PMP6020
230 VAC In / 17W Output LED Driver Using No Magnetic Components Test Report

November 04, 2014

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1 Introduction

The TPS92411 reference design is an offline triac dimmable power factor corrected current regulator utilizing four TPS92411 floating switches to achieve high efficiency. The LED stack voltages are chosen close to a 8:4:2:1 ratio to create 16 different operating states ranging from 0000, all switches closed, to 1111, all switches open. The power factor is above 0.9 and Total Harmonic Distortion is under 20% at 230 VAC, 50 Hz. The reference design uses no magnetics. Unlike other offline LED linear current regulators this design has energy storage to provide low light flicker and better LED utilization than non-energy storage designs.

2 Description

This reference design's input voltage range is 200-265 VAC, input power is 20 watts at 230 VAC. The current regulator is a discrete circuit that provides power factor correction, input line regulation and a triac dimmer detect with a DC offset circuit to prevent triac dimmer misfire. It uses 6 volt LEDs connected in series to create four LED stack voltages of 18, 36, 78 and 168 volts. This is not exactly an 8:4:2:1 ratio, it was optimized for efficiency for the input voltage range. The design is also optimized for efficiency while still enabling triac dimming. The upper 168 volt stack uses an external cascode arranged MOSFET to allow the TPS92411 to bypass a string voltage above 100 volts and control turn-on and turn-off slew rates for EMI control. The design achieves 89% efficiency.

2.1 Typical Applications

This design is suitable recessed lighting, can lights or other LED lighting applications with 230 VAC input. It can be adjusted to other input voltage levels by adjusting the number of LEDs. It can be adjusted for higher or lower output power as well.

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. An 806 Kohm Rsns resistor will cause the TPS92411 to close as it crosses 3.0 volts from its common to the system common. The threshold voltage is set high enough to prevent the discrete 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 and triac misfire 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 create a voltage drop on the Rset resistor. As the voltage source to theTPS92411 rises the current in Rsns rises increasing the voltage drop on Rset. As it crosses an internal 1.25 volt threshold it trips a comparator causing the TPS92411 MOSFET to open 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 drain of 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 when two or more TPS92411s are switching.

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 discrete current regulator using a MOSFET, Q3, current sense resistors, R26 and R31, and a transistor, Q4 regulates current from the rectified AC. The reference to this regulator is a resistor divider from rectified AC, R17, R20 and R29. Note that Q4 collector and emitter are in this divider but it is a fixed voltage, the Vgs threshold of Q3 plus the Vbe of Q4. The Vgs is small compared to the rectified AC voltage so it will have little effect. The Vbe drop of Q4 will add some DC offset to the power factor correction however the line regulation circuit overcompensates by subtracting a DC offset as the input voltage rises.

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 input line compensation when dimming. It sources current into the base of Q4.

2.2.1.7 Leading edge dim detect and DC offset

A damper RC is used to prevent the triac dimmer from mis-firing during the fast rising edge of the input voltage. Without a rising edge the maximum voltage on the damper capacitor, C1, is less than eight volts, D11 blocks that. When a triac, leading edge, dimmer is present the voltage across the capacitor is much higher during the triac firing. Some of the energy from the damper capacitor is used to charge a low voltage ceramic capacitor to providing a 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 satisfying its holding current requirement.

2.2.1.8 EMI control

A capacitor, C11, across the discrete current regulator MOSFET gate to source, Q3, along with the TPS92411 slew control allows the reference design to pass QP conducted EMI with 4.3dB of margin with only a 0.12 uF capacitor, C2, across rectified AC. Radiated EMI is not an issue with this topology. The EMI capacitor value is proportional to the input current. Doubling the power would require doubling the capacitor value, C2. 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	207	230/240	264	V
Voltage range	Maximum range	200		265	V
Maximum input current	At 230 Vrms input		0.090		A rms
Input power			20	22.5	watts
Output Characteristics					
Output voltage, stack 1 (top)	Nominal		168		V
Output voltage, stack 2	Nominal		78		V
Output voltage, stack 3	Nominal		36		V
Output voltage, stack 4 (bottom)	Nominal		18		V

4 Schematic

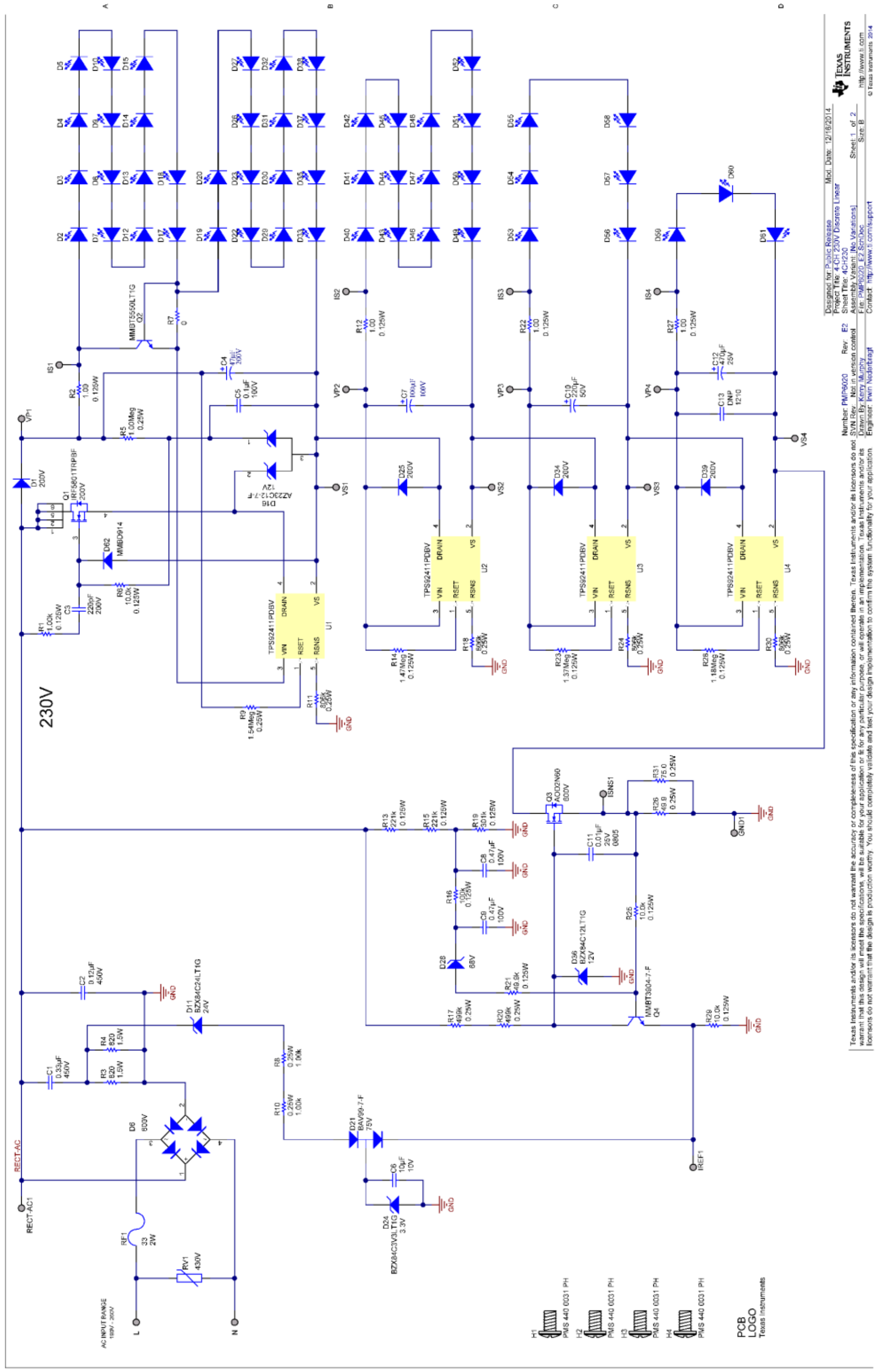

Figure 1: TPS92411 discrete linear Schematic

5 Performance Data and Typical Characteristic Curves

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

5.1 Efficiency

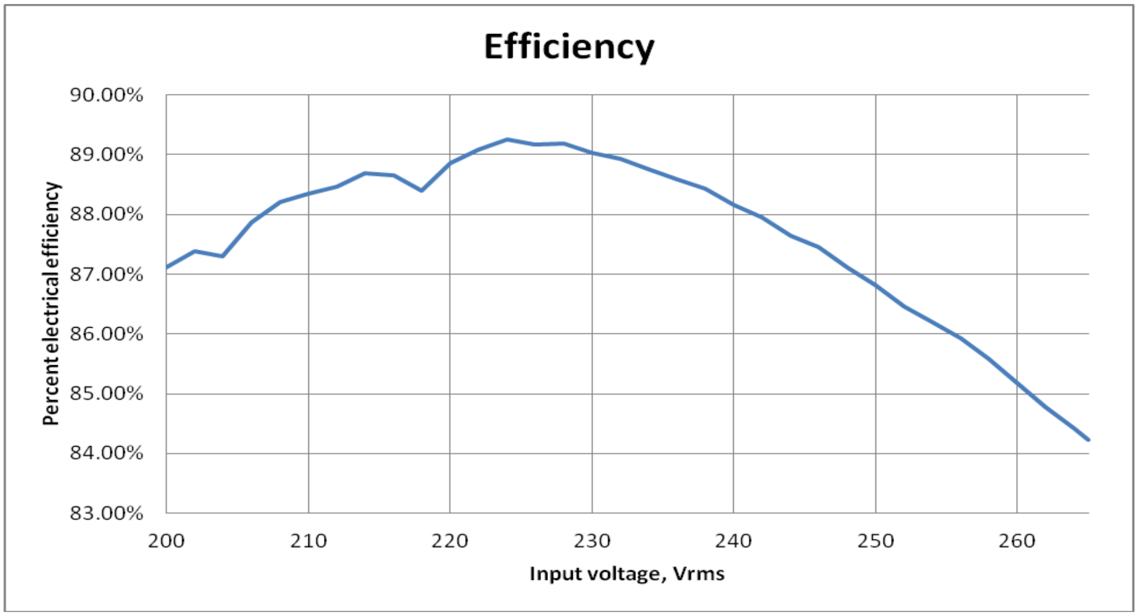

Figure 2: Efficiency

5.2 Line Regulation

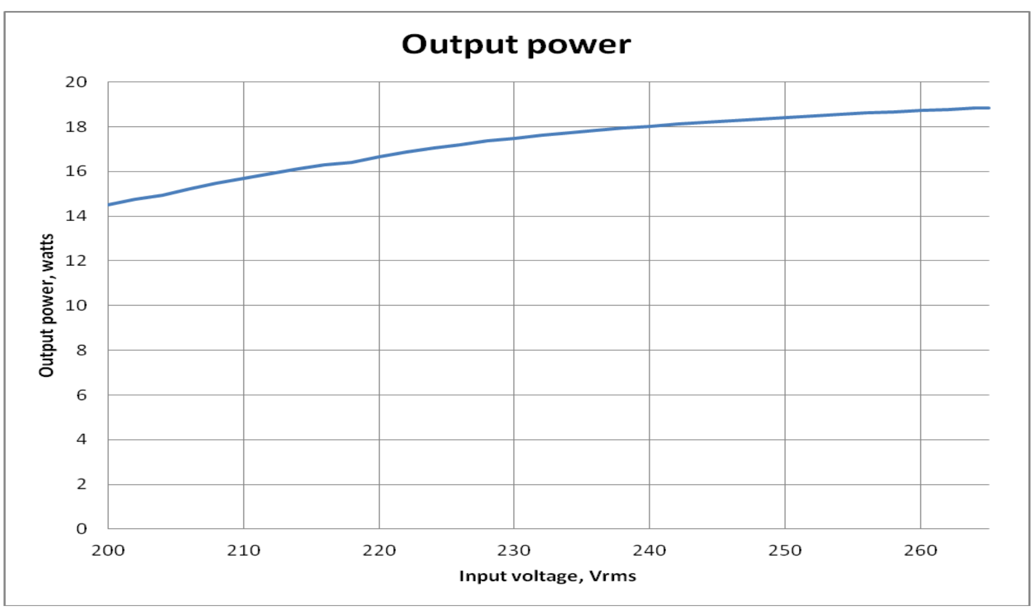

Figure 3: Line Regulation

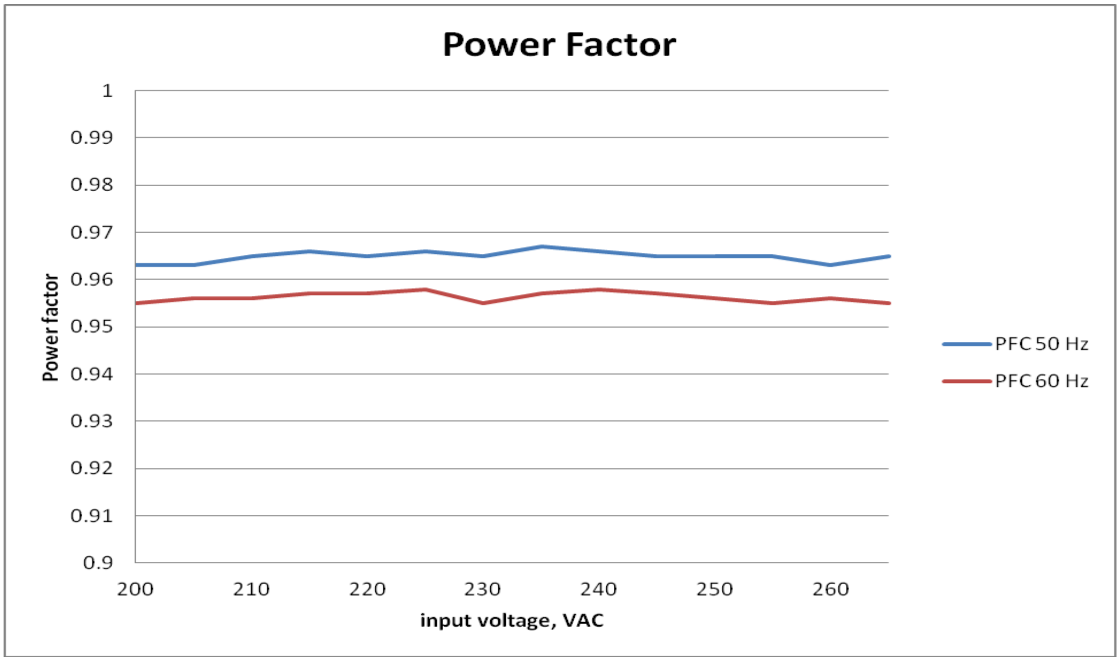

Figure 4: Power factor correction at 50 Hz and 60 Hz

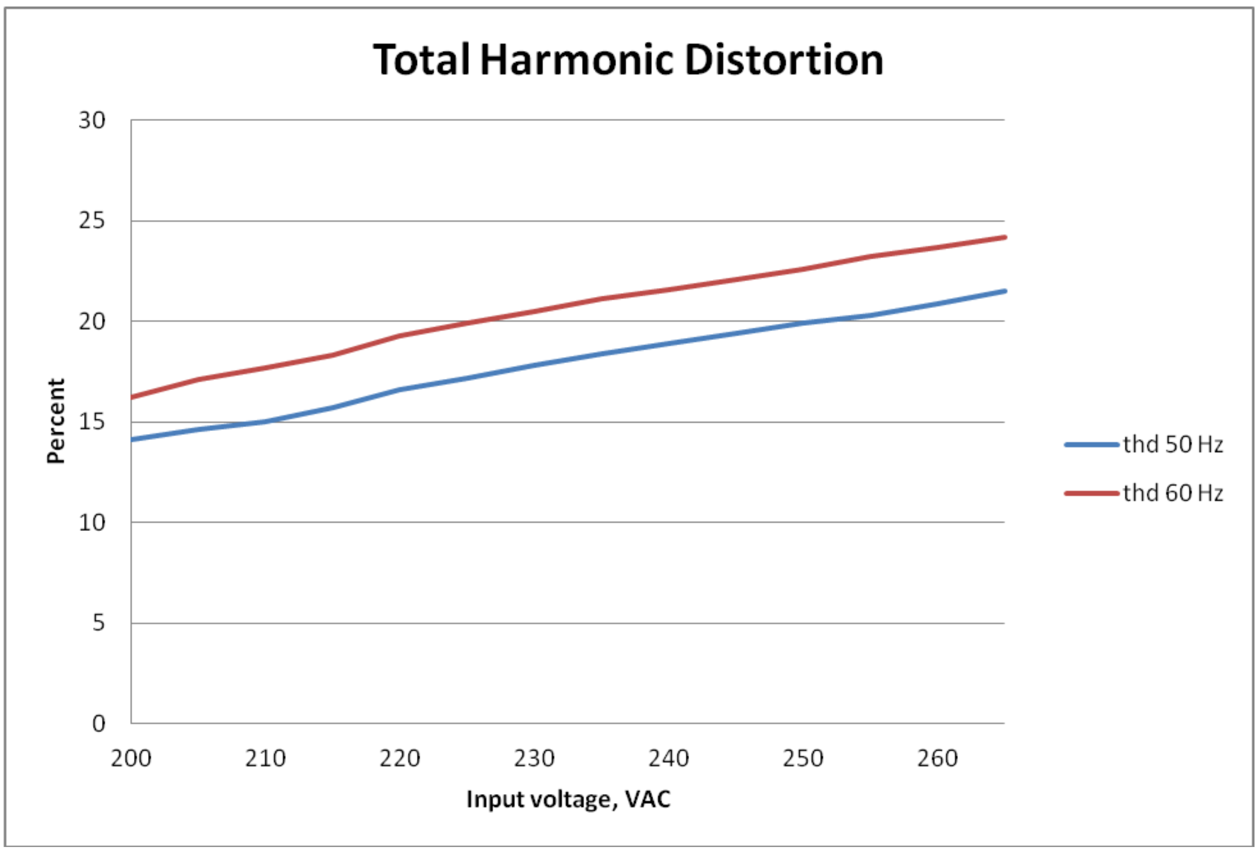

Figure 5: Total Harmonic Distortion at 50 Hz and 60 Hz, at 60 Hz line modification of line regulation circuit will lower thd level

5.3 Drain voltage of current regulator

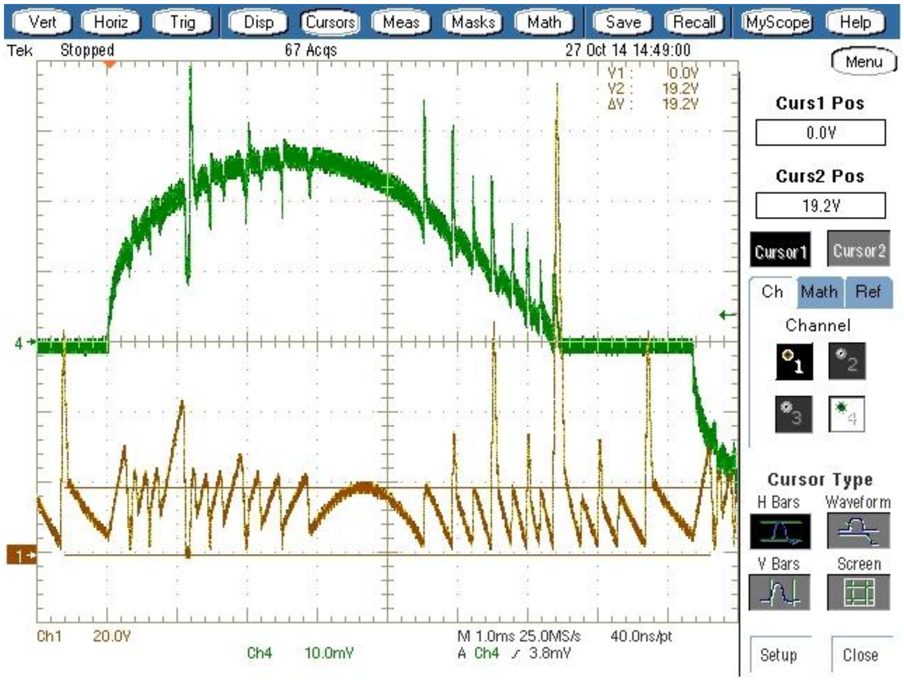

Figure 6: Current regulator drain waveform (Brown), input current (green)

5.4 Current sense

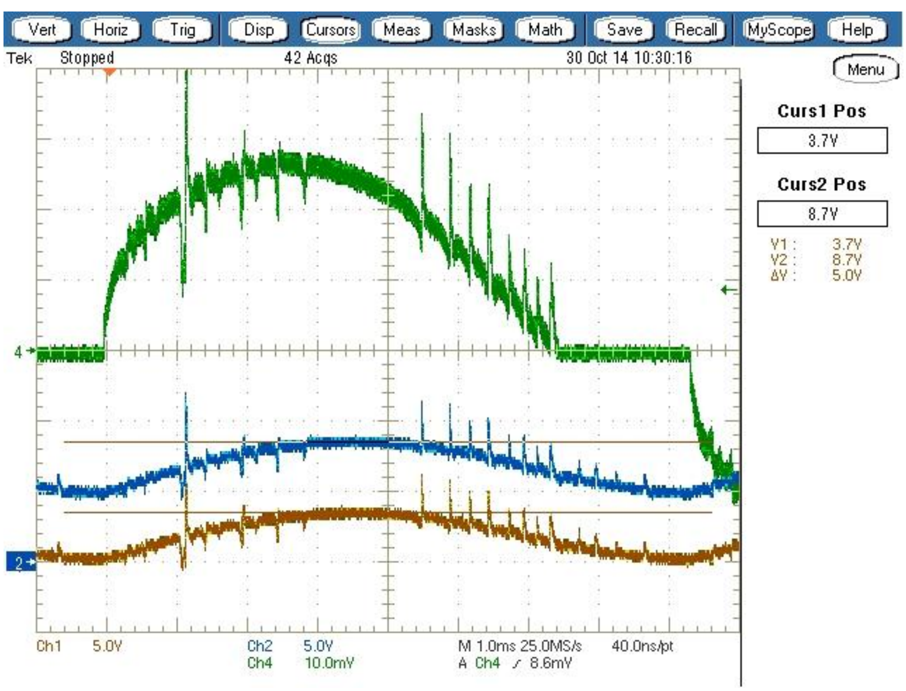

Figure 7: Voltage at current sense resistors, R26/R31 (Brown), Q3 MOSFET gate (blue)

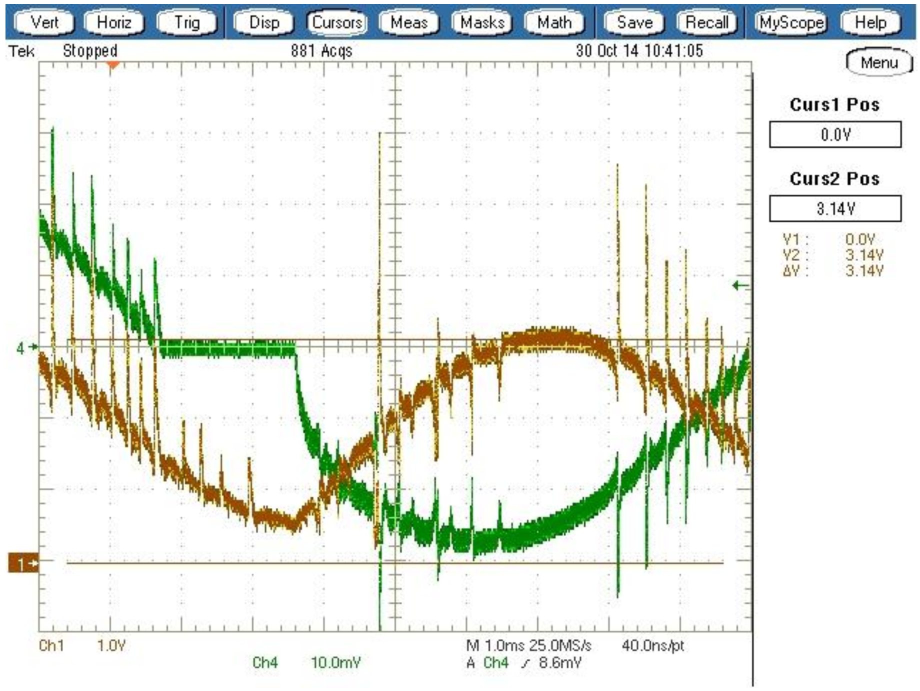

Figure 8: PFC command, R29 voltage (brown)

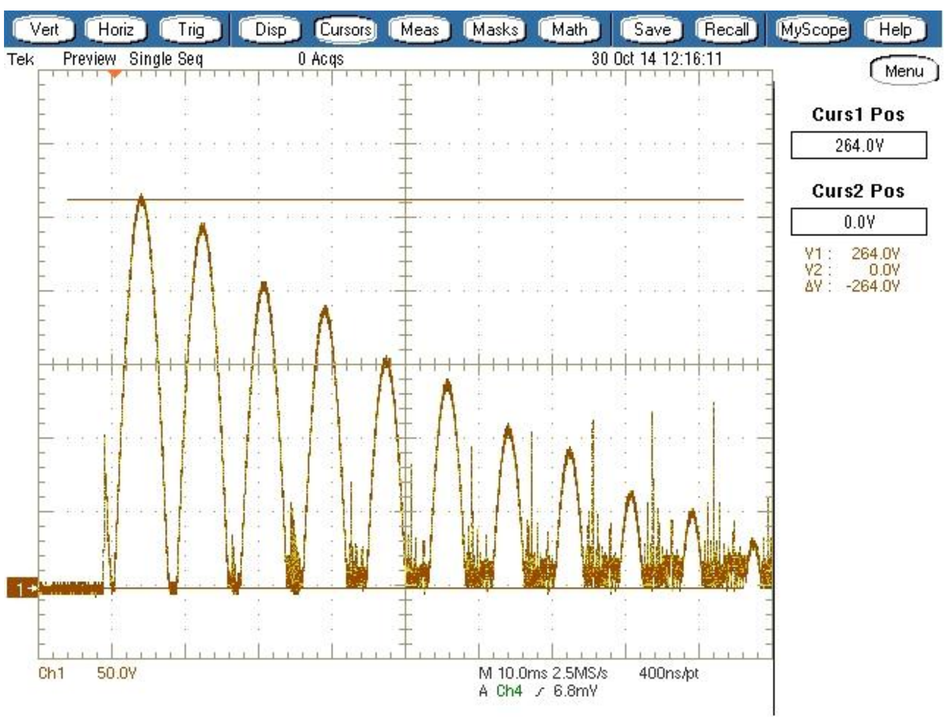

Figure 9: Current regulator drain voltage during power on, energy storage capacitors charging

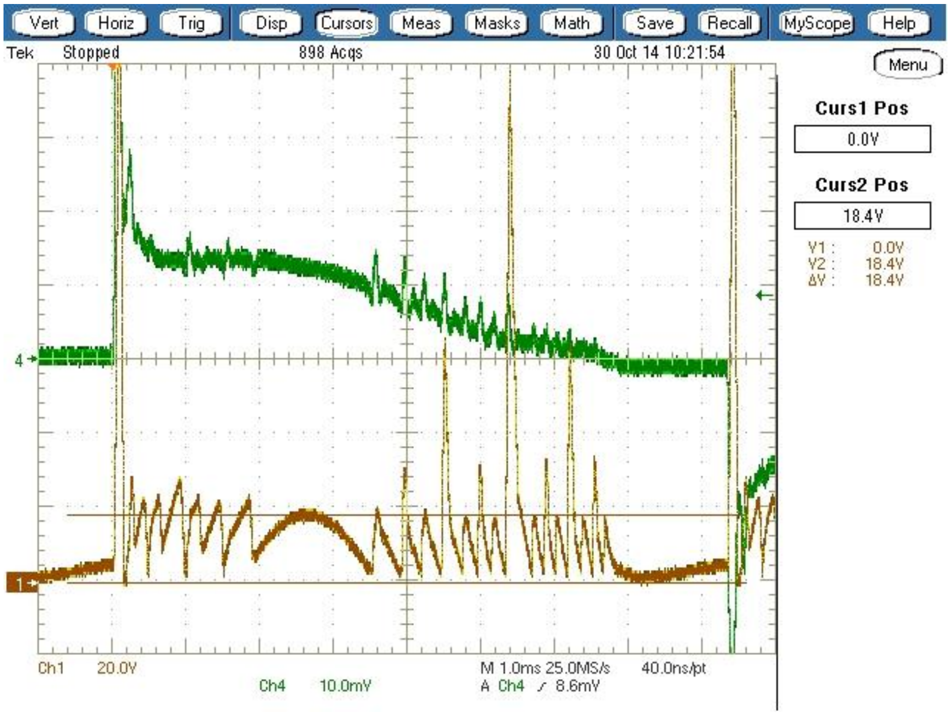

Figure 10: Current regulator drain voltage when forward phase dimming (dimmer at maximum)

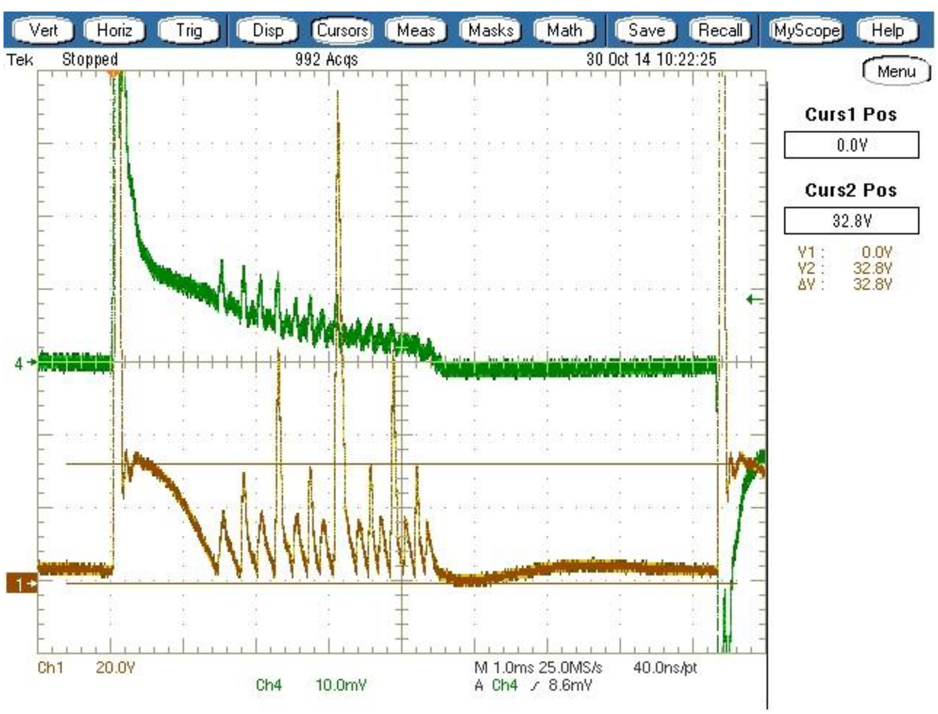

Figure 11: Current regulator drain voltage when forward phase dimming (dimmer set to peak of rectified AC)

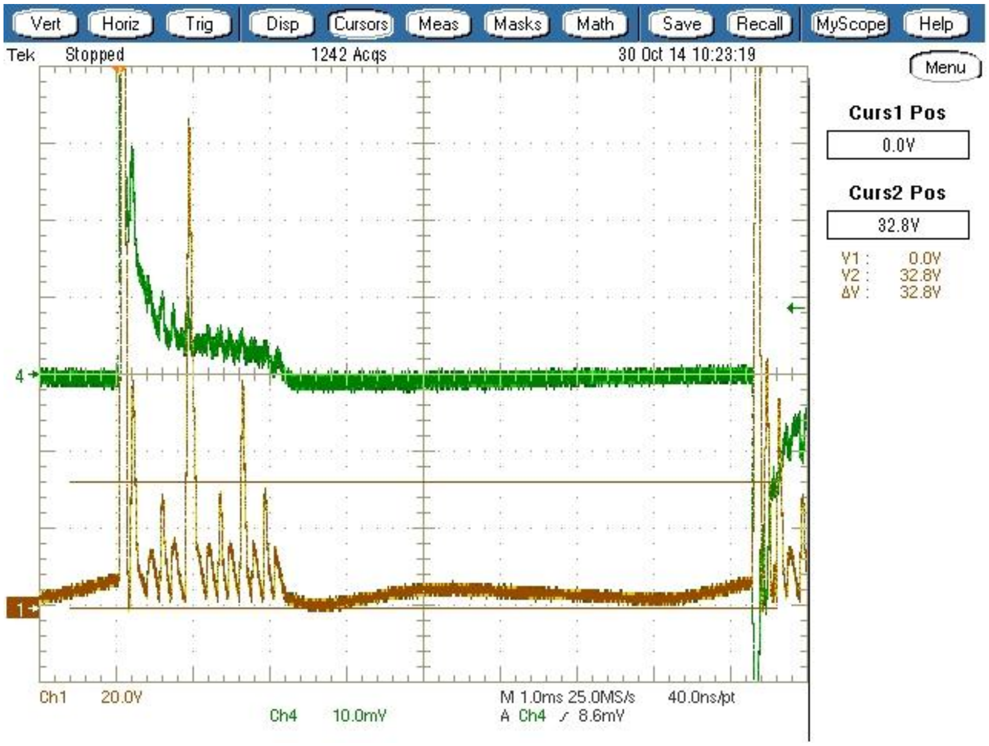

Figure 12: Current regulator drain waveform when forward phase dimming (dimmer set to about ¼)

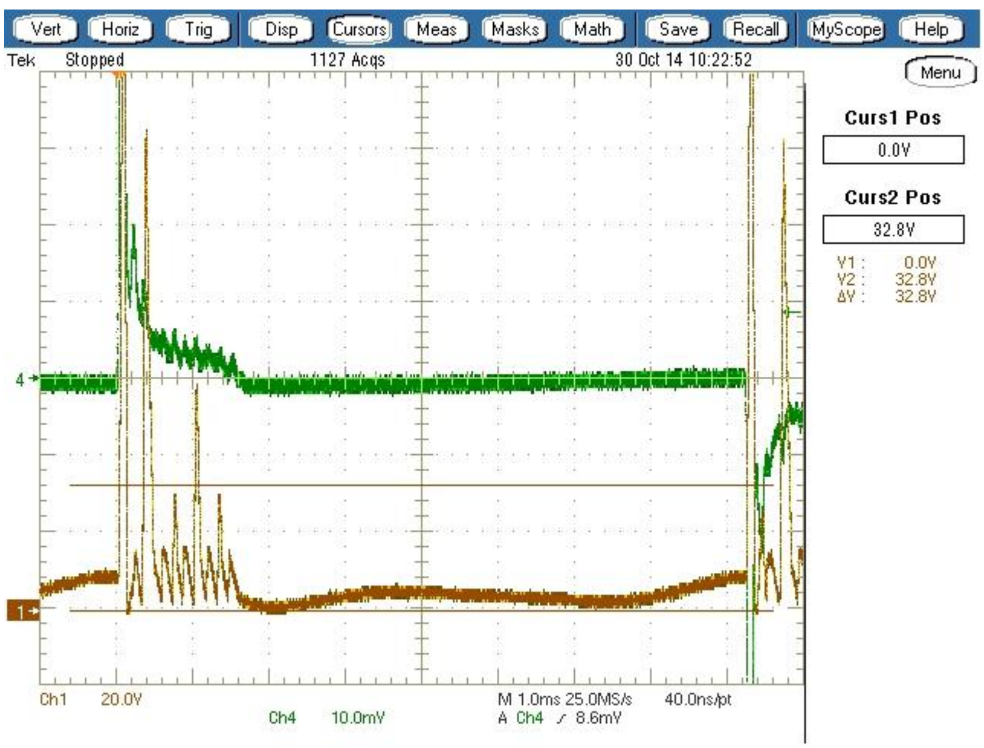

Figure 13: Current regulator drain waveform when forward phase dimming (dimmer at minimum)

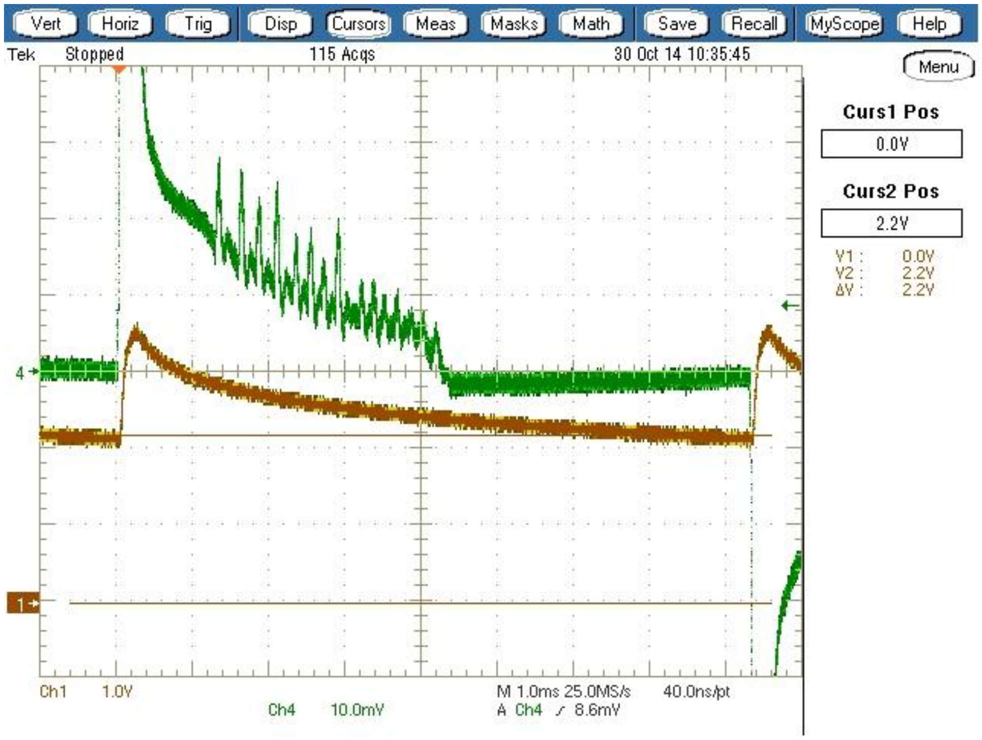

Figure 14: Voltage on DC offset circuit, C6, holding command up when forward phase dimming (brown)

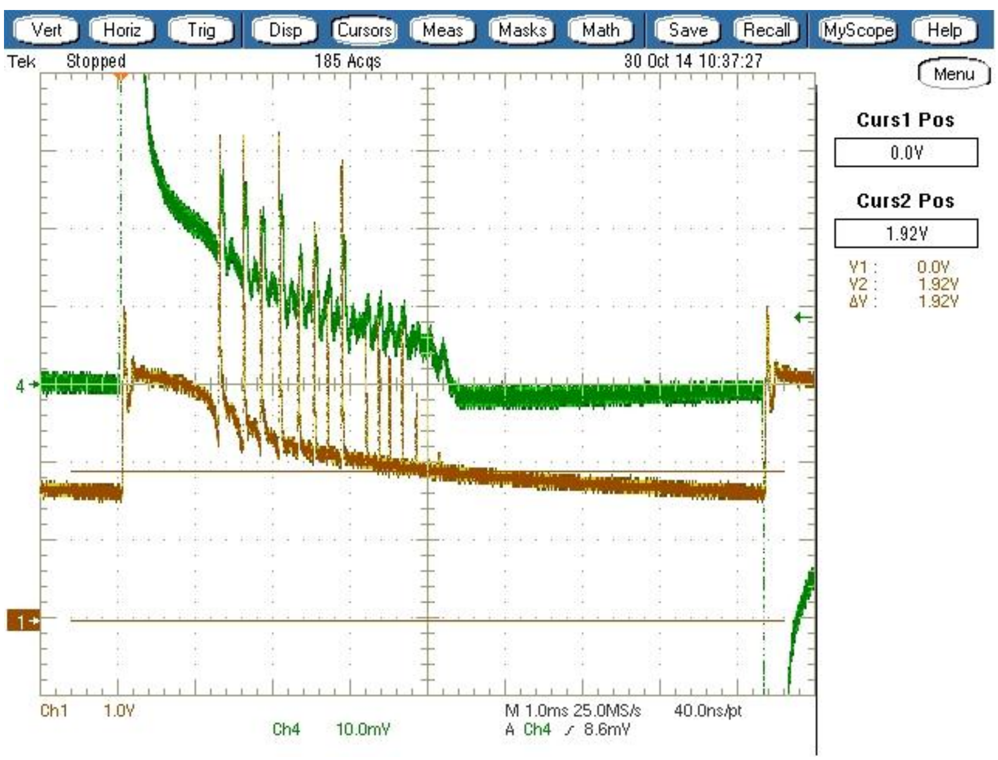

Figure 15: Current reference with DC offset, R29 (brown), shows DC offset held up by C6

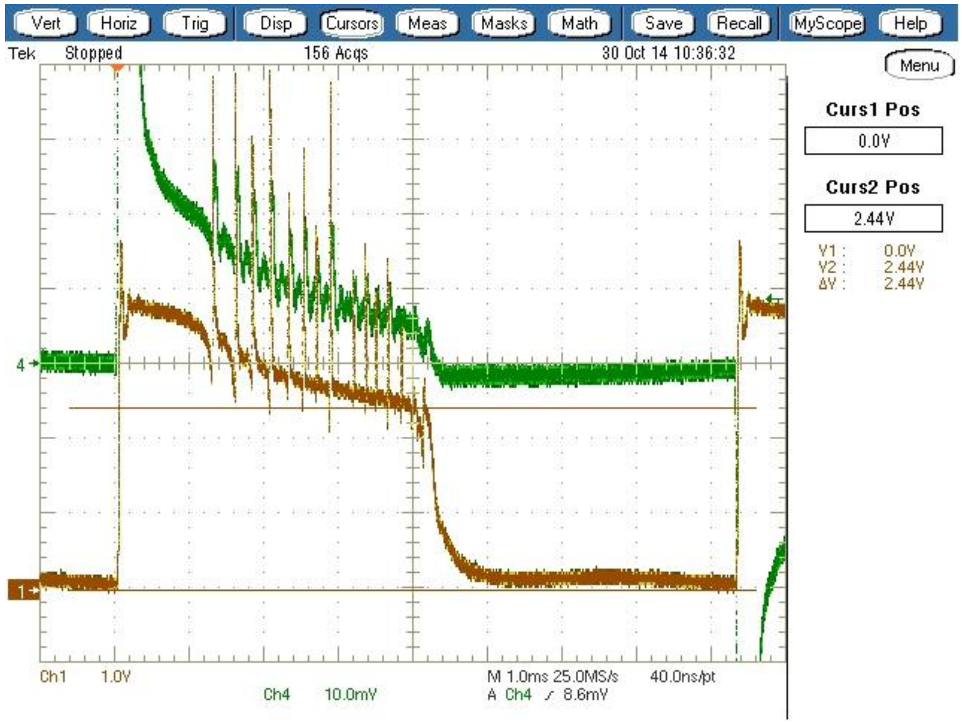

Figure 16: Current sense voltage while forward phase dimming, R15 (brown)

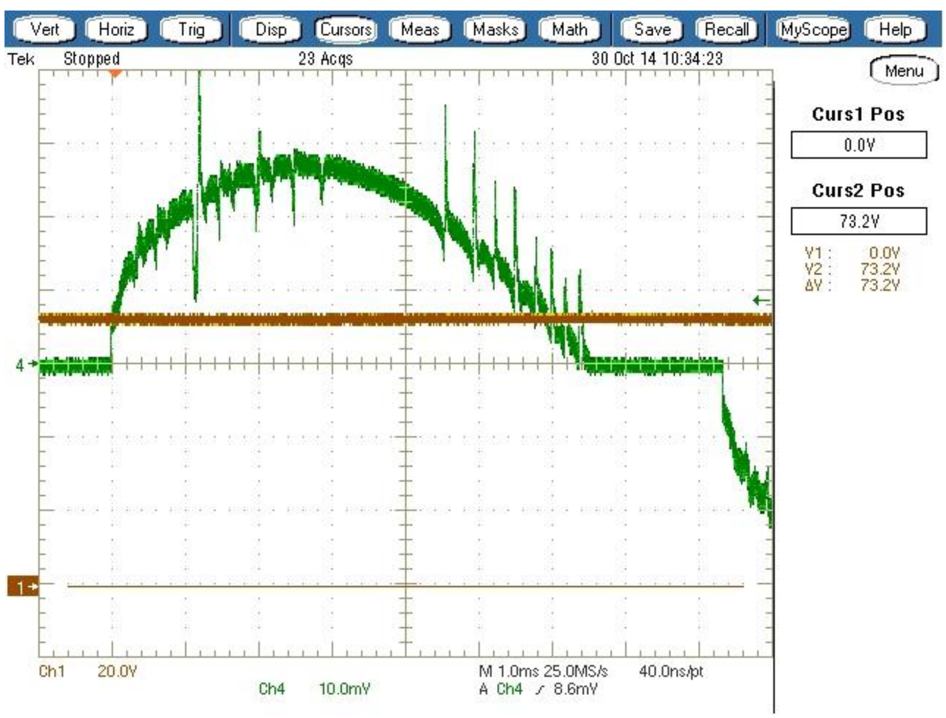

Figure 17: Input averaging voltage used for line regulation, D28 (brown)

Figure 18: Rectified AC, reference for next oscilloscope plots (brown), note the line regulation circuit prevents the current regulator from sinking current when the rectified AC voltage is low

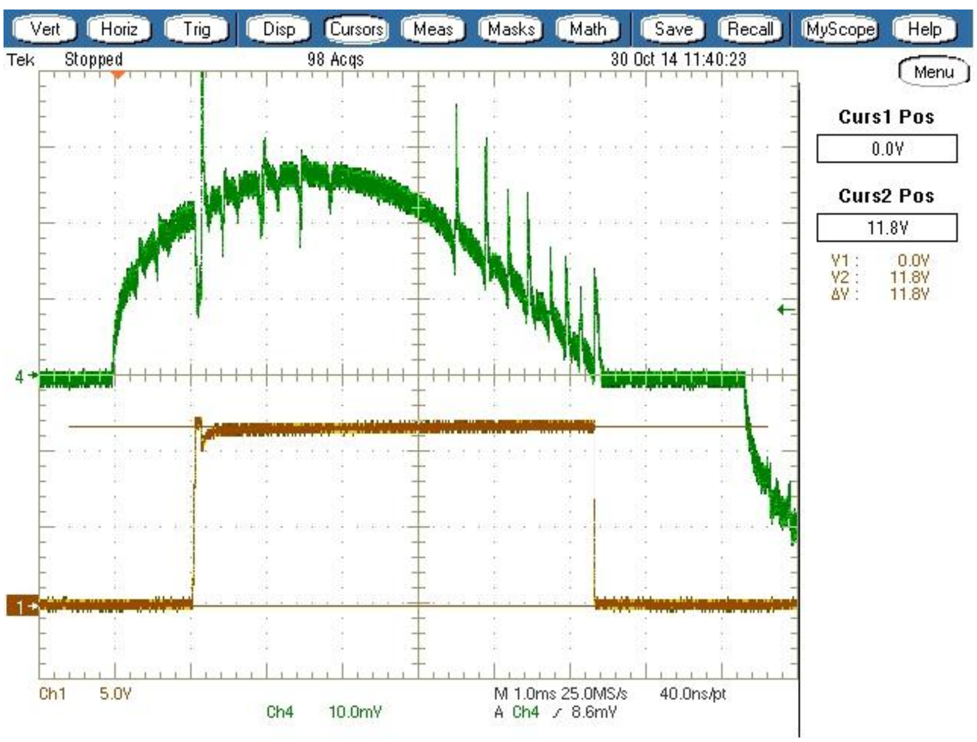

Figure 19: Upper TPS92411 drain waveform, cascode drive, allows slew control and no inversion

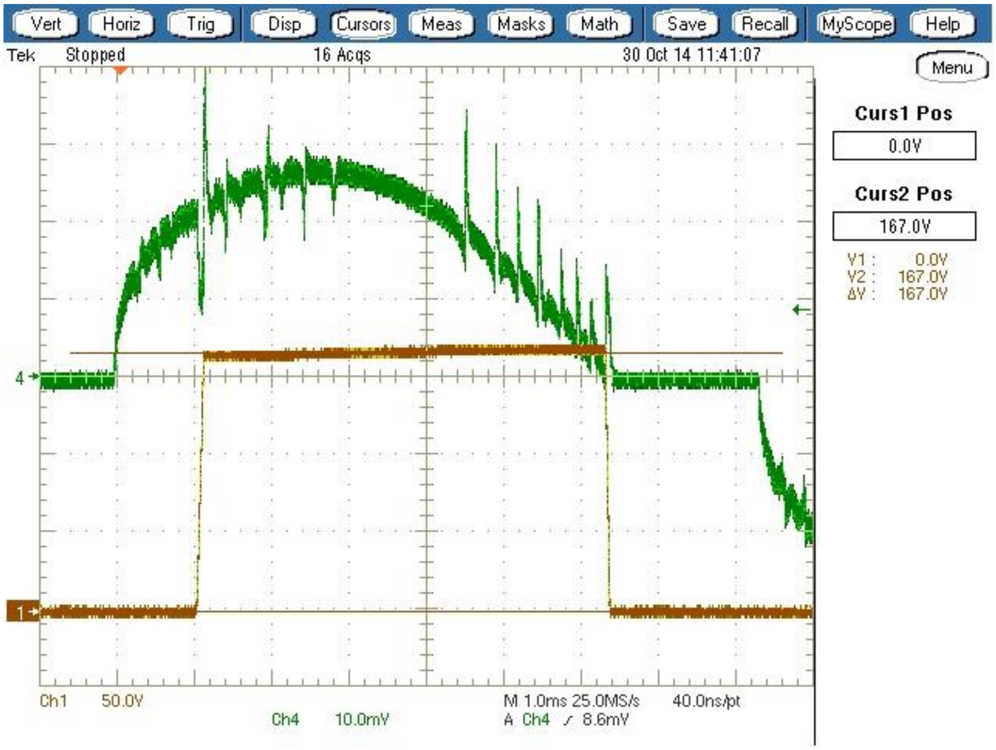

Figure 20: Drain of cascode MOSFET showing slew control, turn-on faster than turn-off. 1st stack, 168 volt, 1xxx in count sequence

Figure 21: Drain of cascode MOSFET, open slew, 1.9V/uS

Figure 22: Drain of cascode MOSFET, close slew, -2.9V/uS

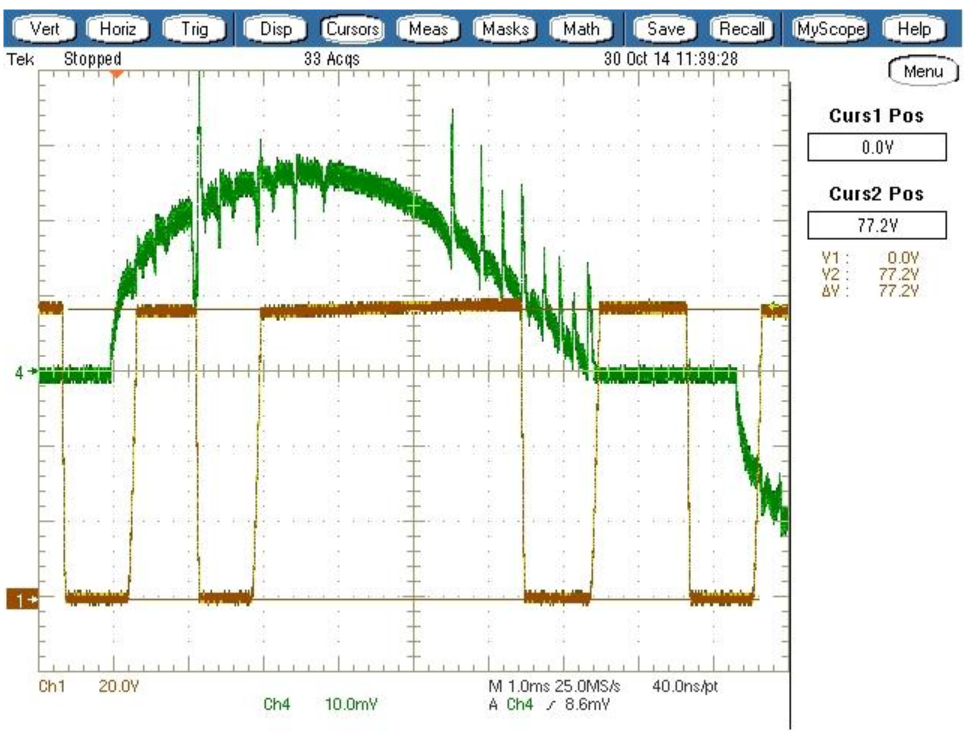

Figure 23: 2nd TPS92411 drain, 78 volt stack, x1xx in count sequence

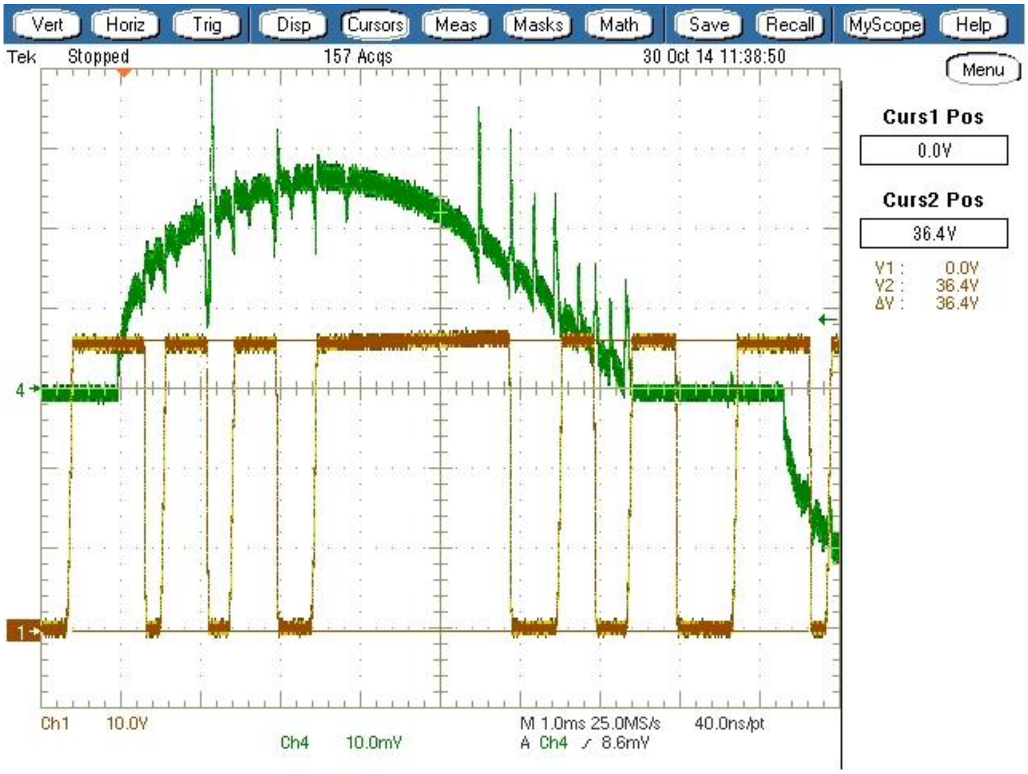

Figure 24: 3rd TPS92411 drain, 36 volts, xx1x in count sequence

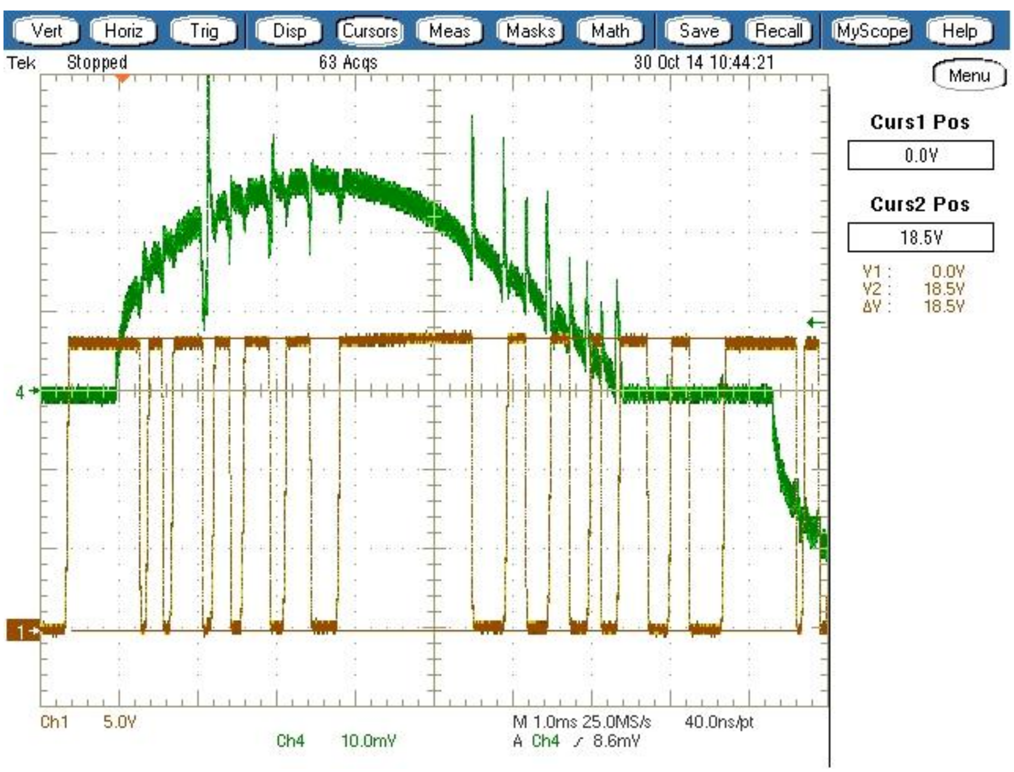

Figure 25: 4th TPS92411 drain, 18 volts, xxx1 in count sequence

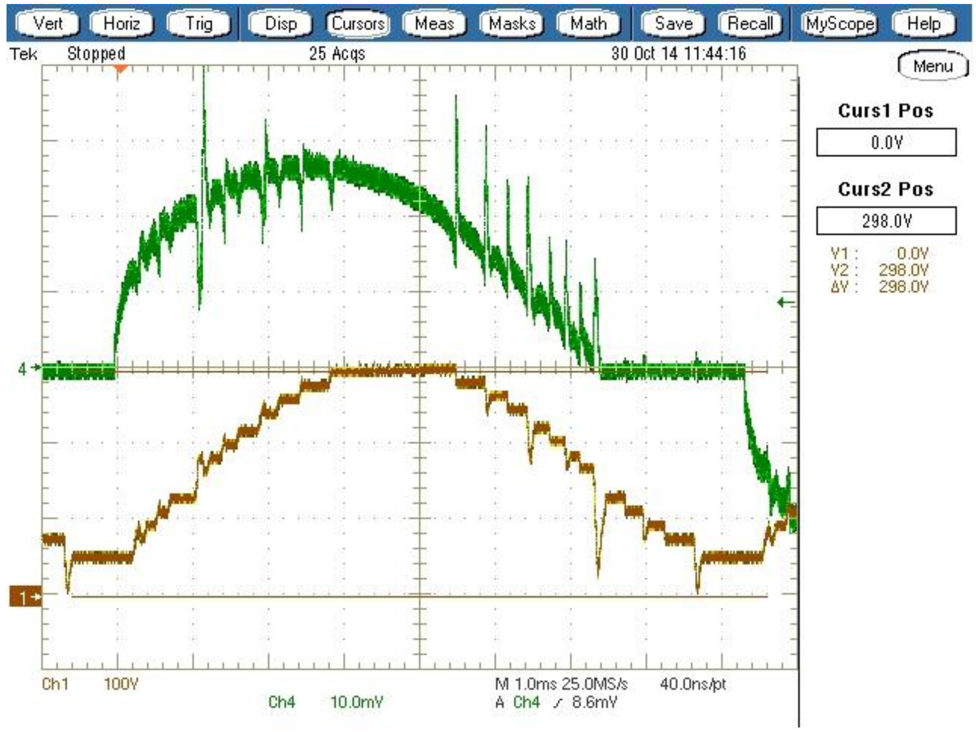

Figure 26: Series load voltage, sum of the LED stacks as the input voltage rises and falls

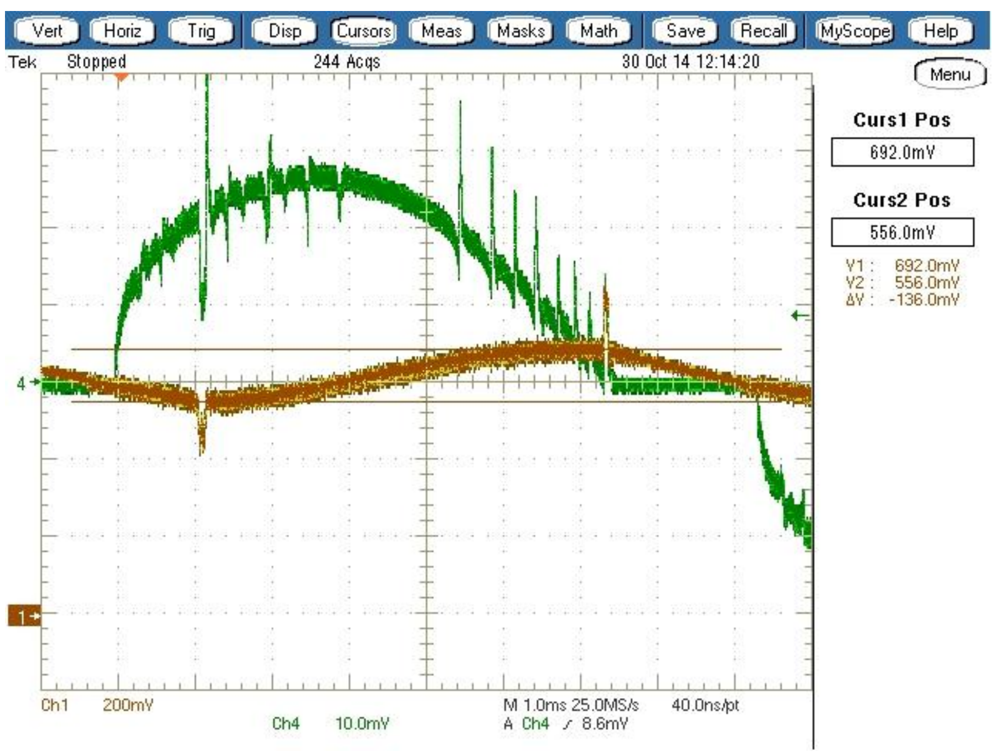

Figure 27: current ripple stack 1, 168 volt, voltage across 10 ohm resistor, approximately 22% peak to peak over average

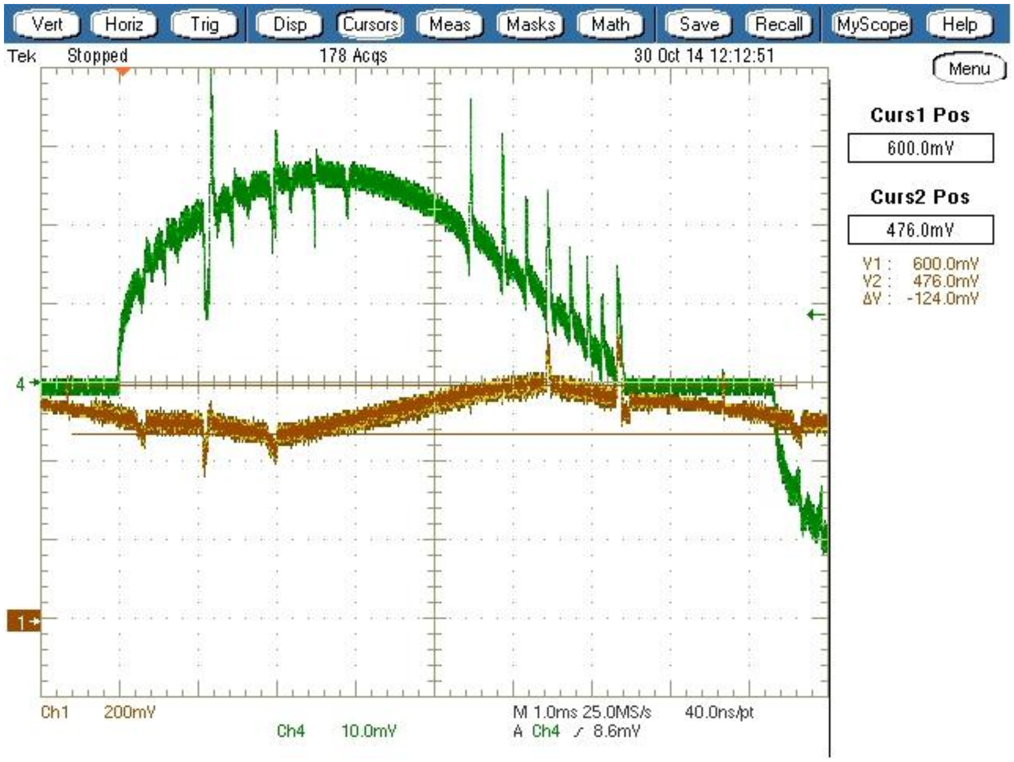

Figure 28: current ripple stack 2, 78 volt, voltage across 10 ohm resistor, approximately 23% peak to peak over average

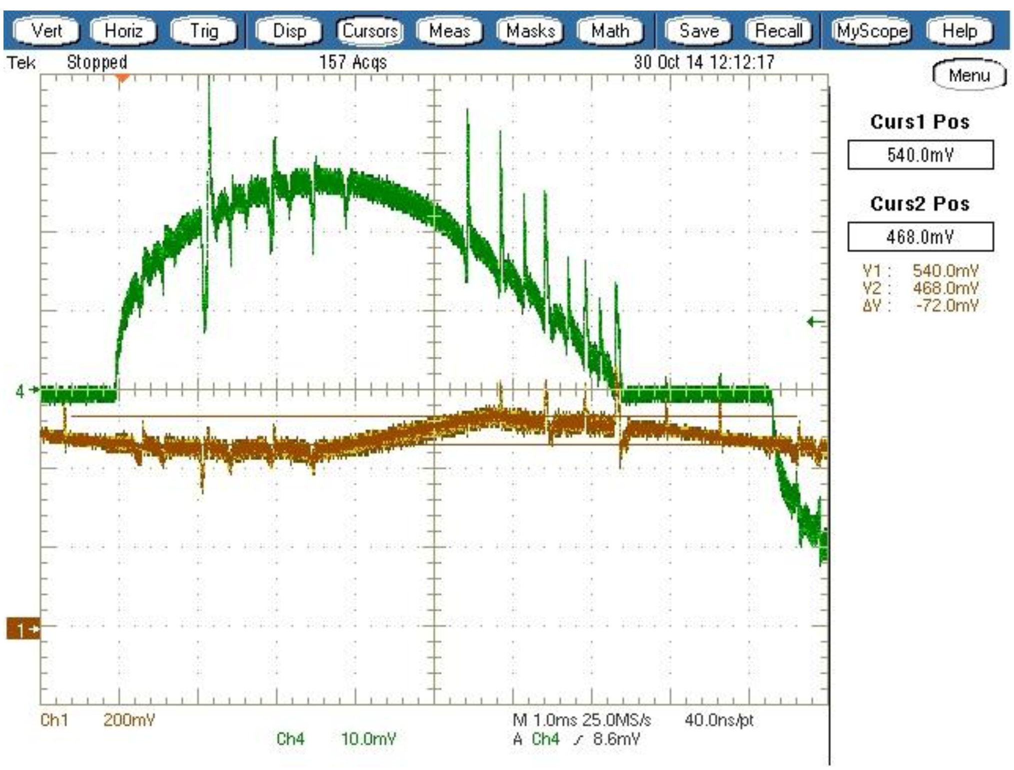

Figure 29: current ripple stack 3, 36 volt, voltage across 10 ohm resistor, approximately 14% peak to peak over average

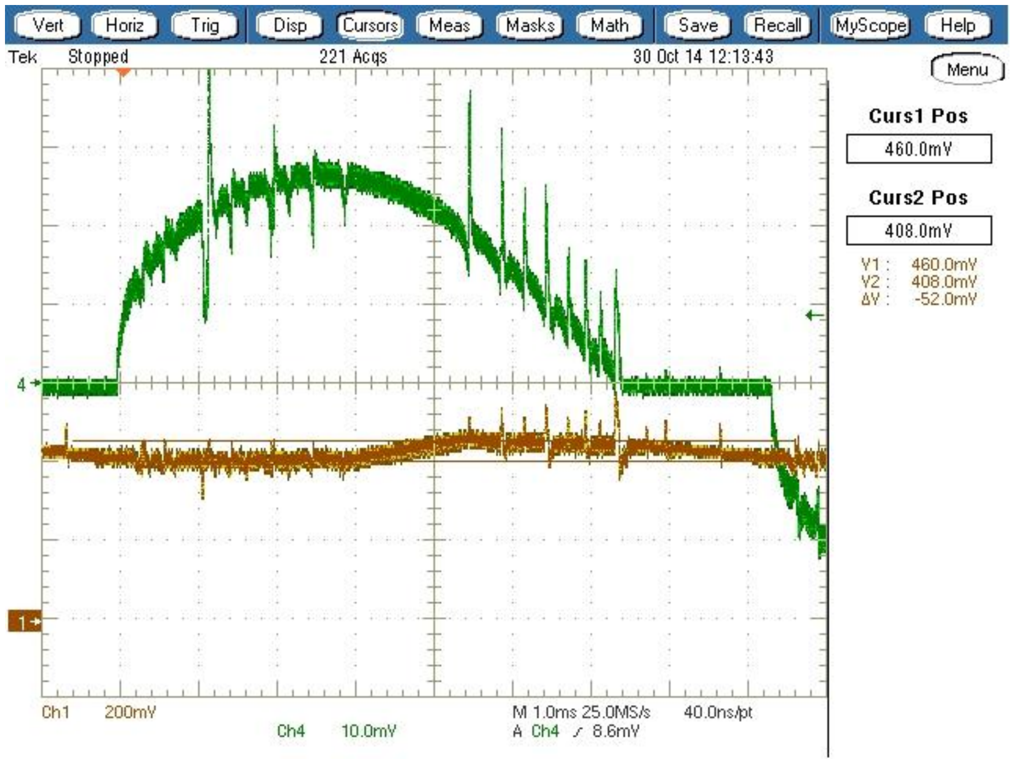

Figure 30: current ripple stack 4, 18 volt, voltage across 10 ohm resistor, approximately 12% peak to peak over average

5.5 EMI Performance

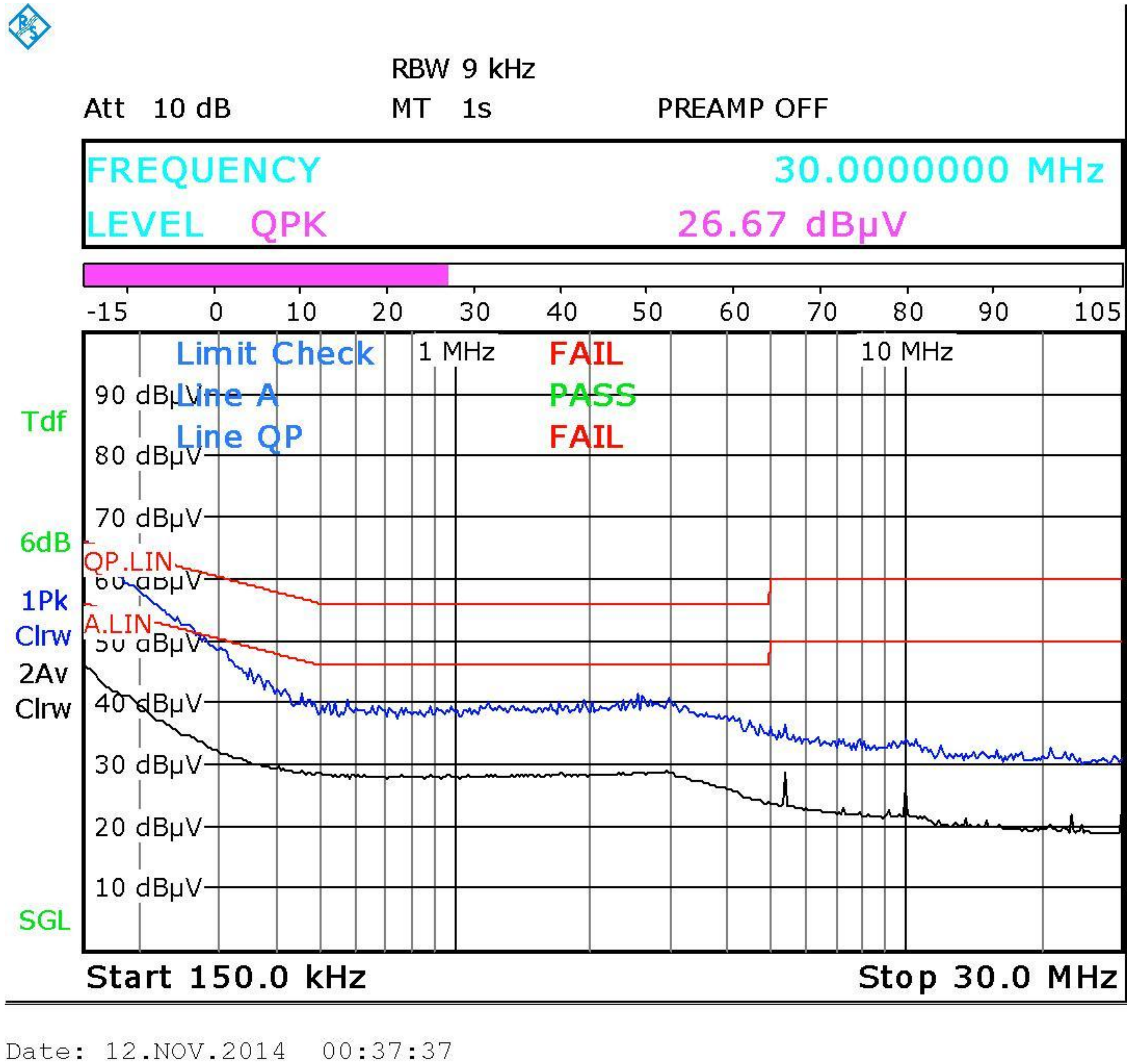

Figure 31: Conducted EMI scan peak and average, Quasi-peak measures -4.3 dB for both line and neutral at 150 KHz

5.6 TPS92411 test hardware, designed mounting to heatsink though printed circuit board, 0.031" thick.

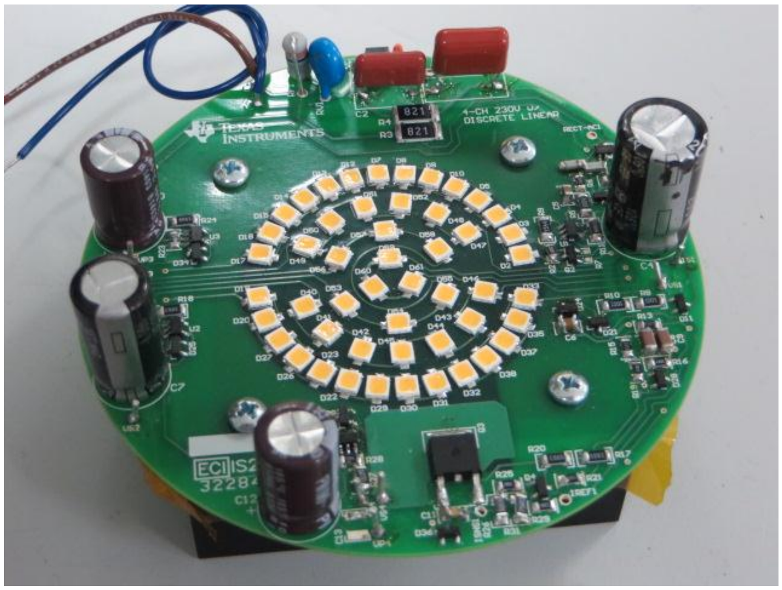

Figure 32: Four layer board with heat spreading planes, mounted to ½-brick heatsink for testing

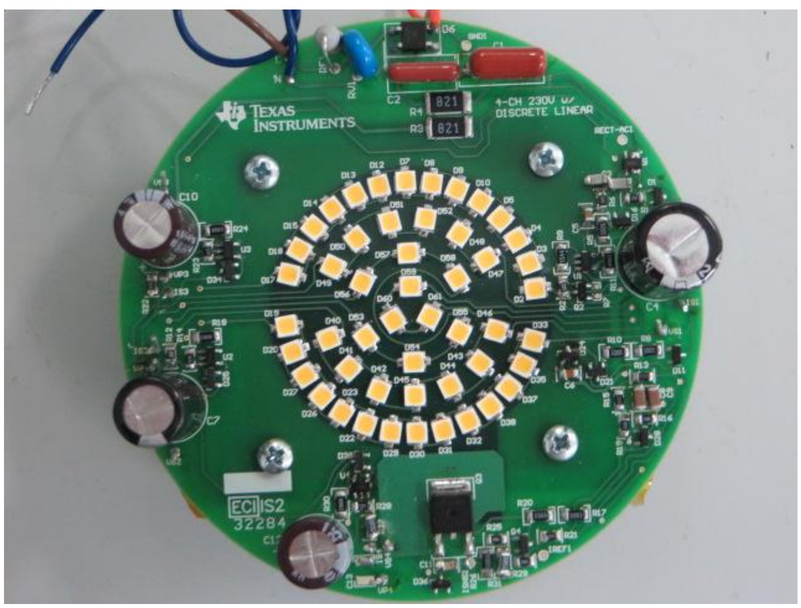

Figure 33: FR4 SMT section including three TPS92411

6 TPS92411 Reference Design PCB layout

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

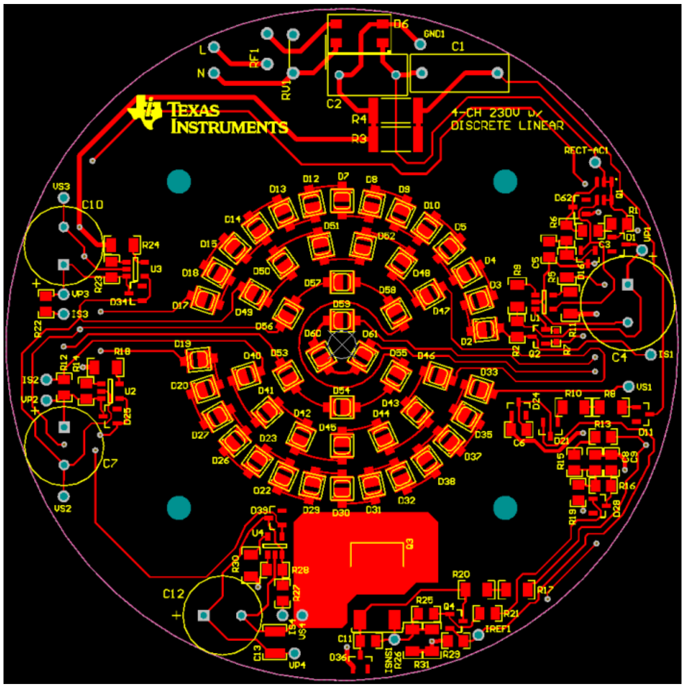

Figure 34: Top Layer and Top Overlay (Top view)

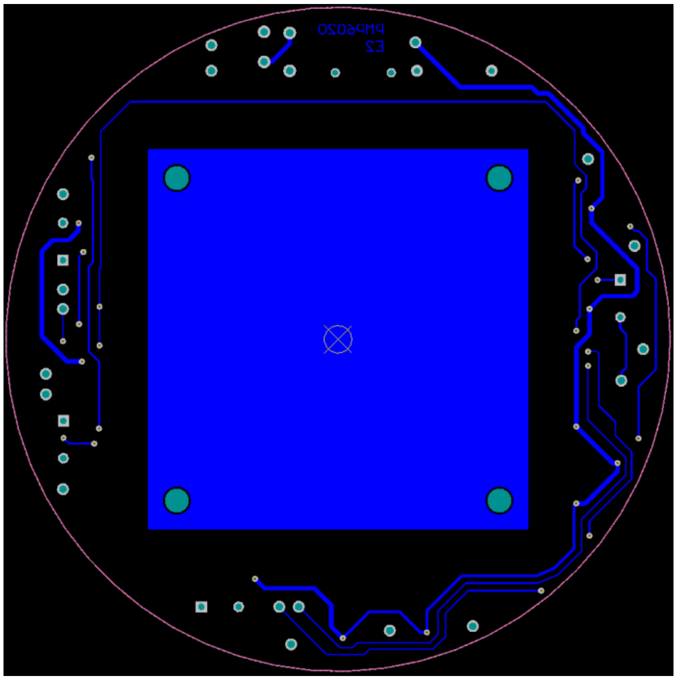

Figure 35: Bottom Layer and Bottom Overlay (Bottom view)

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, 450V, Radial	Radial	Panasonic	ECW-FD2W334KQ
C2	1	0.12µF	CAP, FILM, 0.12uF, 450V, Radial	Radial	Panasonic	ECW-FD2W124J4
C3	1	220pF	CAP, CERM, 220uF, 200V, X7R, 10%, 0805	0805 (2012 Metric)	Yageo	CC0805KRX7RABB221
C4	1	47uF	CAP, AL, 47uF, 200V, +/-20%, 0.380955 ohm, TH	12.5x20	Panasonic	EEUED2D470
C5	1	0.1uF	CAP, CERM, 0.1uF, 100V, +/-10%, X7R, 0805	0805	Samsung	CL21B104KCFSFNE
C6	1	10uF	CAP, CERM, 10uF, 10V, +/-10%, X7R, 0805	0805	MuRata	GRM21BR71A106KE51L
C7	1	100uF	CAP, AL, 100uF, 100V, +/-20%, TH	10x20mm	Panasonic	ECA-2AHG101
C8, C9	2	0.47uF	CAP, CERM, 0.47 µF, 100 V, +/-10%, X7R, 0805	0805	MuRata	GRM21BR72A474KA73L
C10	1	220µF	CAP, Alum, 220uF, 50V, +/-20%, Radial	Radial, Can	Nichicon	UPW1H221MPD
C11	1	0.01uF	CAP, CERM, 0.01 µF, 25 V, +/-5%, C0G/NP0, 0805	0805	TDK	C2012C0G1E103J
C12	1	470µF	CAP, Alum, 470uF, 25V, +/-20%, Radial	Radial, Can	Nichicon	UPW1E471MPD
D1, D25, D34, D39	4	200V	Diode, Switching, 200V, 0.2A, SOT-23	SOT-23	Diodes Inc.	BAS21-7-F
D2, D3, D4, D5, D7, D8, D9, D10, D12, D13, D14, D15, D17, D18, D19, D20, D22, D23, D26, D27, D29, D30, D31, D32, D33, D35, D37, D38, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D52, D53, D54, D55, D56, D57, D58, D59, D60, D61	50		LED SMD NEUTRAL WHITE 4000K	2-SMD, No Lead	Seoul Semi	STW8C2SA-J19K24-EA
D6	1		Diode, Switching-Bridge, 600V, 0.8A, MiniDIP	MiniDIP	Diodes Inc.	HD06-T
D11	1	24V	Diode, Zener, 24V, 225mW, SOT-23	SOT-23	ON Semi	BZX84C24LT1G
D16	1	12V	Diode, Zener, 12V, 300mW, SOT-23	SOT-23	Diodes Inc.	AZ23C12-7-F
D21	1	75V	Diode, Switching, 75V, 0.3A, SOT-23	SOT-23	Diodes Inc.	BAV99-7-F
D24	1	3.3V	Diode, Zener, 3.3 V, 225 mW, SOT-23	SOT-23	ON Semi	BZX84C3V3LT1G
D28	1	68V	Diode, Zener, 68V, 225mW, SOT-23	SOT-23	ON Semi	BZX84C68LT1G
D36	1	12V	Diode, Zener, 12V, 225mW, SOT-23	SOT-23	ON Semi	BZX84C12LT1G

D62	1	100V	Diode, P-N, 100 V, 0.2 A, SOT-23	SOT-23	Fairchild	MMBD914
H1, H2, H3, H4	4		MACHINE SCREW PAN PHILLIPS 4-40		B&F Fastener Supply	PMS 440 0031 PH
Q1	1	200V	MOSFET, N-CH, 200V, 0.6A, TSOP-6	TSOP-6	IR	IRF5801TRPBF
Q2	1	0.25V	Transistor, NPN, 140V, 0.6A, SOT-23	SOT-23	ON Semi	MMBT5550LT1G
Q3	1	600V	MOSFET, N-CH, 600V, 2A, DPAK	DPAK	AOS	AOD2N60
Q4	1	0.2V	Transistor, NPN, 40V, 0.2A, SOT-23	SOT-23	Diodes Inc.	MMBT3904-7-F
R1	1	1.00k	RES, 1.00k ohm, 1%, 0.125W, 0805	0805	Vishay-Dale	CRCW08051K00FKEA
R2, R12, R22, R27	4	1.00	RES, 1.00 ohm, 1%, 0.125W, 0805	0805	Stackpole	RMCF0805FT1R00
R3, R4	2	820	RES, 820 ohm, 5%, 1.5W, 2512	2512	Stackpole	RPC2512JT820R
R5	1	1.00M	RES, 1.00Meg ohm, 1%, 0.25W, 1206	1206	Vishay-Dale	CRCW12061M00FKEA
R6, R25, R29	3	10.0k	RES, 10.0k ohm, 1%, 0.125W, 0805	0805	Vishay-Dale	CRCW080510K0FKEA
R7	1	0	RES, 0 ohm, 5%, 0.1W, 0603	0603	Vishay-Dale	CRCW06030000Z0EA
R8, R10	2	1.00k	RES, 1.00k ohm, 1%, 0.25W, 1206	1206	Vishay-Dale	CRCW12061K00FKEA
R9	1	1.54M	RES, 1.54Meg ohm, 1%, 0.25W, 1206	1206	Vishay-Dale	CRCW12061M54FKEA
R11, R18, R24, R30	4	806k	RES, 806k ohm, 1%, 0.25W, 1206	1206	Vishay-Dale	CRCW1206806KFKEA
R13, R15	2	221k	RES, 221k ohm, 1%, 0.125W, 0805	0805	Vishay-Dale	CRCW0805221KFKEA
R14	1	1.47M	RES, 1.47Meg ohm, 1%, 0.125W, 0805	0805	Vishay-Dale	CRCW08051M47FKEA
R16	1	100k	RES, 100k ohm, 1%, 0.125W, 0805	0805	Vishay-Dale	CRCW0805100KFKEA
R17, R20	2	499k	RES, 499k ohm, 1%, 0.25W, 1206	1206	Vishay-Dale	CRCW1206499KFKEA
R19	1	301k	RES, 301 k, 1%, 0.125 W, 0805	0805	Panasonic	ERJ-6ENF3013V
R21	1	49.9k	RES, 49.9 k, 1%, 0.125 W, 0805	0805	Vishay-Dale	CRCW080549K9FKEA
R23	1	1.37M	RES, 1.37Meg ohm, 1%, 0.125W, 0805	0805	Vishay-Dale	CRCW08051M37FKEA
R26	1	49.9	RES, 49.9, 1%, 0.25 W, 1206	1206	Vishay-Dale	CRCW120649R9FKEA
R28	1	1.18M	RES, 1.18Meg ohm, 1%, 0.125W, 0805	0805	Vishay-Dale	CRCW08051M18FKEA
R31	1	75.0	RES, 75.0, 1%, 0.25 W, 1206	1206	Vishay-Dale	CRCW120675R0FKEA
RF1	1	33	RES 33 OHM 2W 10% AXIAL	Axial	Welwyn	EMC2-33RKI
RV1	1	430V	Metal Oxide Varistor, TH	9.00 mm Diameter	Bourns	MOV-07D431K
U1, U2, U3, U4	4		Switch Controlled Direct Drive Switch for Offline LED Drivers, DBV0005A	DBV5A	TI	TPS92411PDBV

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