PMP6022
120 VAC, 7W, PFC, Wall Dimmable AC Linear TPS92411 Floating Switch LED Driver Test Report

July, 2014

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1 Introduction

The TPS92411 reference design is a discrete linear Power Factor Corrected current regulator utilizing three TPS92411s using no magnetics. Unlike other linear solutions the TPS92411 design utilizes energy storage capacitors to achieve low flicker, high LED utilization. The TPS92411 determines if there is enough voltage available to supply current to its LED string or, if there isn't enough voltage, bypass it. If the three LED stack voltages are setup as a ratio of four, two, and one there will be eight different switch states which relate to eight different total string voltages the current regulator sees. The highest voltage the current regulator will see is the lower stack voltage plus the designed headroom for the current regulator. This design uses LEDs with a Vf of 22 volts at an input power of approximately 8.7 watts, power factor is above 0.9 and thd below 20%.

2 Description

This reference design has an input voltage range from 85-135 VAC though a more optimal range is 108 to 132 VAC. The current regulator is a discrete circuit that provides power factor correction, input line regulation and triac detect with a DC offset circuit to prevent triac dimmer misfire. It uses 22 volt LEDs in series/parallel combinations to satisfy the current requirement and provide the necessary stack voltages. The lower stack consists of three 22 volt LEDs in parallel. The middle stack has twice as many LEDs to double the stack voltage, 44 volts, and the upper stack utilizes 12 22 volt LEDs creating a stack voltage of 88 volts. This gives the four, two, and one ratio desired for this design, though not necessary.

2.1 Typical Applications

This design is suitable for a variety of light bulbs, can lights or other LED lighting application using an AC input. It can be adjusted for higher or lower output power to suit different power levels.

2.2 Features

2.2.1 Feature description

This section describes certain features of the reference design board and some considerations of each.

2.2.1.1 Rsns pin

The Rsns pin tells the TPS92411 when to close its internal MOSFET bypassing the current going to its LED stack and energy storage capacitor. The internal current source is 4 uA and internal trip threshold is 0.210 volts. A 1 Mohm Rsns resistor will cause the TPS92411 to close as it crosses 3.79 volts from its common to the system common. The threshold voltage is set high enough to prevent the current regulator from dropping out, it is the voltage headroom for the current regulator. It has a negative effect on efficiency if set too high and can cause interruptions in the power factor corrected current waveform if set too low. The Rsns pin functions as the voltage source to the TPS92411 is falling.

2.2.1.2 Rset pin

The Rset pin tells the TPS92411 when to open its internal MOSFET allowing current to flow to its LED stack and energy storage capacitor. It uses half the current through the Rsns resistor to trip an internal 1.25 volt threshold. When the Rset voltage rises and crosses the 1.25 volt internal threshold, because the Rsns current is high enough, the TPS92411 MOSFET opens allowing current to flow to the LEDs and storage capacitor. The Rset pin functions as the voltage source to the TPS92411 is rising.

2.2.1.3 Slew controlled drain connection

This is the connection to the internal MOSFET that allows the TPS92411 to bypass its LED section, MOSFET closed, or allows the current to power its LED stack and charge the energy storage capacitor, MOSFET open. The MOSFET state is set by the Rsns and Rset thresholds via an internal RS latch. The drain connection is slew rate controlled to reduce conducted EMI. The MOSFET also closes faster than it opens to prevent the current regulator from dropping out.

2.2.1.4 Over Voltage Protection

The TPS92411 used on this design has built in over voltage protection. If the LED section opens the current regulator will continue to charge the energy storage capacitor beyond the LED section voltage. When the voltage reaches 100 volts the TPS92411 closes bypassing the open LED section. As the energy storage capacitor discharges the TPS92411 will open again until reaching the 100 volt threshold. The hysteresis is four volts.

2.2.1.5 Power factor correction

A simple current regulator using a MOSFET, Q1, a current sense resistor, R15 and a transistor, Q2 to regulate current from the rectified AC. The reference to this regulator is a resistor divider from rectified AC, R8 and R13. Note that Q2 collector and emitter are in this divider but will be a fixed voltage which is the Vgs threshold of Q1 plus the Vbe of Q2. The Vgs is small compared to the rectified AC voltage so it will have little effect. The Vbe drop of Q2 will add some DC offset however the line regulation circuit actually overcompensates for that.

2.2.1.6 Line regulation

The TPS92411 reference design uses a circuit that averages the rectified AC input and forces the current set point lower as the input voltage rises. A zener diode is part of the circuit to prevent the circuit from interfering with dimming.

2.2.1.7 Leading edge dim detect and DC offset

A damper RC is used to prevent the triac from mis-firing when the rising edge of the dimmer occurs. Without a rising edge the maximum voltage on the capacitor is less than four volts. When a triac, leading edge, dimmer is present the voltage across the capacitor is much higher during the rising edge of the dimmer. Some of the energy from the dimmer pulse is stored in another capacitor providing a low DC voltage. This is applied to the PFC current reference which prevents the current from dropping below the triac hold current. This circuit prevents triac mis-fire at the end of each half cycle by keeping current flow through the triac dimmer.

2.2.1.8 EMI control

A capacitor, C7, across the discrete current regulator MOSFET, Q1, along with the TPS92411 slew control allows the reference design to pass conducted EMI with 8dB of margin with only a 0.1 uF capacitor, C2, across rectified AC. Radiated EMI is not an issue with this topology. C2 value could be reduced if less margin is acceptable, or the output power could be increased by lowering R15. The EMI capacitor value is proportional to the input current. Doubling the power would require doubling the capacitor, C2 and the triac damper capacitor would also need to double.

3 Electrical Performance Specifications

Table 1: TPS92411 discrete linear Electrical Performance Specifications

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Input Characteristics					
Voltage range	Normal operation	108	120	132	V
Voltage range	Maximum range	85		135	V
Maximum input current	At 120 Vrms input		0.075		A rms
Input power			8.7	9.1	watts
Output Characteristics					
Output voltage, upper stack	At maximum output		88		V
Output voltage, middle stack	At maximum output		44		V
Output voltage lower stack	At maximum output		22		V

4 Schematic

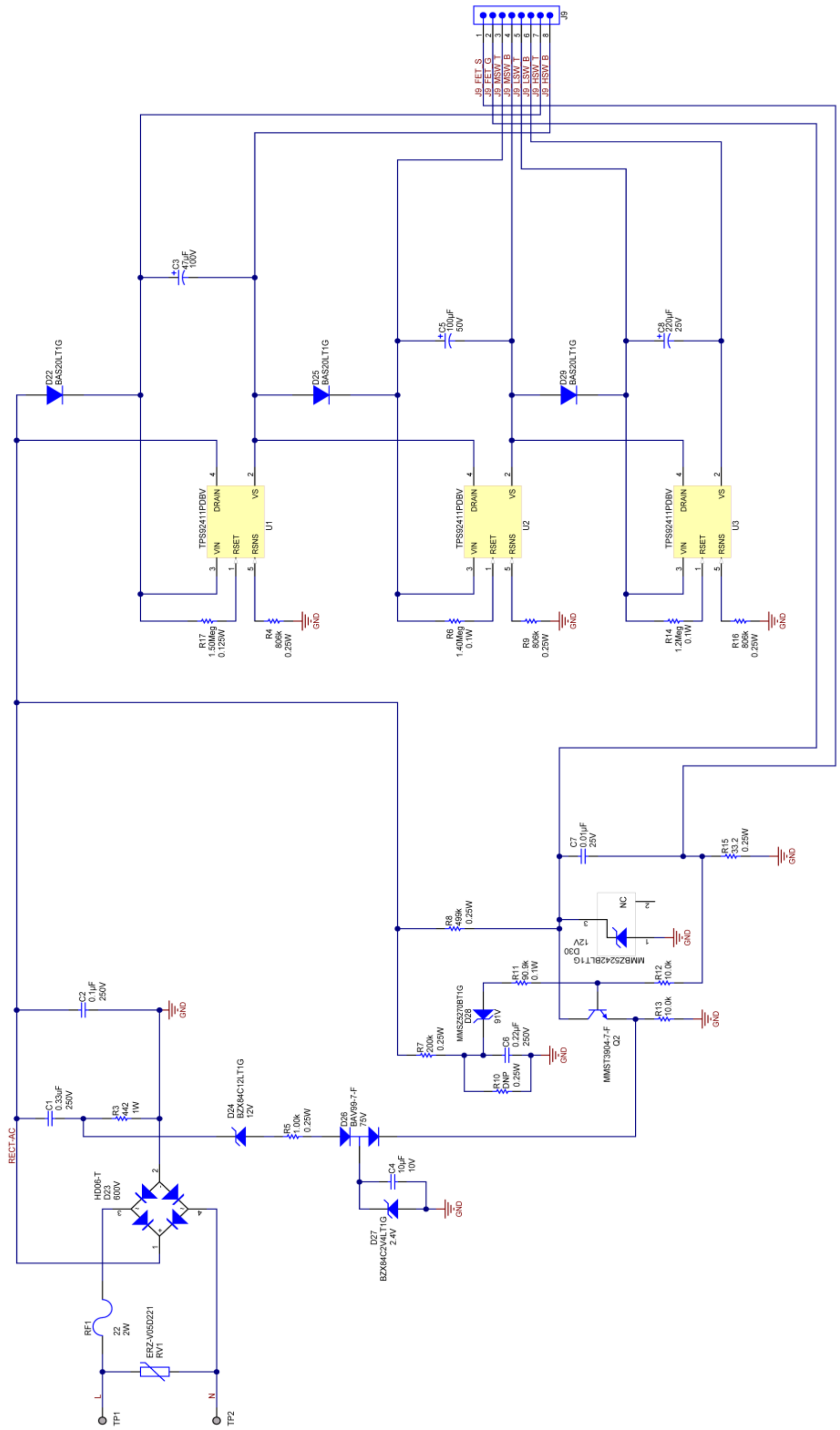

Figure 1: TPS92411 discrete linear Schematic

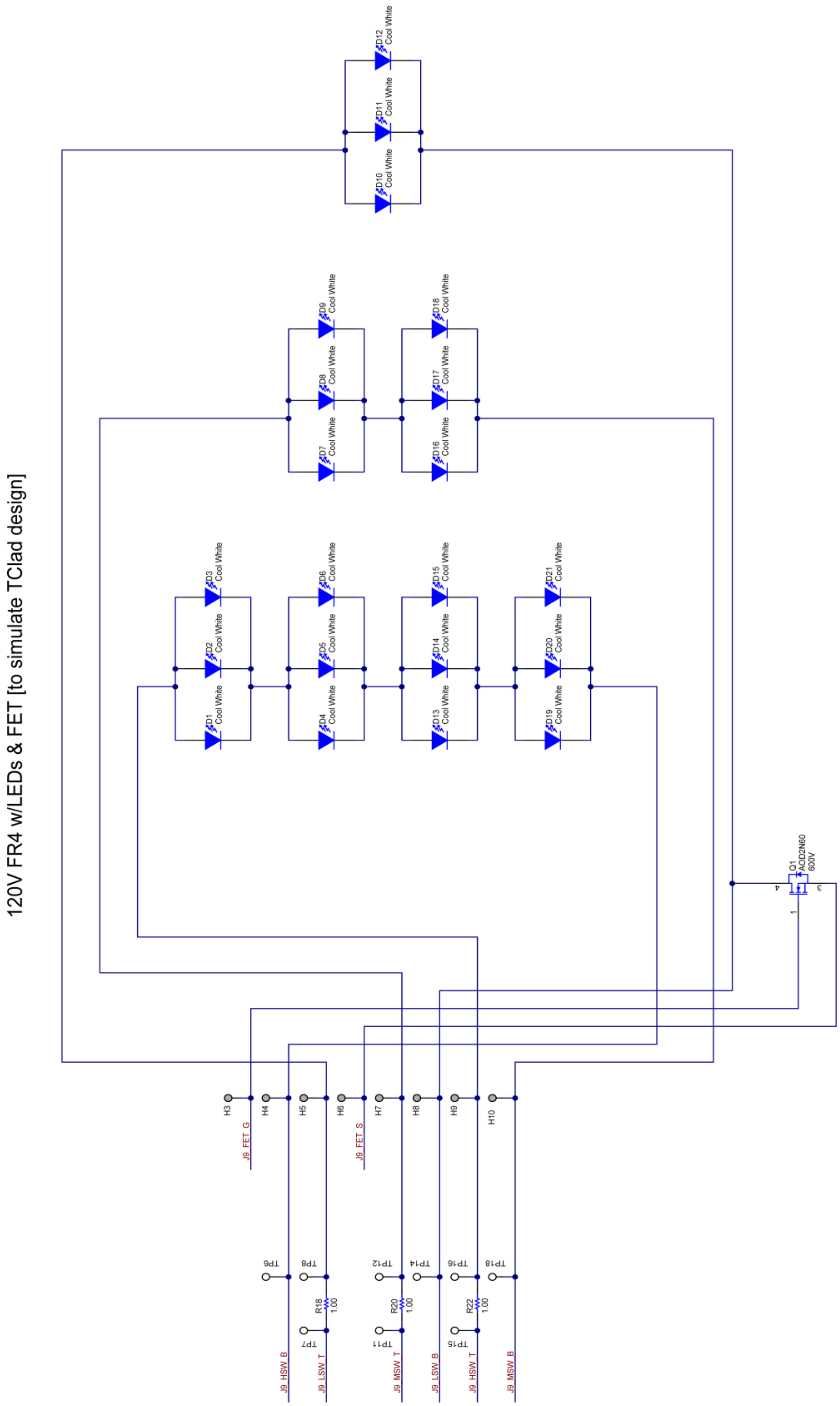

Figure 1: TPS92411 discrete linear Schematic

5 Performance Data and Typical Characteristic Curves

Figures 2 through 23 present typical performance curves for TPS92411 discrete design.

5.1 Efficiency

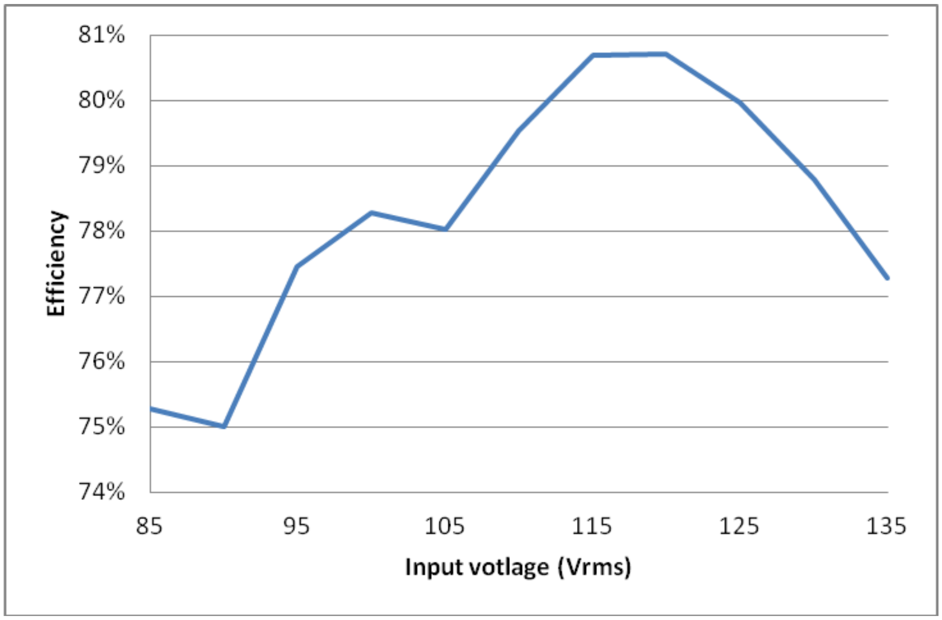

Figure 2: Efficiency

5.2 Line Regulation

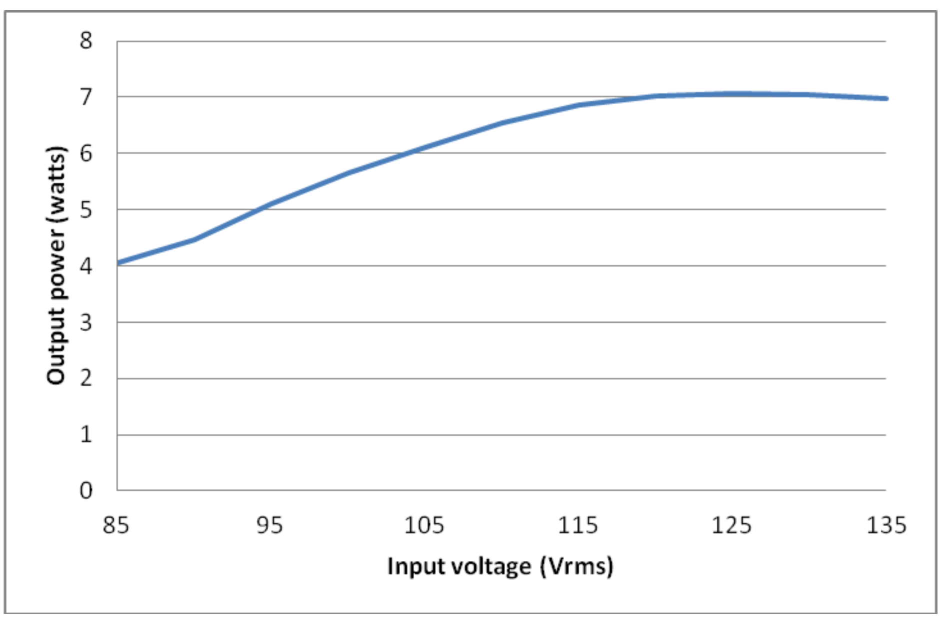

Figure 3: Line Regulation

5.3 Drain voltage of current regulator

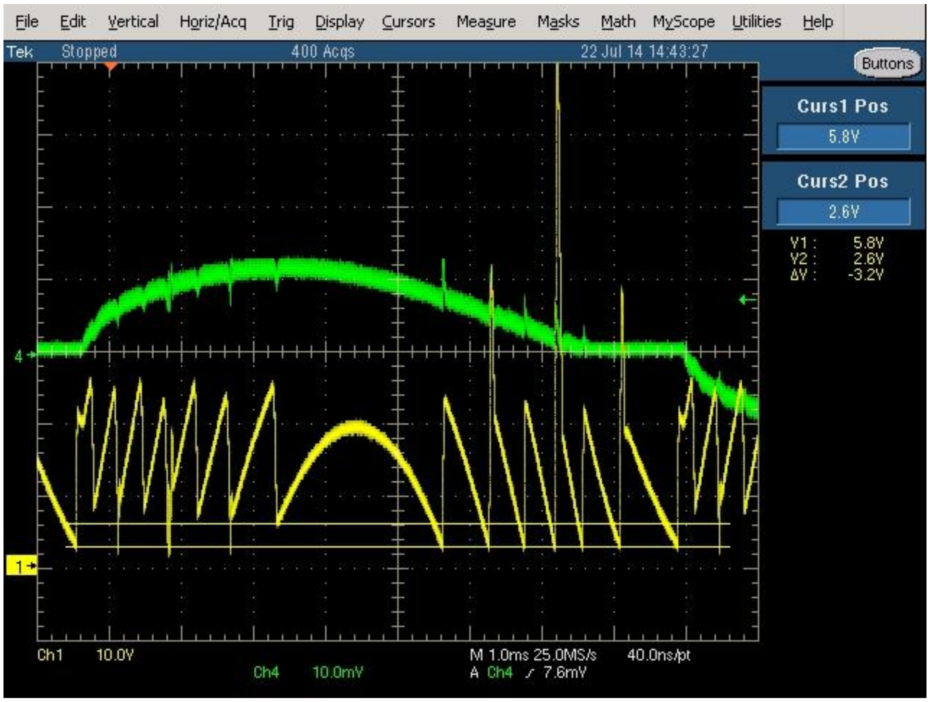

Figure 4: Current regulator drain waveform (yellow), input current (green)

5.4 Current sense

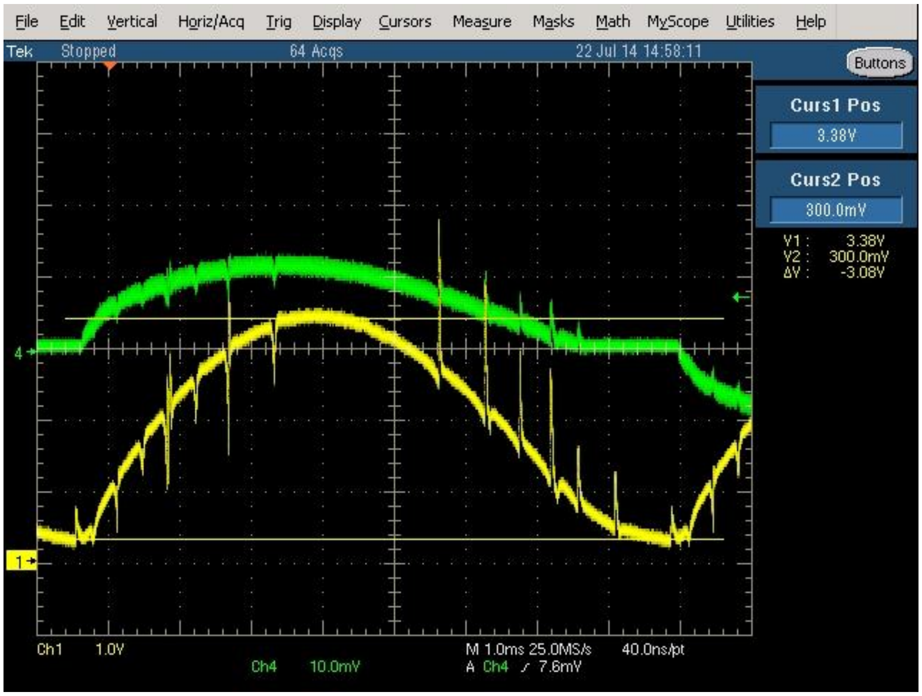

Figure 5: Voltage at current sense resistor, R15 (yellow)

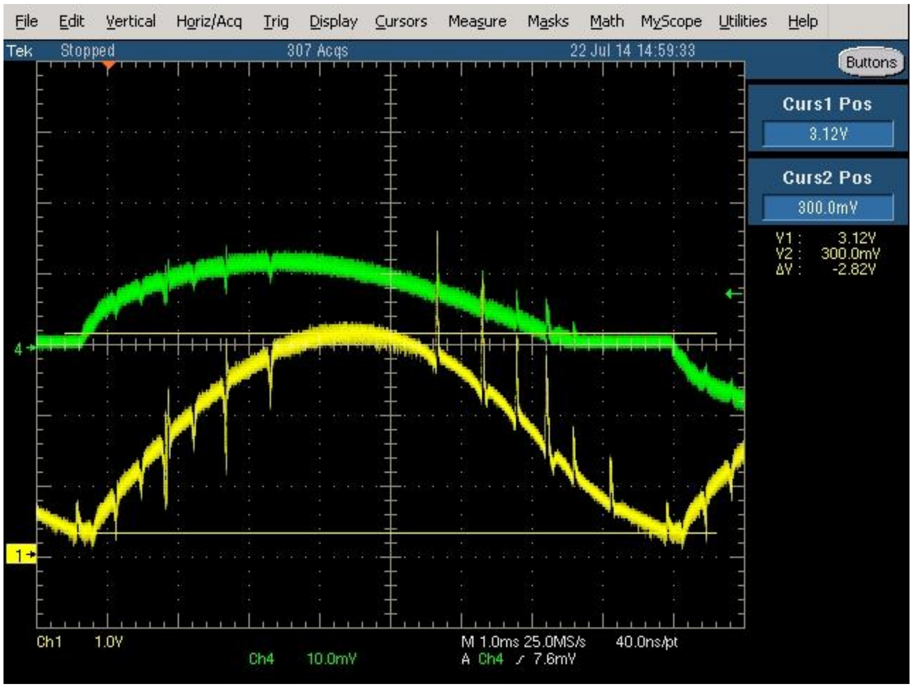

Figure 6: PFC command, R13 voltage

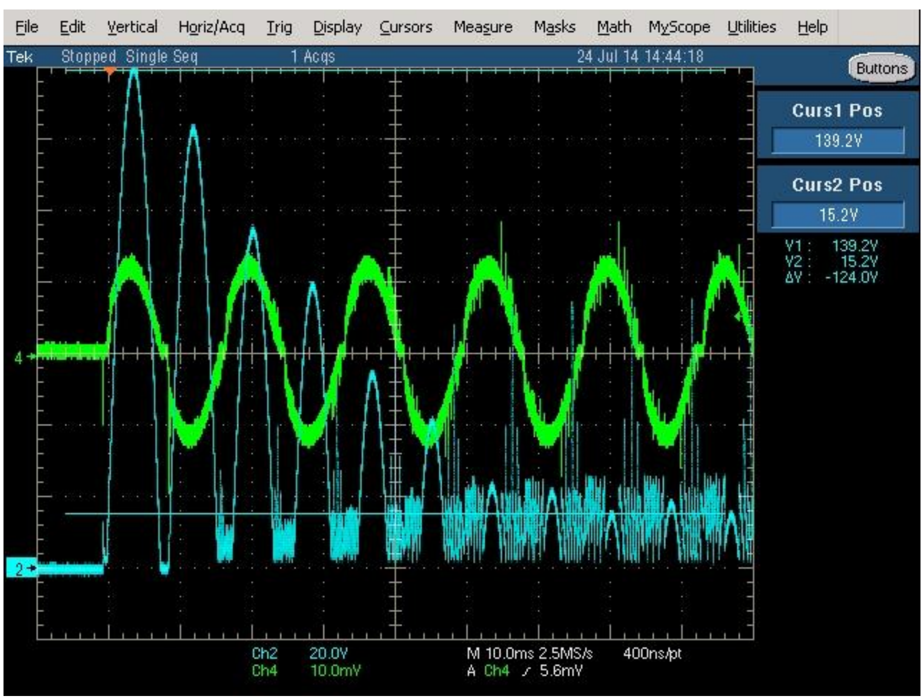

Figure 7: Current regulator drain voltage during power on, storage capacitors charging

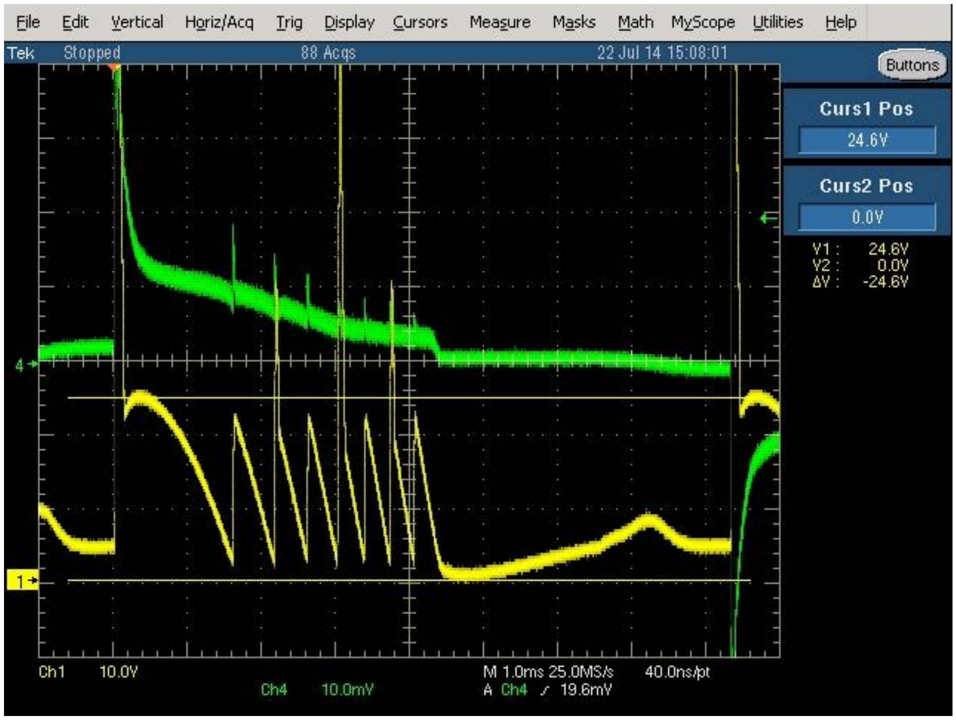

Figure 8: Current regulator drain voltage when forward phase dimming

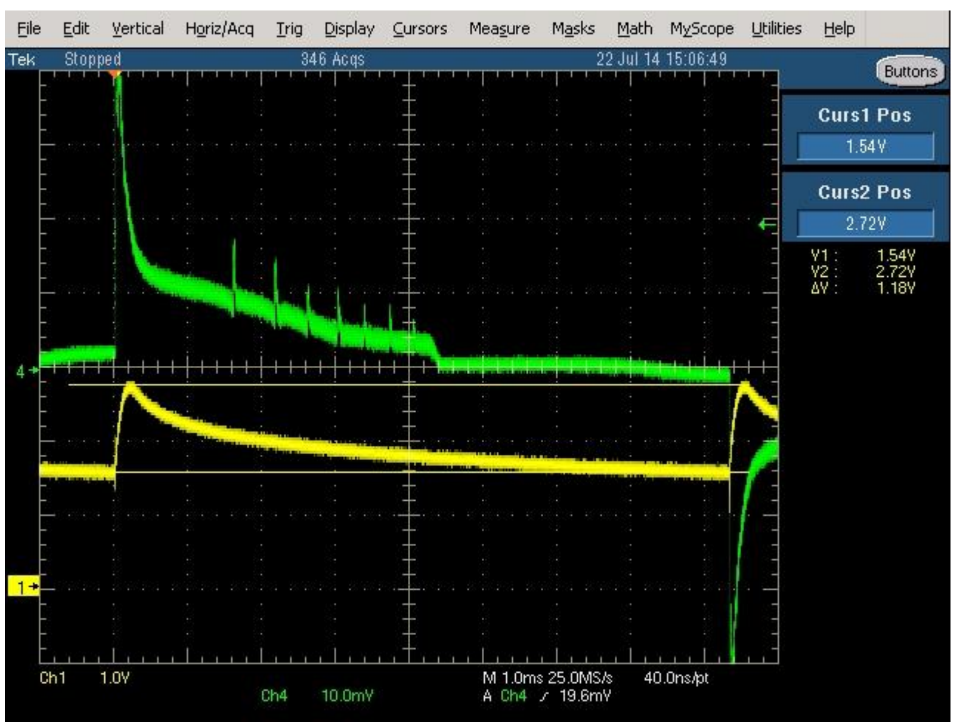

Figure 9: Voltage on DC offset circuit, C4 holding command up when forward phase dimming

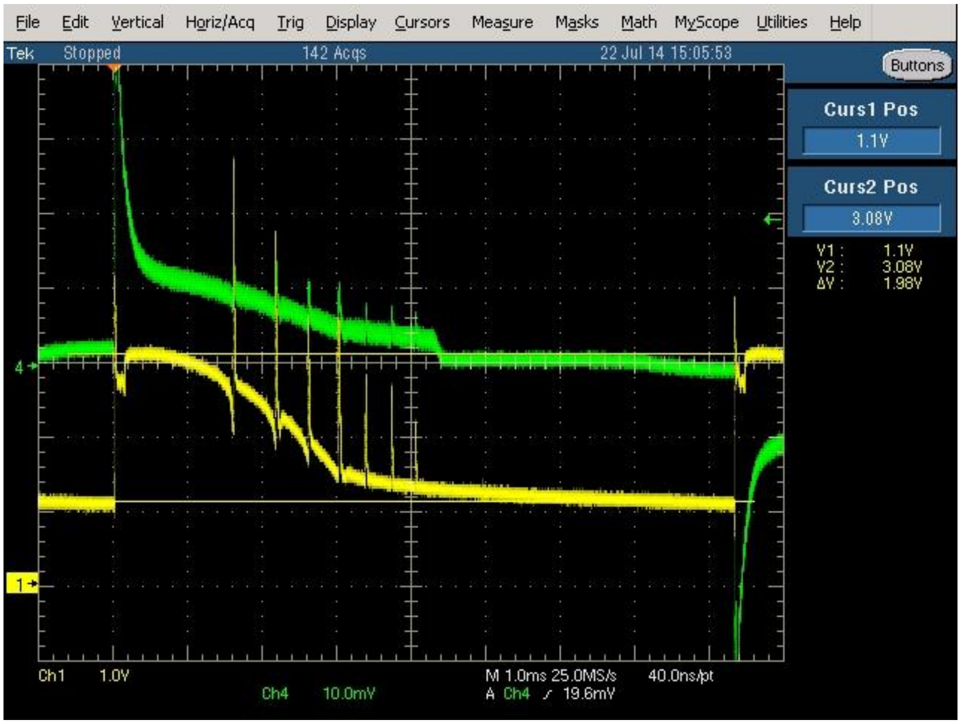

Figure 10: Current reference with DC offset, R13

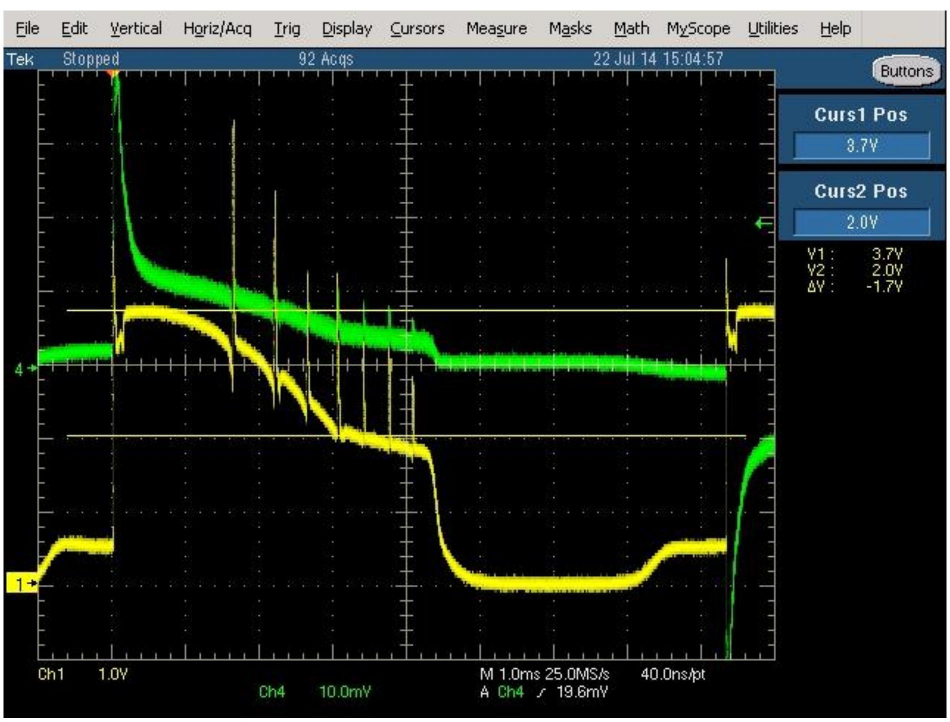

Figure 11: Current sense voltage while forward phase dimming, R15

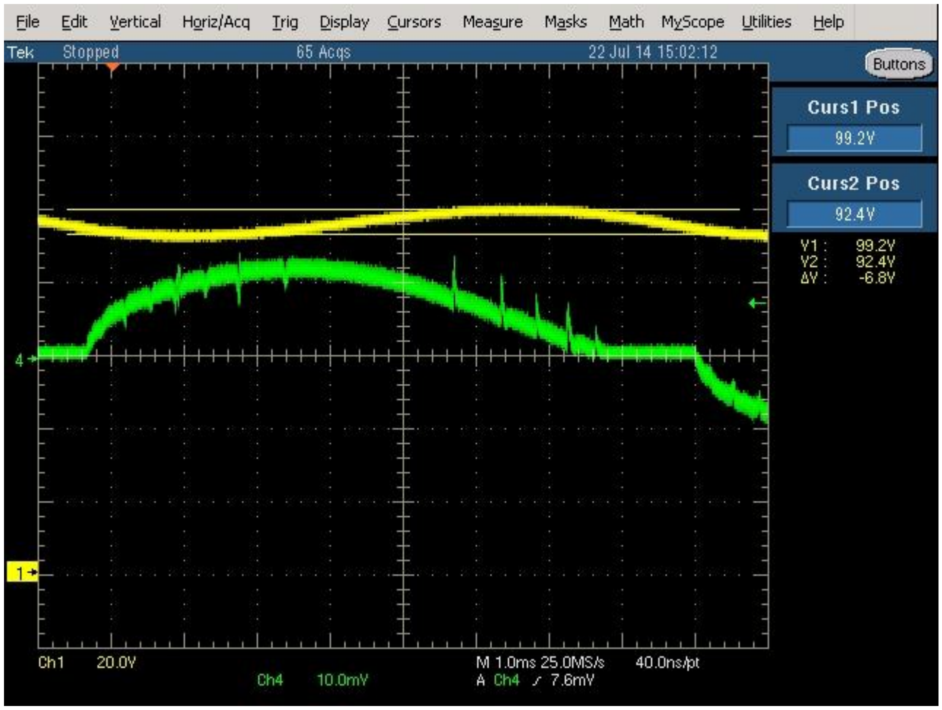

Figure 12: Input averaging voltage used for line regulation, C6

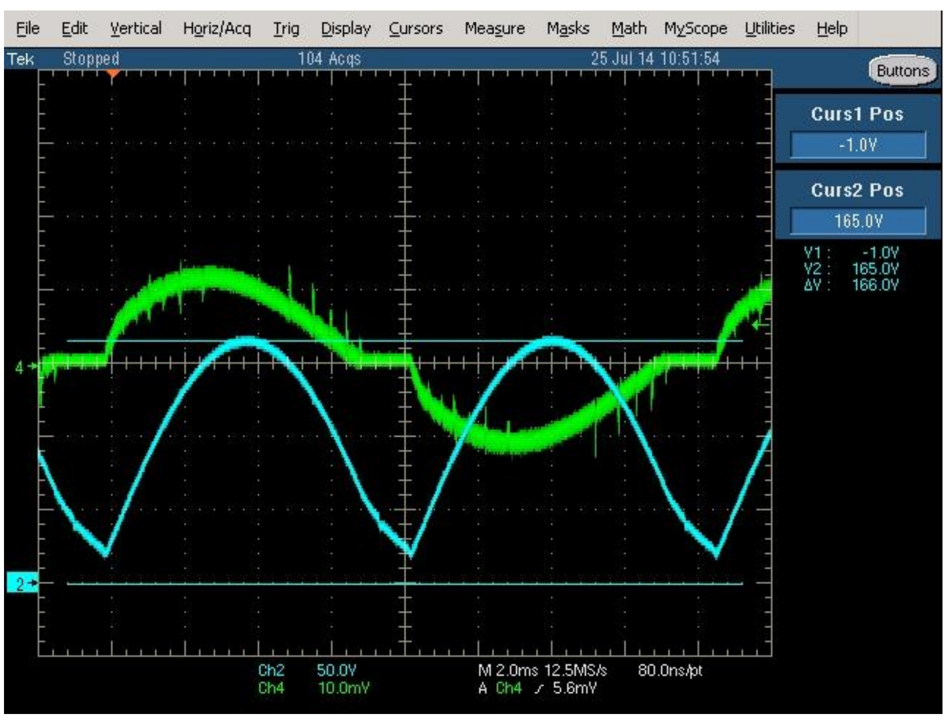

Figure 13: Rectified AC, reference for next oscilloscope plots

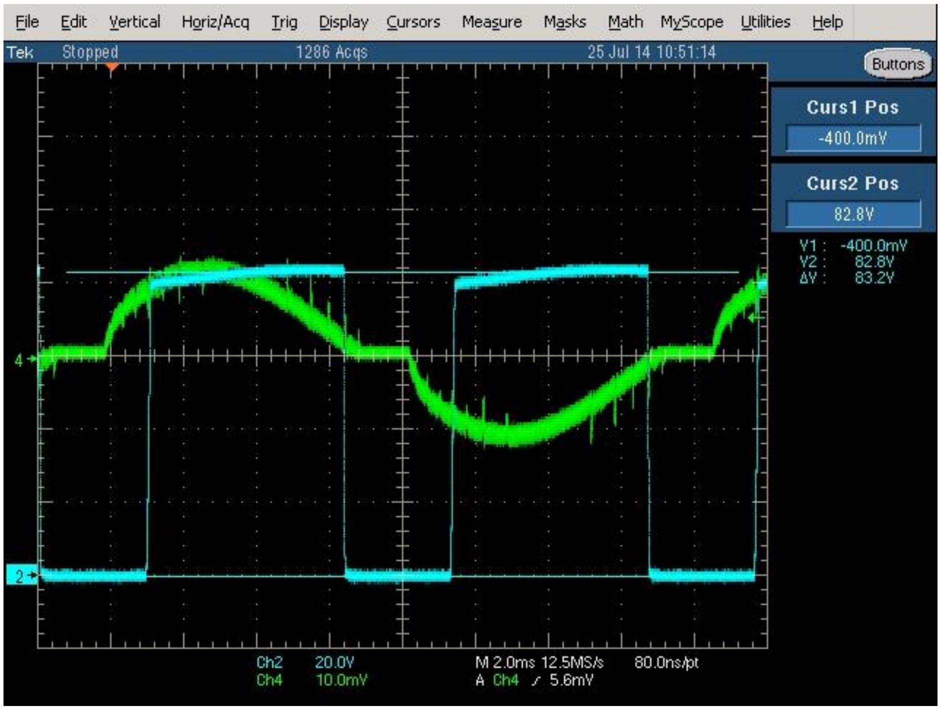

Figure 14: Upper TPS92411 drain waveform

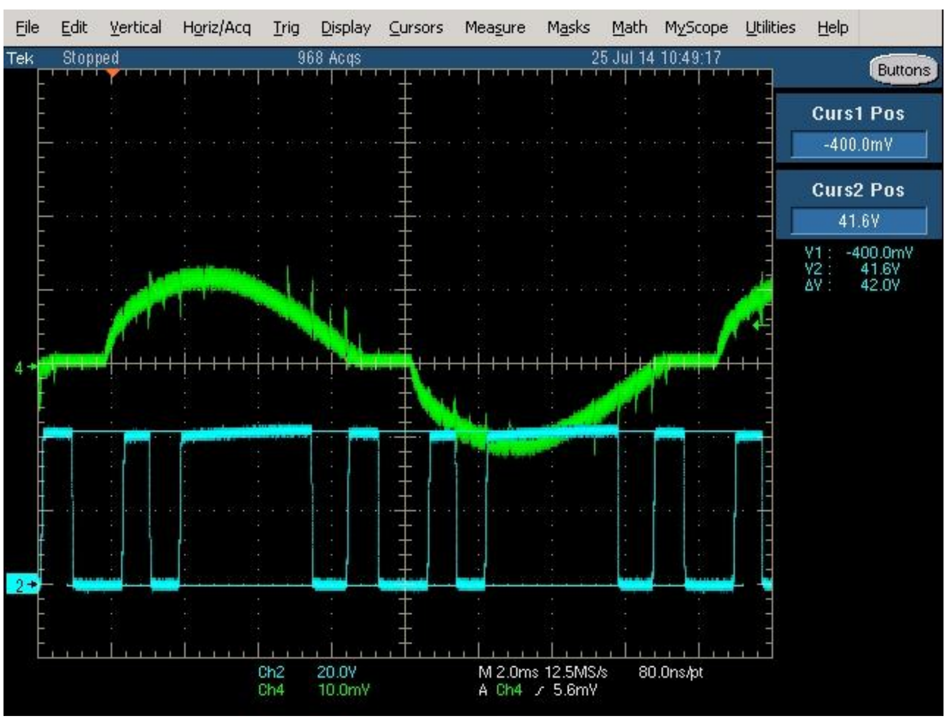

Figure 15: Middle TPS92411 drain waveform

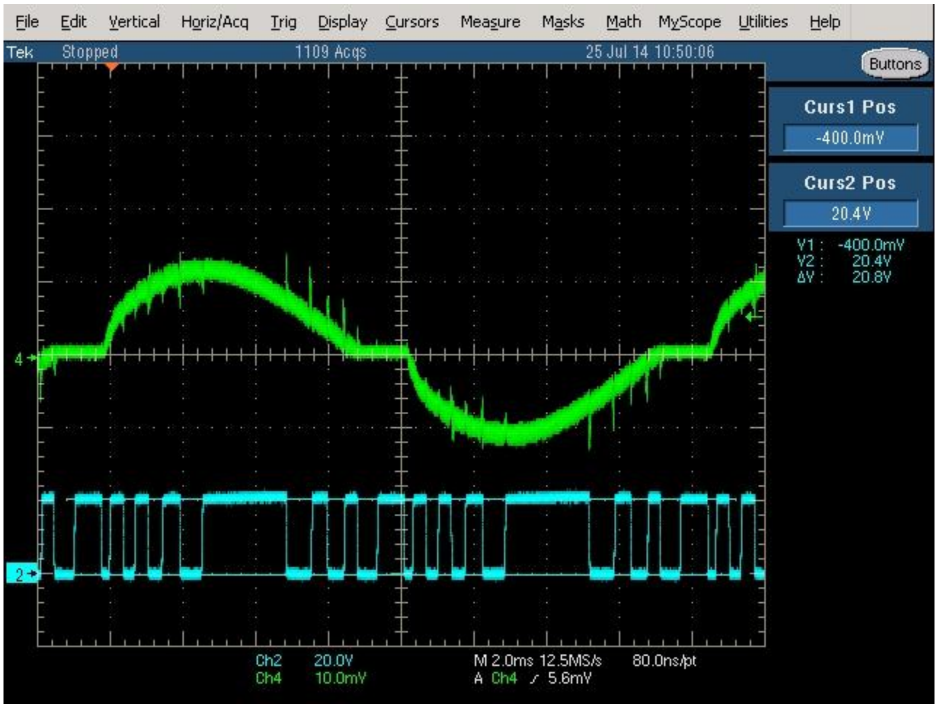

Figure 16: Lower TPS92411 drain waveform

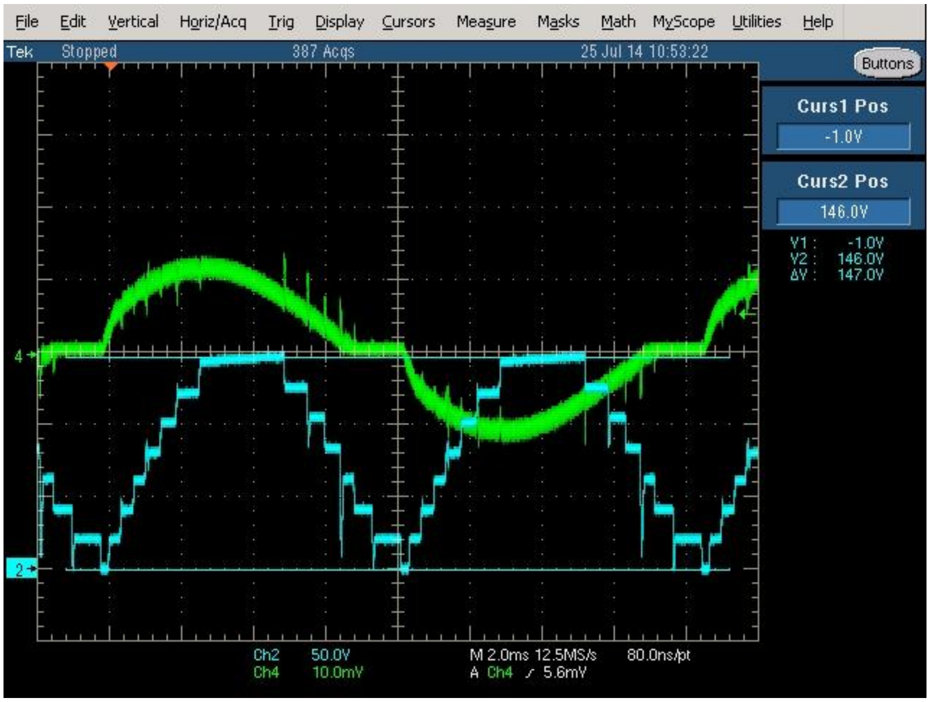

Figure 17: Series load voltage for linear regulator MOSFET (sum of the LED stacks)

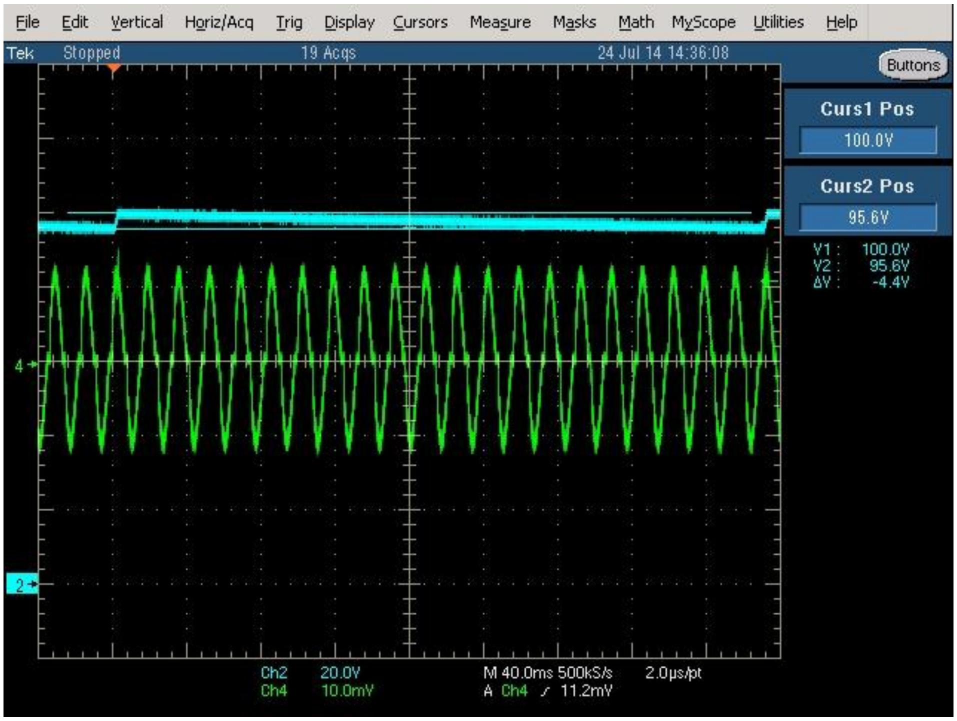

Figure 18: Open upper stack voltage during Over Voltage Protection

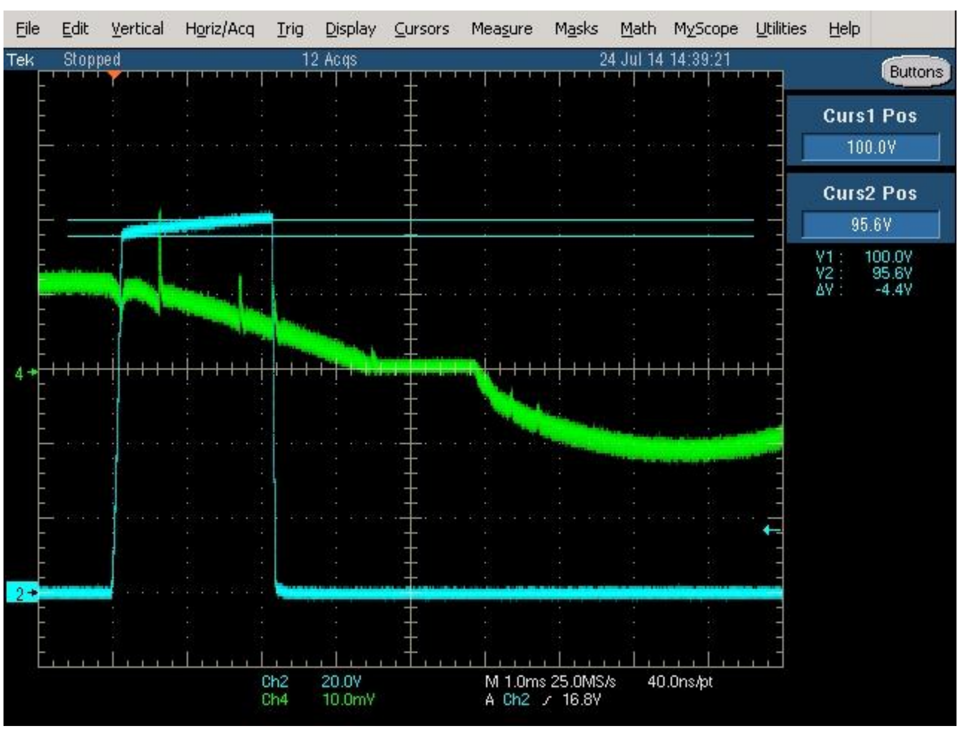

Figure 19: Over voltage protection, hysteresis when TPS92411 opens and closes

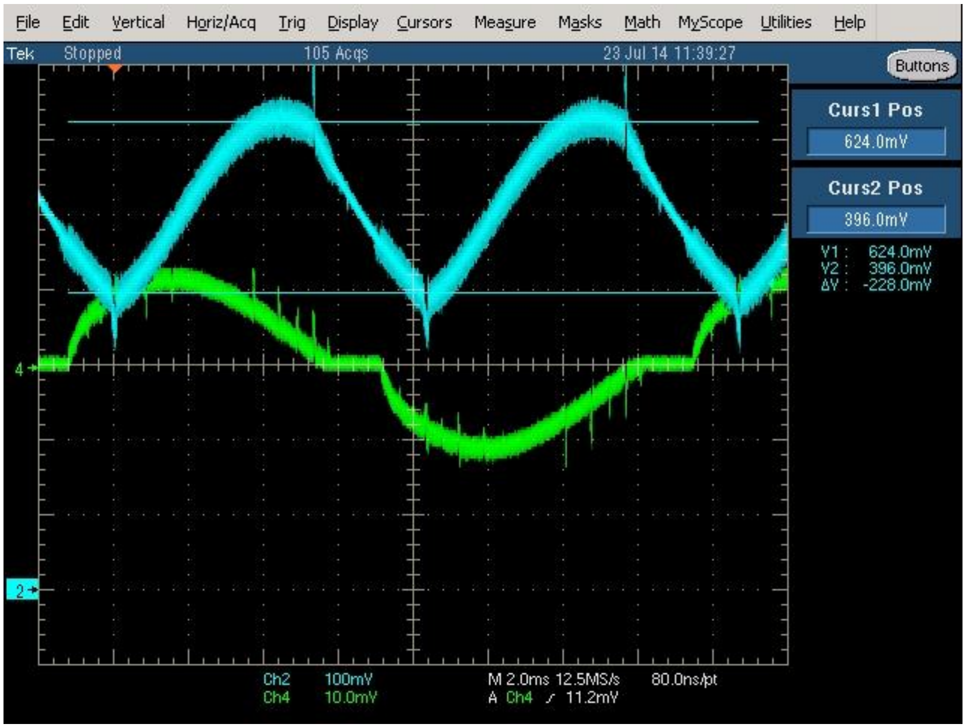

Figure 20: Upper stack current ripple (10 mV equals 1 mA)

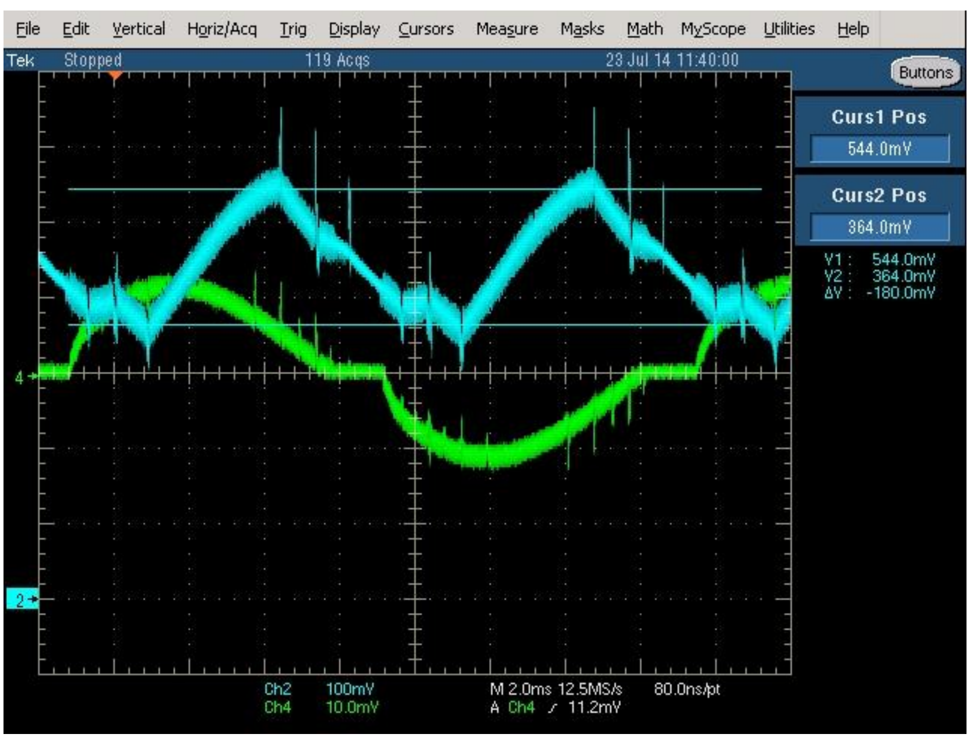

Figure 21: Middle stack current ripple (10 mV equals 1 mA)

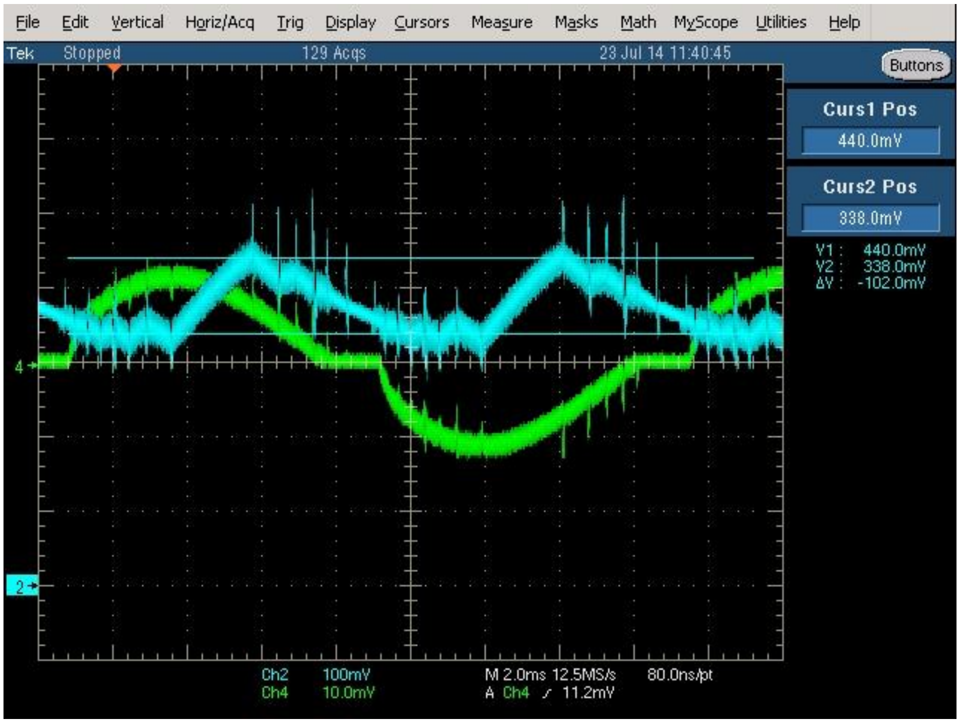

Figure 22: Current ripple lower stack (10 mV equals 1 mA)

5.5 *EMI Performance*

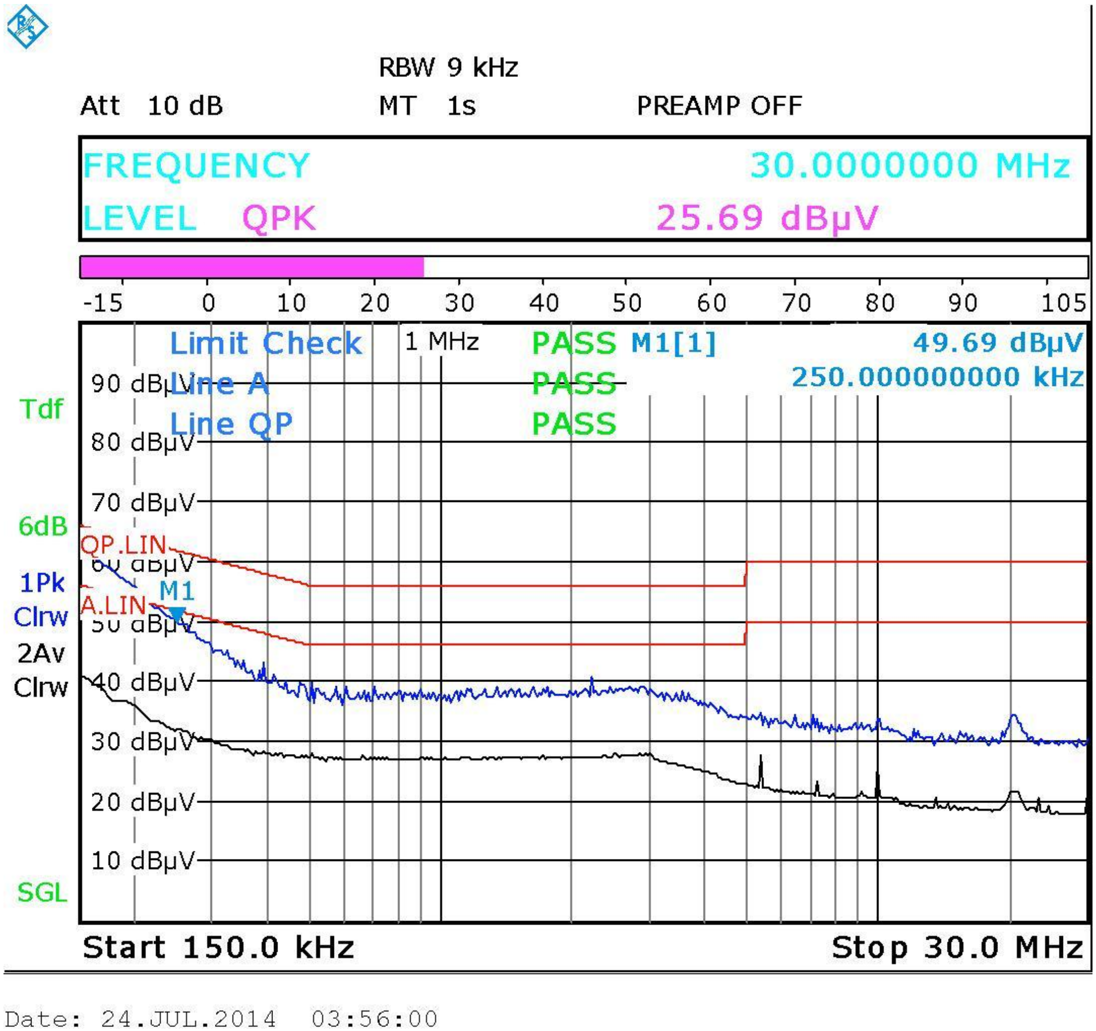

Figure 23: Conducted EMI scan peak and average, Quasi-peak measures -8.1 dB for both line and neutral at 150 KHz

5.6 TPS92411 test hardware, designed for A19 bulb

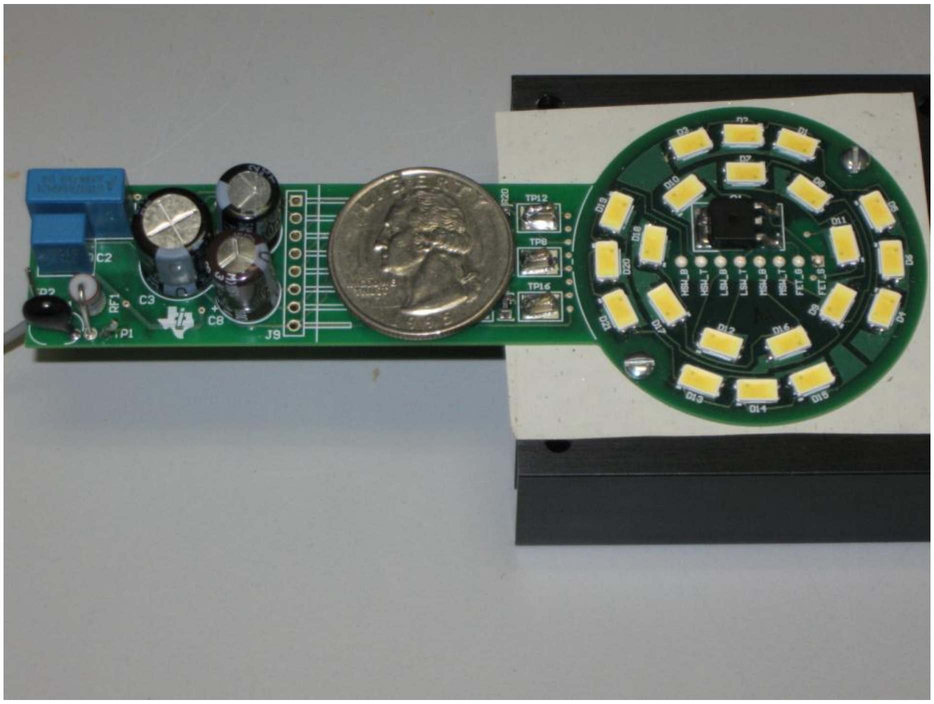

Figure 24: When used in bulb the test point section is removed, right angle connector connects component board to LED board. 0.031" FR4 with copper spreader for heatsinking on LED section

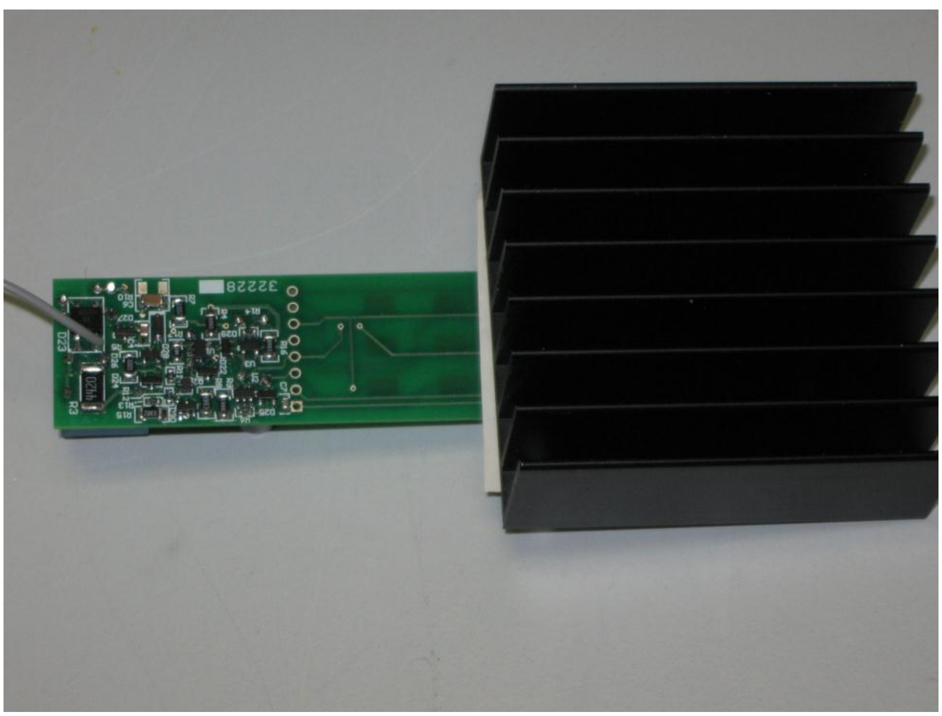

Figure 25: FR4 SMT section including three TPS92411

6 TPS92411 Reference Design PCB layout

The following figures (Figure 26 through Figure 27) show the design of the TPS92411 printed circuit board.

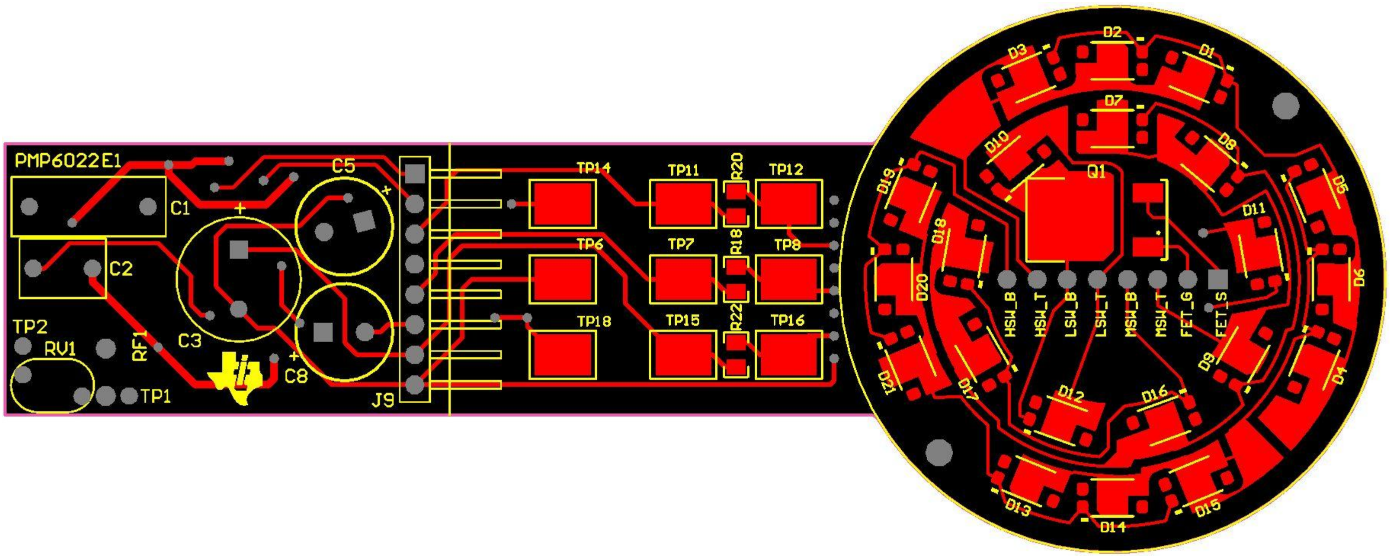

Figure 26: Top Layer and Top Overlay (Top view)

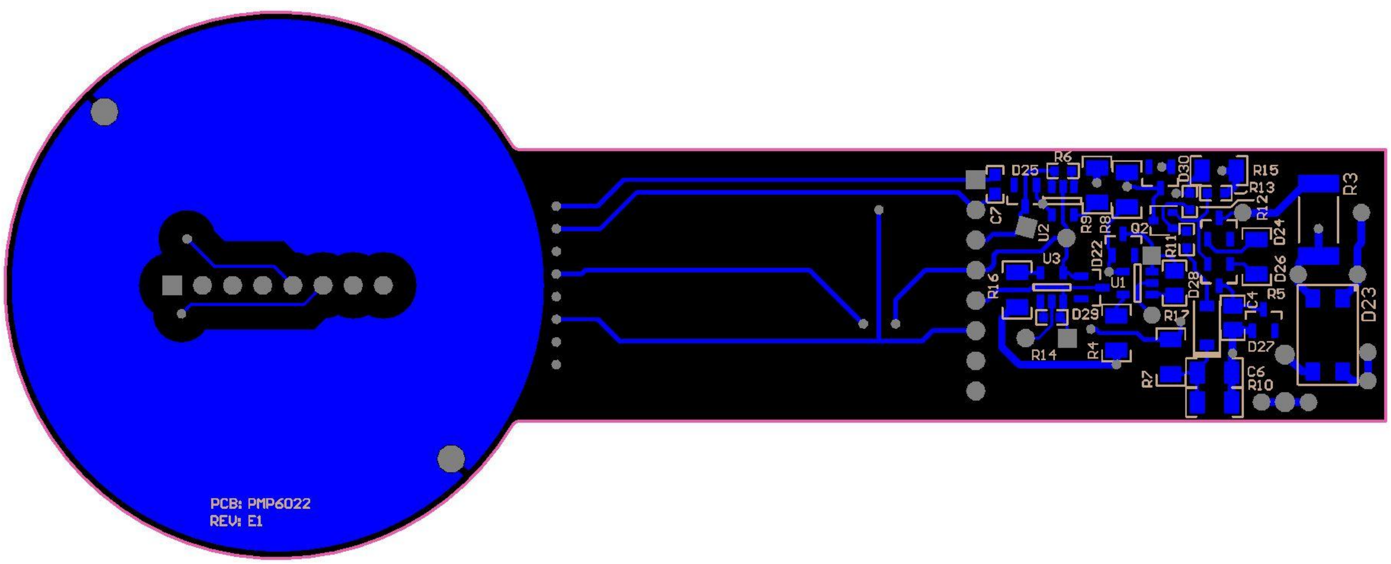

Figure 27: Bottom Layer and Bottom Overlay (Bottom view)

7 Bill of Materials

Table 2: The TPS92411 discrete linear components list according to the schematic shown in Figure 1

REFERENCE DESIGNATOR	QTY	VALUE	DESCRIPTION	SIZE	MFR	PART NUMBER
C1	1	0.33µF	Cap, Film, 0.33uF, 250V, +/-10%, Radial	Radial	EPCOS Inc	B32521C3334K189
C2	1	0.1uF	CAP, Film, 0.1uF, 250V, +/-10%, TH	4.5x9.5x7.3mm	EPCOS Inc	B32529C3104K
C3	1	47uF	CAP, AL, 47uF, 100V, +/-20%, 0.43 ohm, TH	10x12.5mm	Nichicon	UHE2A470MPD
C4	1	10uF	CAP, CERM, 10uF, 10V, +/-10%, X7R, 0805	0805	MuRata	GRM21BR71A106KE51L
C5	1	100µF	CAP, Alum, 100uF, 50V, +/-20%, Radial	Radial, Can	Rubycon	50YXJ100MT78X11.5
C6	1	0.22uF	CAP, CERM, 0.22uF, 250V, +/-10%, X7T, 1206	1206	TDK	CGA5L3X7T2E224K160AE
C7	1	0.01uF	CAP, CERM, 0.01uF, 25V, +/-5%, C0G/NP0, 0603	0603	TDK	C1608C0G1E103J
C8	1	220µF	CAP, Alum, 220uF, 25V, +/-20%, Radial	Radial, Can	United Chemi-Con	EKY-250ELL221MHB5D
D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D16, D17, D18, D19, D20, D21	21		LED, Cool White, SMD	3x.75x5.2mm	Seoul Semiconductor	SAW8KG0B-Y1Z4-CA
D22, D25, D29	3		Diode, Switch, 200V, 0.2A, SOT-23	TO-236-3, SC-59, SOT-23-3	ON Semiconductor	BAS20LT1G
D23	1		Diode, Switching-Bridge, 600V, 0.8A, MiniDIP	MiniDIP	Diodes Inc.	HD06-T
D24	1		Diode, Zener, 12V, 225mW, SOT-23	SOT-23	ON Semiconductor	BZX84C12LT1G
D26	1		Diode, Switching, 75V, 0.3A, SOT-23	SOT-23	Diodes Inc.	BAV99-7-F
D27	1		Diode, Zener, 2.4V, 225mW, SOT-23	SOT-23	ON Semiconductor	BZX84C2V4LT1G
D28	1		Diode, Zener, 91V, 500mW, SOD-123	SOD-123	ON Semiconductor	MMSZ5270BT1G
D30	1		Diode, Zener, 12V, 225mW, SOT-23	SOT-23	ON Semiconductor	MMBZ5242BLT1G
J9	1		CONN HEADER 8POS 1ROW RA		MULTICOMP	MC34753
Q1	1		MOSFET, N-CH, 600V, 2A, DPAK	DPAK	AOS	AOD2N60
Q2	1		Transistor, NPN, 20V, 0.2A, SOT-323	SOT-323	Diodes Inc.	MMST3904-7-F
R3	1	442	RES, 442 ohm, 1%, 1W, 2512	2512	Vishay-Dale	CRCW2512442RFKEG
R4, R9, R16	3	806k	RES, 806k ohm, 1%, 0.25W, 1206	1206	Vishay-Dale	CRCW1206806KFKEA
R5	1	1.00k	RES, 1.00k ohm, 1%, 0.25W, 1206	1206	Vishay-Dale	CRCW12061K00FKEA
R6	1	1.40Meg	RES, 1.40Meg ohm, 1%, 0.1W, 0603	0603	Vishay-Dale	CRCW06031M40FKEA
R7	1	200k	RES, 200k ohm, 1%, 0.25W, 1206	1206	Vishay-Dale	CRCW1206200KFKEA

R8	1	499k	RES, 499k ohm, 1%, 0.25W, 1206	1206	Vishay-Dale	CRCW1206499KFKEA
R10	1	DNP	DNP	1206	Vishay-Dale	
R11	1	90.9k	RES, 90.9k ohm, 1%, 0.1W, 0603	0603	Vishay-Dale	CRCW060390K9FKEA
R12, R13	2	10.0k	RES, 10.0k ohm, 1%, 0.1W, 0603	0603	Vishay-Dale	CRCW060310K0FKEA
R14	1	1.2Meg	RES, 1.2Meg ohm, 1%, 0.1W, 0603	0603	Vishay-Dale	CRCW06031M20FKEA
R15	1	33.2	RES, 33.2 ohm, 1%, 0.25W, 1206	1206	Vishay-Dale	CRCW120633R2FKEA
R17	1	1.50Meg	RES, 1.50Meg ohm, 1%, 0.125W, 0805	0805	Vishay-Dale	CRCW08051M50FKEA
R18, R20, R22	3	1.00	RES, 1.00 ohm, 1%, 0.125W, 0805	0805	Stackpole Electronics Inc	RMCF0805FT1R00
RF1	1	22	RES, 22 ohm, 10%, 2W, Fusible, TH	Axial resistor	TT Electronics /IRC	EMC2-22RKI
RV1	1		Varistor, 140VAC, 180VDC, 6.5J, 5MM, Disc	Disc 5mm	Panasonic Electronic Components	ERZ-V05D221
TP6, TP7, TP8, TP11, TP12, TP14, TP15, TP16, TP18	9	SMT	Test Point, Compact, SMT	Testpoint_Keystone_Compact	Keystone	5016
U1, U2, U3	3		Switch Controlled Direct Drive Switch for Offline LED Drivers, DBV0005A	DBV0005A	Texas Instruments	TPS92411PDBV

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