Test Report: PMP22396

2460-W Bidirectional Boost Converter Reference Design for Automotive Applications

1 Description

This reference design is a 2460-W bidirectional boost converter for automotive applications. The circuit is powered from the nominal 12-V battery to provide an output voltage of 48 V at 51.25 A. The design uses two dual-phase synchronous bidirectional controllers operating at a switching frequency of 200 kHz per phase. The 48-V output is designed to drive a motor. When the load current reverses and the output voltage reaches 54 V, hysteretic direction control allows the load current to be returned to the 12-V battery. Normal boost operation resumes when the output voltage returns to 48 V. Mounting holes are provided for a bottom-side heat sink underneath the MOSFETs.

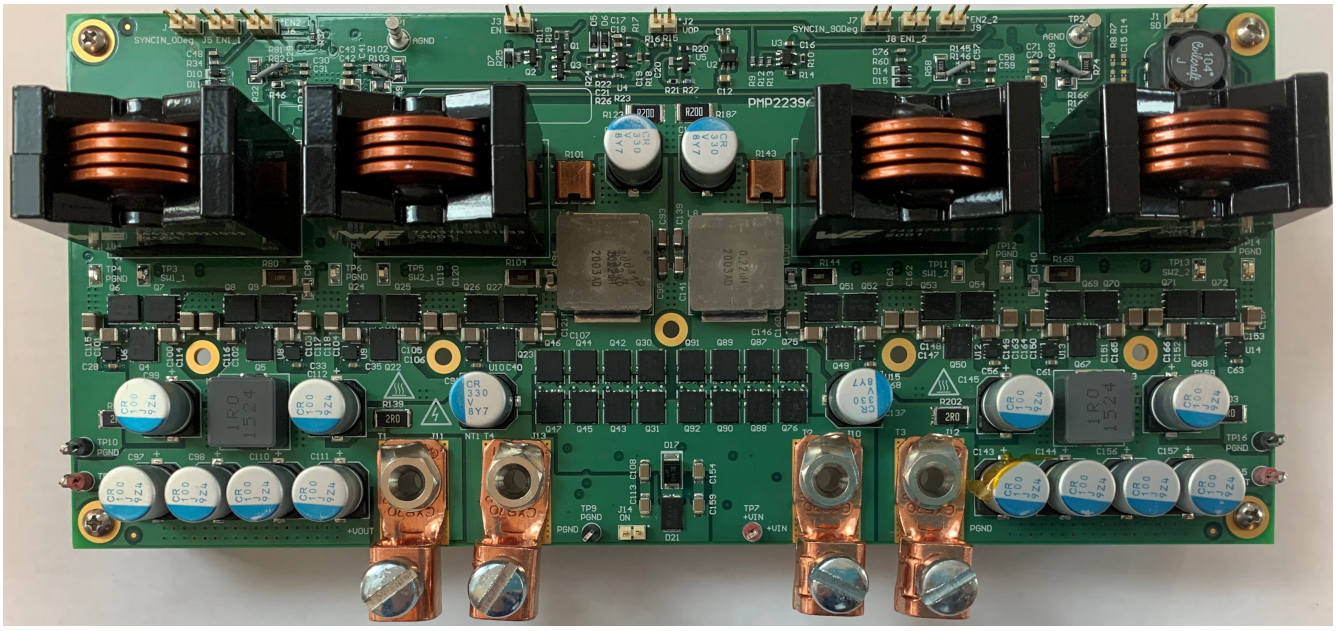

Figure 1-1. Top Photo

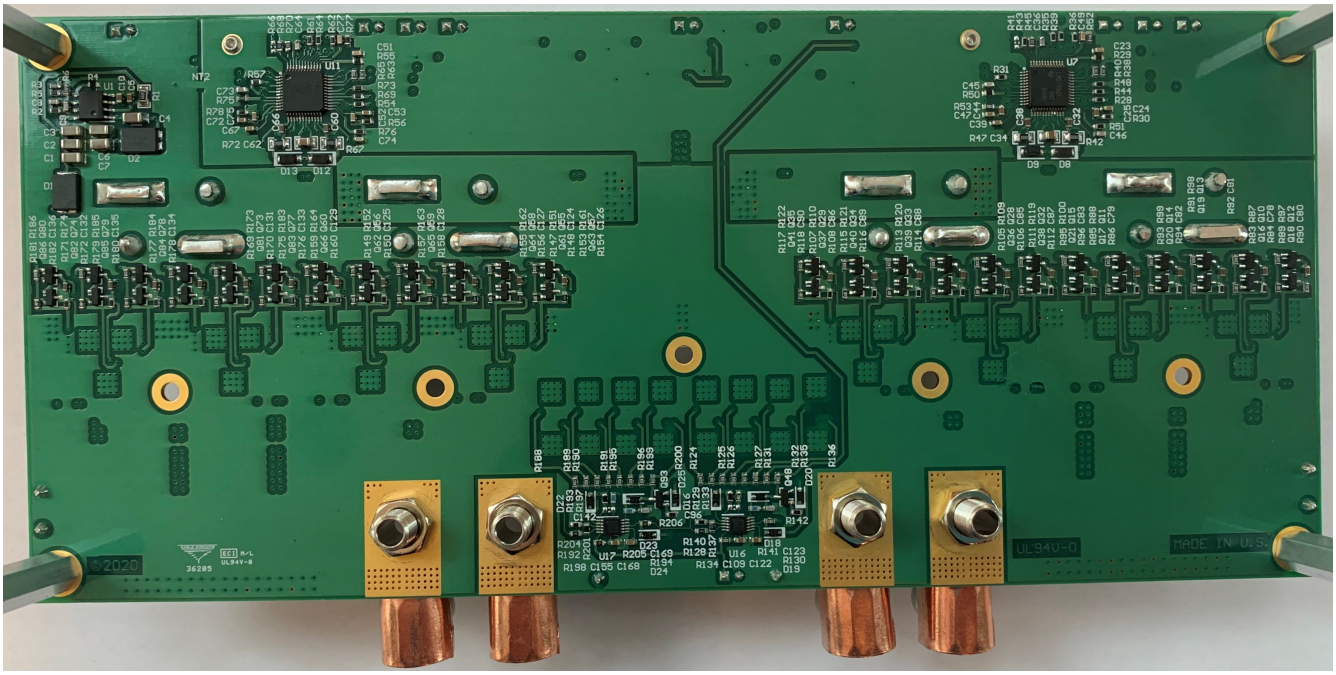

Figure 1-2. Bottom Photo

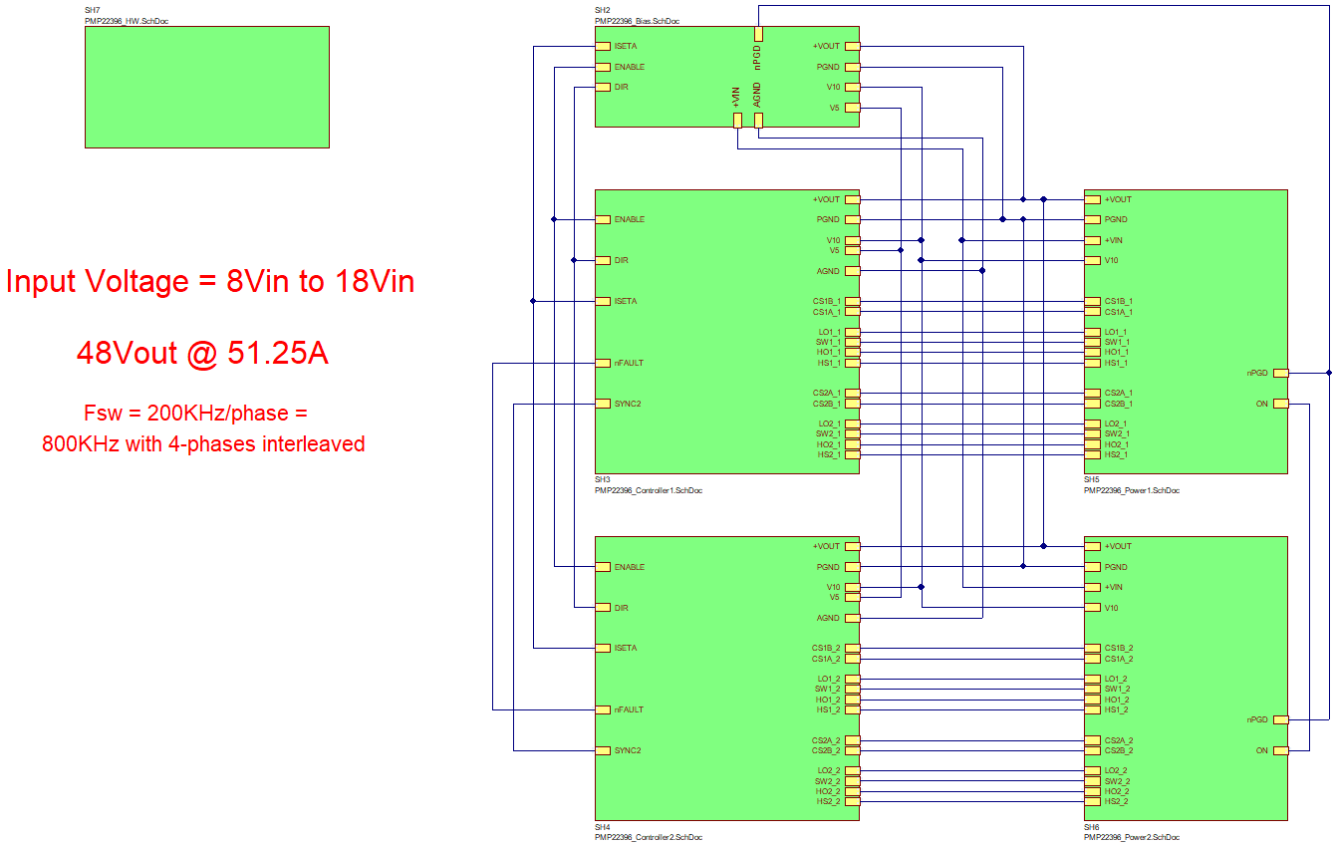

Figure 1-3. Block Diagram

2 Test Prerequisites

2.1 Design Requirements

Table 2-1. Design Requirements

Parameter	Specifications
Input Voltage	8 V to 18 V
Output Voltage	48 V
Output Current	51.25 A

2.2 Required Equipment

- DC power supply
- Electronic load
- Oscilloscope

2.3 Considerations

All tests were performed at room temperature on an open bench.

2.4 Dimensions

The design was built on the PMP22396 Rev A printed circuit board. This is an 8-layer PCB with 2 oz copper on all layers. Board dimensions are 8.8 in × 3.9 in.

2.5 Test Setup

The test setup is shown in the following picture. All tests were performed at room temperature on an open bench.

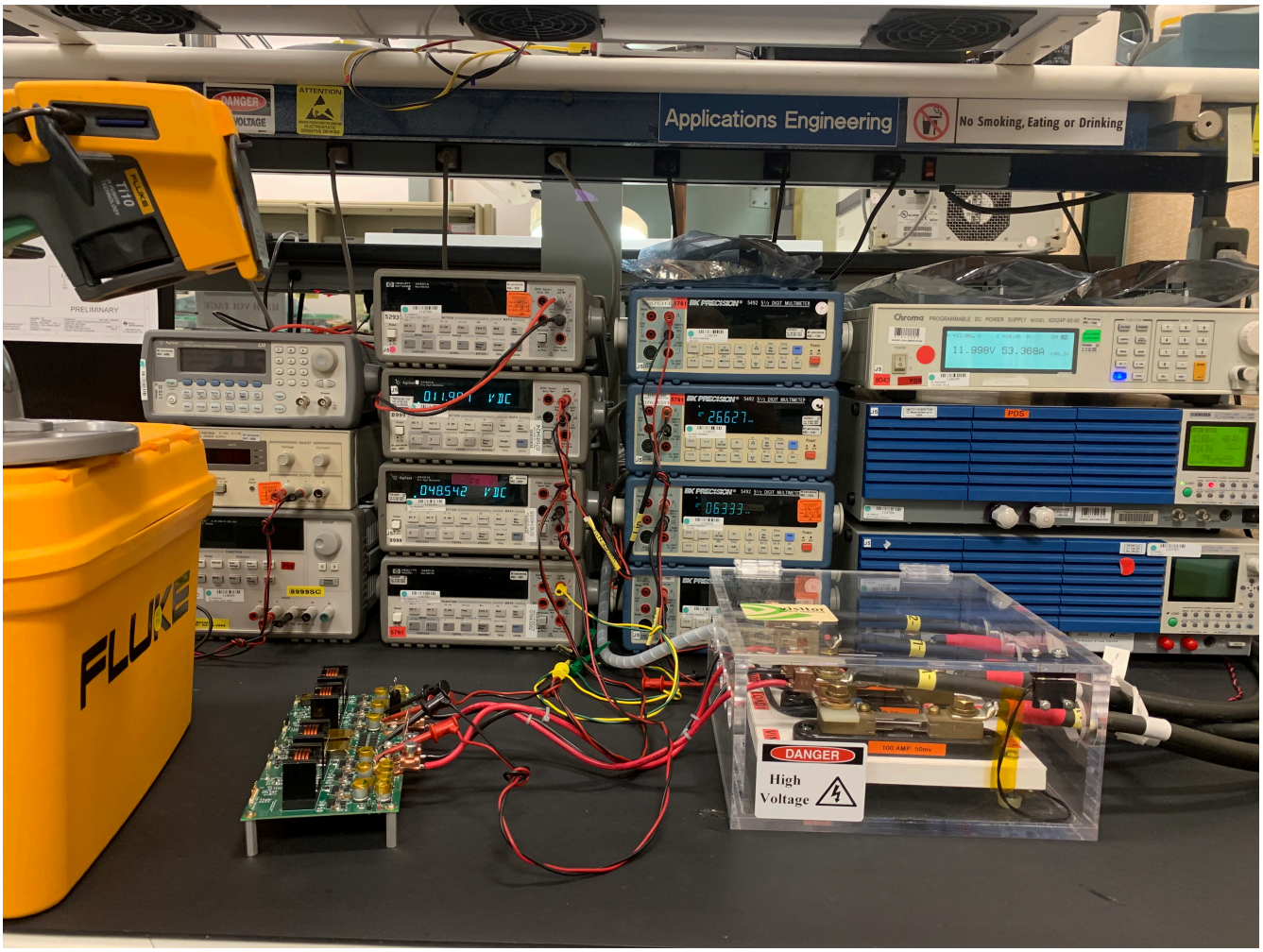

Figure 2-1. Test Setup

3 Testing and Results

3.1 Efficiency Graphs

The following figures show the converter efficiency with 8-V, 10-V, 12-V, 14-V and 18-V inputs.

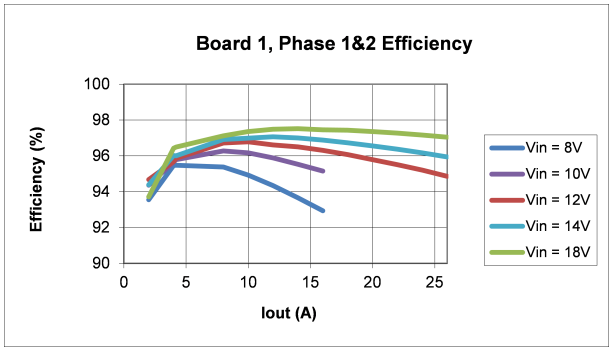

Figure 3-1. Board 1, Phase 1 & 2 Efficiency

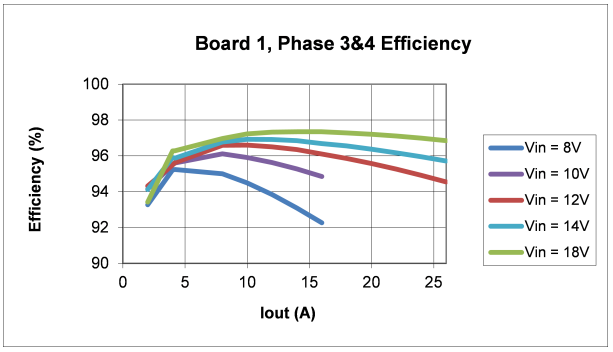

Figure 3-2. Board 1, Phase 3 & 4 Efficiency

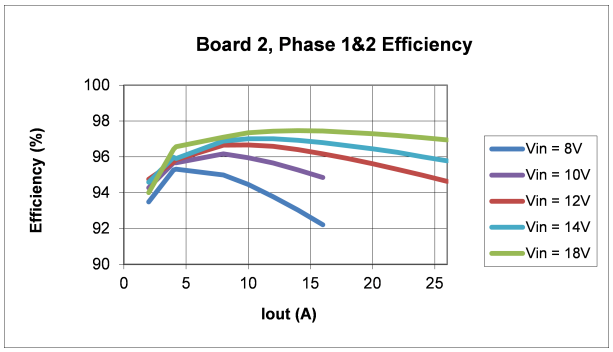

Figure 3-3. Board 2, Phase 1 & 2 Efficiency

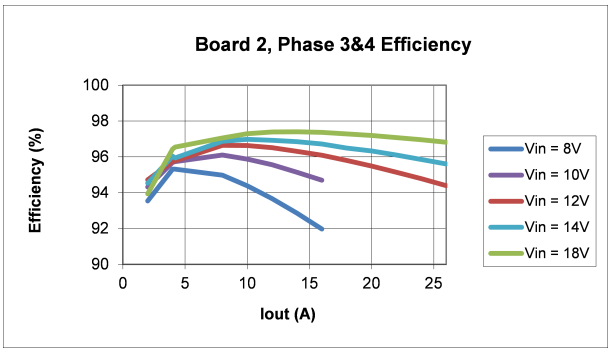

Figure 3-4. Board 2, Phase 3 & 4 Efficiency

3.2 Efficiency Data

Efficiency data is shown in the following tables.

Table 3-1. Efficiency Data 8-V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	Losses (W)	Efficiency (%)
7.998	0.404	48.574	0.004	3.231	0.194	3.037	6.01
7.997	12.972	48.573	1.998	103.741	97.049	6.692	93.55
7.997	25.436	48.572	3.998	203.422	194.192	9.230	95.46
7.998	26.692	48.572	4.196	213.472	203.808	9.664	95.47
7.997	50.920	48.570	7.996	407.216	388.366	18.850	95.37
7.997	63.958	48.568	9.996	511.472	485.490	25.981	94.92
7.997	77.218	48.567	11.994	617.488	582.515	34.972	94.34
7.996	90.732	48.566	13.992	725.538	679.535	46.003	93.66
7.997	104.524	48.564	15.994	835.831	776.740	59.091	92.93

Table 3-2. Efficiency Data 10-V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	Losses (W)	Efficiency (%)
10.001	0.396	48.573	0.004	3.960	0.194	3.766	4.91
10.001	10.284	48.572	1.998	102.846	97.047	5.799	94.36
10.000	20.280	48.572	3.994	202.809	193.995	8.814	95.65
10.001	21.276	48.572	4.196	212.778	203.806	8.972	95.78
10.000	40.328	48.570	7.994	403.294	388.268	15.027	96.27
10.000	50.488	48.569	9.996	504.895	485.496	19.399	96.16
10.000	60.756	48.568	11.994	607.570	582.529	25.041	95.88
10.000	71.136	48.567	13.992	711.372	679.554	31.817	95.53
10.000	81.630	48.566	15.992	816.287	776.673	39.614	95.15

Table 3-3. Efficiency Data 12-V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	Losses (W)	Efficiency (%)
11.998	0.396	48.572	0.004	4.751	0.194	4.557	4.09
11.998	8.544	48.572	1.998	102.513	97.048	5.465	94.67
11.998	16.908	48.572	3.996	202.863	194.092	8.771	95.68
11.998	17.728	48.572	4.198	212.707	203.903	8.804	95.86
11.998	33.462	48.570	7.994	401.474	388.271	13.203	96.71
11.998	41.814	48.570	9.996	501.687	485.503	16.184	96.77
11.998	50.220	48.569	11.984	602.536	582.051	20.485	96.60
11.998	58.692	48.568	13.990	704.162	679.470	24.692	96.49
11.998	67.222	48.567	15.992	806.505	776.688	29.817	96.30
11.997	75.812	48.567	17.990	909.547	873.714	35.833	96.06
11.997	84.472	48.565	19.988	1013.445	970.726	42.719	95.78
11.997	93.198	48.565	21.988	1118.114	1067.845	50.269	95.50
11.997	102.004	48.564	23.988	1223.740	1164.946	58.794	95.20
11.997	110.898	48.563	25.986	1330.454	1261.955	68.499	94.85

Table 3-4. Efficiency Data 14-V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	Losses (W)	Efficiency (%)
13.997	0.390	48.570	0.004	5.459	0.194	5.265	3.56
13.997	7.346	48.570	1.998	102.824	97.043	5.781	94.38
13.998	14.442	48.570	3.996	202.153	194.086	8.067	96.01
13.997	15.166	48.570	4.196	212.285	203.802	8.484	96.00
13.997	28.622	48.569	7.994	400.635	388.264	12.371	96.91
13.997	35.728	48.569	9.986	500.097	485.010	15.087	96.98
13.997	42.872	48.569	11.992	600.088	582.435	17.653	97.06
13.997	50.056	48.568	13.992	700.644	679.565	21.078	96.99
13.997	57.274	48.568	15.990	801.661	776.600	25.061	96.87
13.997	64.530	48.567	17.988	903.231	873.627	29.604	96.72
13.997	71.830	48.567	19.988	1005.391	970.749	34.642	96.55
13.997	79.166	48.566	21.988	1108.082	1067.860	40.222	96.37
13.996	86.548	48.565	23.986	1211.362	1164.886	46.475	96.16
13.997	93.980	48.564	25.986	1315.395	1261.993	53.403	95.94

Table 3-5. Efficiency Data 18-V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	Losses (W)	Efficiency (%)
17.998	0.358	48.570	0.004	6.443	0.194	6.249	3.02
17.998	5.754	48.570	1.998	103.558	97.043	6.515	93.71
17.997	11.190	48.570	3.998	201.392	194.183	7.208	96.42
17.997	11.736	48.570	4.196	211.218	203.801	7.417	96.49
17.998	22.220	48.570	7.996	399.907	388.363	11.544	97.11
17.997	27.704	48.570	9.994	498.602	485.406	13.196	97.35
17.997	33.206	48.570	11.994	597.620	582.543	15.077	97.48
17.997	38.730	48.569	13.994	697.037	679.676	17.362	97.51
17.997	44.268	48.569	15.986	796.712	776.423	20.289	97.45
17.997	49.828	48.568	17.988	896.765	873.649	23.116	97.42
17.997	55.410	48.569	19.988	997.219	970.790	26.428	97.35
17.997	61.008	48.568	21.988	1097.966	1067.909	30.057	97.26
17.997	66.626	48.567	23.986	1199.074	1164.934	34.139	97.15
17.997	72.270	48.567	25.986	1300.631	1262.067	38.563	97.04

3.3 Thermal Images

The following figures show thermal performance for operation at 12-V input with no airflow. The images were taken with the board at thermal equilibrium.

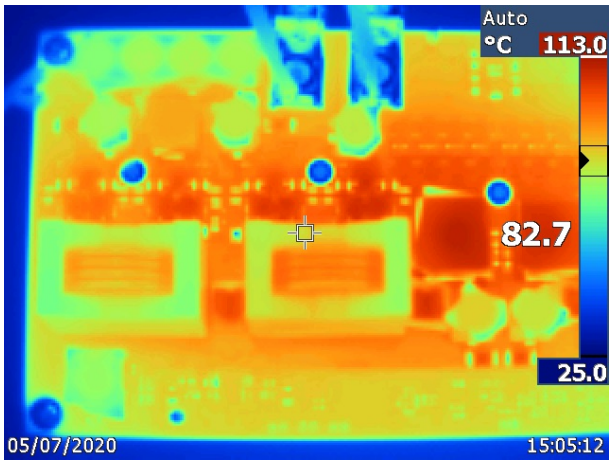

Figure 3-5. Board 1, 4-Phase, 12-V Input, 1230-W Load

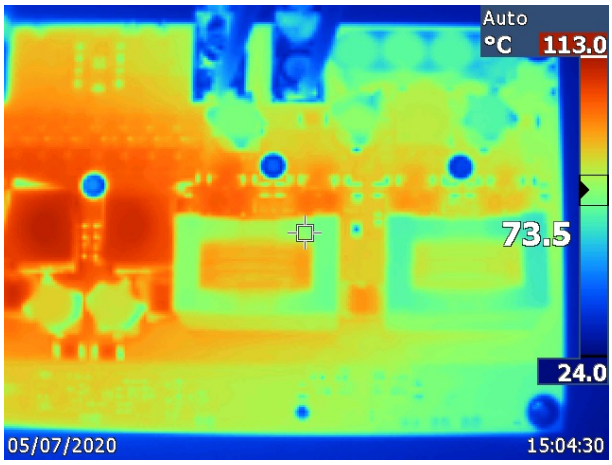

Figure 3-6. Board 1, 4-Phase, 12-V Input, 1230-W Load

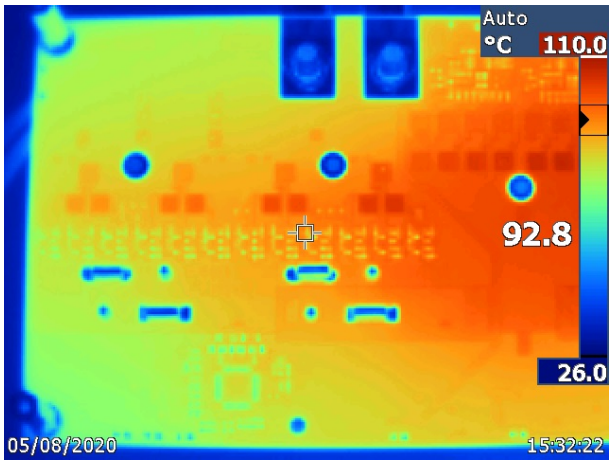

Figure 3-7. Board 1, Bottom, 4-Phase, 12-V Input, 1230-W Load

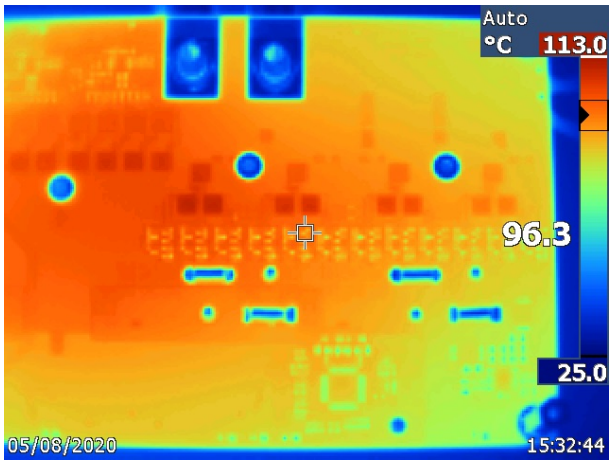

Figure 3-8. Board 1, Bottom, 4-Phase, 12-V Input, 1230-W Load

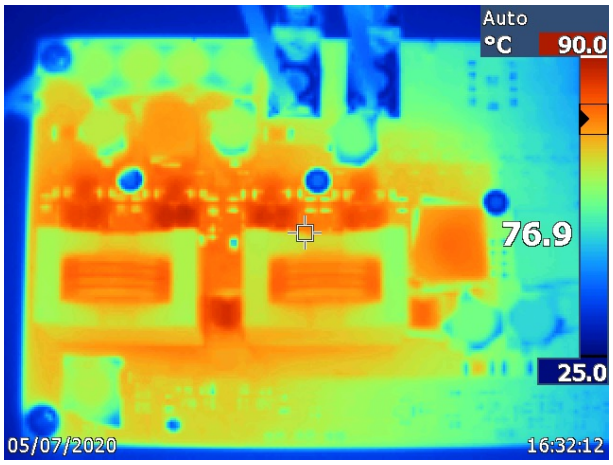

Figure 3-9. Board 1, 2-Phase, 12-V Input, 616-W Load

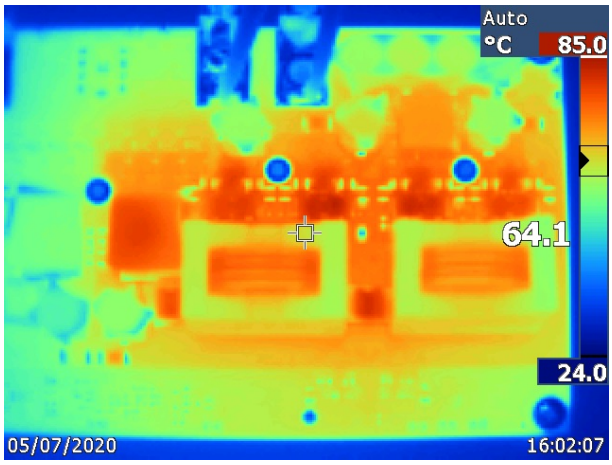

Figure 3-10. Board 1, 2-Phase, 12-V Input, 616-W Load

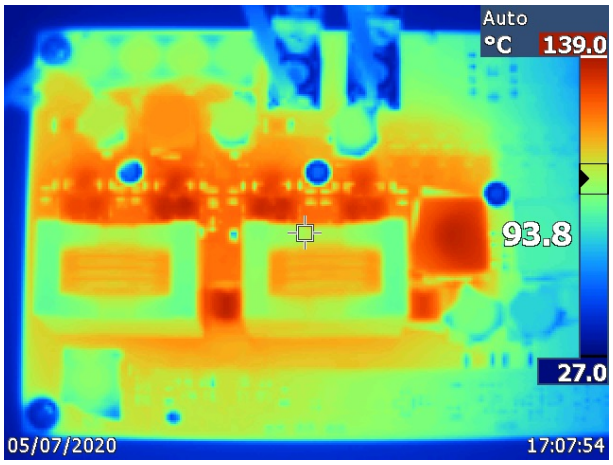

Figure 3-11. Board 1, 2-Phase, 12-V Input, 915-W Load

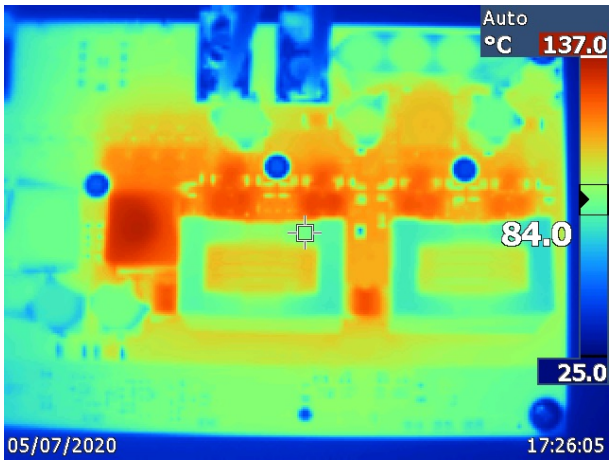

Figure 3-12. Board 1, 2-Phase, 12-V Input, 915-W Load

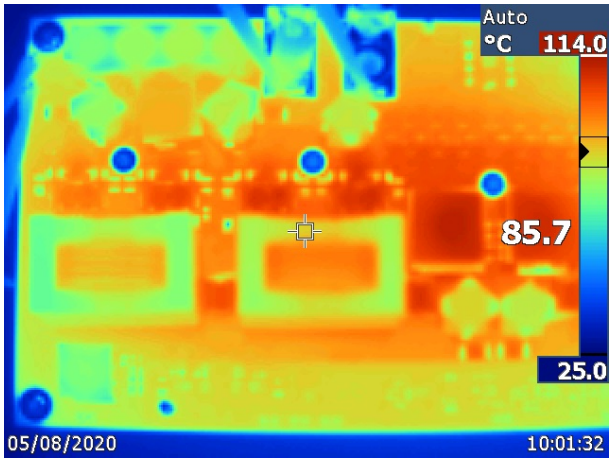

Figure 3-13. Board 2, 4-Phase, 12-V Input, 1228-W Load

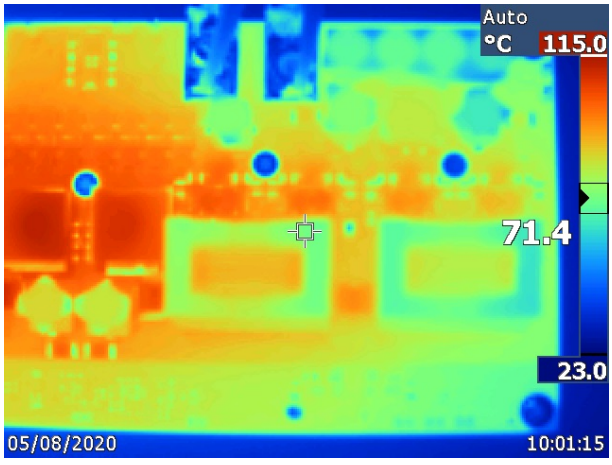

Figure 3-14. Board 2, 4-Phase, 12-V Input, 1228-W Load

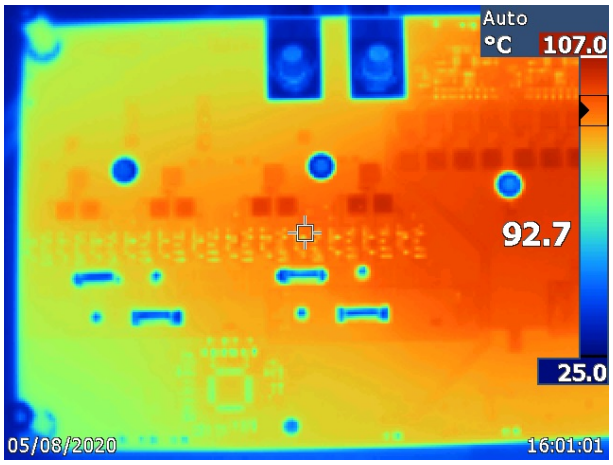

Figure 3-15. Board 2, Bottom, 4-Phase, 12-V Input, 1228-W Load

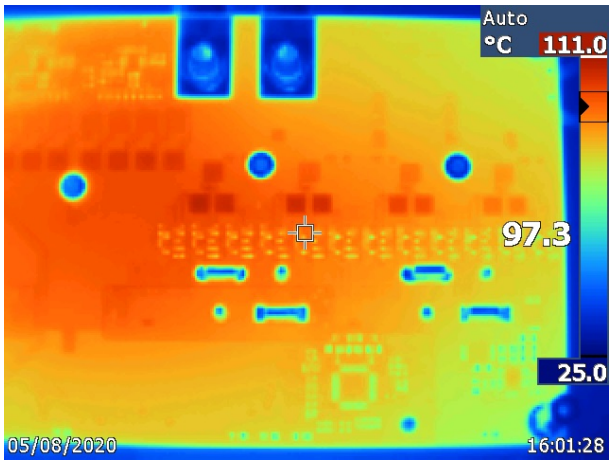

Figure 3-16. Board 2, Bottom, 4-Phase, 12-V Input, 1228-W Load

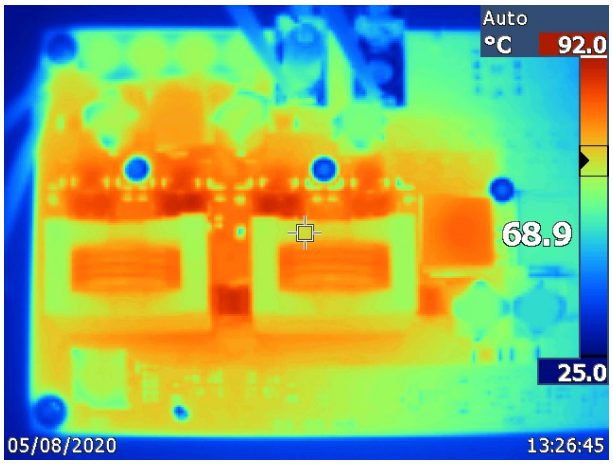

Figure 3-17. Board 2, 2-Phase, 12-V Input, 615-W Load

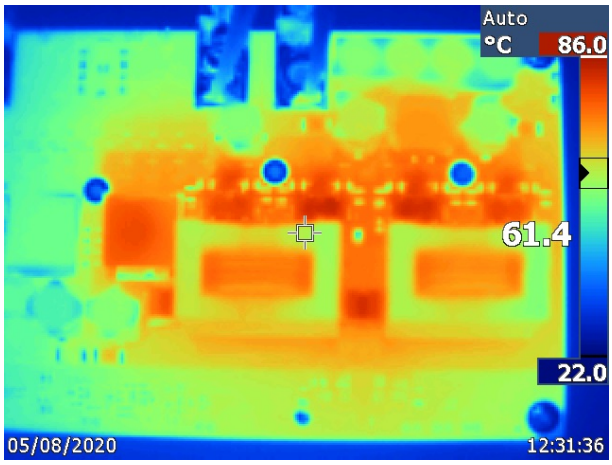

Figure 3-18. Board 2, 2-Phase, 12-V Input, 615-W Load

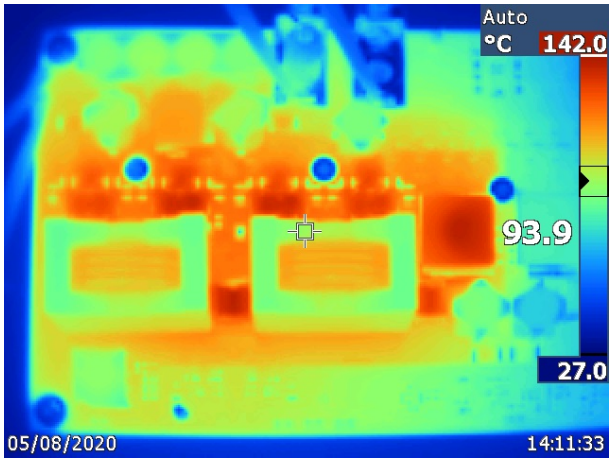

Figure 3-19. Board 2, 2-Phase, 12-V Input, 903-W Load

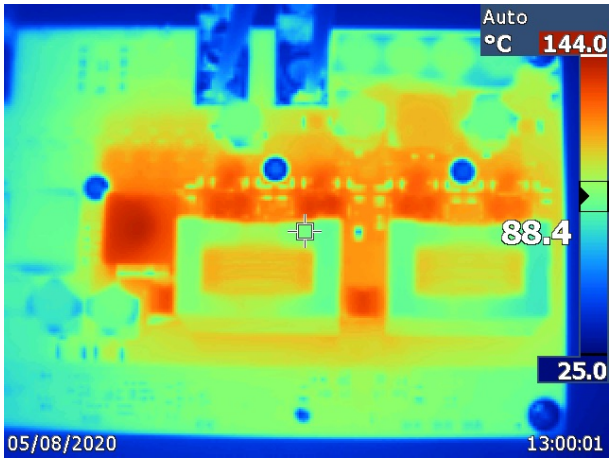

Figure 3-20. Board 2, 2-Phase, 12-V Input, 913-W Load

3.4 Frequency Response

Frequency response is shown in the following figures.

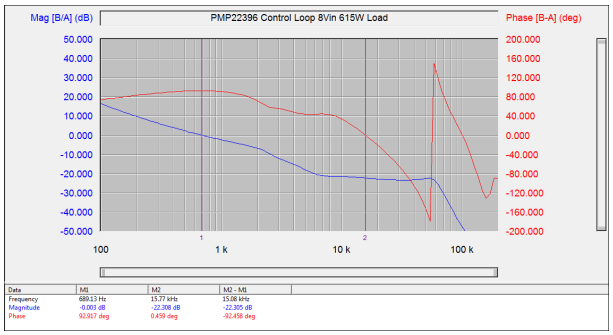

Figure 3-21. 8-V Input, 615-W Load

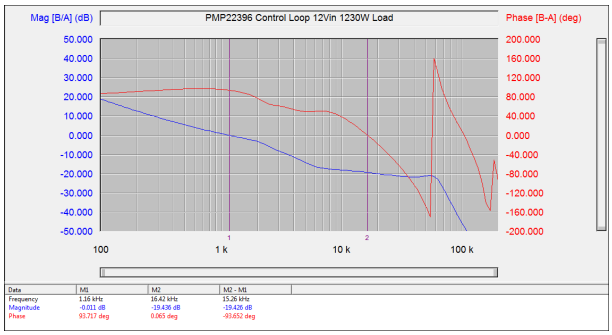

Figure 3-22. 12-V Input, 1230-W Load

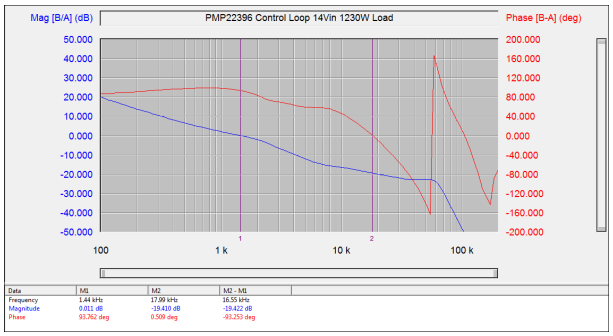

Figure 3-23. 14-V Input, 1230-W Load

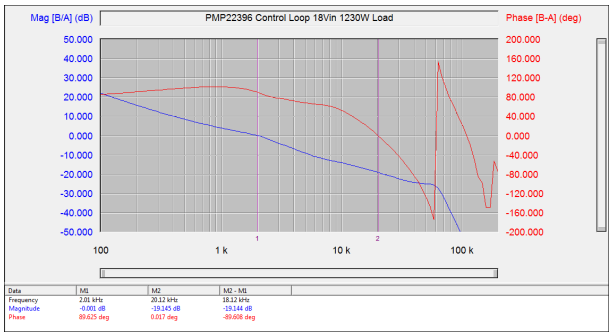

Figure 3-24. 18-V Input, 1230-W Load

3.5 Load Sharing

The following table shows the load sharing of the converter by measuring the current sense resistors voltage.

Table 3-6. Load Sharing

Board	I_{IN}	V_{CS1-1}	V_{CS2-1}	V_{CS1-2}	V_{CS2-2}
1	53.348 A	9.396 mV	9.260 mV	9.363 mV	9.410 mV
2	53.214 A	9.438 mV	9.290 mV	9.170 mV	9.340 mV

4 Waveforms

4.1 Switching

The switching behavior is shown in the following figures.

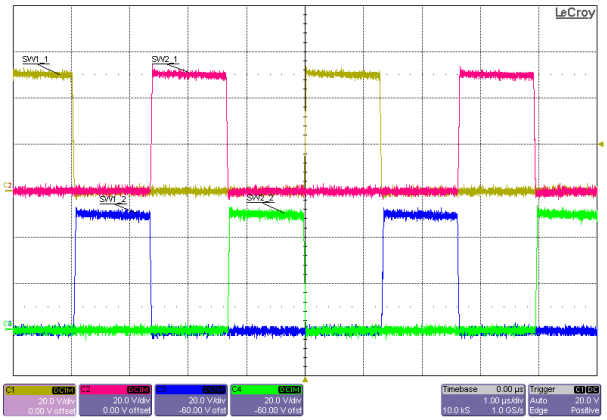

Figure 4-1. 4-Phase Switching, 12-V Input, 0-W Load

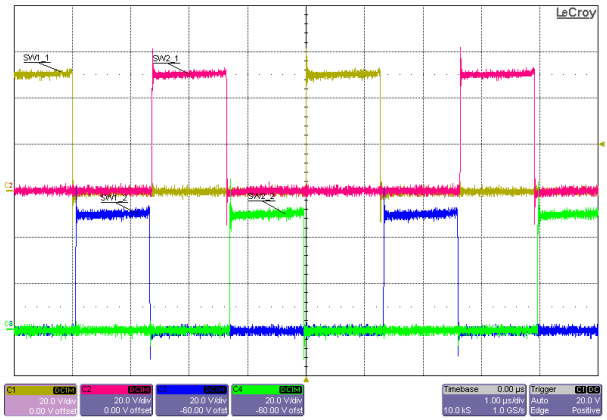

Figure 4-2. 4-Phase Switching, 12-V Input, 1230-W Load

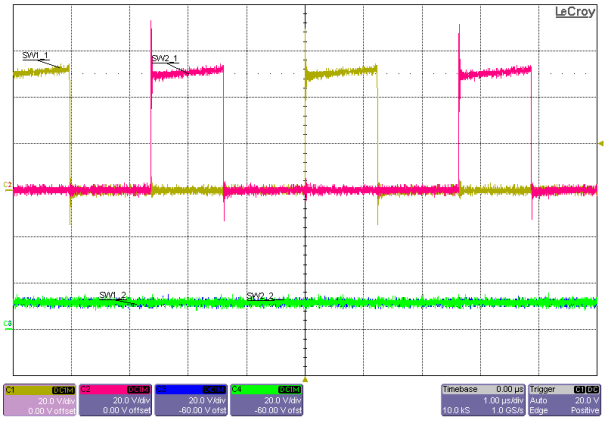

Figure 4-3. 2-Phase Switching, 12-V Input, 1230-W Load

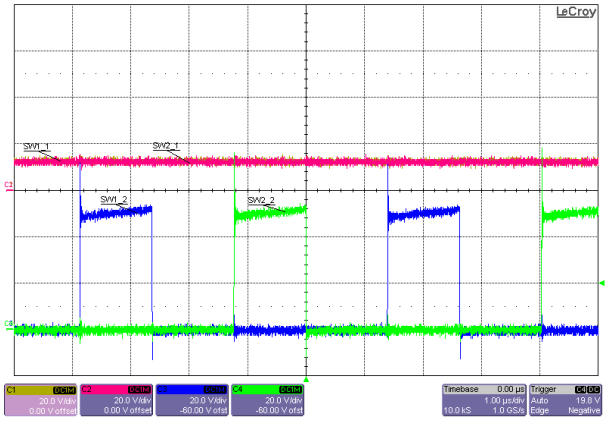

Figure 4-4. 2-Phase Switching, 12-V Input, 1230-W Load

4.2 Output Voltage Ripple

The following figures show the output voltage ripple of the converter as measured at the terminals across a 0.1µF capacitor.

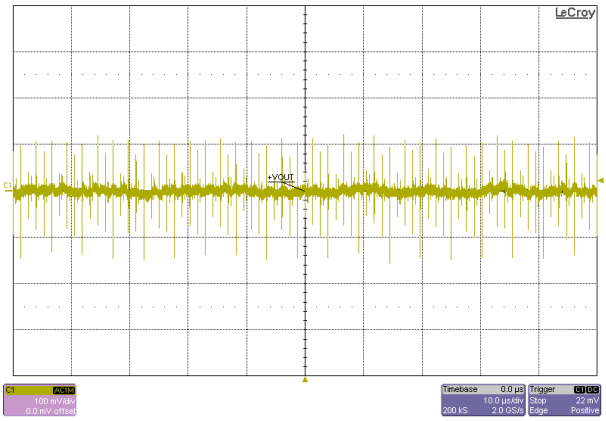

Figure 4-5. Ripple, 8-V Input, 615-W Load

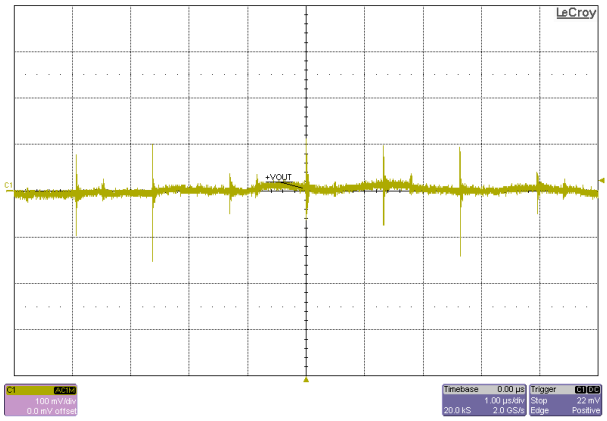

Figure 4-6. Ripple, 8-V Input, 615-W Load

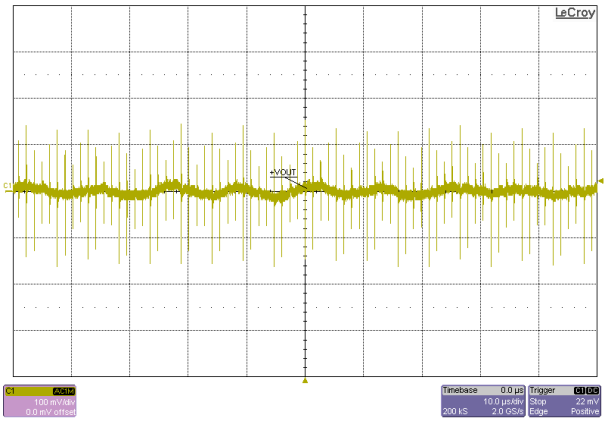

Figure 4-7. Ripple, 12-V Input, 1230-W Load

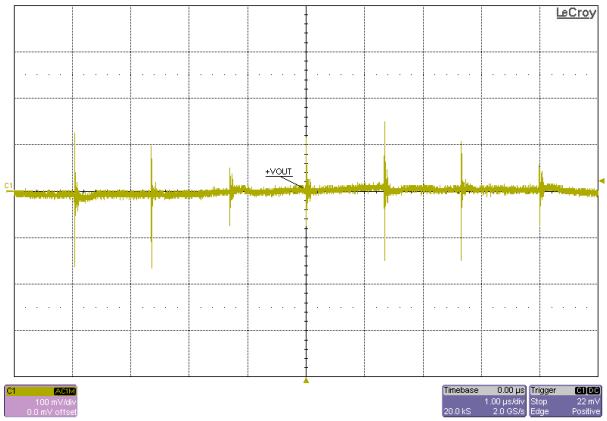

Figure 4-8. Ripple, 12-V Input, 1230-W Load

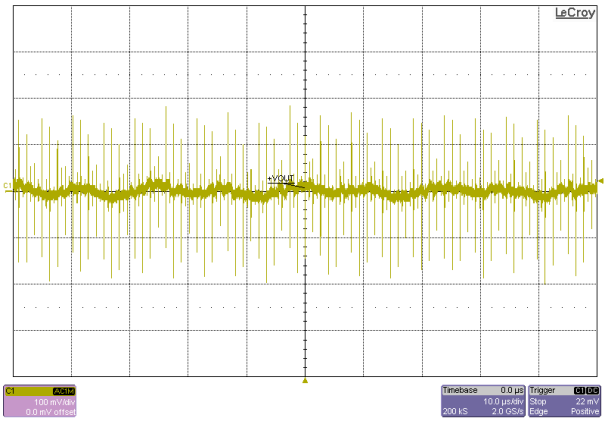

Figure 4-9. Ripple, 18-V Input, 1230-W Load

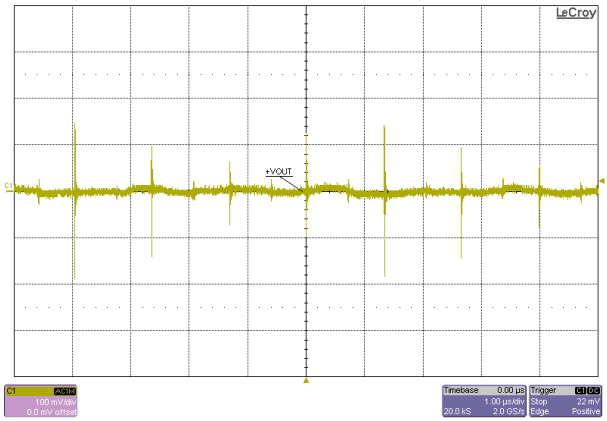

Figure 4-10. Ripple, 18-V Input, 1230-W Load

4.3 Load Transients

The load transient response is shown in the following figures.

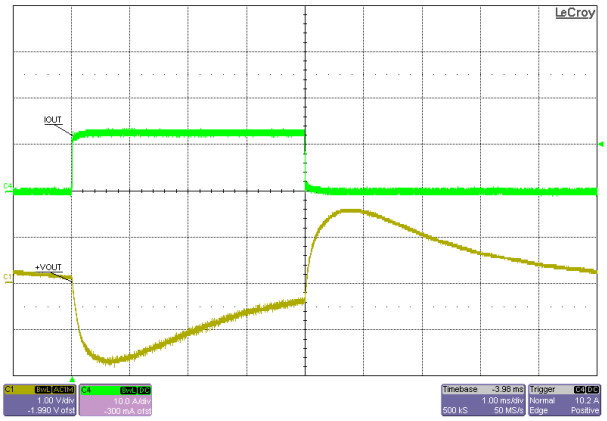

Figure 4-11. Transient, 8-V Input, 0-A to 12.5-A Load Step

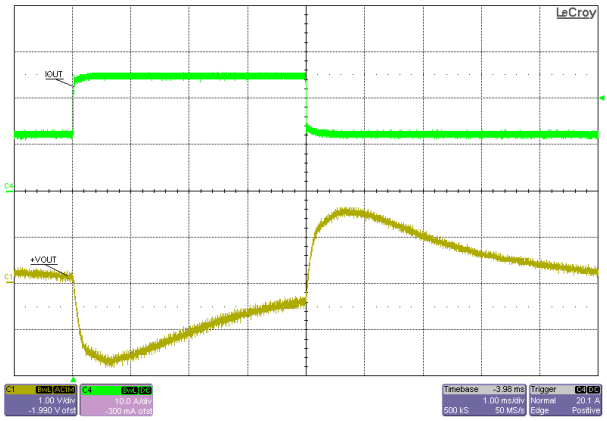

Figure 4-12. Transient, 8-V Input, 12.5-A to 25-A Load Step

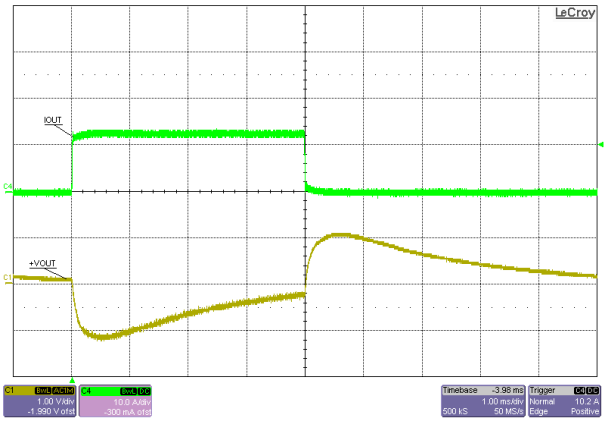

Figure 4-13. Transient, 12-V Input, 0-A to 12.5-A Load Step

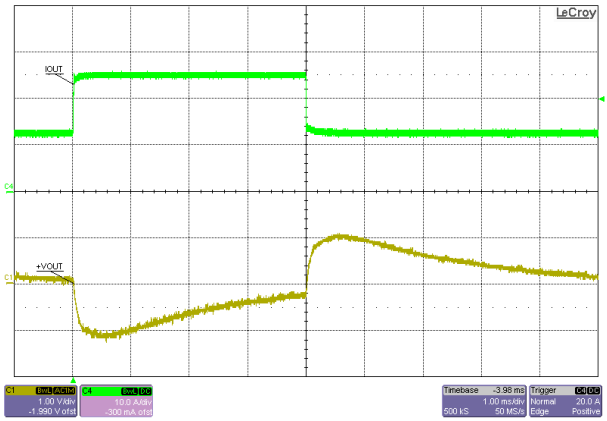

Figure 4-14. Transient, 12-V Input, 12.5-A to 25-A Load Step

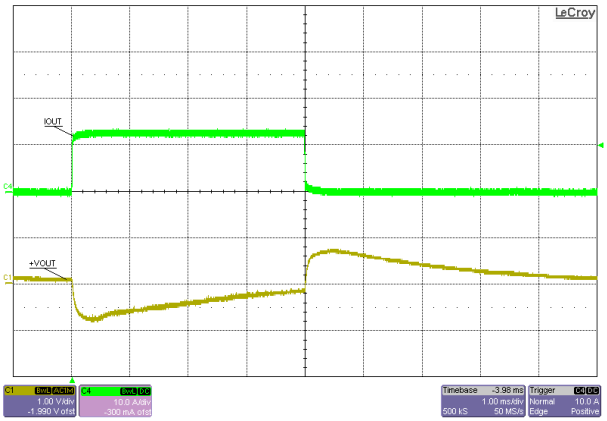

Figure 4-15. Transient, 18-V Input, 0-A to 12.5-A Load Step

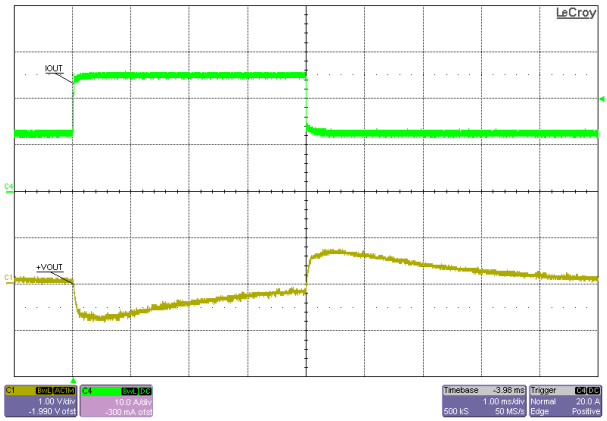

Figure 4-16. Transient, 18-V Input, 12.5-A to 25-A Load Step

4.4 Start-up

The start-up behavior is shown in the following figures.

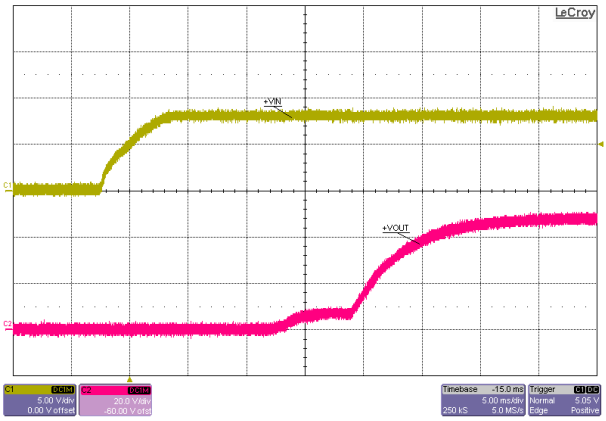

Figure 4-17. Startup, 2-Phase, 8-V Input, 615-W Load

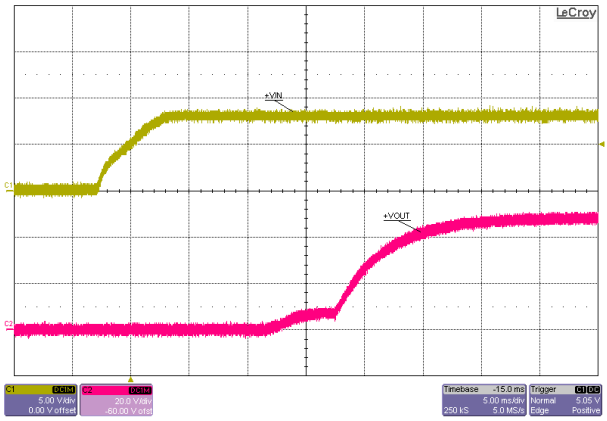

Figure 4-18. Startup, 4-Phase, 8-V Input, 615-W Load

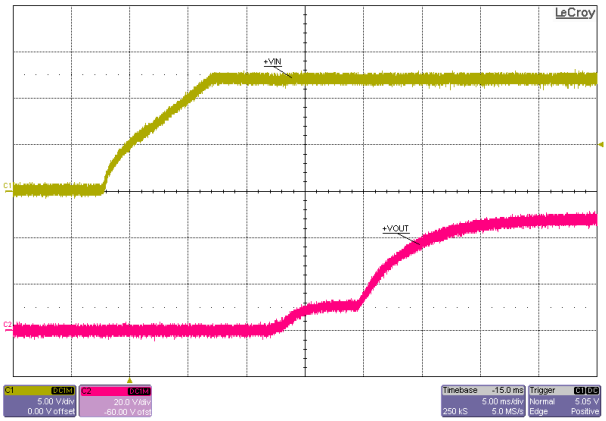

Figure 4-19. Startup, 2-Phase, 12-V Input, 1230-W Load

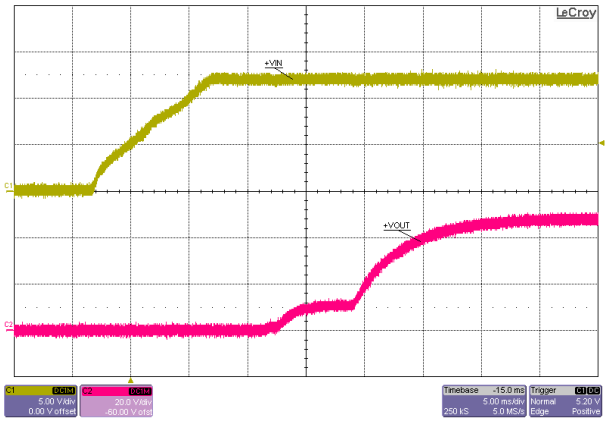

Figure 4-20. Startup, 4-Phase, 12-V Input, 1230-W Load

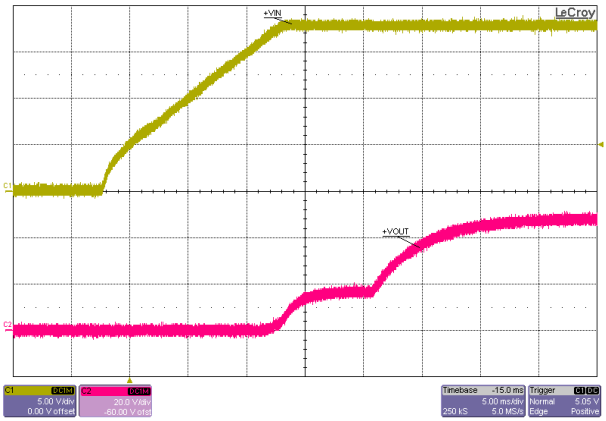

Figure 4-21. Startup, 2-Phase, 18-V Input, 1230-W Load

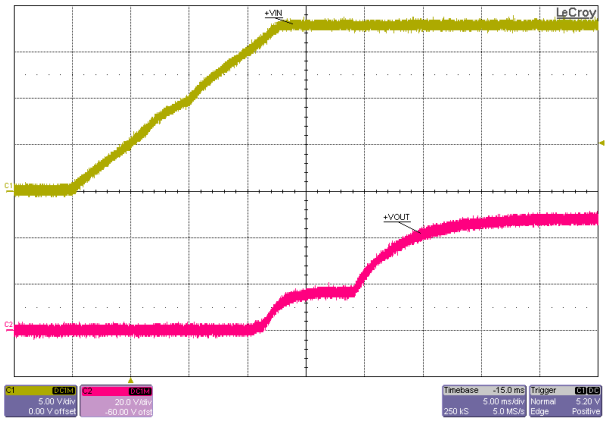

Figure 4-22. Startup, 4-Phase, 18-V Input, 1230-W Load

4.5 Reverse Switching

The following figures show reverse switching for two-phase operation. A 14-V constant voltage load is connected across the 12-V input voltage source. The output is powered at no load, and a 54-V 8-A source is connected to the output to test direction reversal. Average power from the 54-V source is 420 W; 12-V source is 56 W; 14-V load is 344 W.

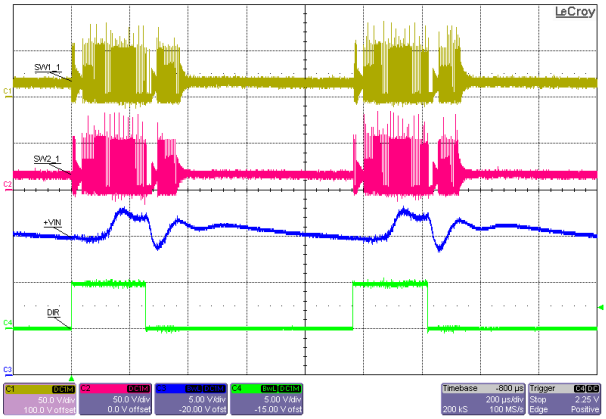

Figure 4-23. Reverse Switching, Phase 1 & 2, Direction Control

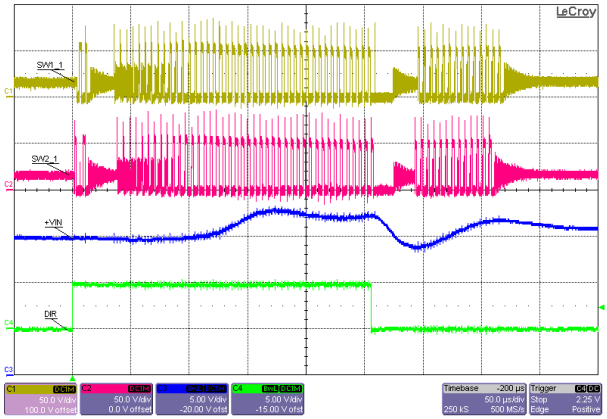

Figure 4-24. Reverse Switching, Phase 1 & 2, Direction Control

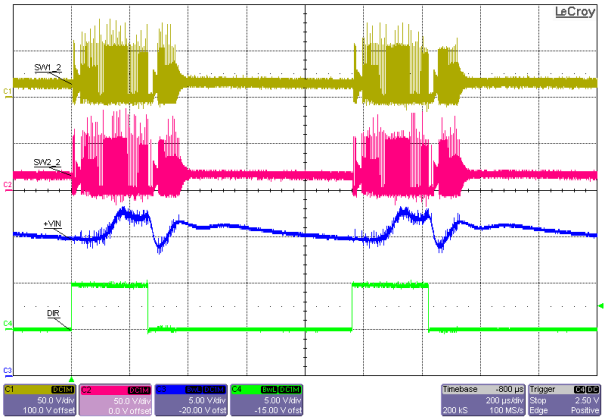

Figure 4-25. Reverse Switching, Phase 3 & 4, Direction Control

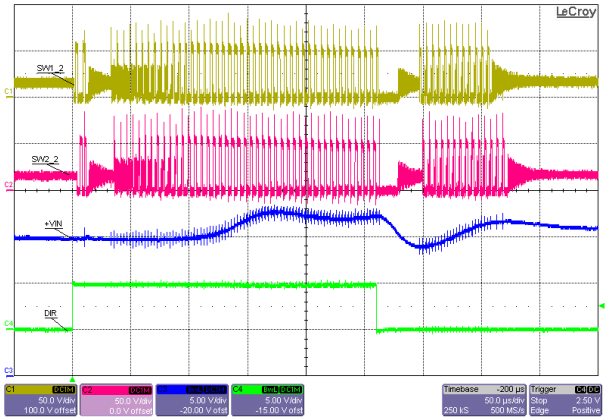

Figure 4-26. Reverse Switching, Phase 3 & 4, Direction Control

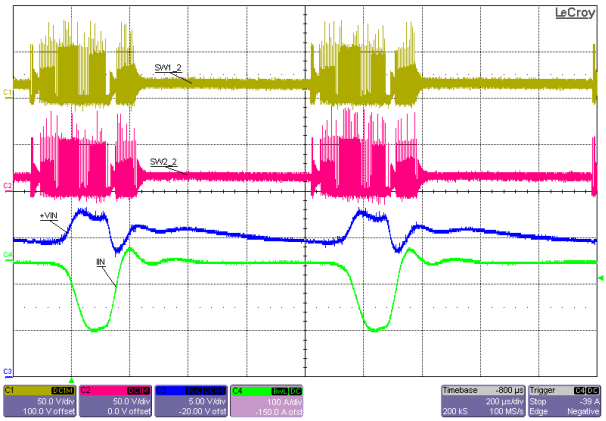

Figure 4-27. Reverse Switching, Phase 3 & 4, Input Voltage and Current

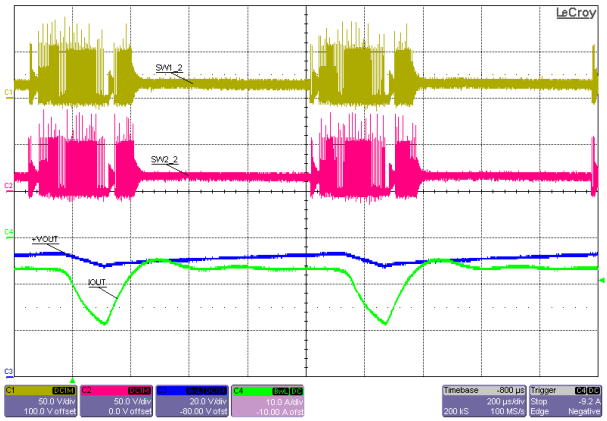

Figure 4-28. Reverse Switching, Phase 3 & 4, Output Voltage and Current

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