LM5116 2-Phase Buck

TI reference design number: PMP7282 Rev B

Input: 35V – 60V
Output: 12V @ 50A

DC – DC Test Results

Table of Contents

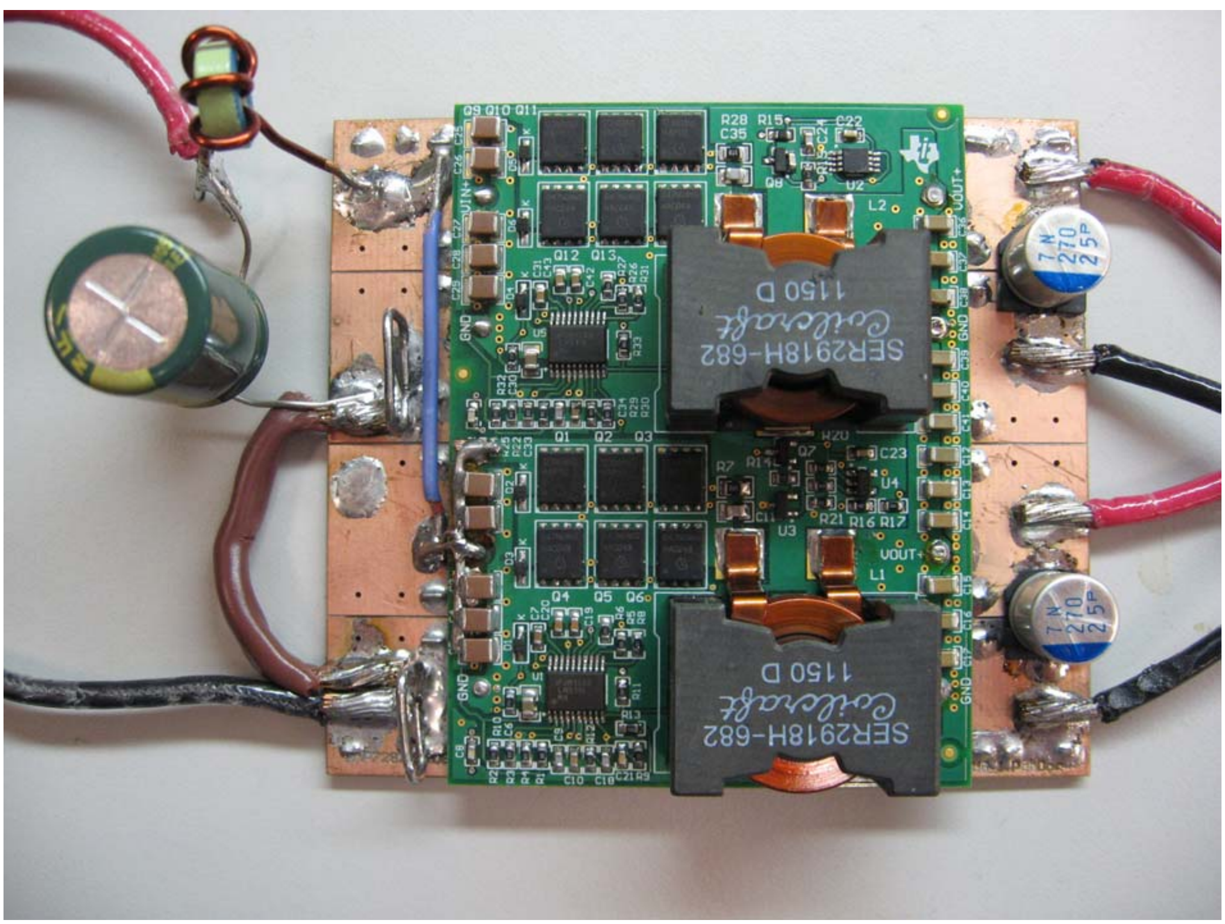
1 Circuit Description

PMP7282 is a 2-phase buck converter capable of 600W output power. This design uses two LM5116 emulated current-mode synchronous buck controllers in a master/slave configuration. An LMC555 timer provides synchronization with 180 degrees between the two phases to minimize input and output ripple current. Current sharing is accomplished using an LMC7101 op amp, which forces the control voltage of the slave to follow that of the master. An LMV431 is used to control a pass regulator for the 5V op amp and timer supply. The LMV431 also provides the reference voltage for the op amp, which matches the internal reference of the LM5116 for proper tracking.

Unless otherwise noted, test results are with Cin = 220 μF, Lin = 0.5 μH and Cout external = 2 x 270 μF.

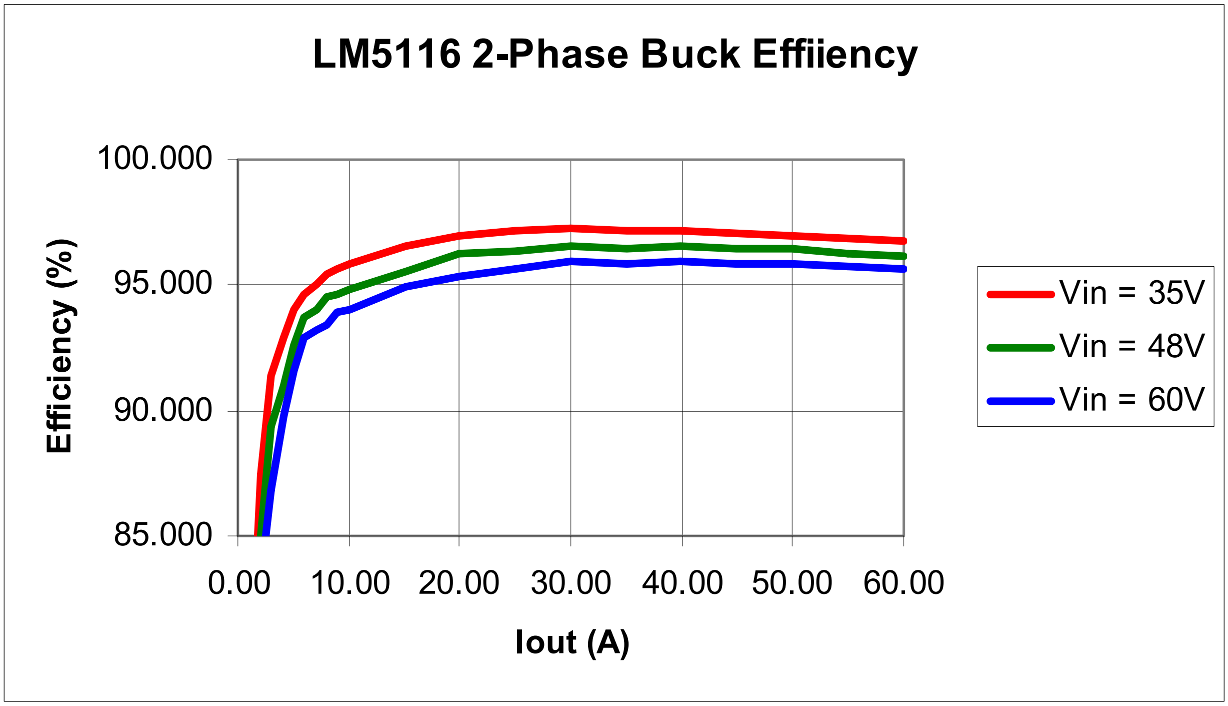
2 Photo

The circuit was built on PMP7282 Rev A printed circuit board. This is a four layer, 2 ounce copper board with overall dimensions of 2.30” x 3.05”, equivalent to two quarter-brick footprints. All components are mounted on the top side of the board.



3 Efficiency

The efficiency data is shown in the graph and tables below.



Vin (V)	Iin (A)	Vout (V)	Iout (A)	Efficiency (%)	Pin (W)	Pout (W)	Losses (W)
34.996	0.11	11.997	0.04	12.466	3.85	0.48	3.37
34.996	0.45	11.996	1.04	79.221	15.75	12.48	3.27
34.996	0.80	11.995	2.04	87.402	28.00	24.47	3.53
34.996	1.14	11.995	3.04	91.401	39.90	36.46	3.43
34.996	1.49	11.994	4.04	92.927	52.14	48.46	3.69
34.996	1.83	11.993	5.02	94.007	64.04	60.20	3.84
34.996	2.18	11.992	6.02	94.627	76.29	72.19	4.10
34.996	2.53	11.992	7.02	95.080	88.54	84.18	4.36
34.996	2.88	11.991	8.02	95.415	100.79	96.17	4.62
34.996	3.23	11.990	9.02	95.676	113.04	108.15	4.89
34.996	3.58	11.989	10.02	95.885	125.29	120.13	5.16
34.996	5.32	11.986	15.00	96.569	186.18	179.79	6.39
34.996	7.06	11.982	20.00	96.992	247.07	239.64	7.43
34.996	8.80	11.978	24.98	97.157	307.96	299.21	8.75
34.996	10.55	11.974	29.98	97.230	369.21	358.98	10.23
34.996	12.31	11.970	34.96	97.138	430.80	418.47	12.33
34.996	14.07	11.967	39.96	97.118	492.39	478.20	14.19
34.996	15.83	11.963	44.94	97.045	553.99	537.62	16.37
34.997	17.61	11.958	49.96	96.937	616.30	597.42	18.88
34.997	19.38	11.954	54.96	96.867	678.24	656.99	21.25
34.998	21.16	11.950	59.94	96.722	740.56	716.28	24.27

Vin (V)	Iin (A)	Vout (V)	Iout (A)	Efficiency (%)	Pin (W)	Pout (W)	Losses (W)
47.997	0.10	11.997	0.04	9.998	4.80	0.48	4.32
47.997	0.35	11.996	1.04	74.266	16.80	12.48	4.32
47.997	0.60	11.996	2.04	84.977	28.80	24.47	4.33
47.997	0.85	11.995	3.04	89.380	40.80	36.46	4.33
47.997	1.11	11.994	4.04	90.951	53.28	48.46	4.82
47.997	1.36	11.993	5.04	92.599	65.28	60.44	4.83
47.997	1.61	11.993	6.04	93.740	77.28	72.44	4.84
47.997	1.87	11.992	7.04	94.061	89.75	84.42	5.33
47.997	2.12	11.991	8.02	94.510	101.75	96.17	5.59
47.996	2.38	11.990	9.02	94.677	114.23	108.15	6.08
47.996	2.64	11.990	10.02	94.815	126.71	120.14	6.57
47.996	3.92	11.986	15.00	95.560	188.14	179.79	8.35
47.995	5.19	11.982	20.00	96.205	249.09	239.64	9.45
47.994	6.47	11.979	24.98	96.366	310.52	299.24	11.29
47.993	7.75	11.975	29.98	96.522	371.95	359.01	12.94
47.992	9.04	11.971	34.96	96.464	433.85	418.51	15.34
47.991	10.32	11.967	39.96	96.554	495.27	478.20	17.07
47.989	11.62	11.963	44.96	96.454	557.63	537.86	19.78
47.987	12.92	11.959	49.98	96.406	619.99	597.71	22.28
47.985	14.22	11.955	54.96	96.292	682.35	657.05	25.30
47.983	15.53	11.950	59.96	96.155	745.18	716.52	28.65

Vin (V)	Iin (A)	Vout (V)	Iout (A)	Efficiency (%)	Pin (W)	Pout (W)	Losses (W)
59.997	0.09	11.998	0.04	8.888	5.40	0.48	4.92
59.997	0.29	11.997	1.04	71.710	17.40	12.48	4.92
59.997	0.49	11.996	2.04	83.242	29.40	24.47	4.93
59.996	0.70	11.995	3.04	86.827	42.00	36.46	5.53
59.996	0.90	11.994	4.04	89.739	54.00	48.46	5.54
59.996	1.10	11.994	5.04	91.597	66.00	60.45	5.55
59.996	1.30	11.992	6.04	92.867	77.99	72.43	5.56
59.996	1.51	11.992	7.04	93.189	90.59	84.42	6.17
59.996	1.72	11.991	8.04	93.424	103.19	96.41	6.79
59.996	1.92	11.991	9.02	93.894	115.19	108.16	7.03
59.996	2.13	11.990	10.02	94.012	127.79	120.14	7.65
59.995	3.16	11.986	15.02	94.960	189.58	180.03	9.55
59.994	4.19	11.983	20.00	95.340	251.37	239.66	11.71
59.994	5.22	11.979	25.00	95.627	313.17	299.48	13.69
59.993	6.24	11.975	29.98	95.901	374.36	359.01	15.35
59.992	7.28	11.971	34.98	95.879	436.74	418.75	18.00
59.991	8.31	11.967	39.96	95.923	498.53	478.20	20.32
59.991	9.35	11.963	44.96	95.889	560.92	537.86	23.06
59.990	10.40	11.959	49.98	95.803	623.90	597.71	26.19
59.989	11.44	11.955	54.96	95.741	686.27	657.05	29.23
59.989	12.49	11.950	59.96	95.630	749.26	716.52	32.74

4 Thermal Test Summary

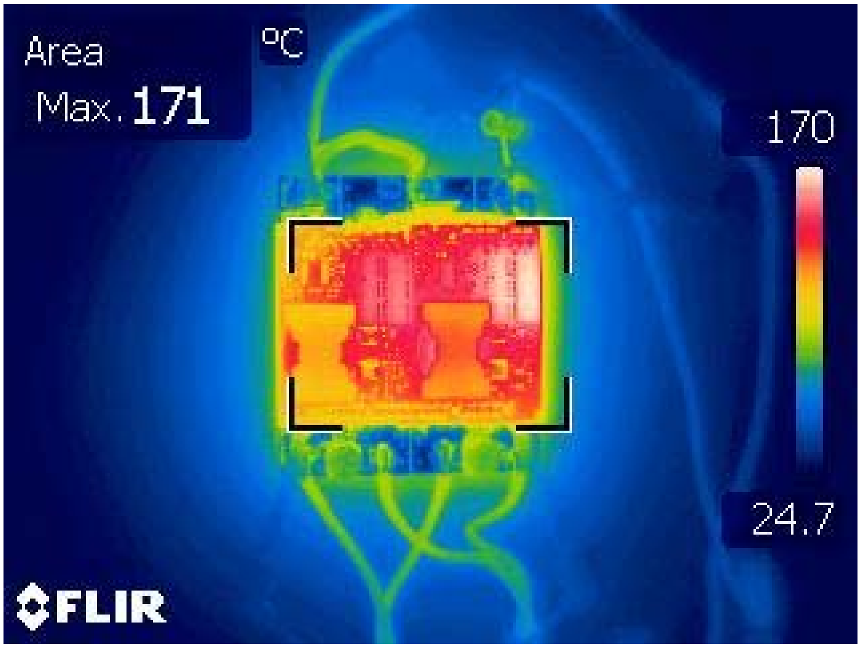
Thermal tests were performed at 25°C ambient. Test conditions are 48V input with 50A load. The test setup and summary of the temperature measurements are shown in the picture and table below.

Airflow (LFM)	PC Board (°C)	Bottom LM5116 (°C)	Bottom MOSFETs (°C)	Bottom Inductor Winding (°C)	Top LM5116 (°C)	Top MOSFETs (°C)	Top Inductor Winding (°C)
1 hour soak time							
0	171	139	161	157	157	176	168
20 minute soak time							
200	126	91.3	113	110	106	129	120
20 minute soak time							
400	105	81.4	98.1	90.5	89.1	105	98.6

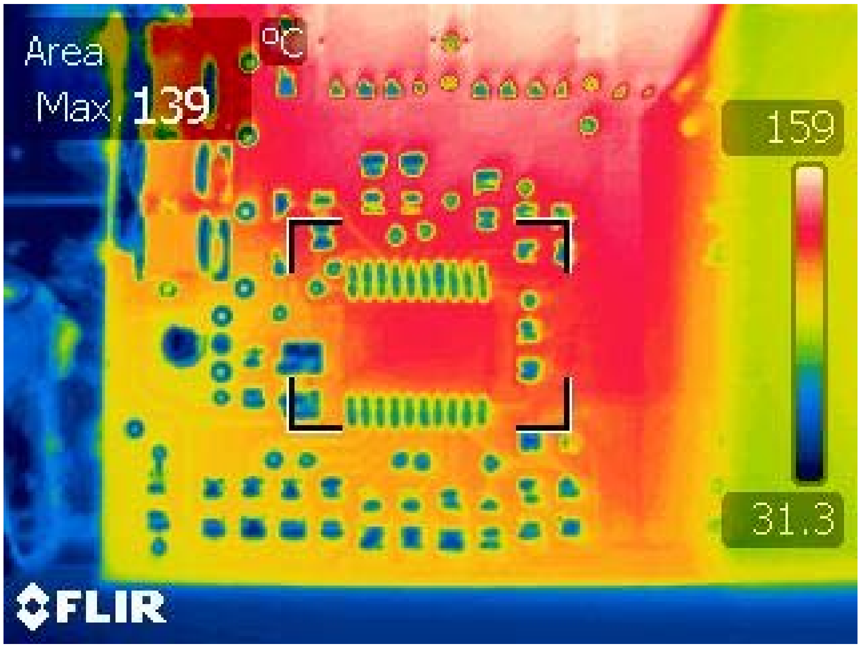
5 Thermal Images – No Airflow

The thermal images show the top view of the board at 25°C ambient with no airflow. Test conditions are 48V input with 50A load.

5.1 PC Board – No Airflow



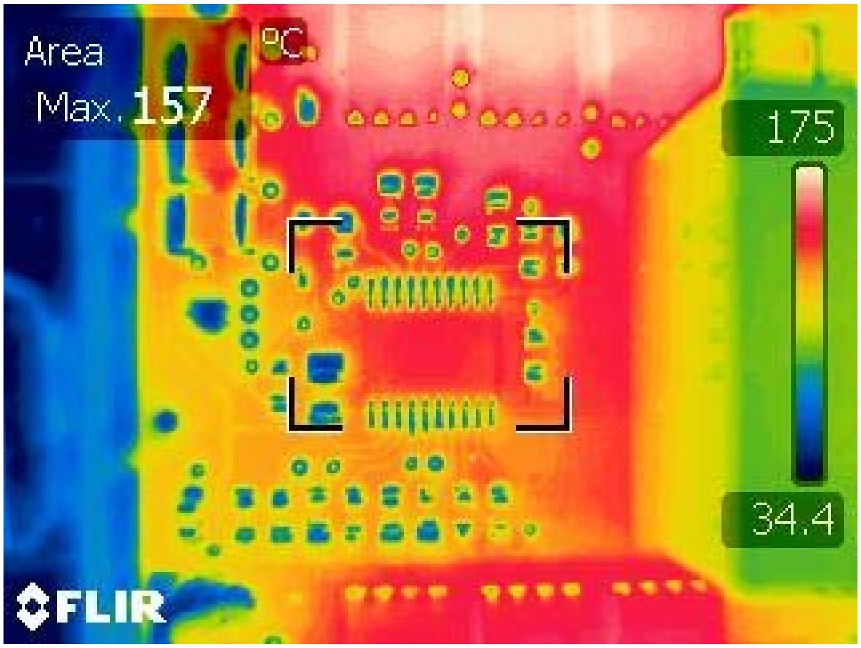
5.2 Bottom LM5116 – No Airflow



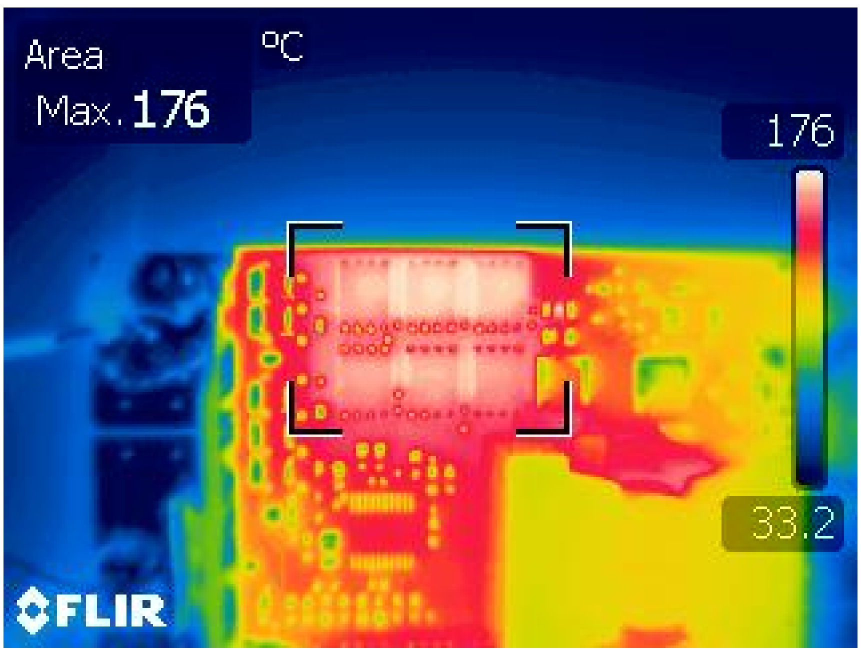
5.3 Bottom MOSFETs – No Airflow

5.4 Bottom Inductor Winding – No Airflow

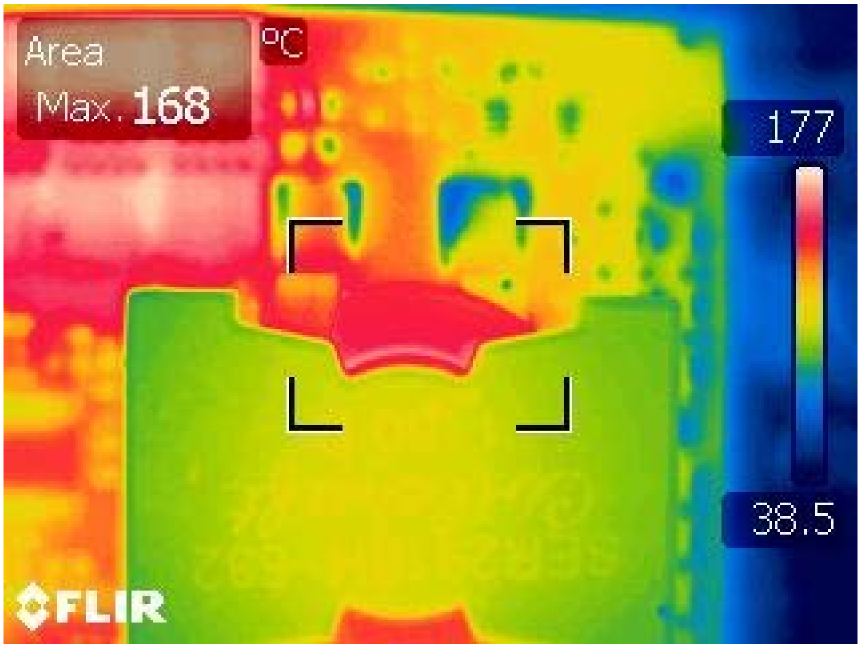
5.5 Top LM5116 – No Airflow



5.6 Top MOSFETs – No Airflow



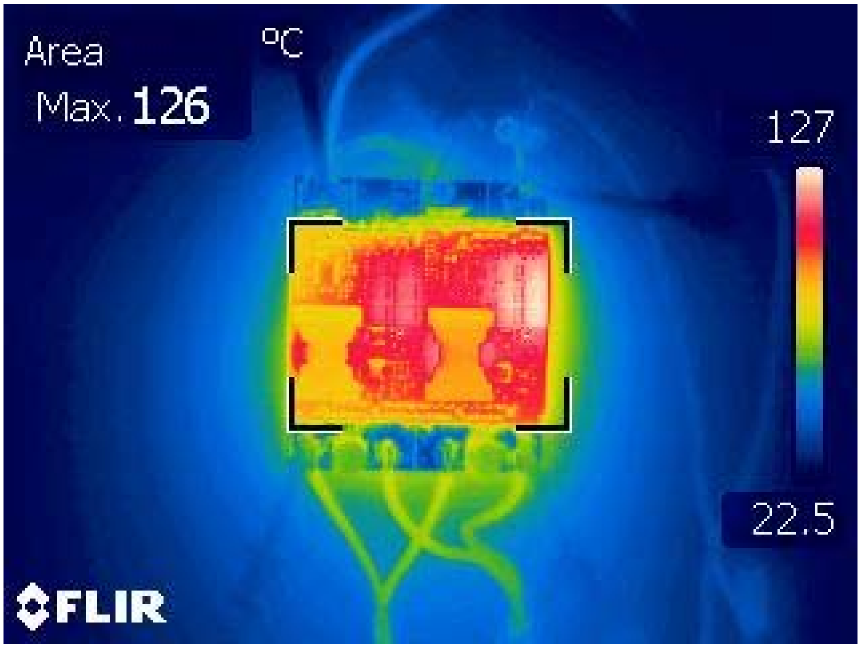
5.7 Top Inductor Winding – No Airflow



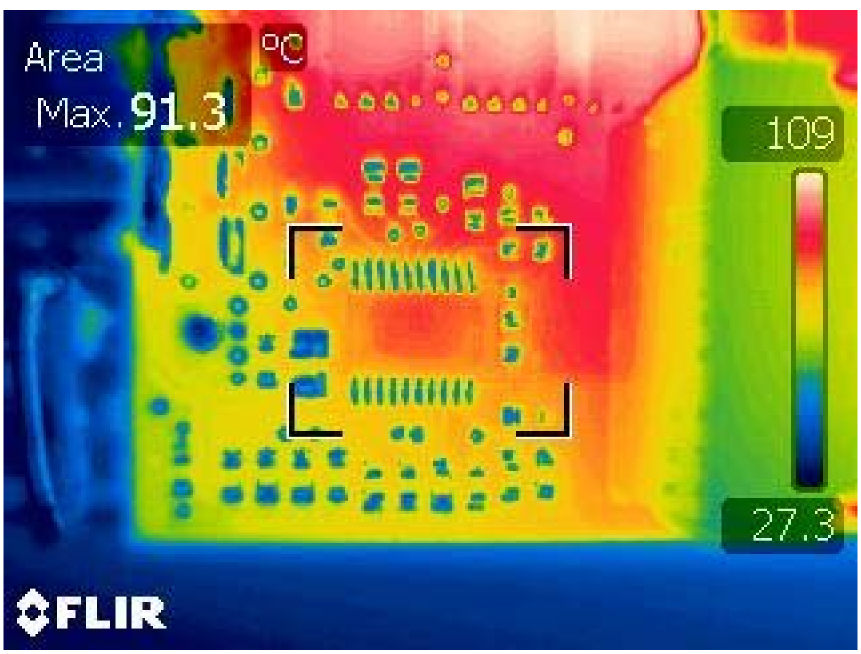
6 Thermal Images – 200 LFM

The thermal images show the top view of the board at 25°C ambient with 200 linear feet per minute airflow. Test conditions are 48V input with 50A load.

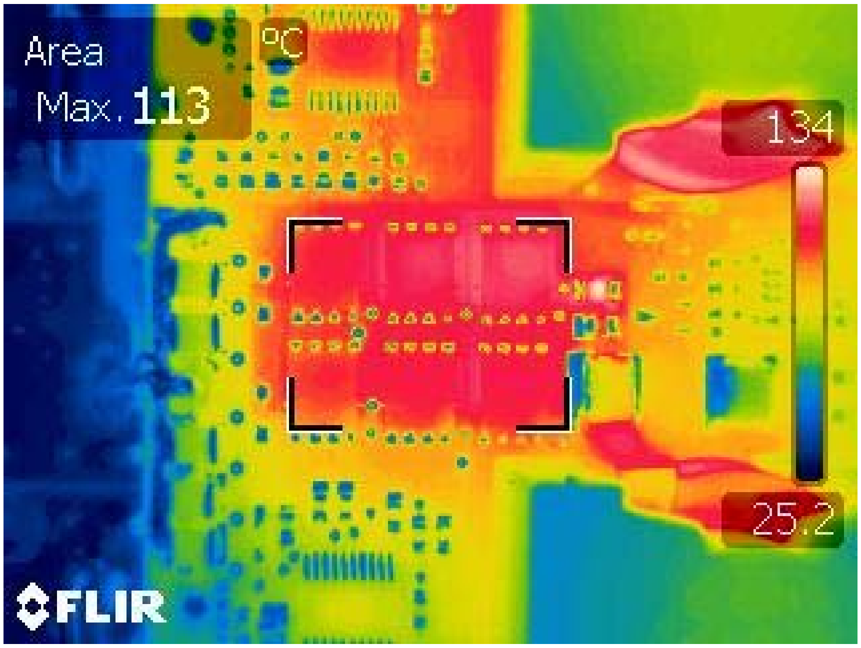
6.1 PC Board – 200 LFM



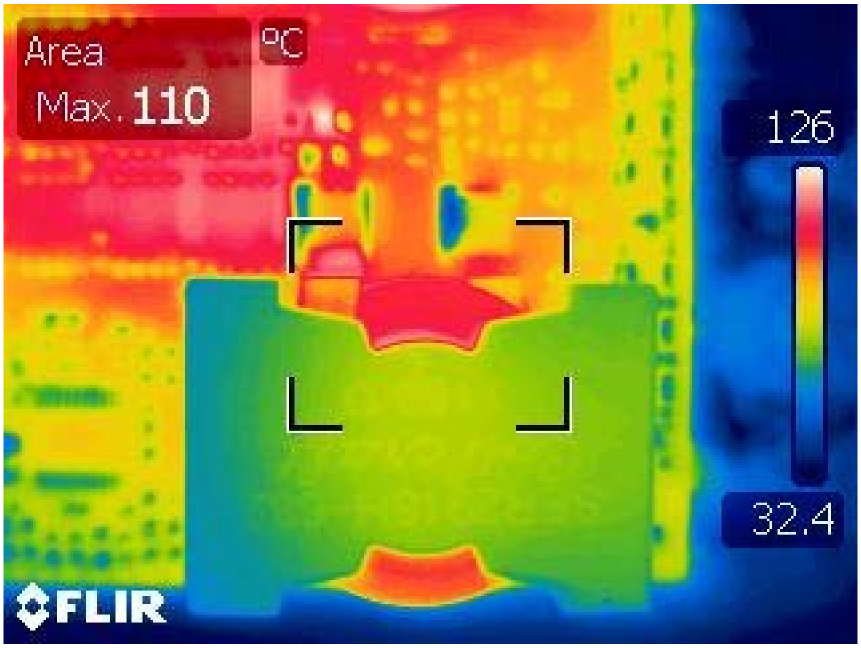
6.2 Bottom LM5116 – 200 LFM



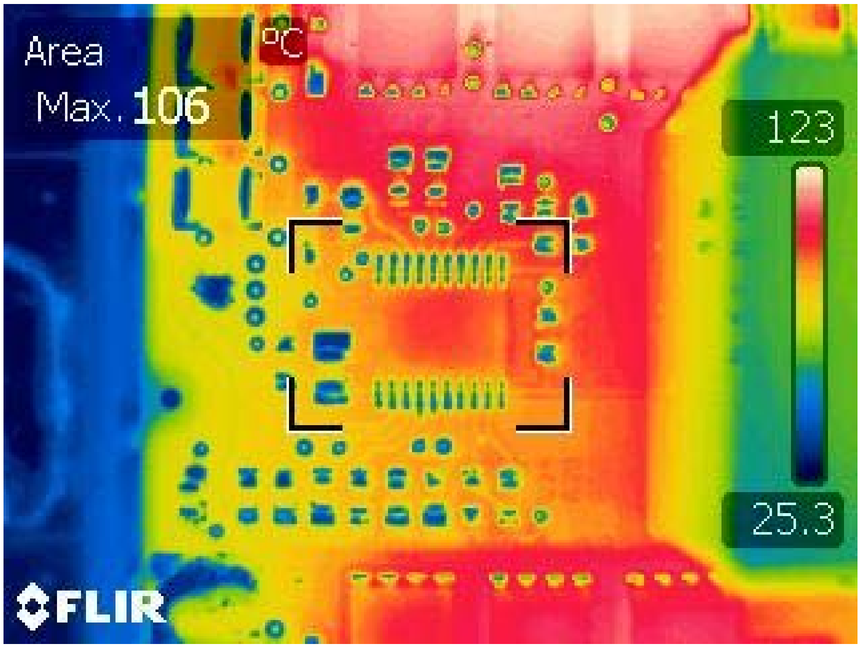
6.3 Bottom MOSFETs – 200 LFM



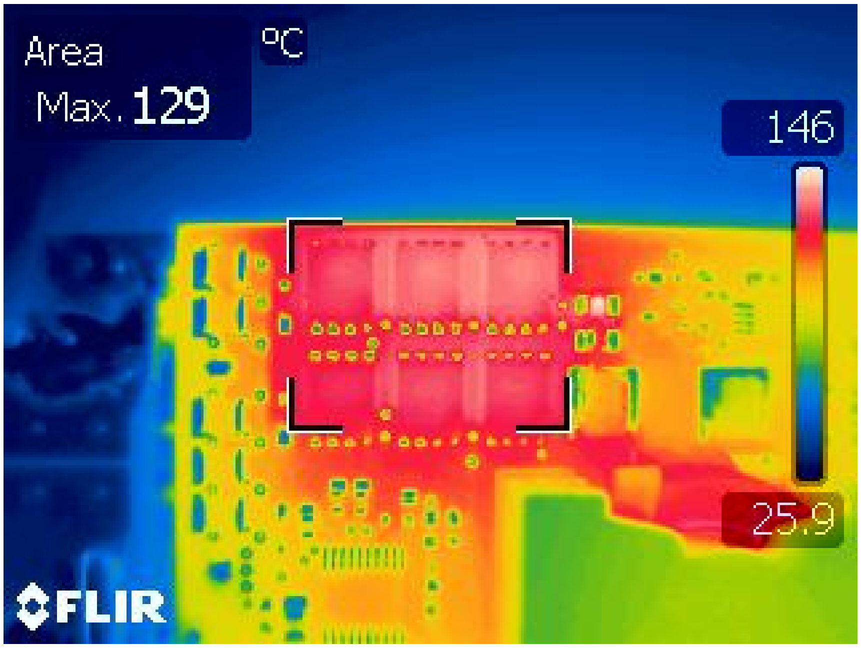
6.4 Bottom Inductor Winding – 200 LFM



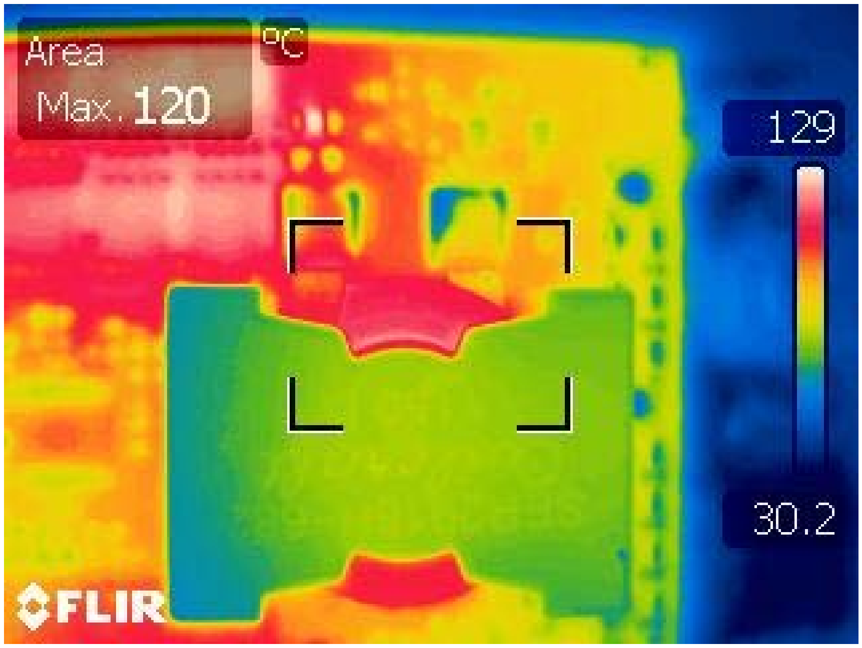
6.5 Top LM5116 – 200 LFM



6.6 Top MOSFETs – 200 LFM



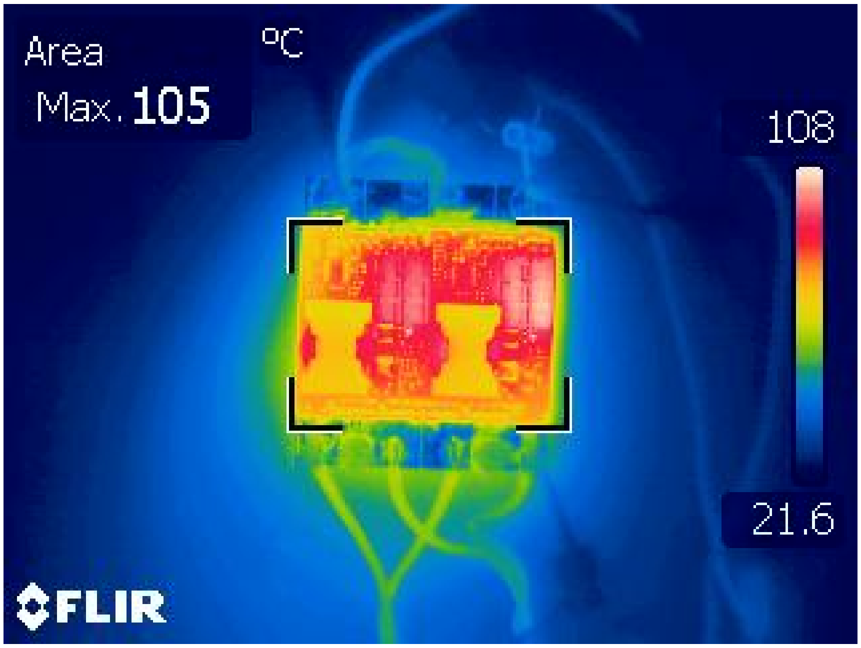
6.7 Top Inductor Winding – 200 LFM



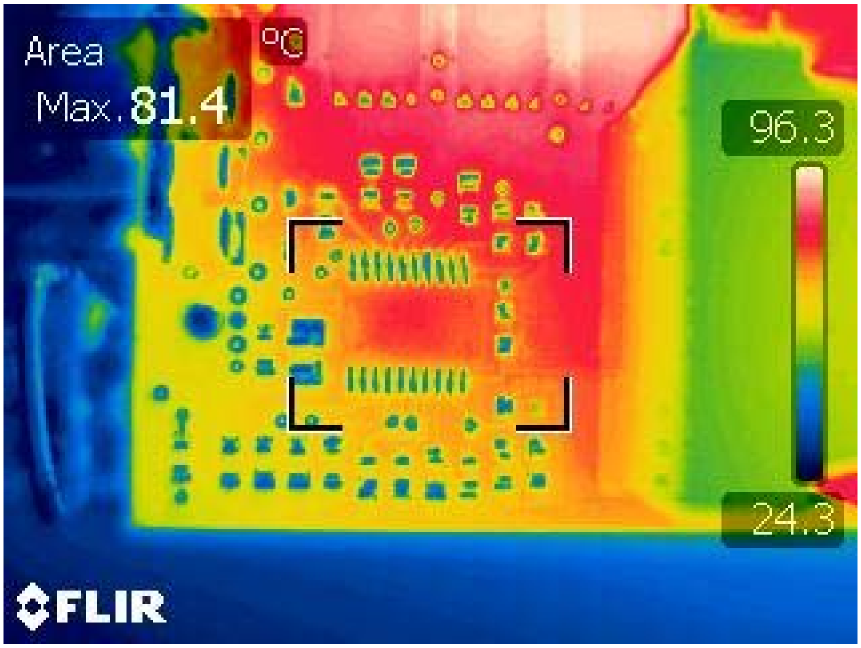
7 Thermal Images – 400 LFM

The thermal images show the top view of the board at 25°C ambient with 400 linear feet per minute airflow. Test conditions are 48V input with 50A load.

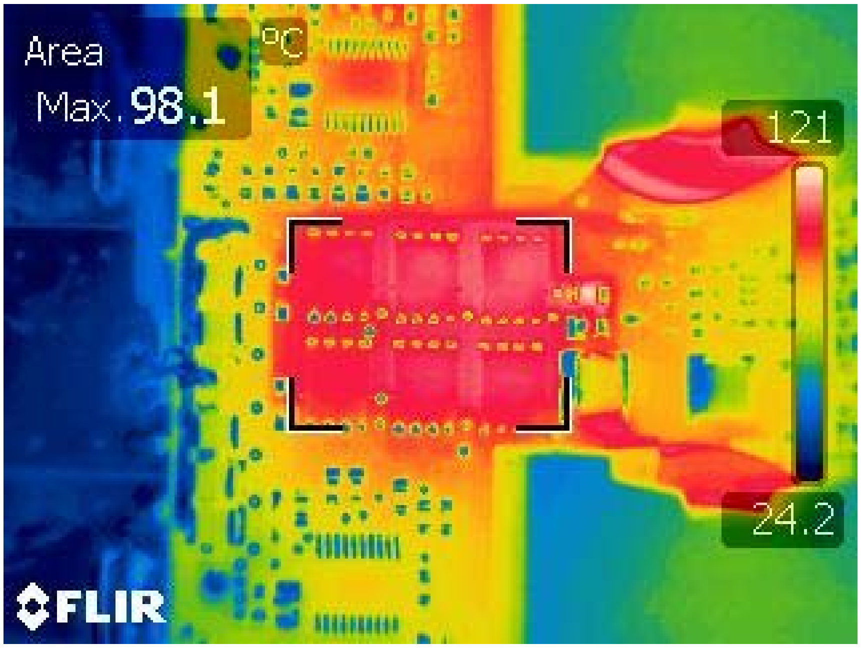
7.1 PC Board – 400 LFM



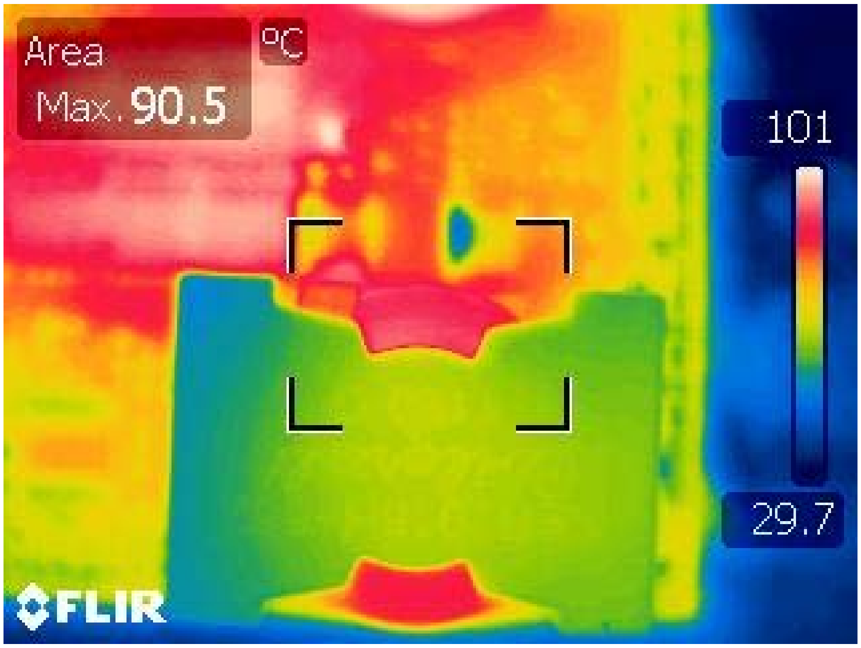
7.2 Bottom LM5116 – 400 LFM



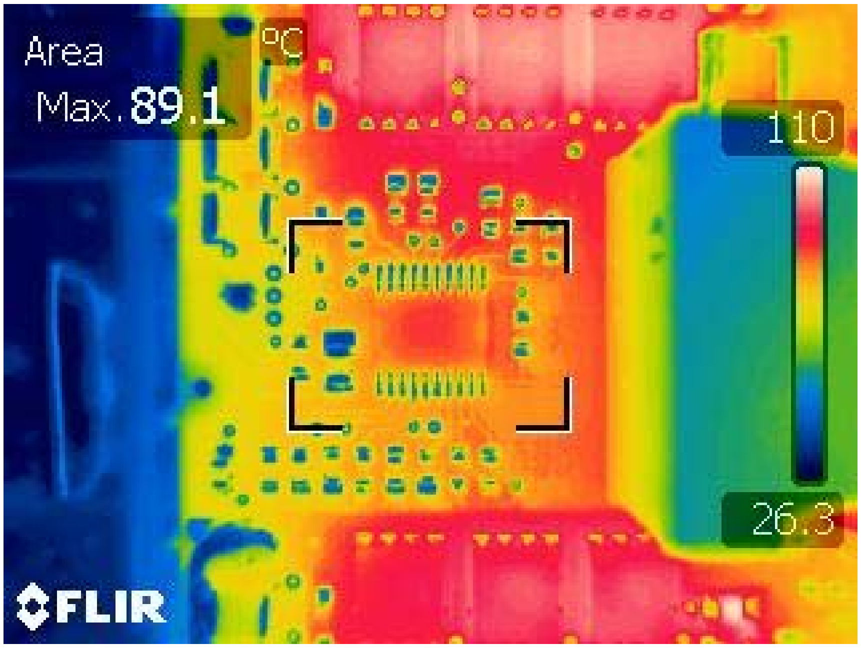
7.3 Bottom MOSFETs – 400 LFM



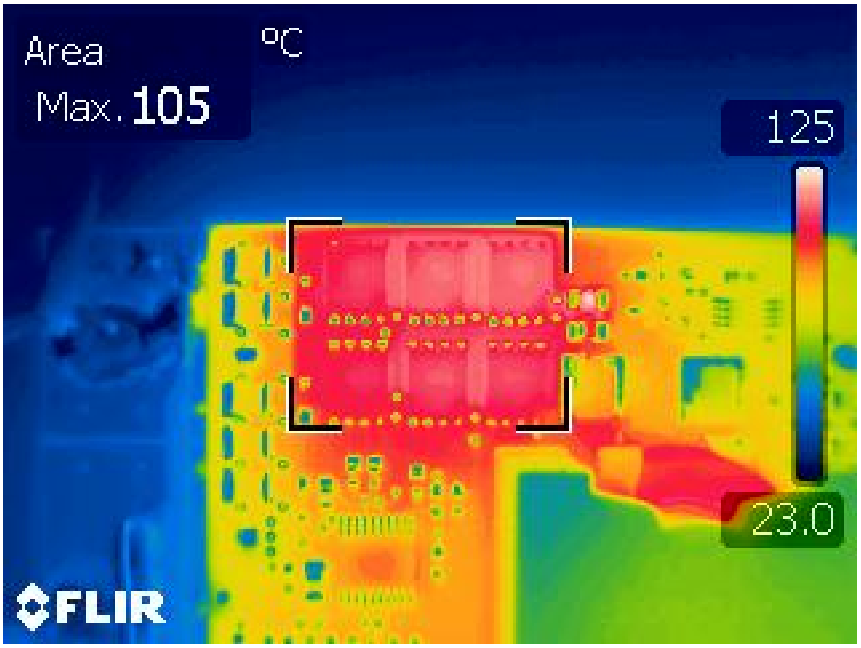
7.4 Bottom Inductor Winding – 400 LFM



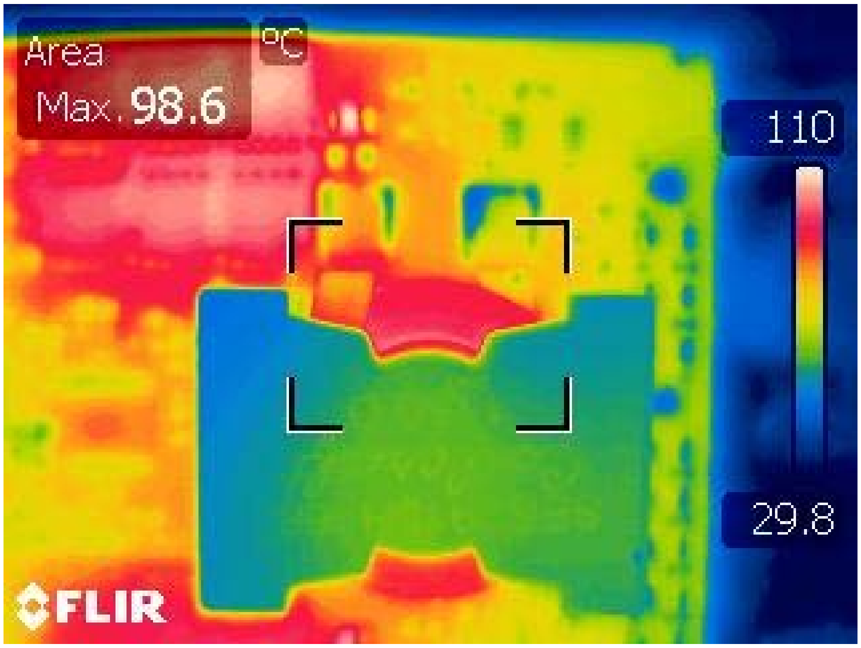
7.5 Top LM5116 – 400 LFM



7.6 Top MOSFETs – 400 LFM

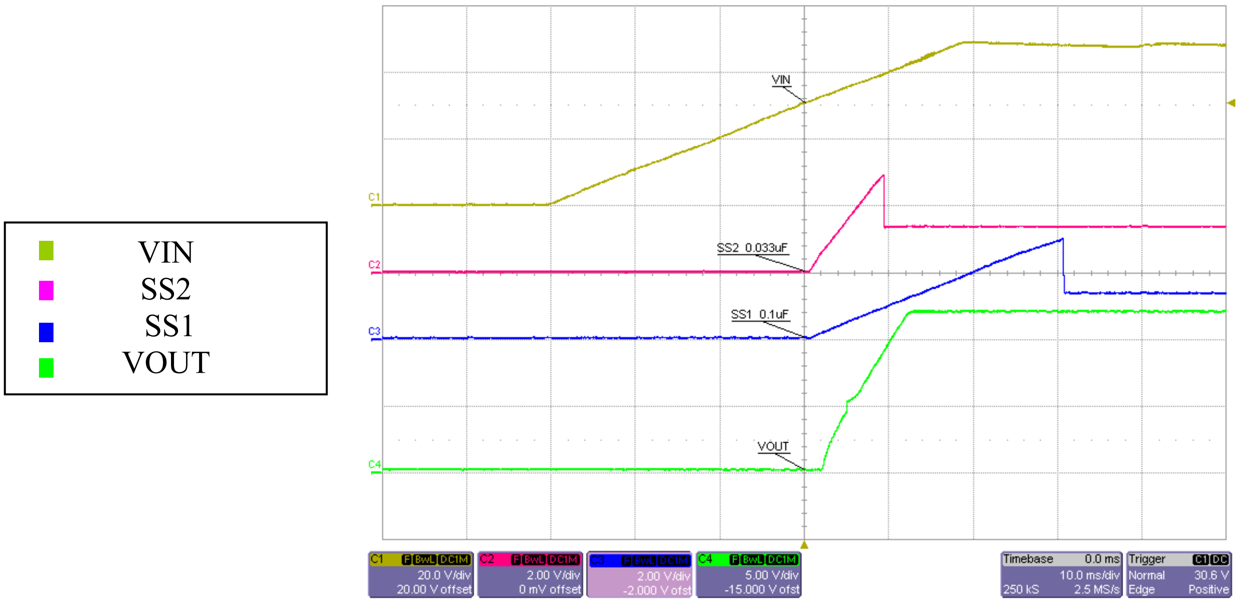


7.7 Top Inductor Winding – 400 LFM

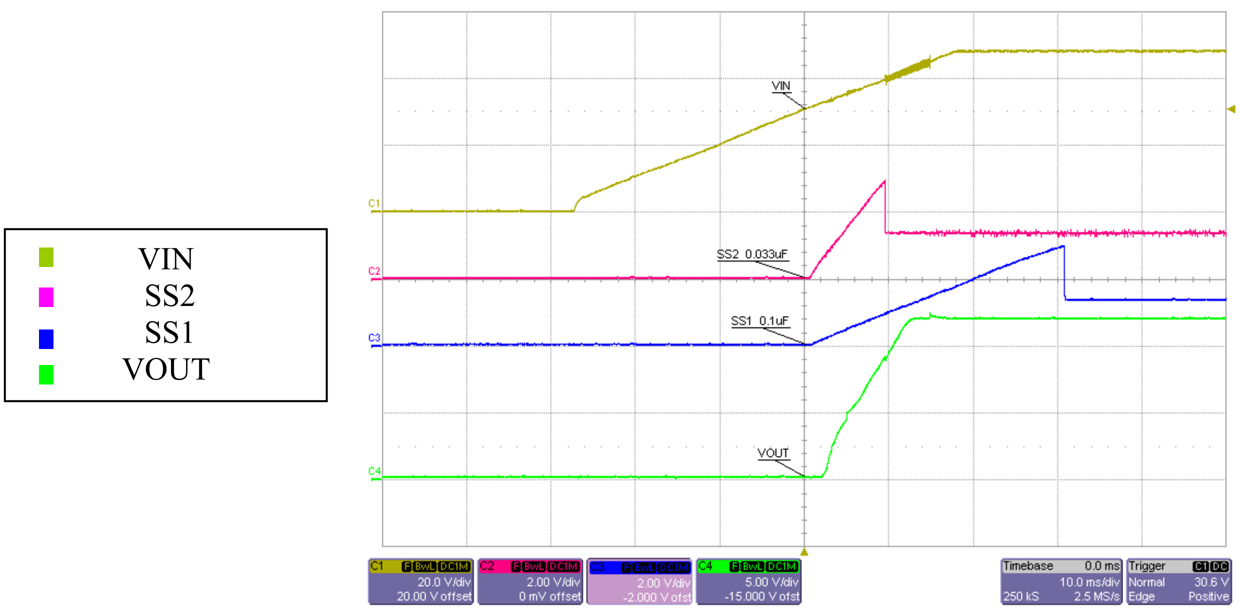


8 Power Up and Power Down

8.1 Power Up at 48V Input – No Load

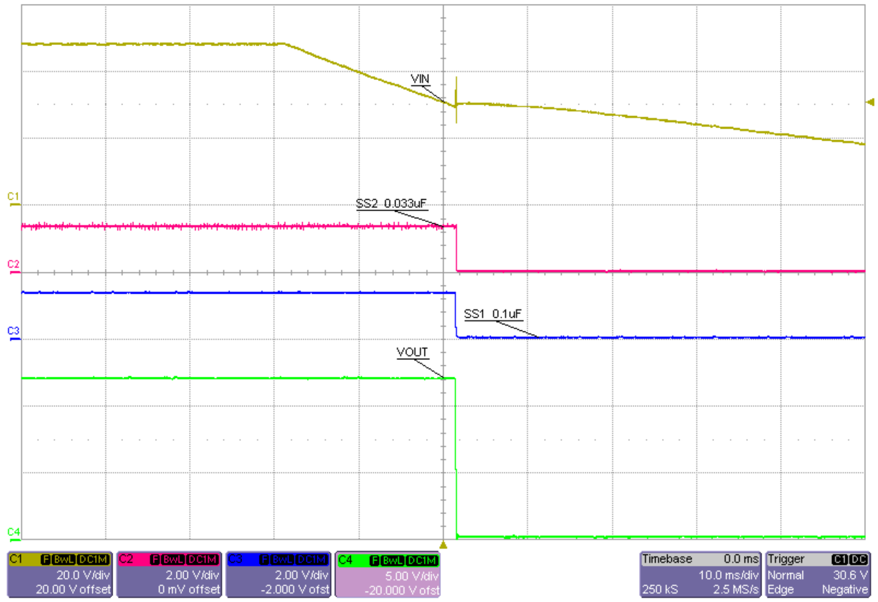


8.2 Power Up at 48V Input – 50A Load



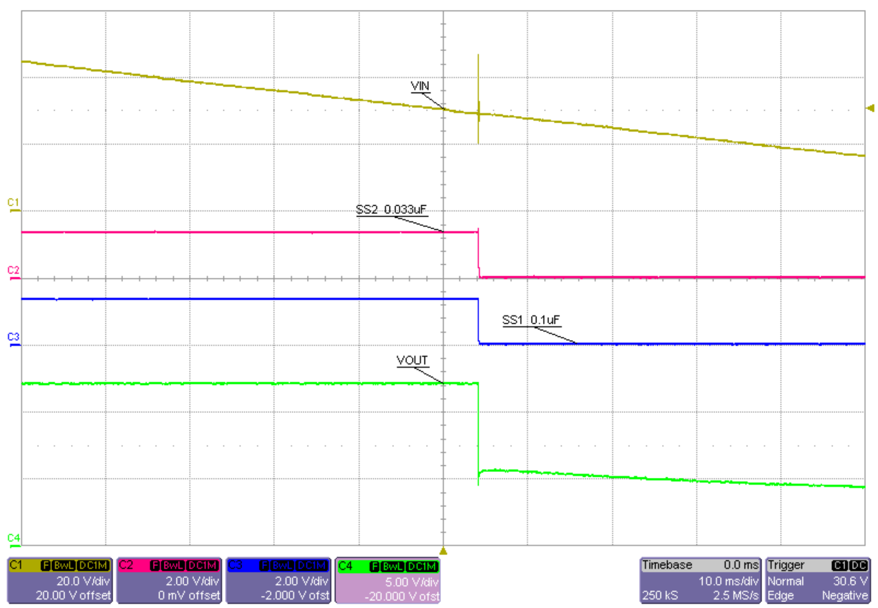
8.3 Power Down at 48V Input – 50A Load

VIN
SS2
SS1
VOUT



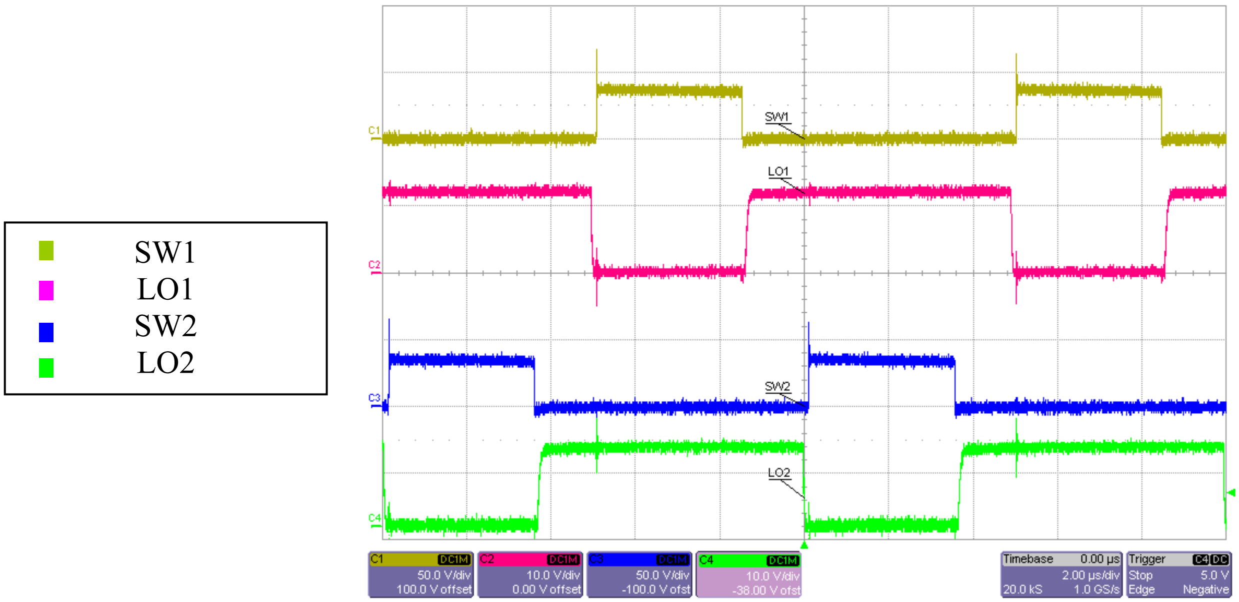
8.4 Power Down at 48V Input – No Load

VIN
SS2
SS1
VOUT

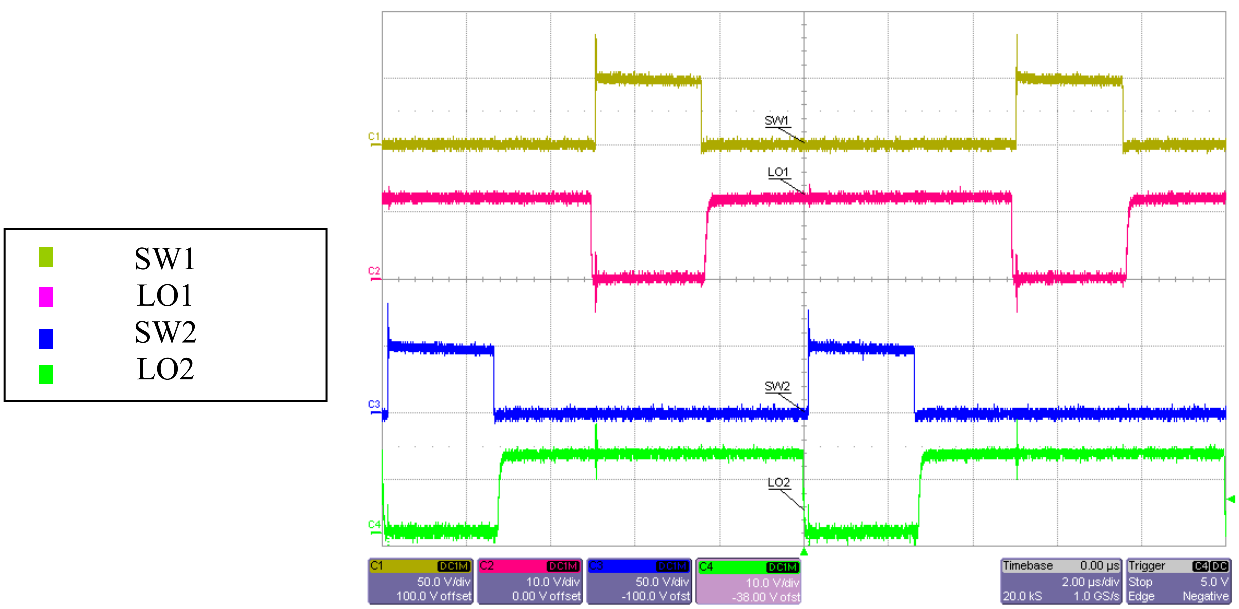


9 Switching

9.1 35V Input – 50A Load

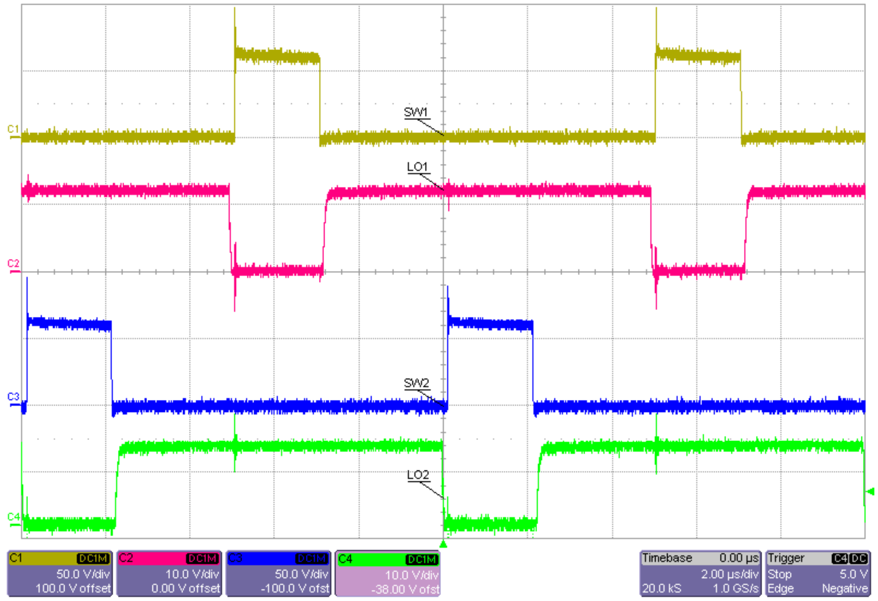


9.2 48V Input – 50A Load



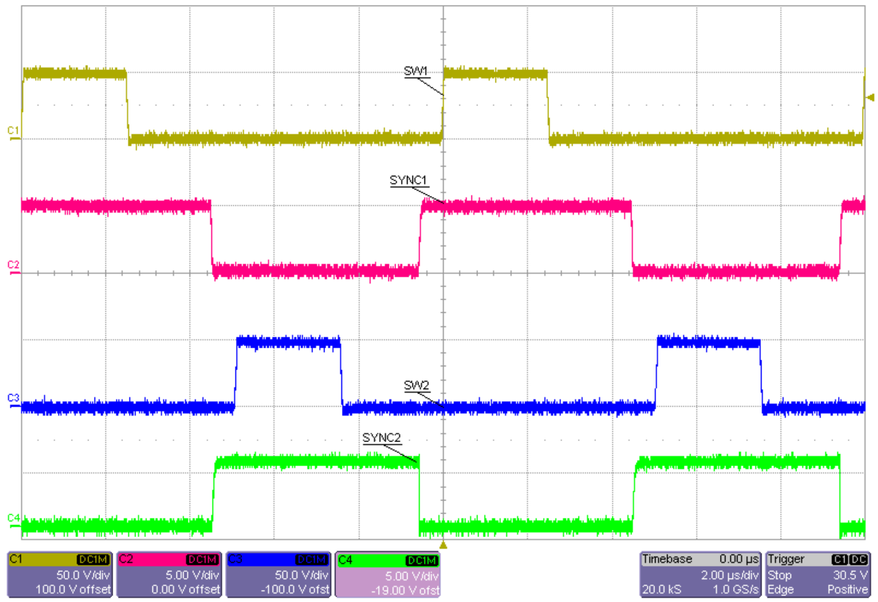
9.3 60V Input – 50A Load

SW1
LO1
SW2
LO2



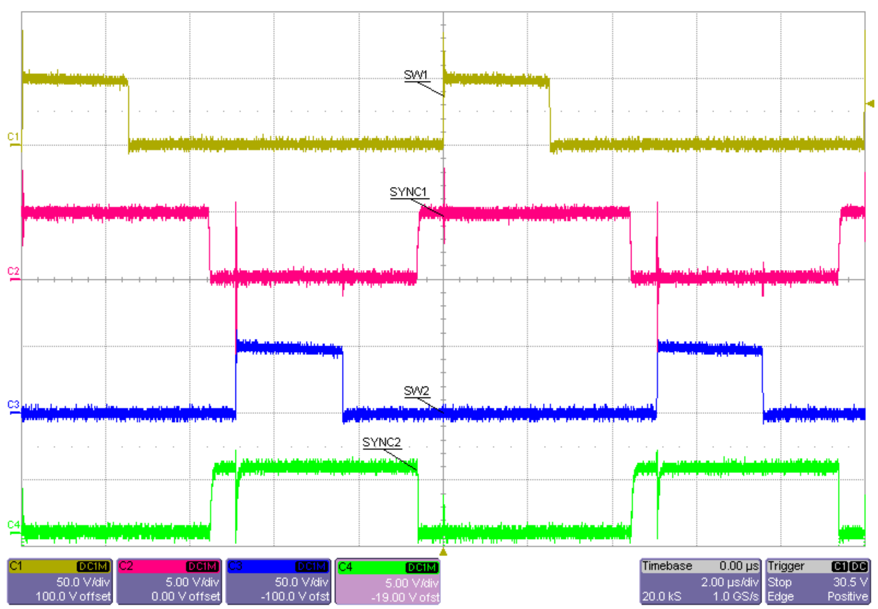
10 Synchronization

10.1 48V Input – No Load



SW1
SYNC1
SW2
SYNC2

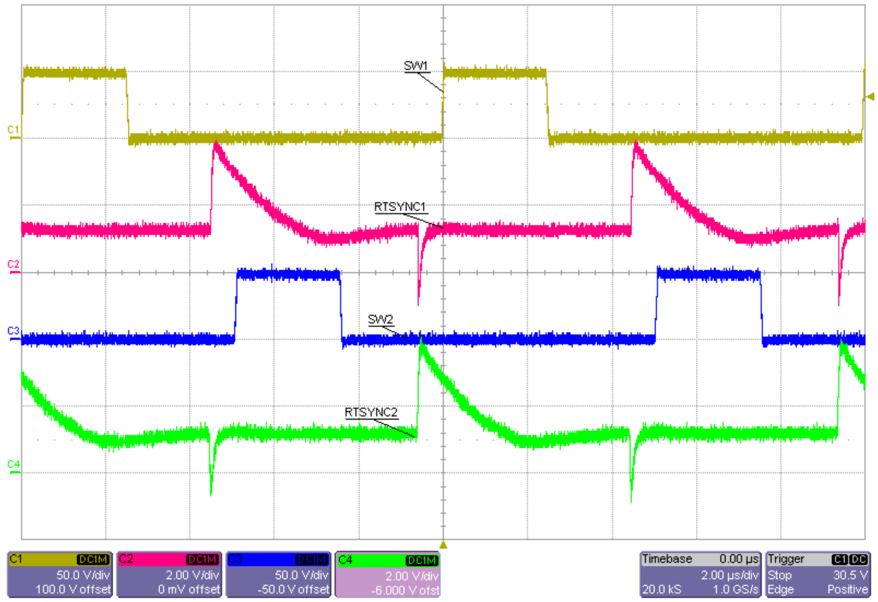
10.2 48V Input – 50A Load



SW1
SYNC1
SW2
SYNC1

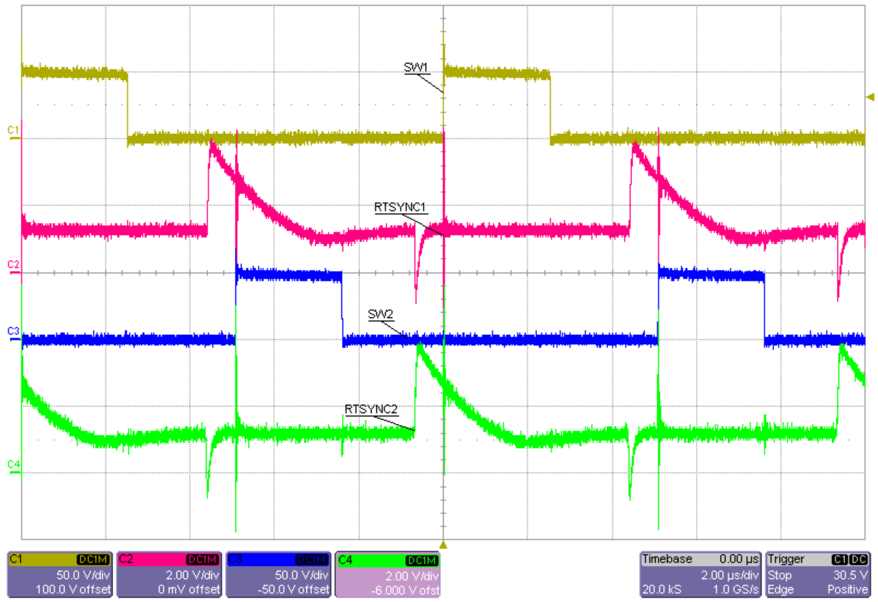
10.3 48V Input – No Load

SW1
RTSYNC1
SW2
RTSYNC2



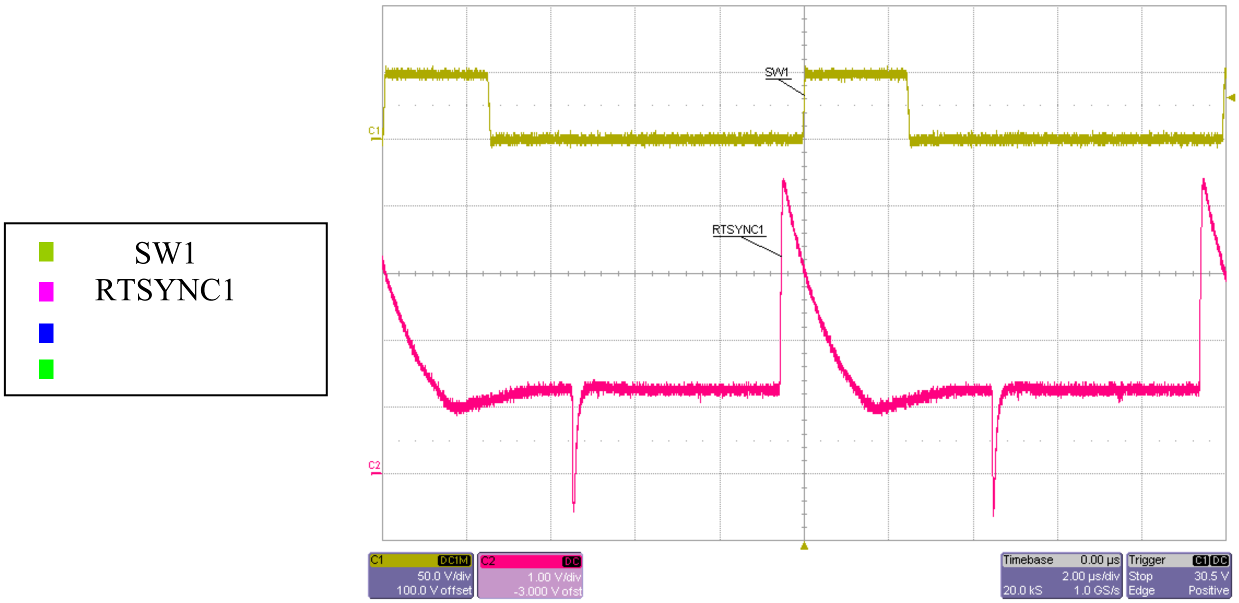
10.4 48V Input – 50A Load

SW1
RTSYNC1
SW2
RTSYNC2



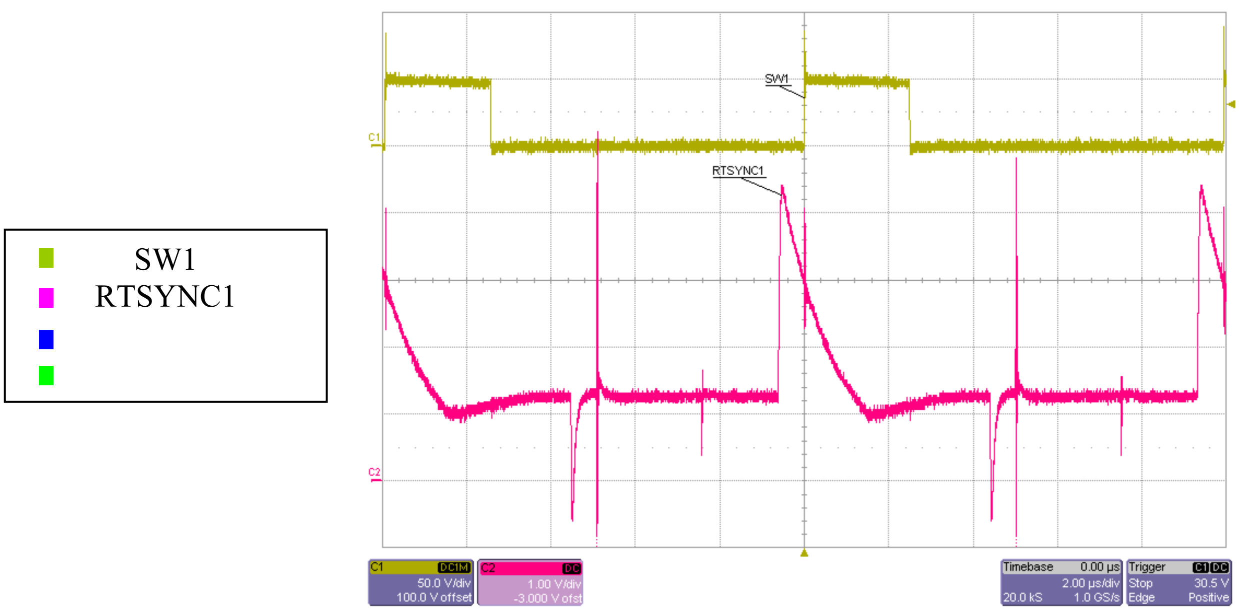
10.5 48V Input – No Load

RTSYNC1 measured with 1.8 pF AP020 probe



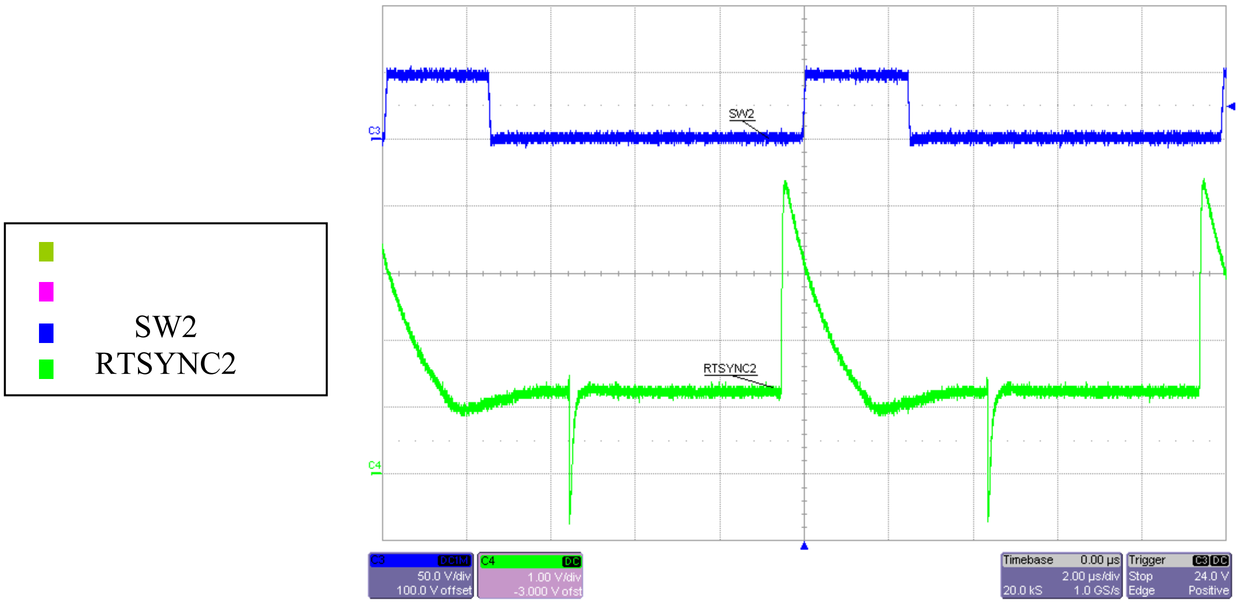
10.6 48V Input – 50A Load

RTSYNC1 measured with 1.8 pF AP020 probe



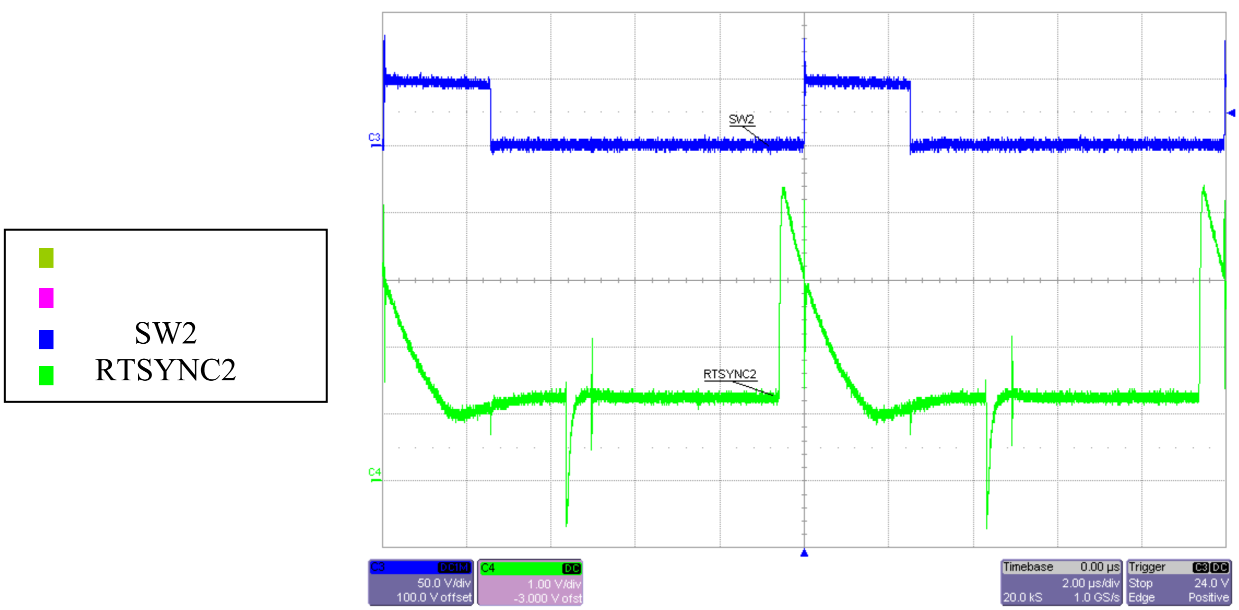
10.7 48V Input – No Load

RTSYNC2 measured with 1.8 pF AP020 probe



10.8 48V Input – 50A Load

RTSYNC2 measured with 1.8 pF AP020 probe

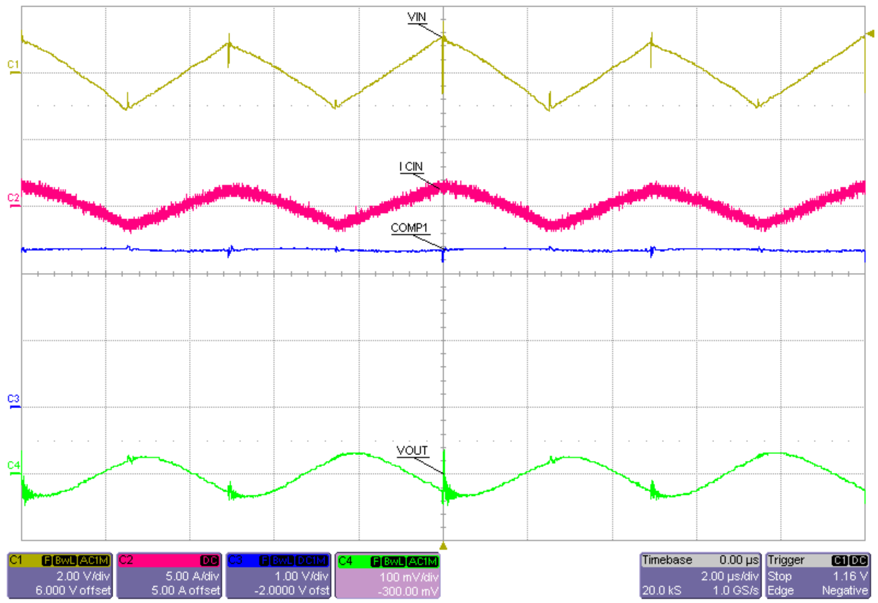


11 Ripple Voltage and Current

11.1 48V Input – 50A Load

Cin = 220 µF + 0.5Ω damping resistor, Lin = 0 µH

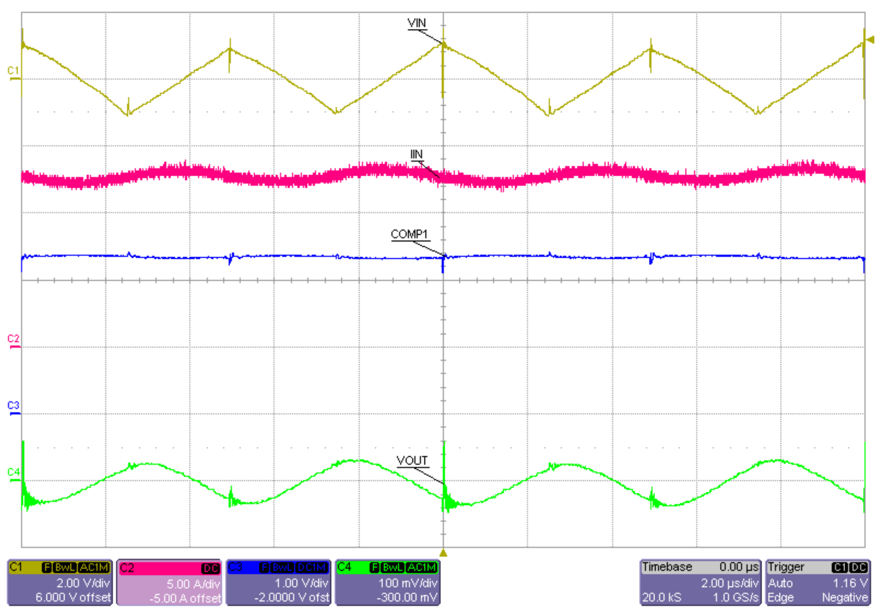
VIN
I CIN
COMP1
VOUT



11.2 48V Input – 50A Load

Cin = 220 µF + 0.5Ω damping resistor, Lin = 0 µH

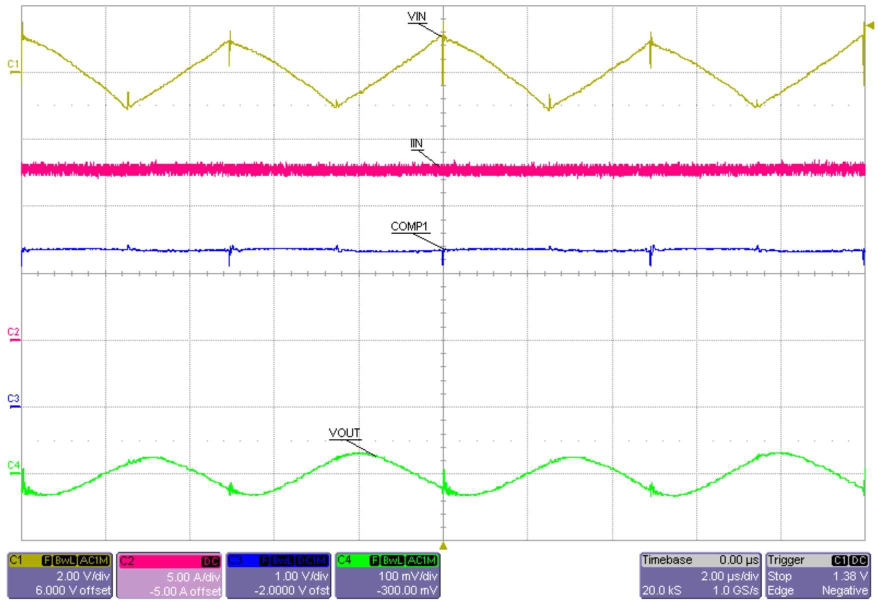
VIN
IIN
COMP1
VOUT



11.3 48V Input – 50A Load

Cin = 220 µF, Lin = 0.5 µH

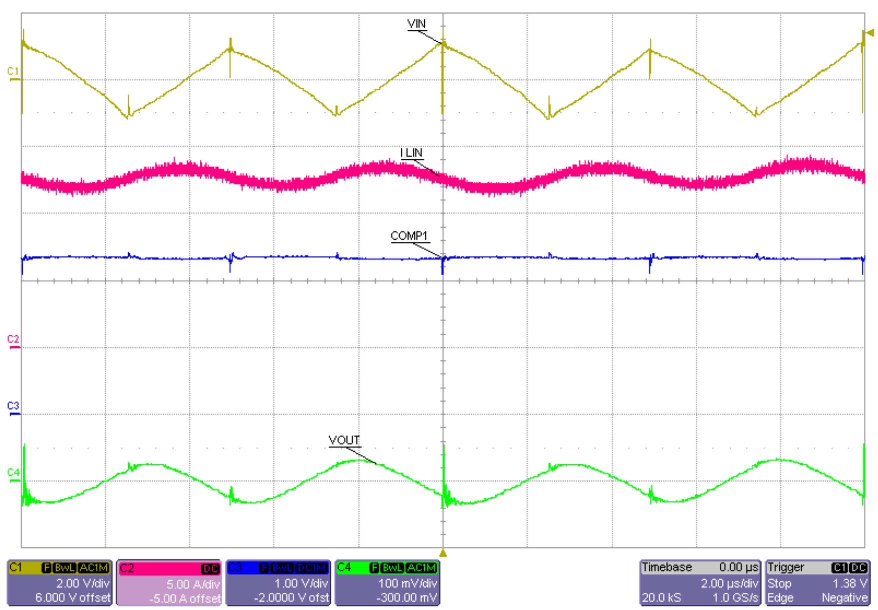
VIN
IIN
COMP1
VOUT



11.4 48V Input – 50A Load

Cin = 220 µF, Lin = 0.5 µH

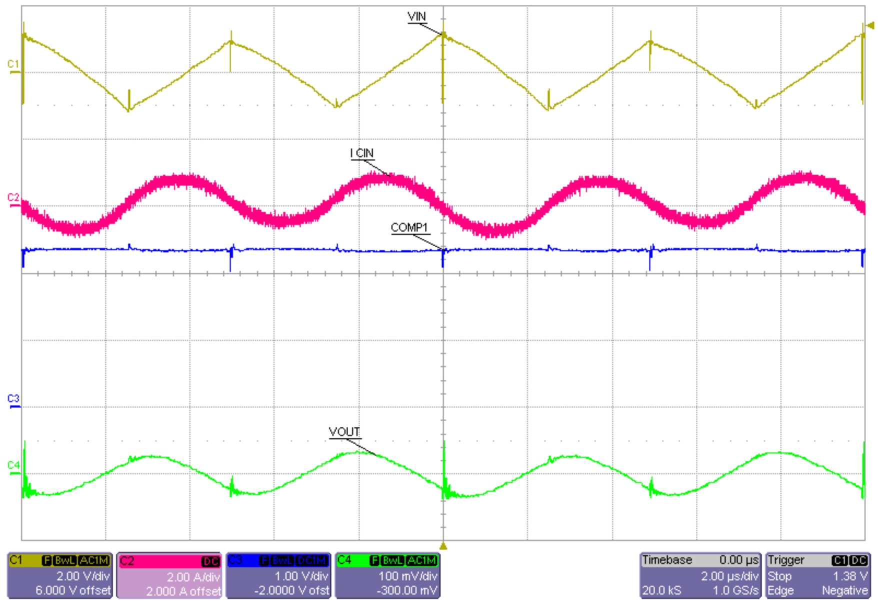
VIN
I LIN
COMP1
VOUT



11.5 48V Input – 50A Load

Cin = 220 µF, Lin = 0.5 µH

VIN
I CIN
COMP1
VOUT

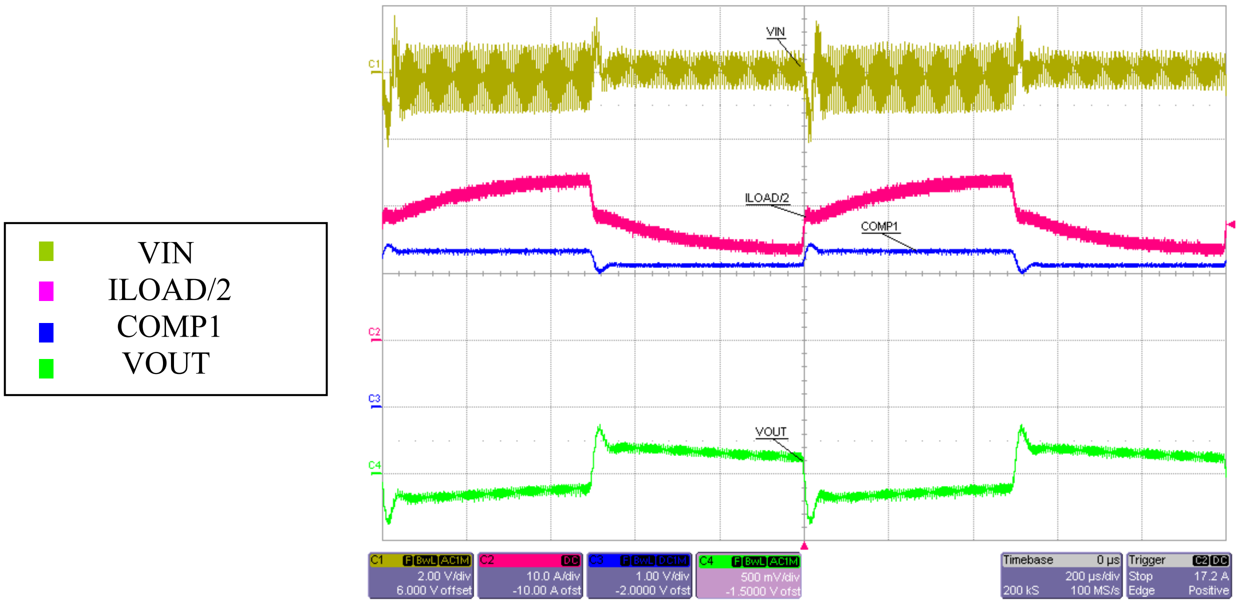


12 Transient Response with Rcomp = 7.5 kΩ (Rev A)

Using Rcomp = 7.5 kΩ allows for higher bandwidth and faster transient response, but requires the use of external capacitors for stability.

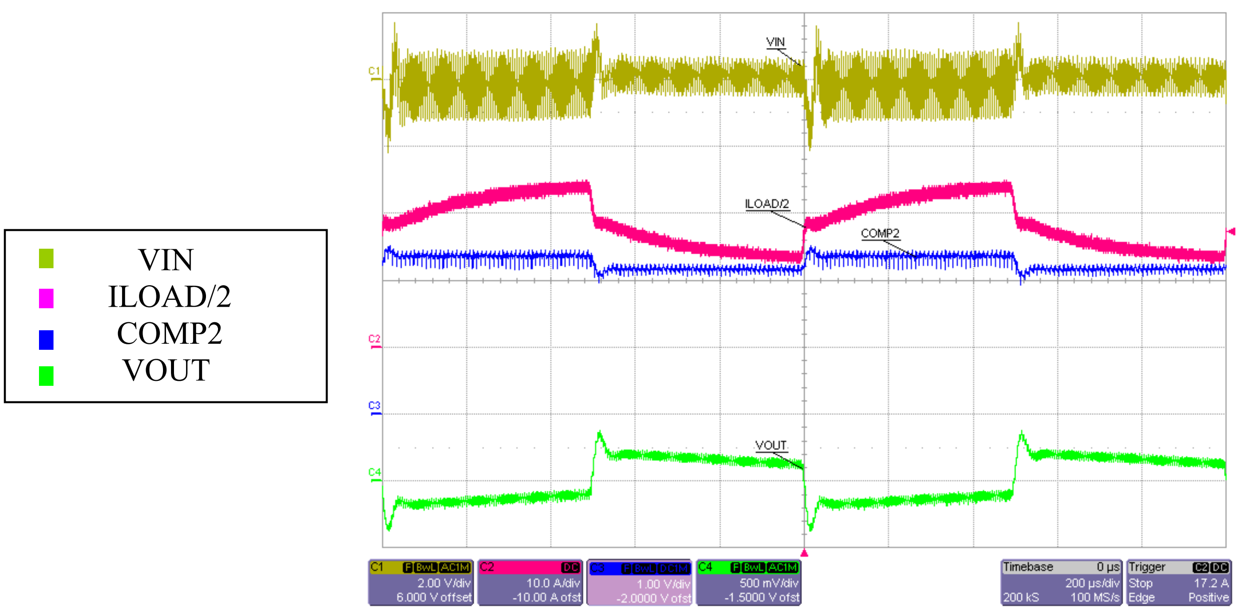
12.1 48V Input – 25A Load Step

Cin = 220 µF + 0.5Ω damping resistor, Lin = 0 µH, Cout external = 2 x 270 µF



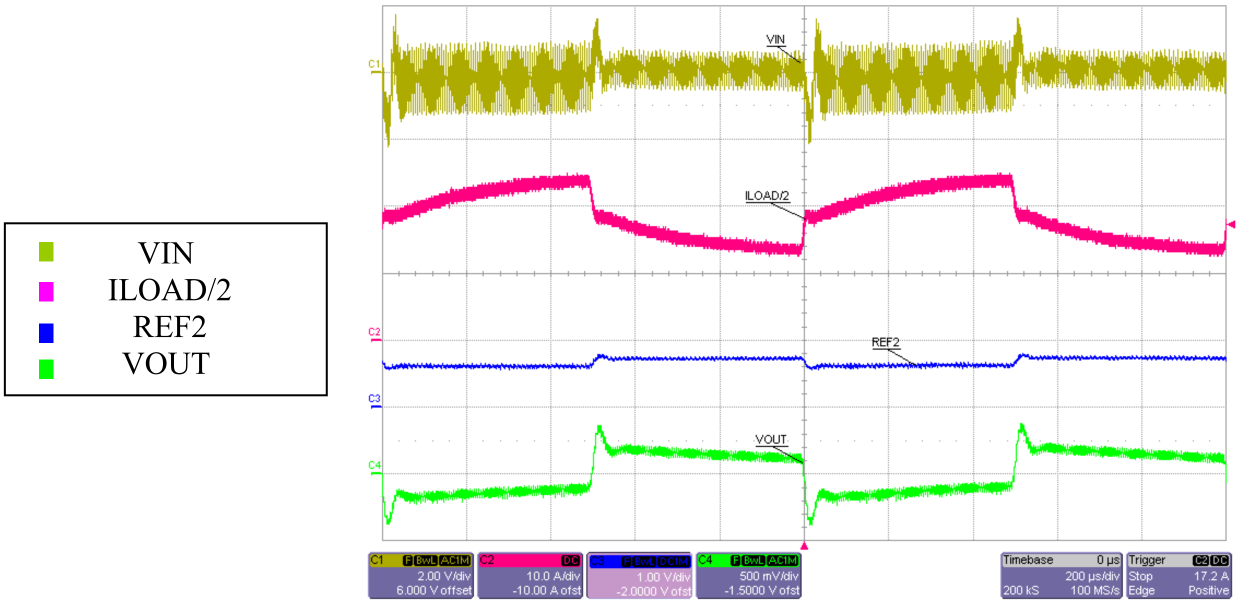
12.2 48V Input – 25A Load Step

Cin = 220 µF + 0.5Ω damping resistor, Lin = 0 µH, Cout external = 2 x 270 µF



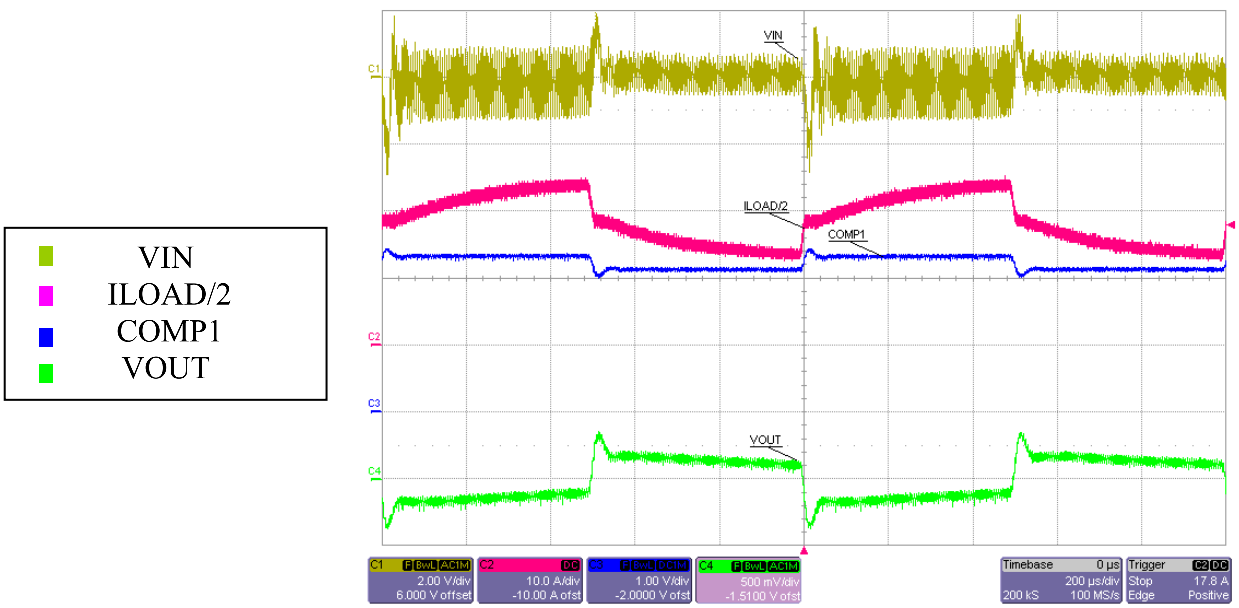
12.3 48V Input – 25A Load Step

Cin = 220 µF + 0.5Ω damping resistor, Lin = 0 µH, Cout external = 2 x 270 µF



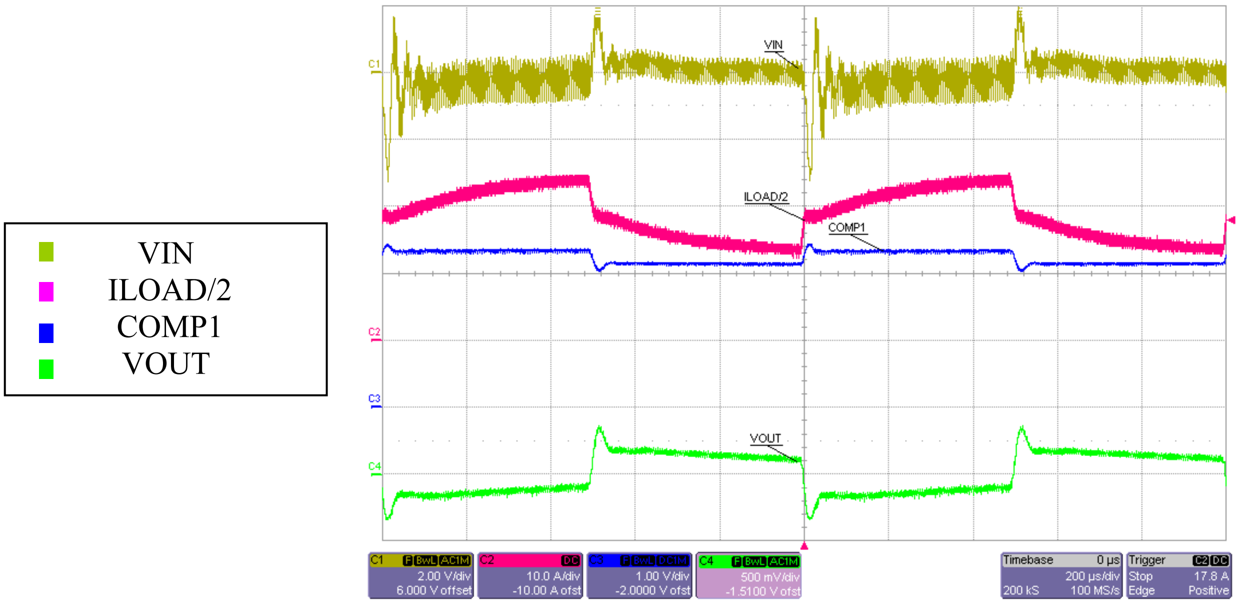
12.4 48V Input – 25A Load Step

Cin = 220 µF, Lin = 0.5 µH, Cout external = 2 x 270 µF



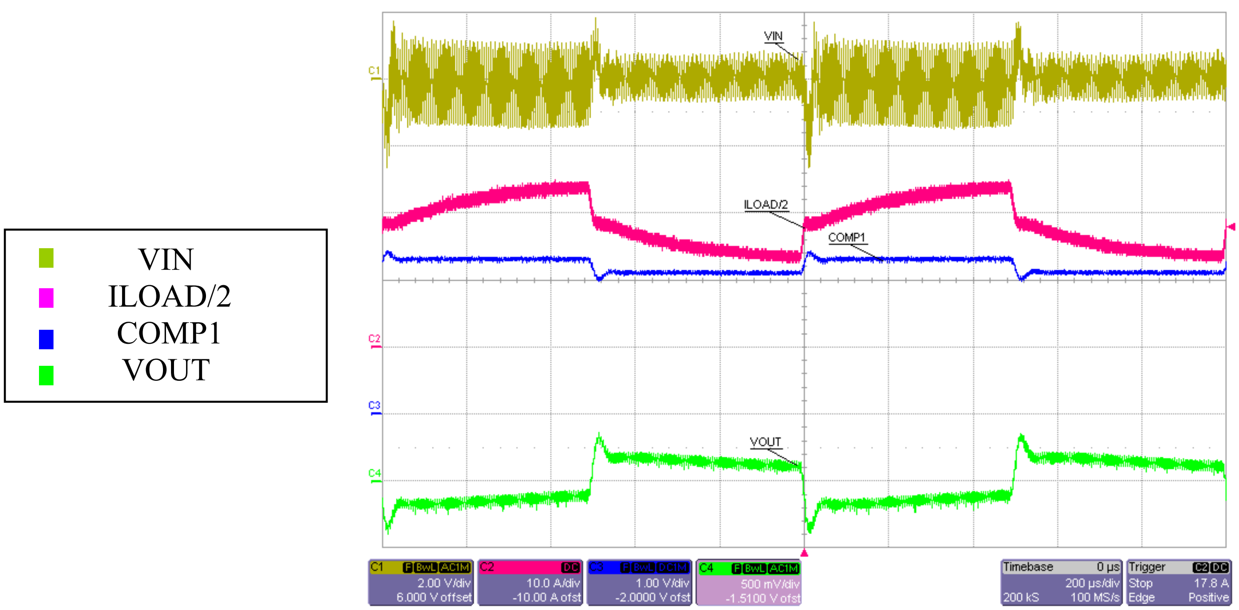
12.5 35V Input – 25A Load Step

Cin = 220 µF, Lin = 0.5 µH, Cout external = 2 x 270 µF



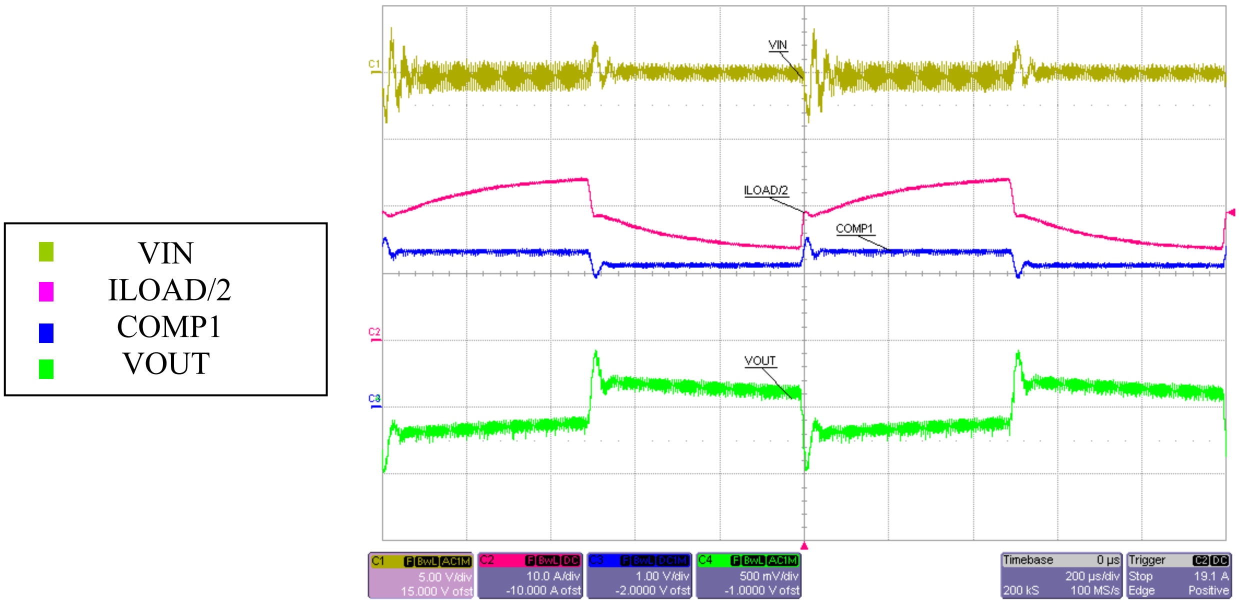
12.6 60V Input – 25A Load Step

Cin = 220 µF, Lin = 0.5 µH, Cout external = 2 x 270 µF



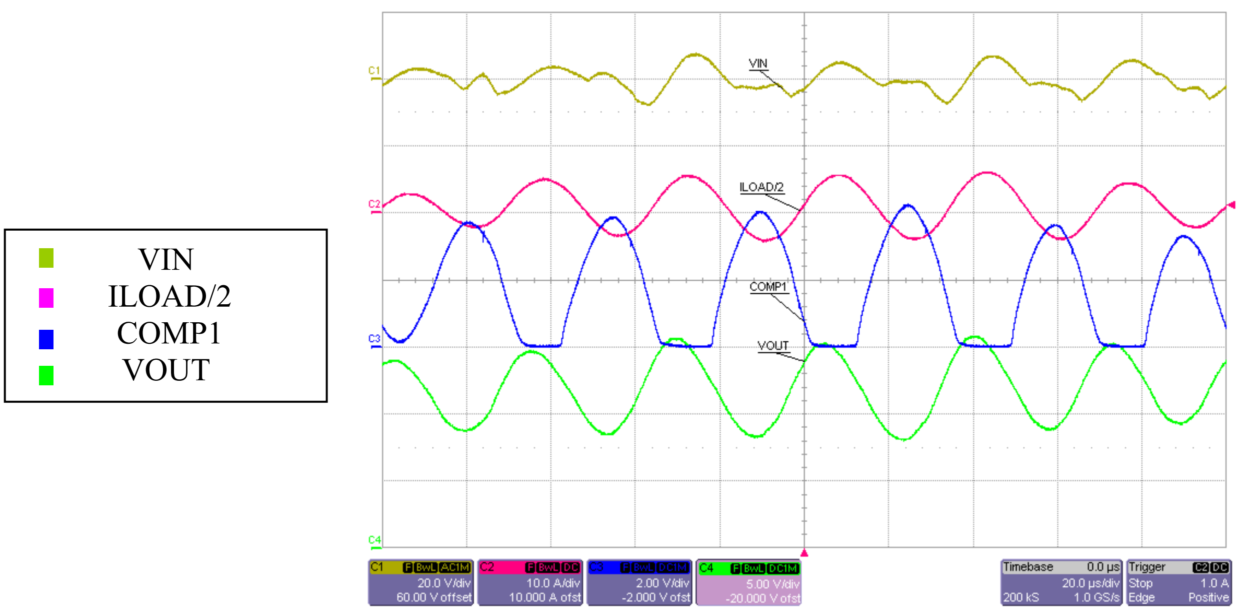
12.7 48V Input – 25A Load Step

Cin = 220 µF, Lin = 0.5 µH, Cout external = 1 x 270 µF



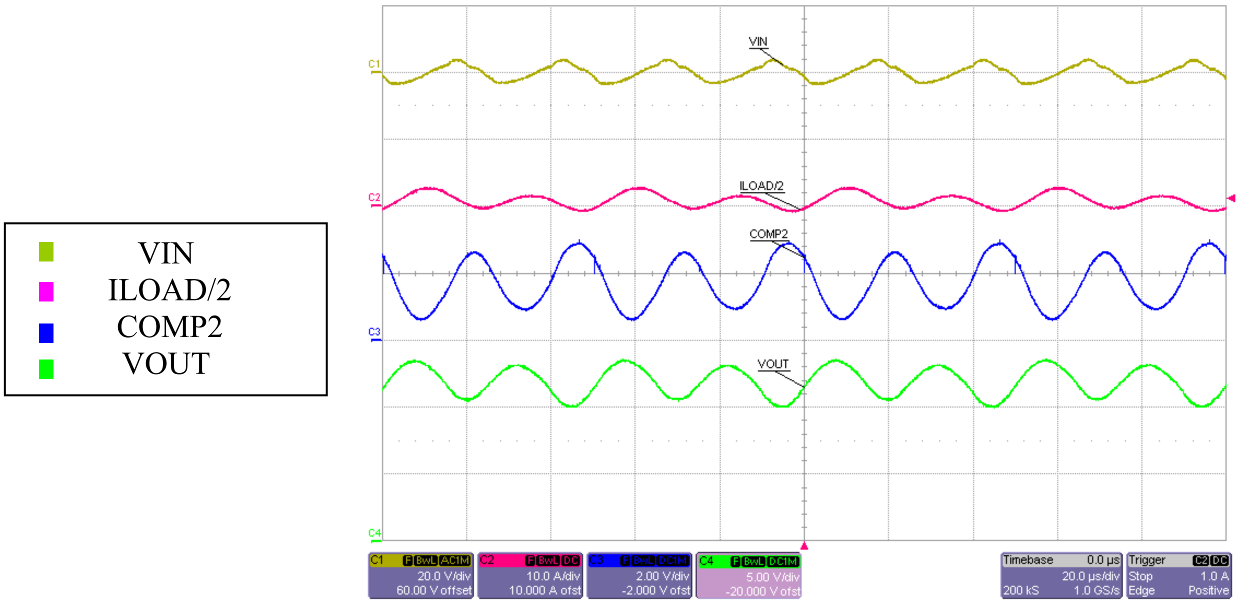
12.8 48V Input – 1A Load

Cin = 220 µF, Lin = 0.5 µH, Cout external = 0 µF resulting in feedback oscillation



12.9 48V Input – 1A Load

Cin = 220 µF, Lin = 0.5 µH, Cout external = 0 µF resulting in feedback oscillation

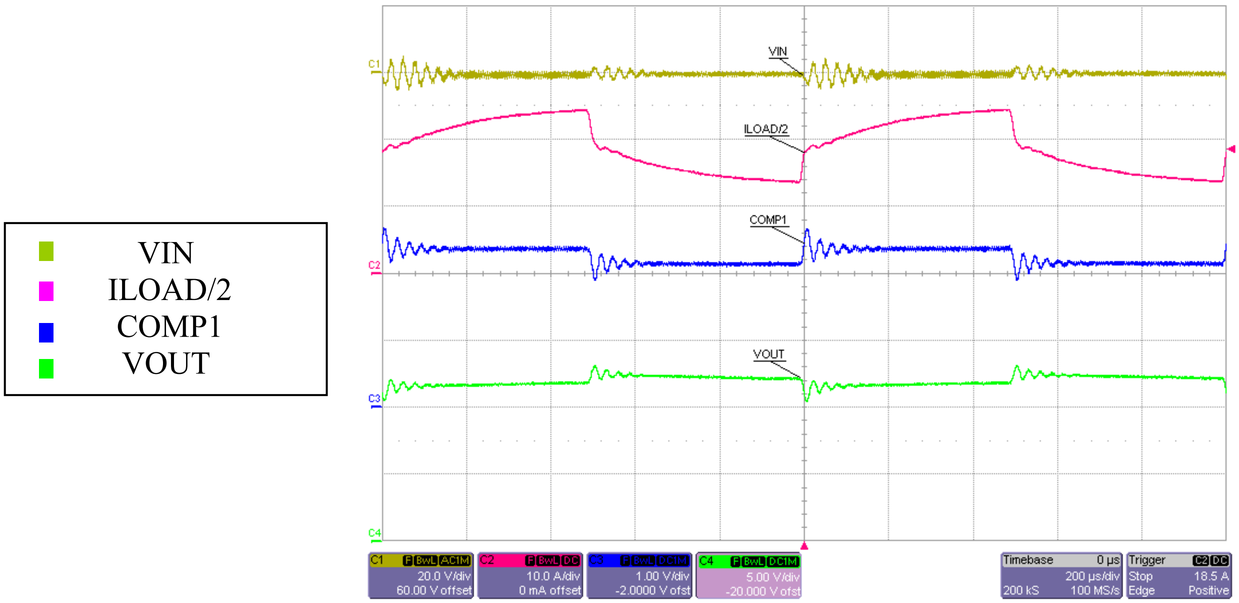


13 Transient Response with Rcomp = 3.6 kΩ (Rev B)

Using Rcomp = 3.6 kΩ results in lower bandwidth and slower transient response, but is stable without the use of external capacitors.

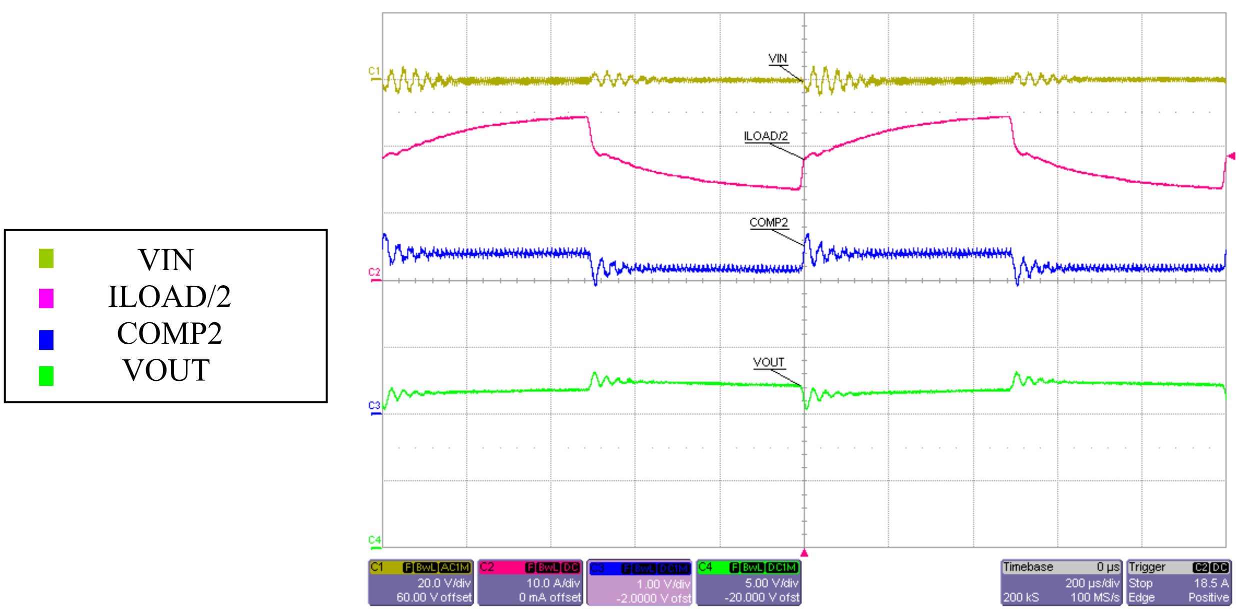
13.1 48V Input – 25A Load Step

Cin = 220 μF, Lin = 0.5 μH, Cout external = 0 μF



13.2 48V Input – 25A Load Step

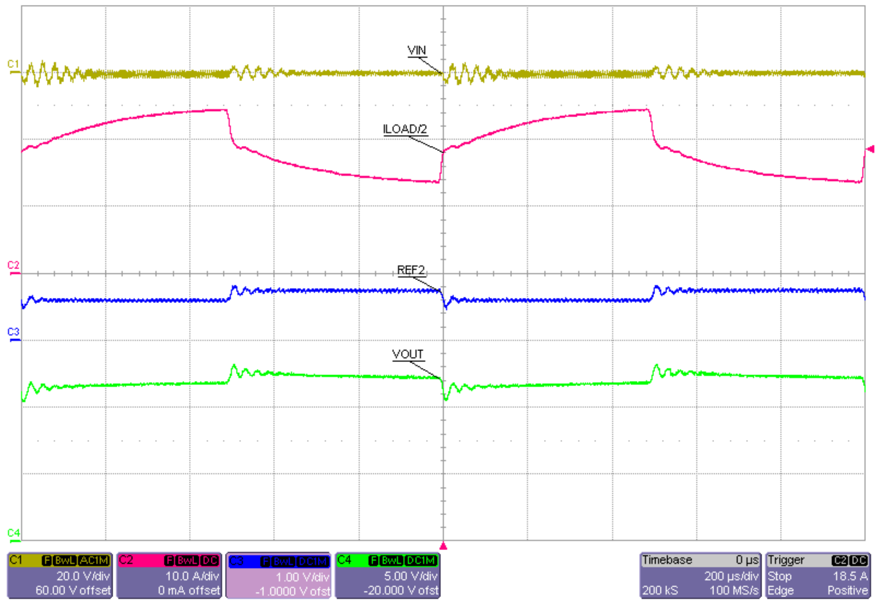
Cin = 220 μF, Lin = 0.5 μH, Cout external = 0 μF



13.3 48V Input – 25A Load Step

Cin = 220 µF, Lin = 0.5 µH, Cout external = 0 µF

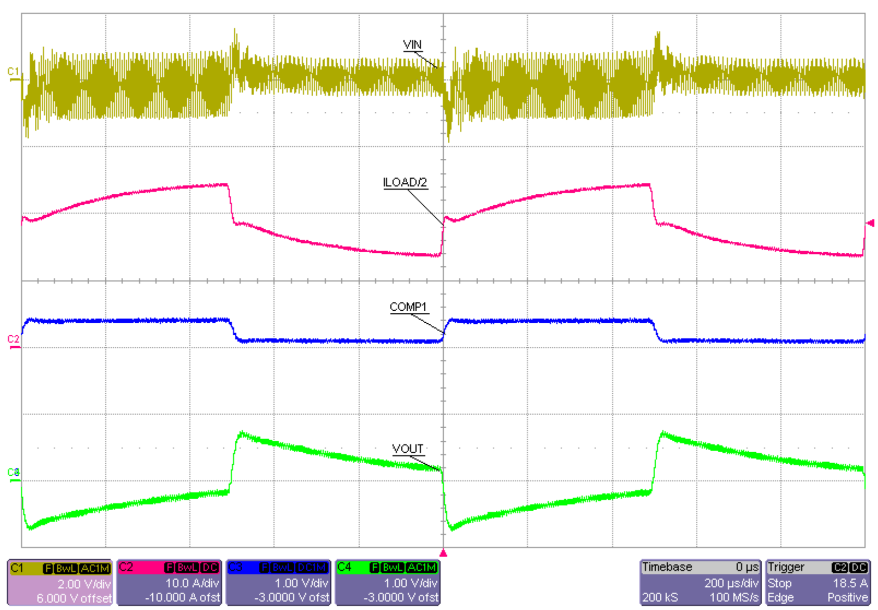
VIN
ILOAD/2
REF2
VOUT



13.4 48V Input – 25A Load Step

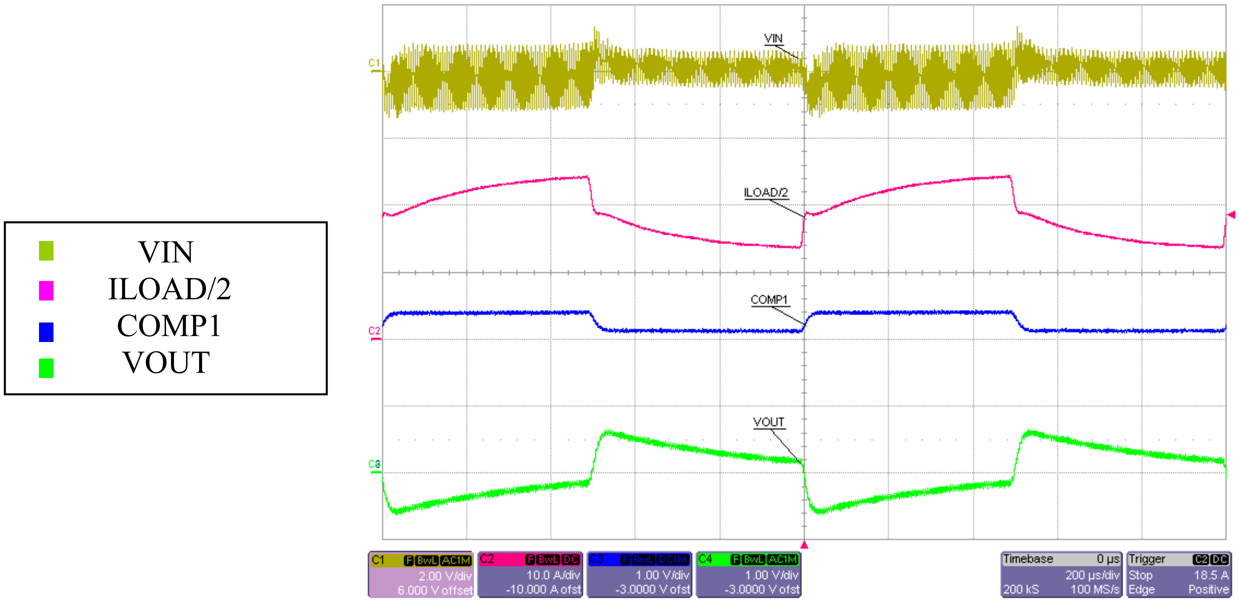
Cin = 220 µF, Lin = 0.5 µH, Cout external = 1 x 270 µF

VIN
ILOAD/2
COMP1
VOUT



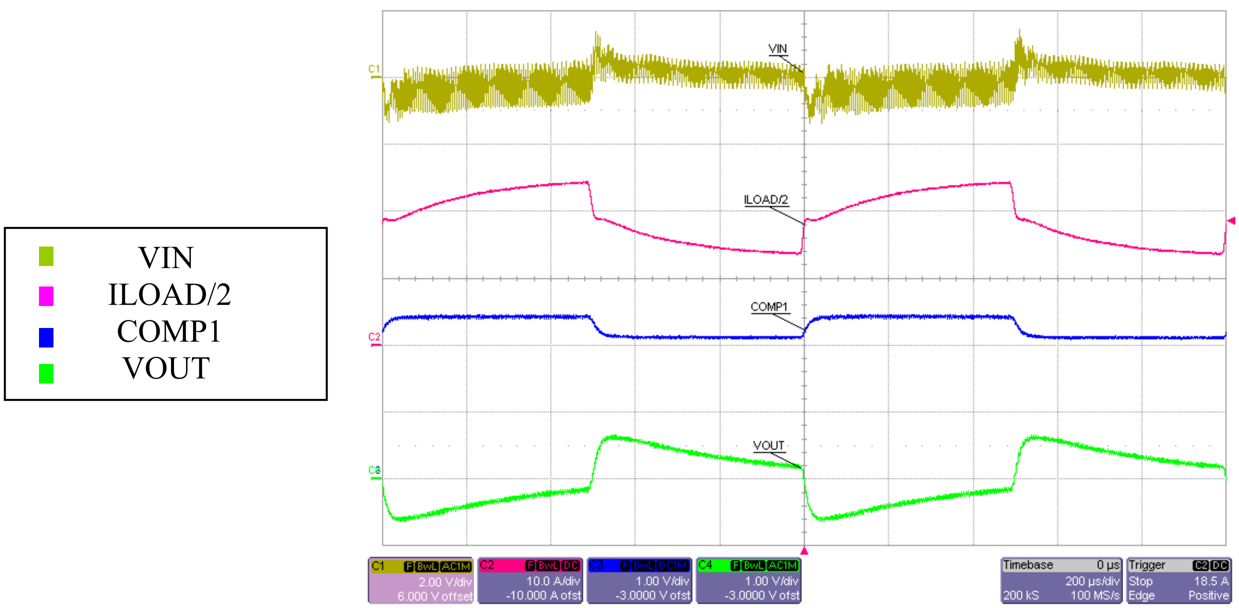
13.5 48V Input – 25A Load Step

Cin = 220 µF, Lin = 0.5 µH, Cout external = 2 x 270 µF



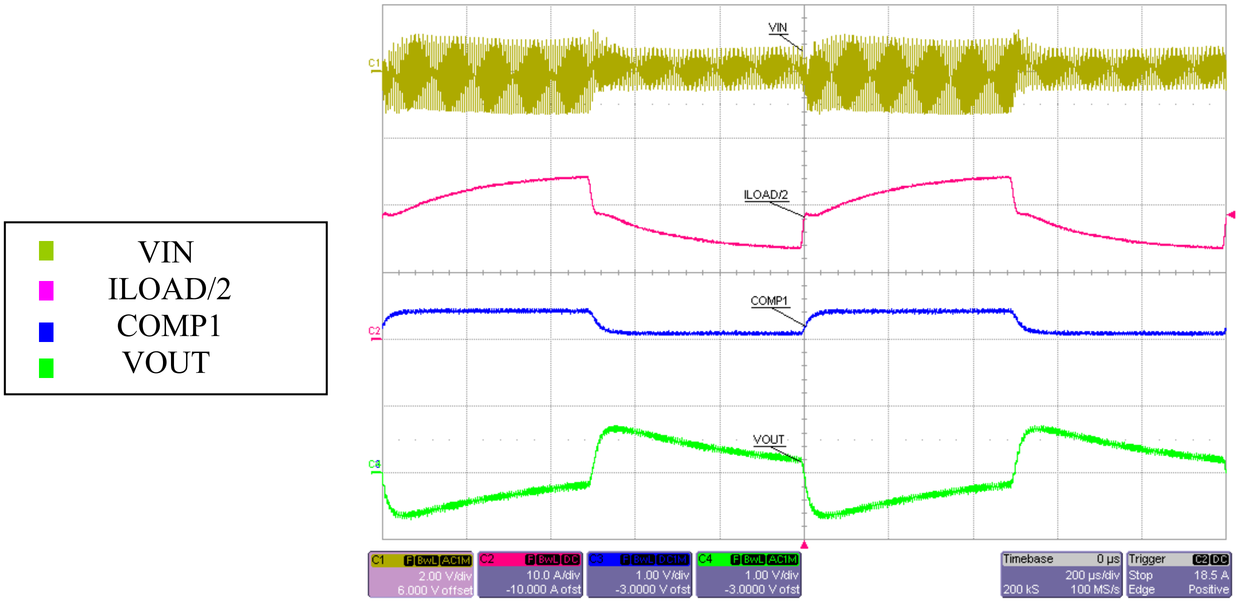
13.6 35V Input – 25A Load Step

Cin = 220 µF, Lin = 0.5 µH, Cout external = 2 x 270 µF



13.7 60V Input – 25A Load Step

Cin = 220 µF, Lin = 0.5 µH, Cout external = 2 x 270 µF

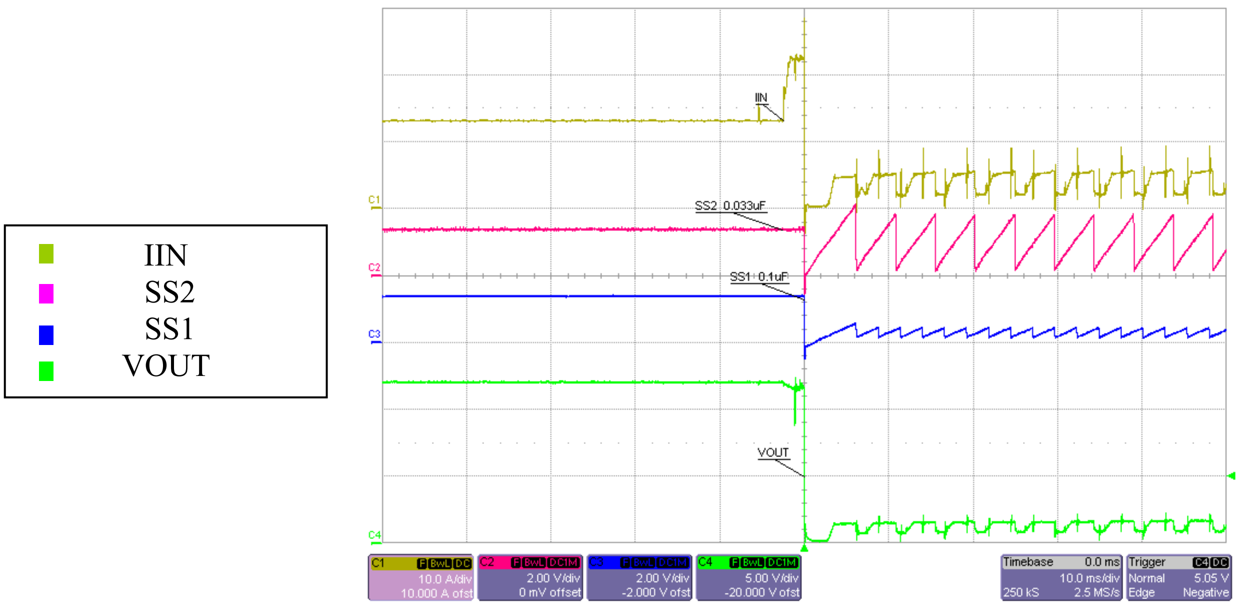


14 Short Circuit

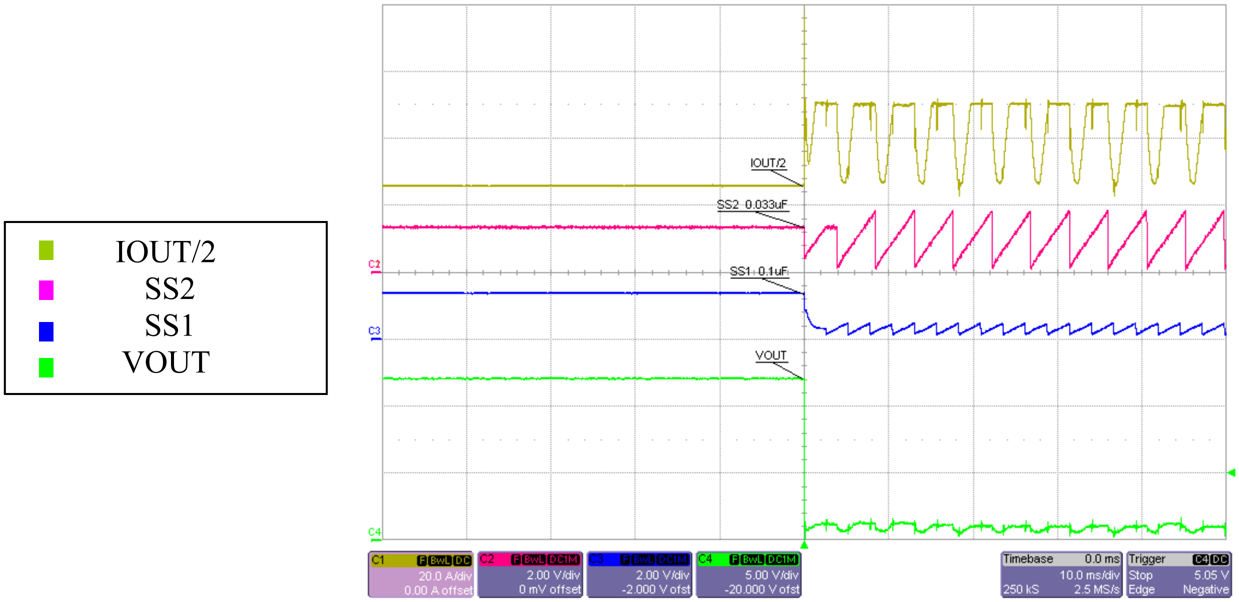
Short circuit current - average value as measured through shunts

Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (W)	Pout (W)	Pdis (W)
35	3.1	0.75	82	108.5	61.5	47.0
48	2.5	0.75	82	120.0	61.5	58.5
60	1.8	0.75	82	108.0	61.5	46.5

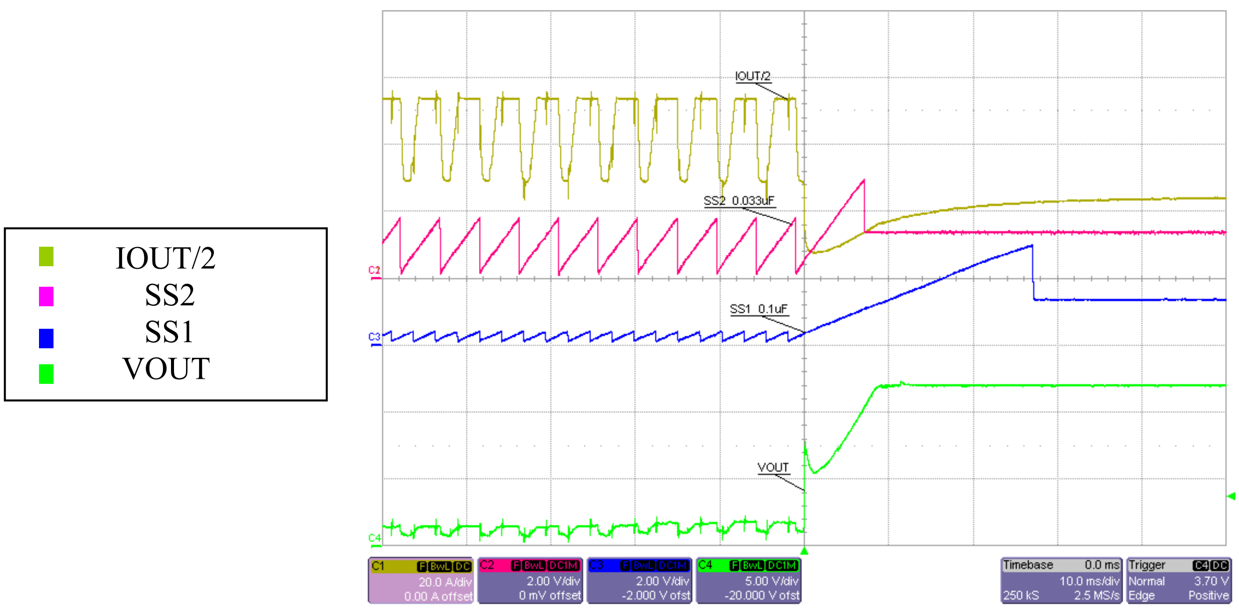
14.1 48V Input – Short Circuit from 50A Load



14.2 48V Input – Short Circuit from 50A Load

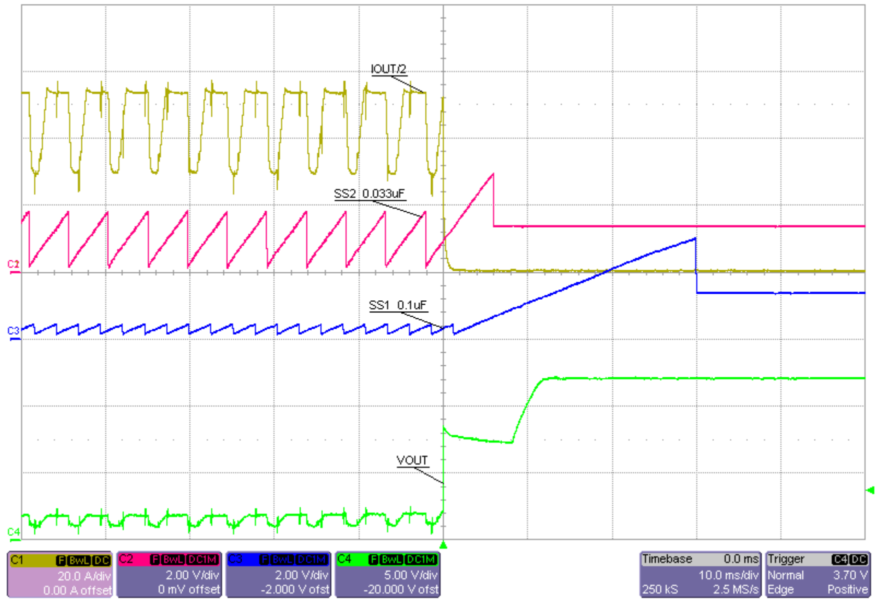


14.3 48V Input – Short Circuit Recovery into 50A Load



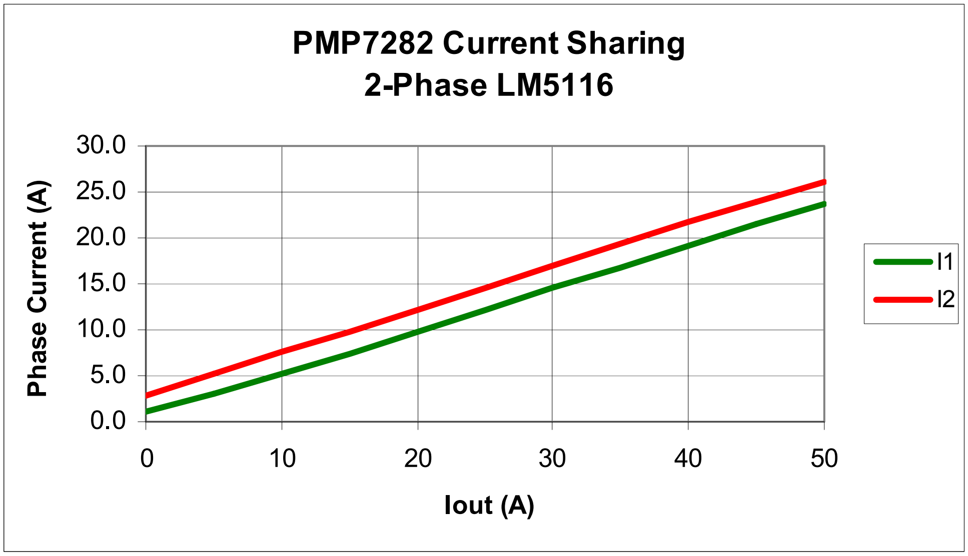
14.4 48V Input – Short Circuit Recovery into No Load

IOUT/2
SS2
SS1
VOUT



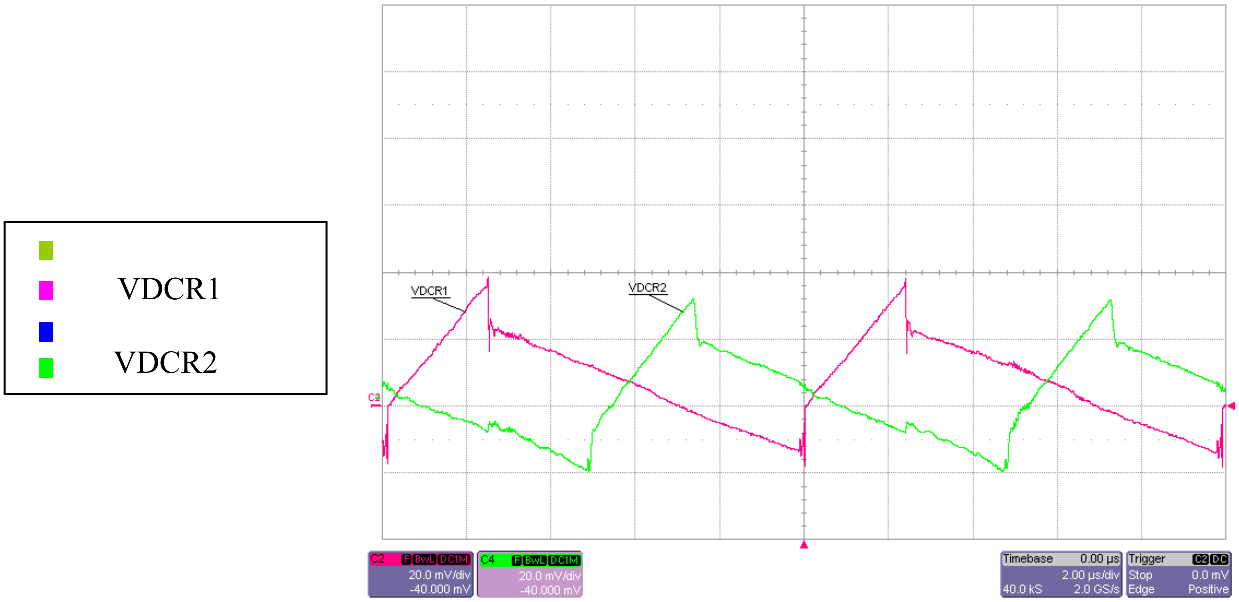
15 Current Sharing

Measured load sharing using DCR sense with SER2918H682KL inductor
Equate time constants R * C = L / Rdcr
Use R = 26.2 kΩ, C = 0.1 µF, L = 6.8 µH, Rdcr = 3 mΩ
Measurement is taken across the capacitor

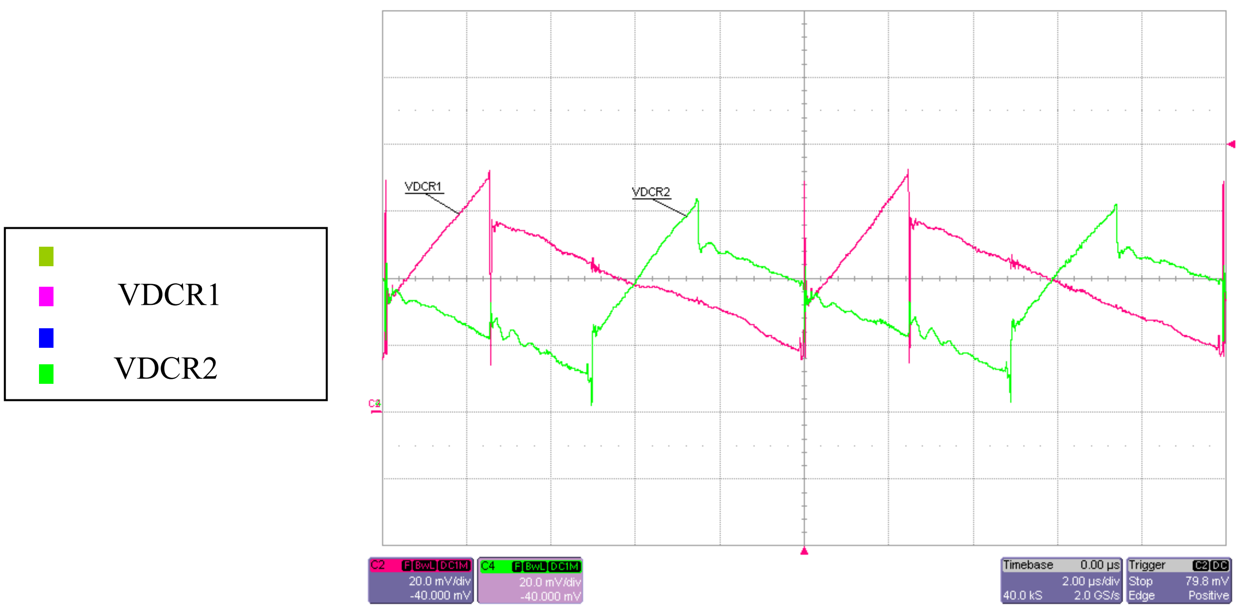


Vin (V)	V1 (mV)	V2 (mV)	I1 (A)	I2 (A)	I1+I2 (A)	Iout (A)
48	3.0	8.2	1.0	2.7	3.7	0
48	9.1	15.5	3.0	5.2	8.2	5
48	15.7	22.6	5.2	7.5	12.8	10
48	22.5	29.6	7.5	9.9	17.4	15
48	29.4	36.7	9.8	12.2	22.0	20
48	36.3	43.8	12.1	14.6	26.7	25
48	43.4	51.0	14.5	17.0	31.5	30
48	50.5	58.0	16.8	19.3	36.2	35
48	57.7	64.9	19.2	21.6	40.9	40
48	64.6	71.7	21.5	23.9	45.4	45
48	71.4	78.2	23.8	26.1	49.9	50

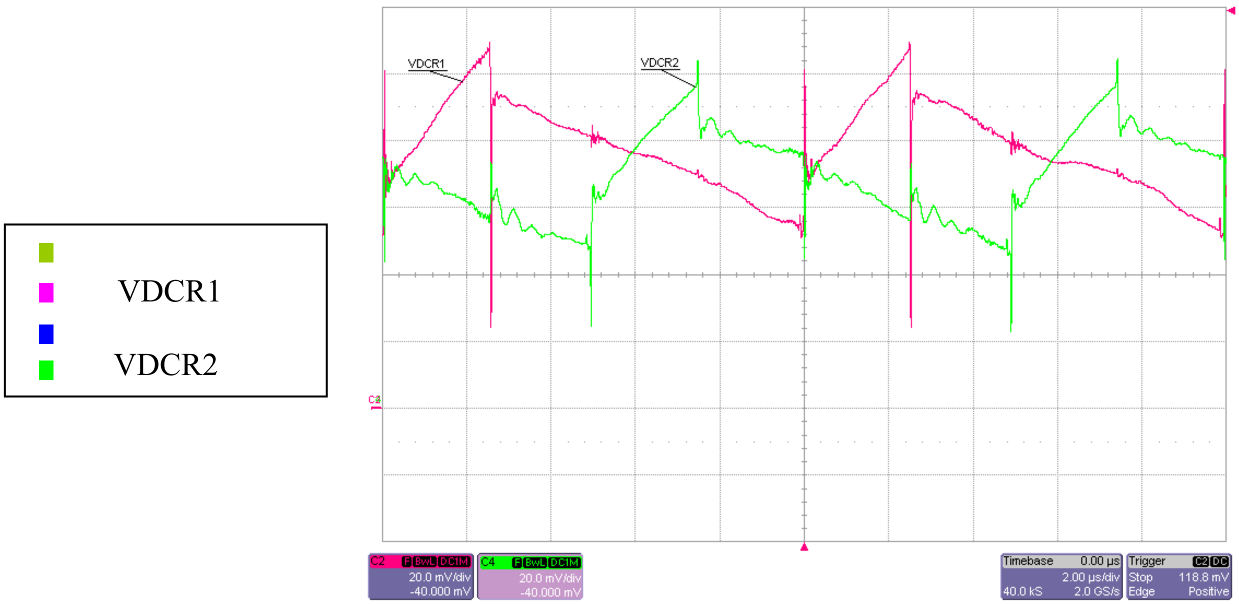
15.1 48V Input – No Load



15.2 48V Input – 25A Load



15.3 48V Input – 50A Load



16 LM5116 Bias Current

LM5116 bias current to VCCX - measured across 1 ohm resistor from VOUT

Vin (V)	I U1 (mA)	I U5 (mA)	Iout (A)
35	32.8	28.9	0
35	33.2	29.1	25
35	33.3	29.2	50
48	33.1	29.2	0
48	33.3	29.2	25
48	33.4	29.3	50
60	33.3	29.4	0
60	33.6	29.6	25
60	33.7	29.5	50