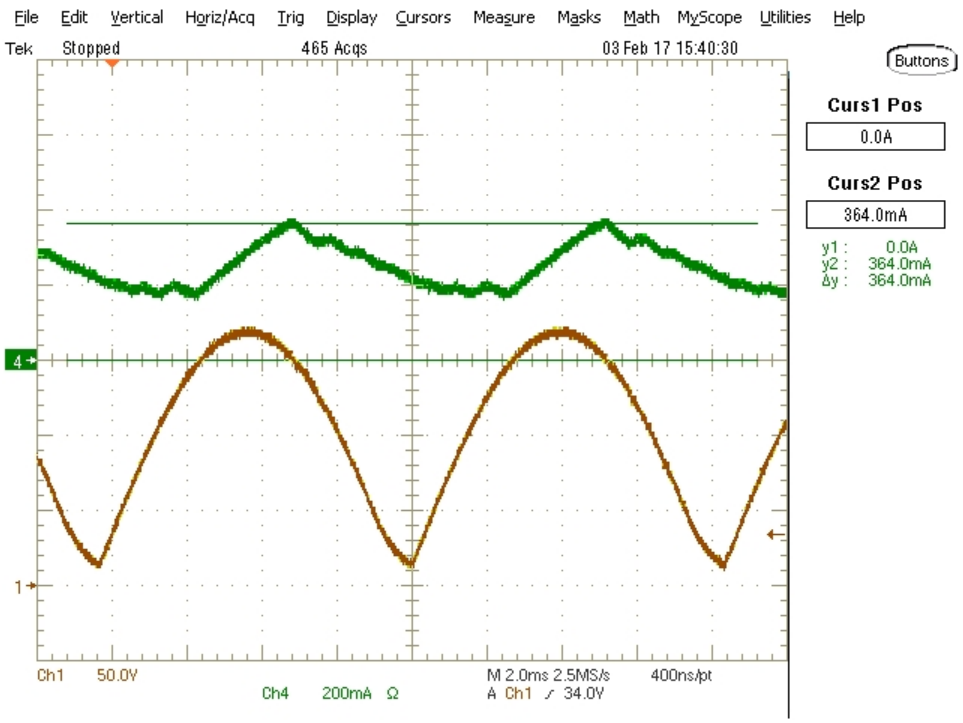


图 **24. LED Stack Three Current, CH4, Rectified AC, CH1**

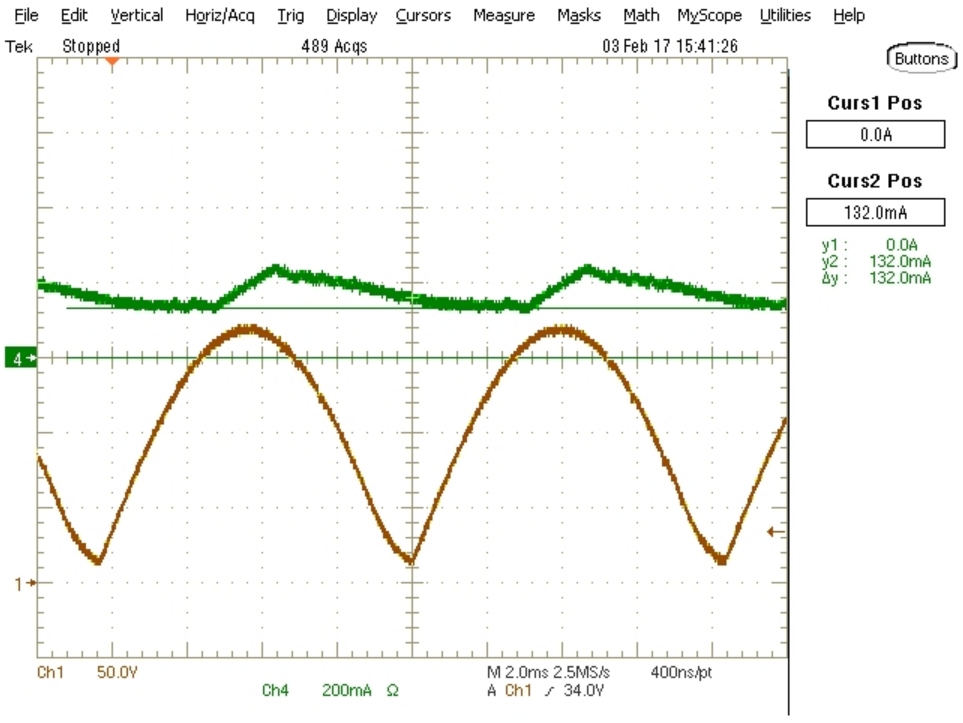


图 **25. LED Stack Four Current, CH4, Rectified AC, CH1**

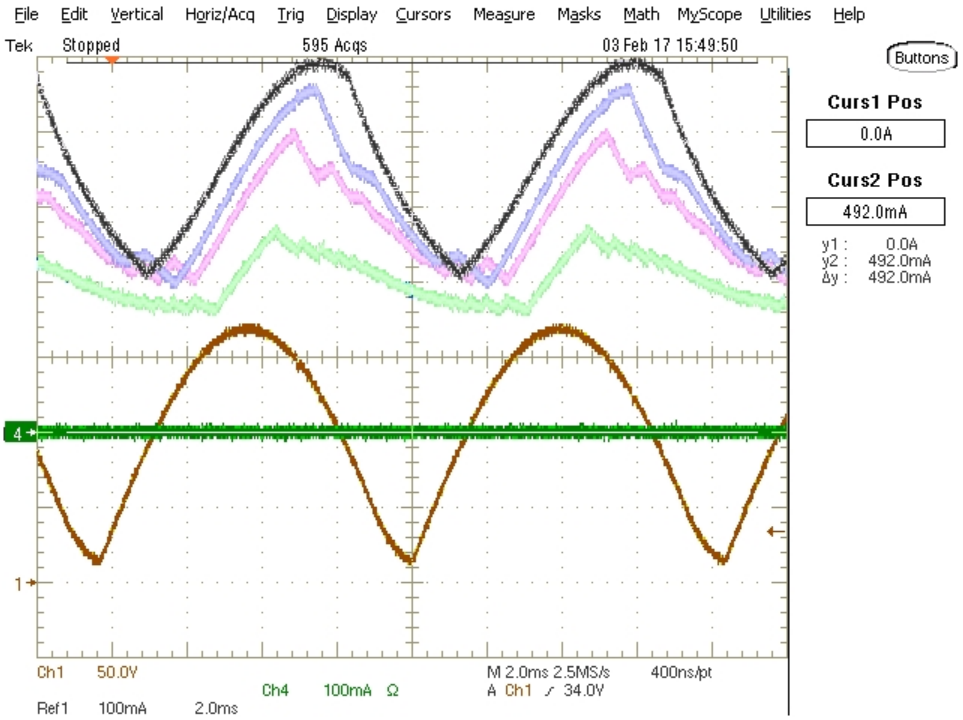


图 26. Current All LED Stacks, Rectified AC, CH1

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 V + 30 V = 45 V). Tolerances and V_f changes with temperature can cause the switching order to change during operation. 图 27 shows a generic layout.

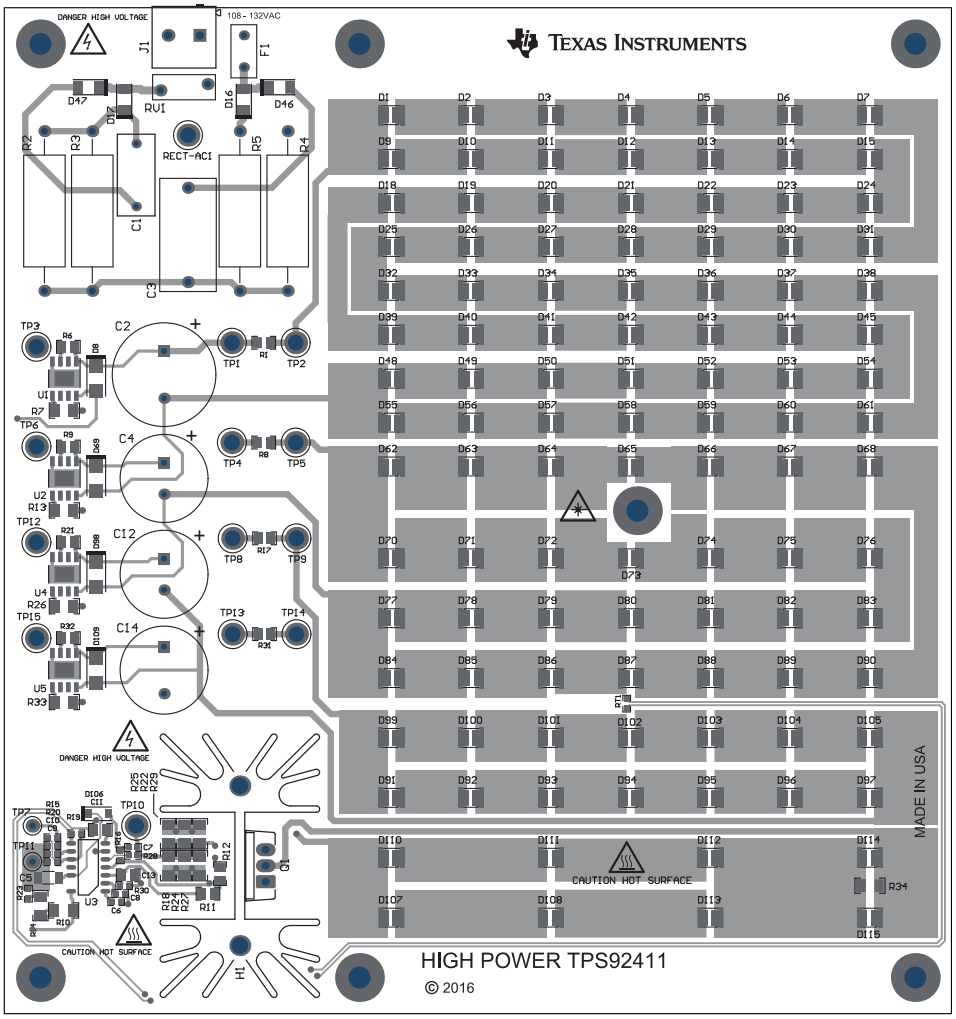


图 **27. PCB Layout**

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 rated of the current-regulating MOSFET, Q1.

4.4 Thermal Scans

图 28 shows a thermal scan of the board running at a room temperature (≈25°C) with no airflow. 表 4 and 表 5 show and list the measured temperatures of key components.

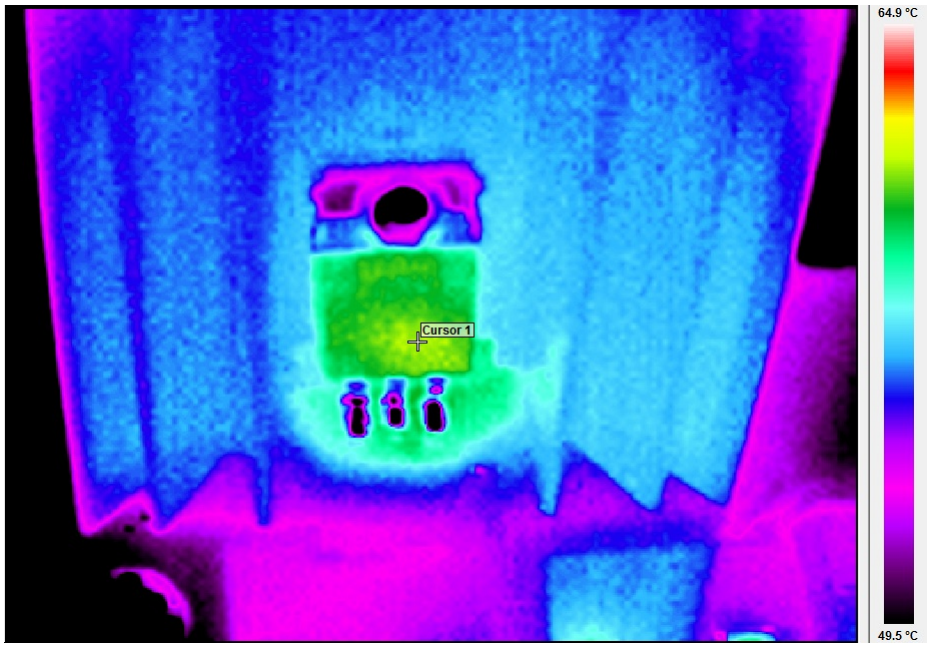


图 **28. Thermal Scan—Linear Regulator FET, Q1: V_{IN} = 120-V AC, Full Power**

表 **4. Component Temperatures**

CURSOR	COMPONENT	TEMPERATURE (°C)
1	Q1	61.3

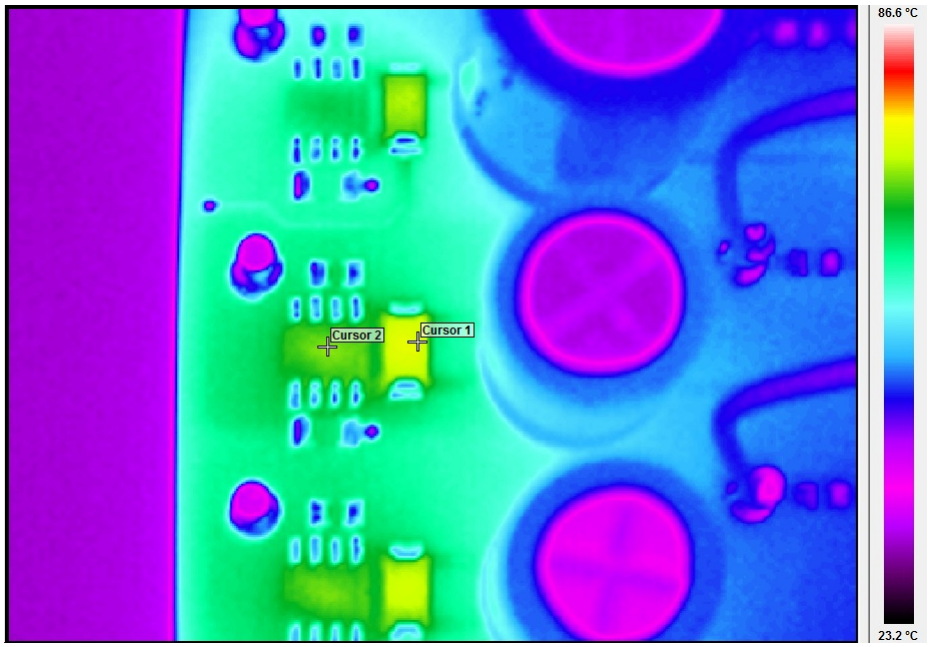


图 **29. Thermal Scan—TPS92411 and Blocking Diode: V_{IN} = 120-V AC, Full Power**

表 **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 商标

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修订历史记录

注：之前版本的页码可能与当前版本有所不同。

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

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