Test Report: PMP23380

24-V_{IN} to 60-V_{IN}, 3.3-V_{OUT}, 60-A, Automotive, 2-Phase Converter Reference Design

Description

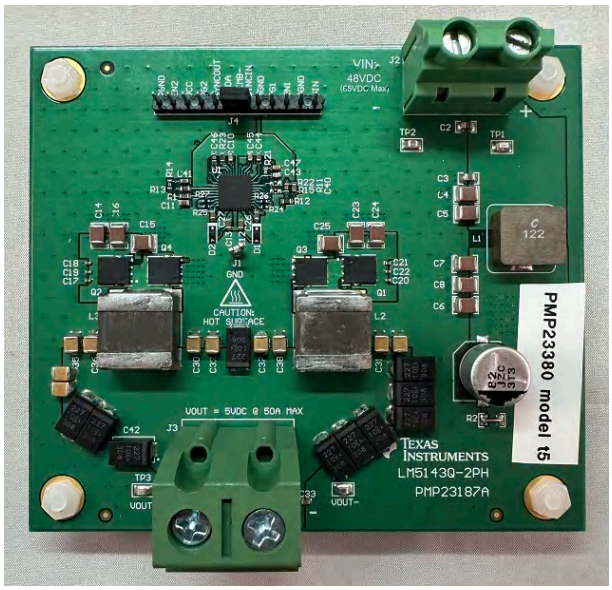
This reference design offers power for automotive advanced driver assistance systems (ADAS), infotainment, and cluster applications. Operation is over the full automotive range, up to 60 V. The design exhibits a peak conversion efficiency of 87% to 93% in the 24-V_{IN} to 60-V_{IN} range. Results demonstrate a 2.7% output voltage undershoot and overshoot for a 30-A step and dump. This test report includes operational data spanning over the full input range and includes Bode plots to verify stability with ample margins, internal waveforms, and thermal images.

Features

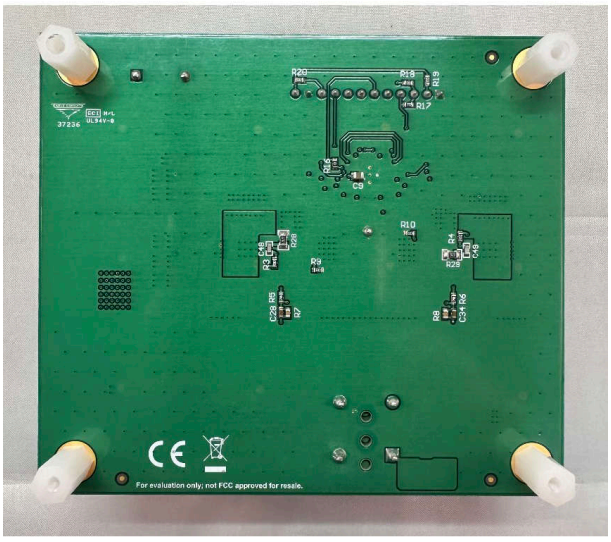
- High current for advanced driver assistance systems (ADAS), infotainment, and cluster applications
- Peak conversion efficiency of 87% to 93% in the 24- to 60-V_{IN} range
- LM5143-Q1 provides two-phase control and gate drive in a single integrated circuit (IC)
- Output voltage undershoot and overshoot 2.7% for 30-A step and dump

Applications

- Driver monitoring
- ADAS domain controller
- Drive assist ECU
- Surround view system ECU
- Radar ECU
- Hybrid instrument cluster
- Digital cockpit processing unit



Top Photo



Bottom Photo

1 Test Prerequisites

This section provides the testing guide used in the detailed testing of the 3.3-V, 60-A power supply.

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input Power	24-V to 60-V steady-state Use J2 onboard (Phoenix Contact 1714971 Receptacle, 9.52 mm, 2 × 1, TH)
3.3-V output	Load up to 60 A Use J3 Terminal Block Eaton EM292902
Various signals: J4	See the schematic for details; connect a conductor (jumper) from the J4 pin 7 (DEMB) to pin 6 (VDDA) for two-phase operation.

1.2 Required Equipment

- V_{IN} power supply 24 V to 60 V, at least 250 W at the input voltage under test, or 11 A for the full load off a 24-V input
- Electronic load to step for efficiency graphs, and for dynamic load testing such as Kikusui PLZ334WL
- Low inductance dynamic load for the 3.3-V output if the load slew rates > 3 A / µs needed
- Oscilloscope such as Tektronix MDO34 with TPP0500B 10 × voltage probes and 30-A TCP0030A current probe
- Digital multimeters such as Fluke 87iii or 87V
- For Bode plots: Vector Network Analyzer such as Bode 100 from OMICRON Lab
- Thermal camera such as FLIR E75
- Keysight 34970 data acquisition, switch unit along with calibrated 100-A and 50-A current shunts for efficiency measurements

1.3 Considerations

When testing for steady-state loads above 30 A for more than a few seconds, use a fan blowing on the board.

1.4 Dimensions

Board dimensions: 4 in by 3.5 in.

1.5 Test Setup

Figure 1-1 illustrates the test setup showing input power and output load connections, and output voltage being monitored with a digital voltmeter (DVM).

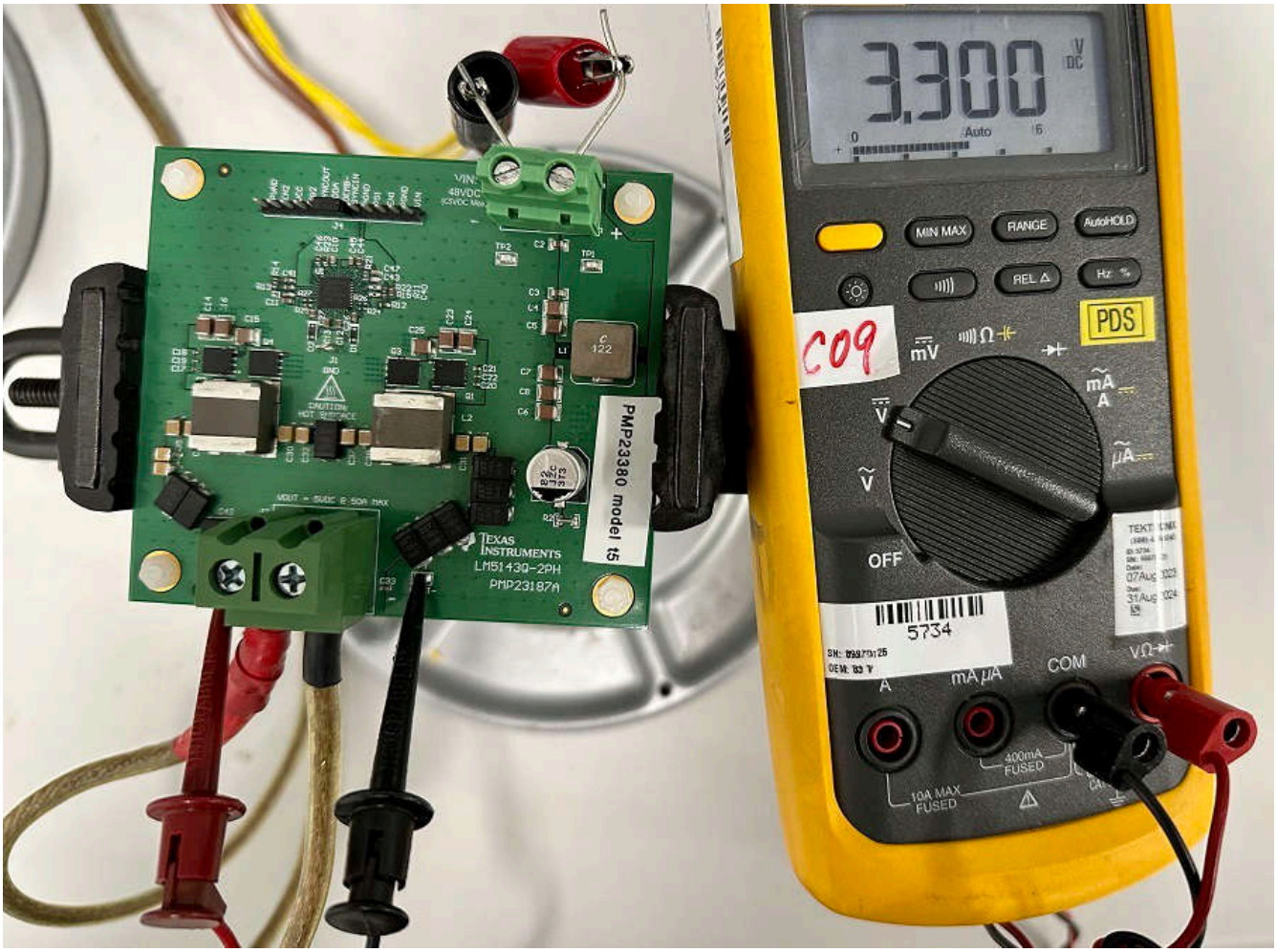


Figure 1-1. Test Setup

2 Testing and Results

2.1 Efficiency Graphs

The efficiency of the system is demonstrated across an input voltage range of 20 V to 60 V.

According to Figure 2-1, when operating at full 60-A load, the efficiency is within the range of 84% to 90%.

The efficiency graph is derived from the conversion loss vs load current graph (Figure 2-2), which also spans over a 24-V to 60-V input range. The no-load loss varies from just over 2 W when the input voltage is 24 V, increasing to just under 8 W when the input voltage reaches 60 V. The range of full-load loss extends from 24 W at 24 V input to 37.3 W at 60-V input.

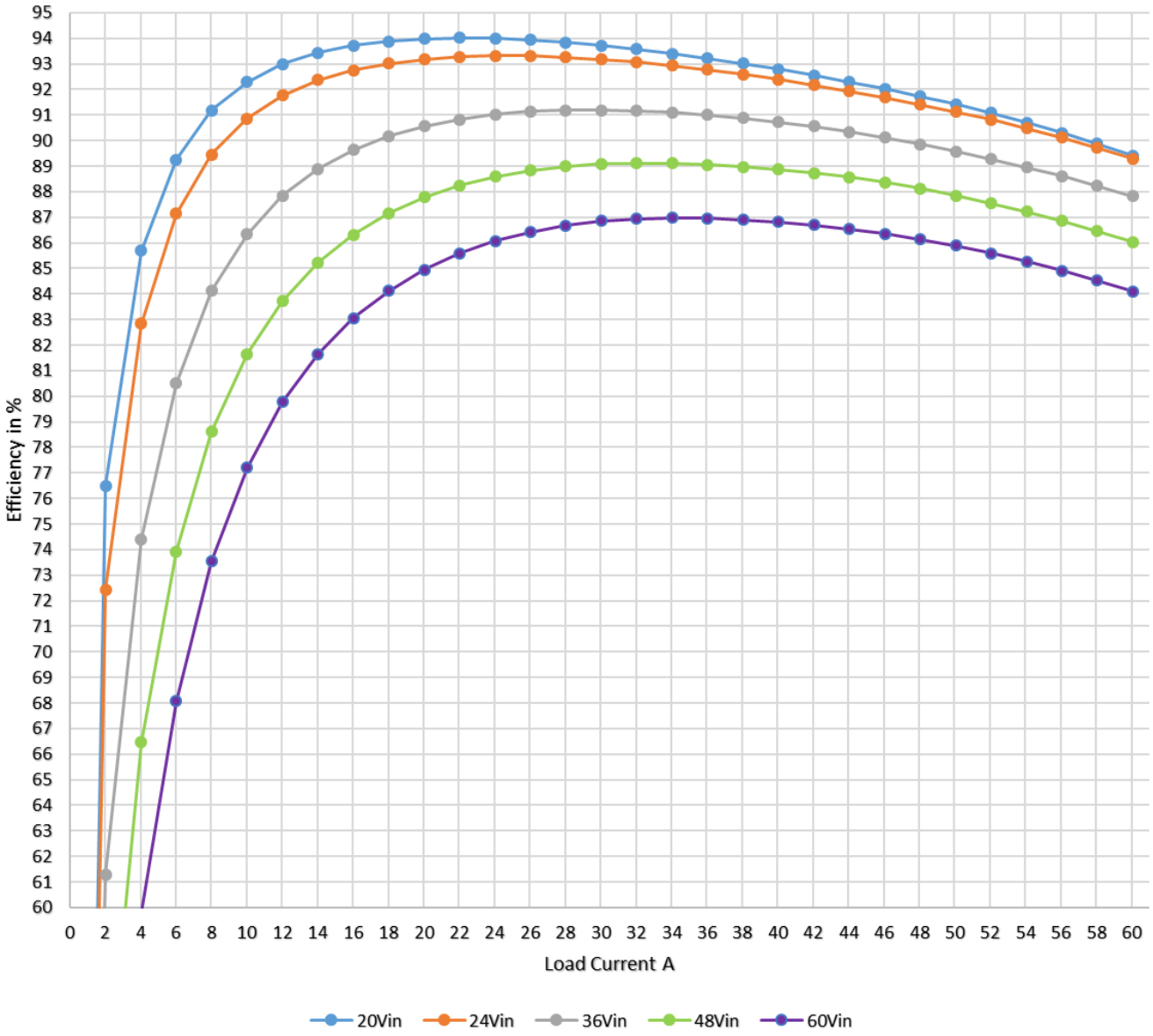


Figure 2-1. 3.3 V, 2-Phase Conversion Efficiency

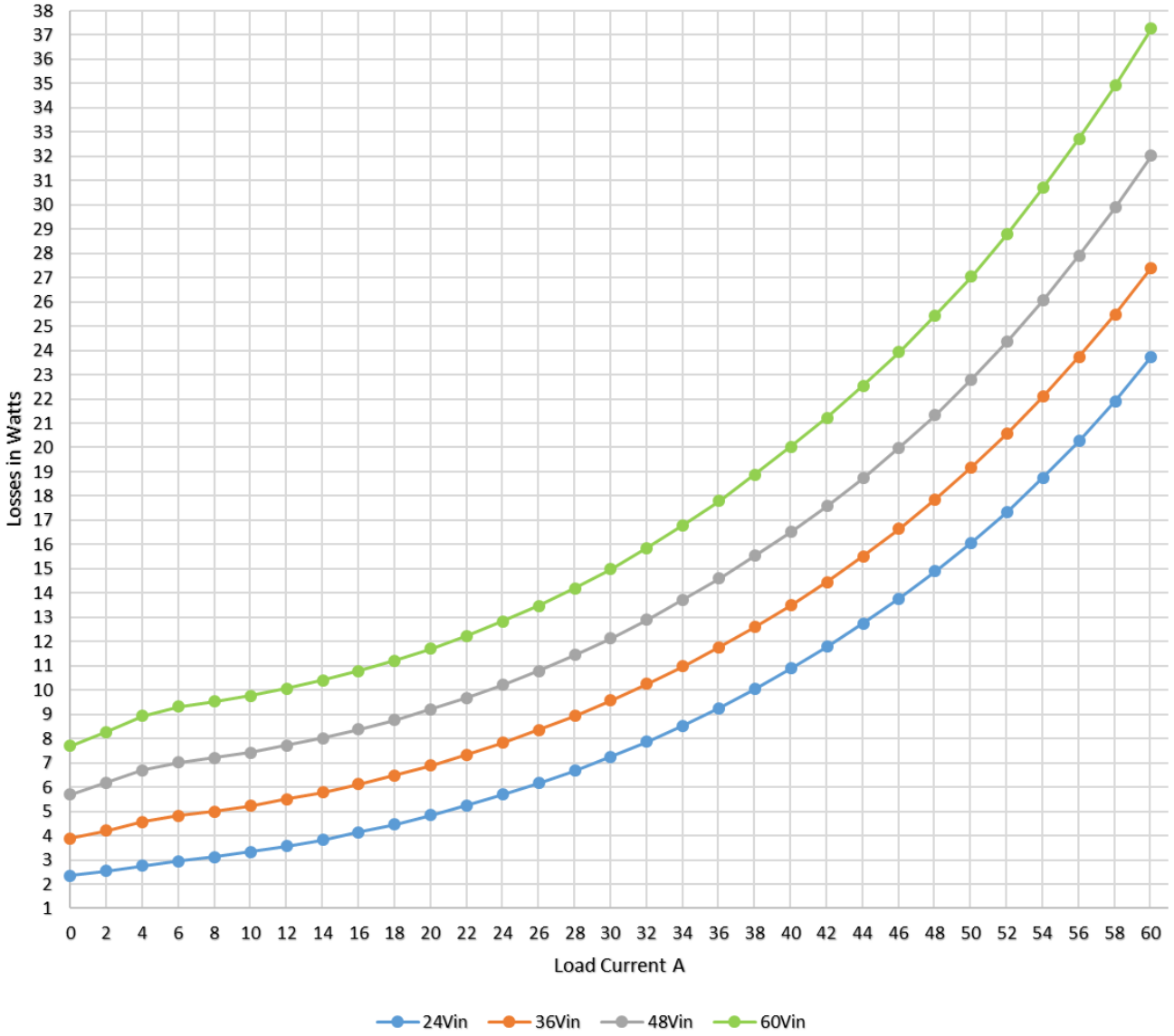


Figure 2-2. 3.3 V, 2-Phase Conversion Losses

2.2 Efficiency Data

This section details the efficiency data at various voltages.

Table 2-1. Efficiency Data 24-V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
23.998	0.098	3.304	0.000	2.354	0.000	2.354	0.000
23.998	0.385	3.303	2.024	9.228	6.685	2.543	72.443
23.998	0.669	3.303	4.024	16.047	13.293	2.755	82.833
23.998	0.952	3.303	6.024	22.836	19.898	2.938	87.133
23.998	1.234	3.303	8.024	29.620	26.499	3.121	89.463
23.998	1.518	3.302	10.025	36.436	33.108	3.328	90.866
23.998	1.803	3.302	12.027	43.275	39.713	3.562	91.769
23.998	2.090	3.302	14.027	50.146	46.315	3.832	92.359
23.998	2.378	3.302	16.030	57.058	52.924	4.134	92.754
23.998	2.667	3.301	18.031	63.995	59.525	4.469	93.016
23.998	2.957	3.301	20.032	70.969	66.128	4.841	93.179
23.998	3.249	3.301	22.035	77.973	72.731	5.242	93.278
23.998	3.543	3.300	24.036	85.017	79.330	5.687	93.311
23.998	3.837	3.300	26.037	92.090	85.926	6.164	93.307
23.998	4.134	3.300	28.039	99.208	92.522	6.686	93.260
23.998	4.433	3.299	30.041	106.375	99.118	7.257	93.178
23.998	4.733	3.299	32.042	113.582	105.712	7.870	93.071
23.998	5.036	3.299	34.048	120.861	112.322	8.538	92.935
23.998	5.341	3.299	36.050	128.173	118.916	9.257	92.778
23.997	5.648	3.298	38.052	135.547	125.498	10.048	92.587
23.997	5.958	3.298	40.056	142.980	132.094	10.886	92.386
23.997	6.270	3.297	42.058	150.472	138.682	11.790	92.165
23.997	6.584	3.297	44.059	158.006	145.263	12.743	91.935
23.997	6.902	3.297	46.062	165.628	151.859	13.769	91.687
23.997	7.222	3.296	48.064	173.307	158.418	14.889	91.409
23.997	7.546	3.296	50.068	181.079	165.006	16.073	91.124
23.997	7.873	3.295	52.070	188.938	171.581	17.357	90.814
23.997	8.205	3.295	54.071	196.894	178.141	18.753	90.475
23.997	8.541	3.294	56.072	204.963	184.703	20.260	90.115
23.997	8.883	3.293	58.073	213.163	191.256	21.907	89.723
23.997	9.231	3.293	60.073	221.524	197.797	23.727	89.289

Table 2-2. Efficiency Data 36-V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
35.998	0.108	3.302	0.000	3.882	0.000	3.882	0.000
35.998	0.303	3.302	2.022	10.891	6.677	4.215	61.303
35.998	0.496	3.302	4.023	17.850	13.283	4.567	74.414
35.998	0.686	3.302	6.023	24.699	19.885	4.814	80.508
35.998	0.875	3.302	8.023	31.493	26.490	5.003	84.113
35.998	1.065	3.301	10.025	38.330	33.094	5.236	86.340
35.998	1.255	3.301	12.025	45.190	39.695	5.494	87.842
35.998	1.447	3.301	14.027	52.089	46.298	5.791	88.883
35.998	1.640	3.300	16.030	59.024	52.902	6.122	89.628
35.998	1.833	3.300	18.031	65.988	59.503	6.486	90.172
35.998	2.028	3.300	20.032	72.995	66.098	6.897	90.551
35.998	2.223	3.299	22.033	80.038	72.697	7.342	90.827
35.998	2.420	3.299	24.034	87.116	79.298	7.818	91.025
35.998	2.618	3.299	26.034	94.234	85.886	8.348	91.141
35.998	2.817	3.299	28.036	101.419	92.480	8.939	91.186
35.998	3.018	3.298	30.037	108.638	99.065	9.573	91.188
35.998	3.220	3.298	32.039	115.900	105.655	10.245	91.160
35.998	3.423	3.297	34.045	123.236	112.260	10.977	91.093
35.997	3.628	3.297	36.046	130.599	118.840	11.759	90.996
35.997	3.834	3.297	38.050	138.024	125.434	12.590	90.879
35.997	4.042	3.296	40.053	145.505	132.016	13.489	90.730
35.997	4.252	3.296	42.056	153.064	138.606	14.459	90.554
35.997	4.464	3.295	44.057	160.691	145.177	15.514	90.345
35.997	4.678	3.295	46.059	168.387	151.754	16.634	90.122
35.997	4.894	3.294	48.061	176.182	158.319	17.863	89.861
35.997	5.114	3.294	50.065	184.081	164.893	19.188	89.576
35.997	5.335	3.293	52.068	192.048	171.462	20.586	89.281
35.997	5.559	3.292	54.070	200.119	178.022	22.097	88.958
35.997	5.786	3.291	56.070	208.277	184.551	23.727	88.608
35.996	6.017	3.291	58.069	216.584	191.102	25.482	88.235
35.996	6.252	3.290	60.069	225.038	197.639	27.399	87.825

Table 2-3. Efficiency Data 48-V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
47.996	0.118	3.301	0.000	5.685	0.000	5.685	0.000
47.996	0.268	3.301	2.024	12.868	6.681	6.187	51.917
47.996	0.416	3.300	4.025	19.986	13.285	6.701	66.470
47.996	0.560	3.300	6.024	26.895	19.881	7.014	73.921
47.996	0.702	3.300	8.024	33.681	26.479	7.202	78.617
47.996	0.844	3.300	10.025	40.514	33.083	7.431	81.657
47.996	0.987	3.299	12.026	47.392	39.680	7.712	83.727
47.996	1.131	3.299	14.027	54.303	46.276	8.026	85.220
47.996	1.276	3.299	16.030	61.260	52.880	8.381	86.320
47.996	1.422	3.299	18.032	68.249	59.482	8.767	87.154
47.996	1.568	3.298	20.033	75.274	66.074	9.200	87.778
47.996	1.716	3.298	22.035	82.349	72.667	9.682	88.242
47.995	1.864	3.298	24.036	89.471	79.263	10.208	88.591
47.995	2.013	3.297	26.036	96.636	85.847	10.789	88.835
47.995	2.164	3.297	28.037	103.876	92.436	11.440	88.987
47.995	2.316	3.296	30.039	111.152	99.020	12.132	89.085
47.995	2.469	3.296	32.041	118.512	105.607	12.905	89.111
47.995	2.624	3.296	34.048	125.927	112.207	13.720	89.105
47.995	2.779	3.295	36.050	133.389	118.789	14.599	89.055
47.995	2.936	3.295	38.052	140.904	125.371	15.533	88.976
47.995	3.093	3.294	40.055	148.467	131.942	16.525	88.869
47.995	3.253	3.294	42.057	156.110	138.521	17.589	88.733
47.995	3.413	3.293	44.058	163.814	145.074	18.740	88.560
47.995	3.576	3.292	46.060	171.622	151.642	19.980	88.358
47.995	3.741	3.292	48.063	179.532	158.201	21.331	88.119
47.995	3.908	3.291	50.066	187.563	164.762	22.802	87.843
47.994	4.078	3.291	52.067	195.702	171.333	24.369	87.548
47.994	4.250	3.290	54.069	203.952	177.889	26.063	87.221
47.994	4.424	3.289	56.068	212.334	184.416	27.918	86.852
47.994	4.601	3.288	58.068	220.839	190.946	29.893	86.464
47.994	4.782	3.287	60.067	229.495	197.463	32.032	86.042

Table 2-4. Efficiency Data 60-V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
59.995	0.128	3.299	0.000	7.705	0.000	7.705	-0.037
59.995	0.250	3.299	2.030	14.974	6.695	8.279	44.712
59.994	0.370	3.298	4.030	22.225	13.292	8.934	59.804
59.994	0.487	3.298	6.029	29.213	19.886	9.327	68.071
59.994	0.600	3.298	8.029	36.006	26.480	9.527	73.542
59.994	0.714	3.298	10.029	42.835	33.072	9.763	77.209
59.994	0.829	3.298	12.029	49.724	39.669	10.055	79.778
59.994	0.944	3.297	14.030	56.663	46.260	10.403	81.641
59.994	1.061	3.297	16.033	63.646	52.858	10.788	83.050
59.994	1.178	3.296	18.034	70.667	59.449	11.218	84.126
59.994	1.296	3.296	20.035	77.738	66.035	11.703	84.946
59.994	1.414	3.296	22.037	84.859	72.630	12.229	85.589
59.994	1.534	3.295	24.038	92.040	79.217	12.823	86.068
59.994	1.655	3.295	26.038	99.276	85.796	13.480	86.422
59.994	1.777	3.295	28.041	106.583	92.383	14.201	86.677
59.994	1.899	3.294	30.042	113.953	98.967	14.986	86.849
59.994	2.023	3.293	32.043	121.379	105.530	15.848	86.943
59.994	2.149	3.293	34.049	128.912	112.125	16.786	86.979
59.994	2.275	3.293	36.051	136.503	118.700	17.803	86.958
59.994	2.403	3.292	38.053	144.142	125.263	18.878	86.903
59.994	2.531	3.291	40.056	151.862	131.834	20.028	86.812
59.993	2.661	3.291	42.059	159.642	138.412	21.230	86.701
59.993	2.792	3.290	44.060	167.502	144.960	22.541	86.543
59.993	2.925	3.289	46.061	175.451	151.512	23.939	86.356
59.993	3.059	3.289	48.063	183.493	158.062	25.431	86.141
59.993	3.195	3.288	50.066	191.671	164.624	27.047	85.889
59.993	3.333	3.287	52.069	199.957	171.156	28.800	85.597
59.993	3.474	3.286	54.070	208.394	177.696	30.698	85.269
59.992	3.616	3.285	56.069	216.938	184.206	32.731	84.912
59.992	3.761	3.284	58.068	225.637	190.715	34.922	84.523
59.992	3.909	3.283	60.067	234.485	197.219	37.266	84.107

2.3 Thermal Images

The thermal image presented in Figure 2-3 was taken with a load of 60 A, 24 V_{IN}, and with a fan blowing on the device. Both low-side FETs reached a temperature of 72°C, with the ambient room temperature at 21°C to 23°C.

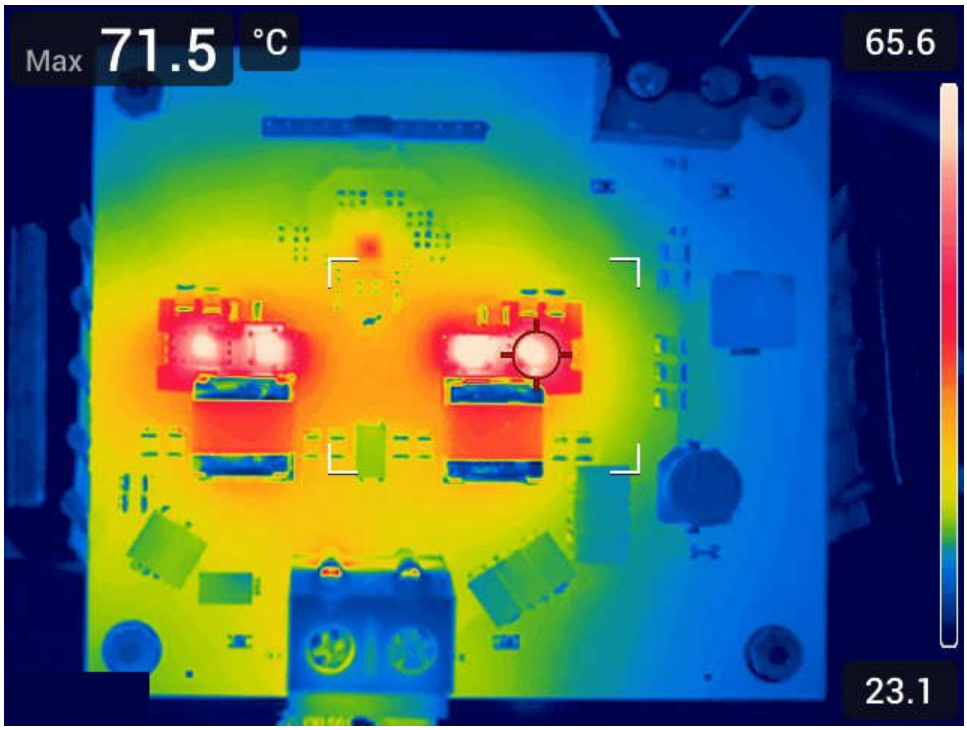


Figure 2-3. 24-V_{IN} Thermal Image

The thermal image displayed in Figure 2-4 was taken with a load of 60 A, 48 V_{IN}, and with a fan. Both low-side FETs reached a temperature of 96°C, with the ambient room temperature at 21°C to 23°C.

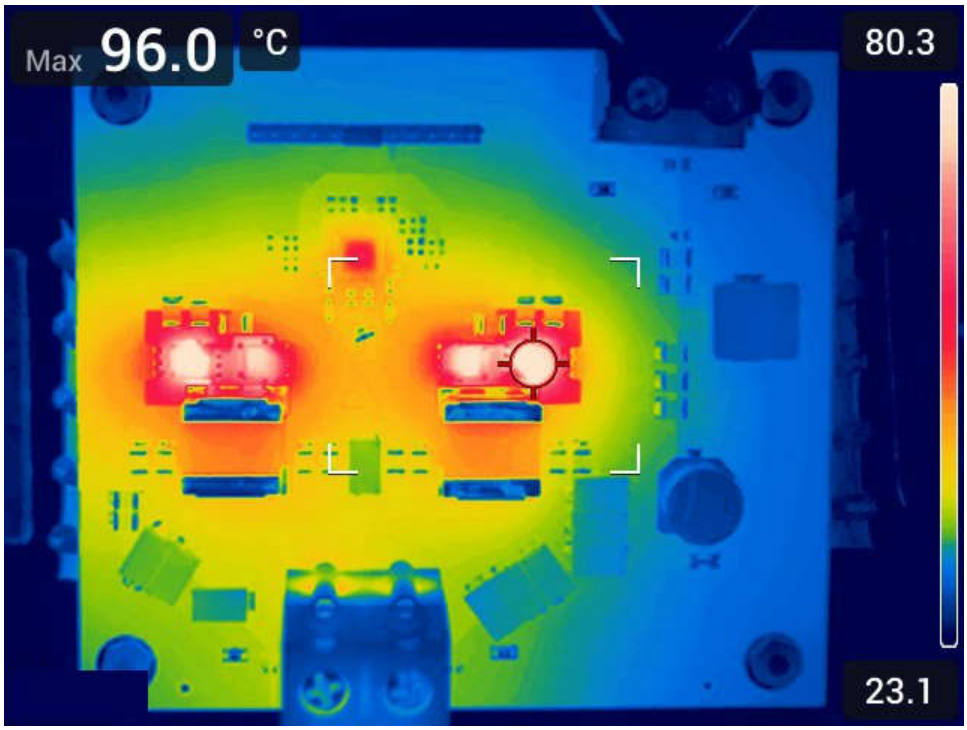


Figure 2-4. 48-V_{IN} Thermal Image

2.4 Bode Plots

Each Bode plot is shown at a 3.3-V output. The Bode plots for different loads exhibit similar results, with the main difference being the slight appearance of noise. Thus, one Bode plot is shown for each input voltage.

Crossover increases with load from 27 kHz at no load to 42 kHz at the maximum 60-A load, but the phase margin has a minimum of 70 degrees with a gain margin of around 10 dB.

The Bode plots in Figure 2-5 and Figure 2-6 were created at a 30-A load with Figure 2-5 having a 24-V input and Figure 2-6 having a 48-V input.

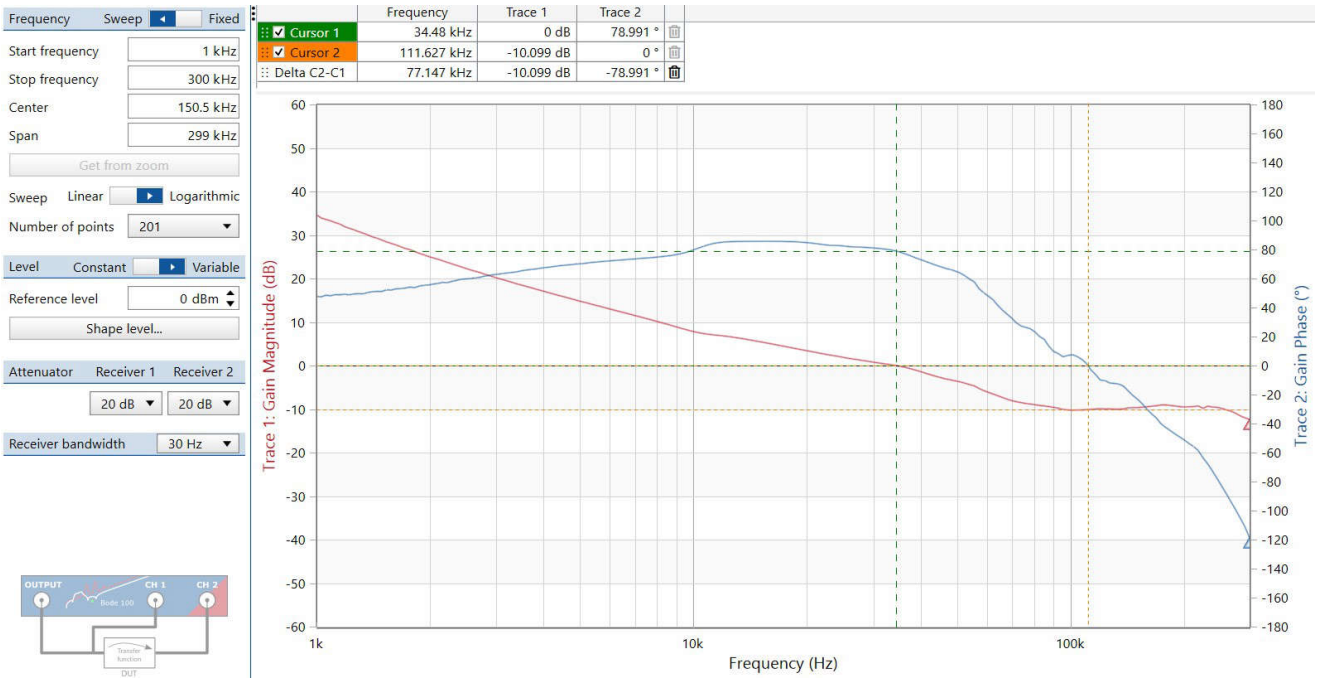


Figure 2-5. 24-V_{IN} Bode Plot

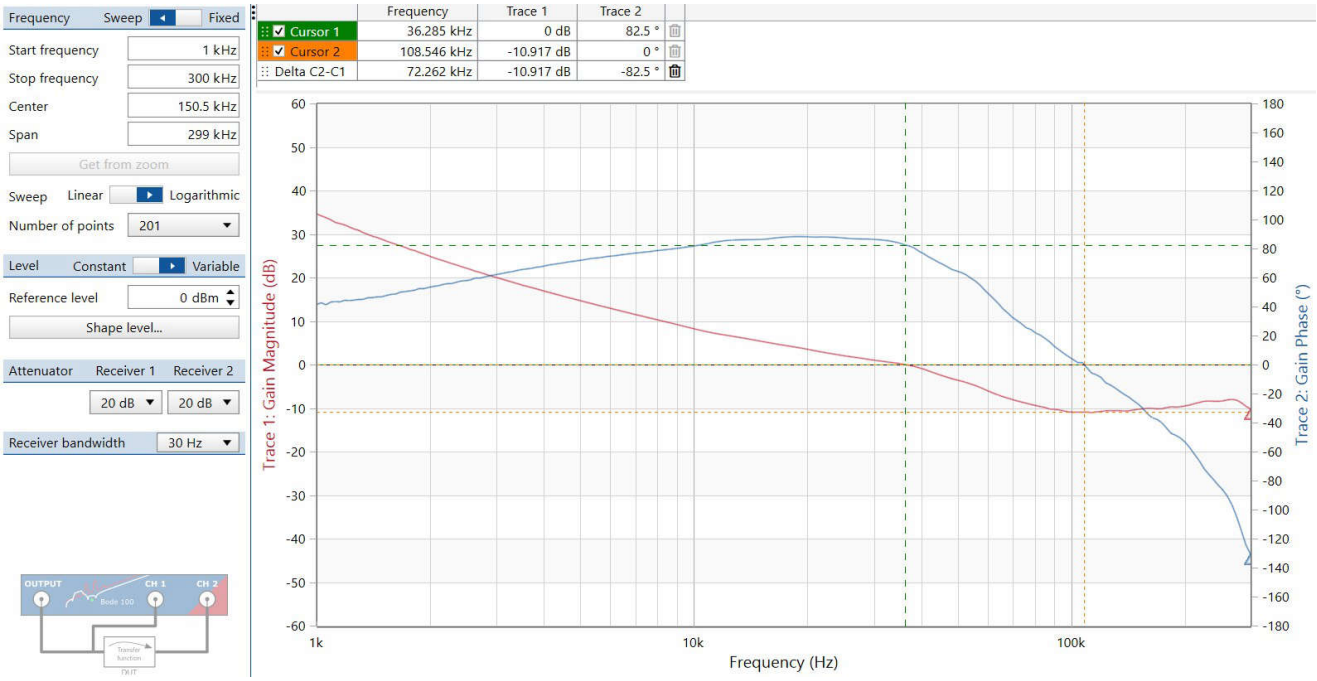


Figure 2-6. 48-V_{IN} Bode Plot

3 Waveforms

3.1 Switching

Figure 3-1 displays the main switching waveform.

The waveform in Figure 3-1 was captured at 60 V_{IN} while operating under a maximum load of 60 A per phase. The waveform is characterized by the following conditions: a switching frequency of 396 kHz, an overshoot of 1.6 V, a rise time of 7.1 ns, and a fall time of 4.7 ns.

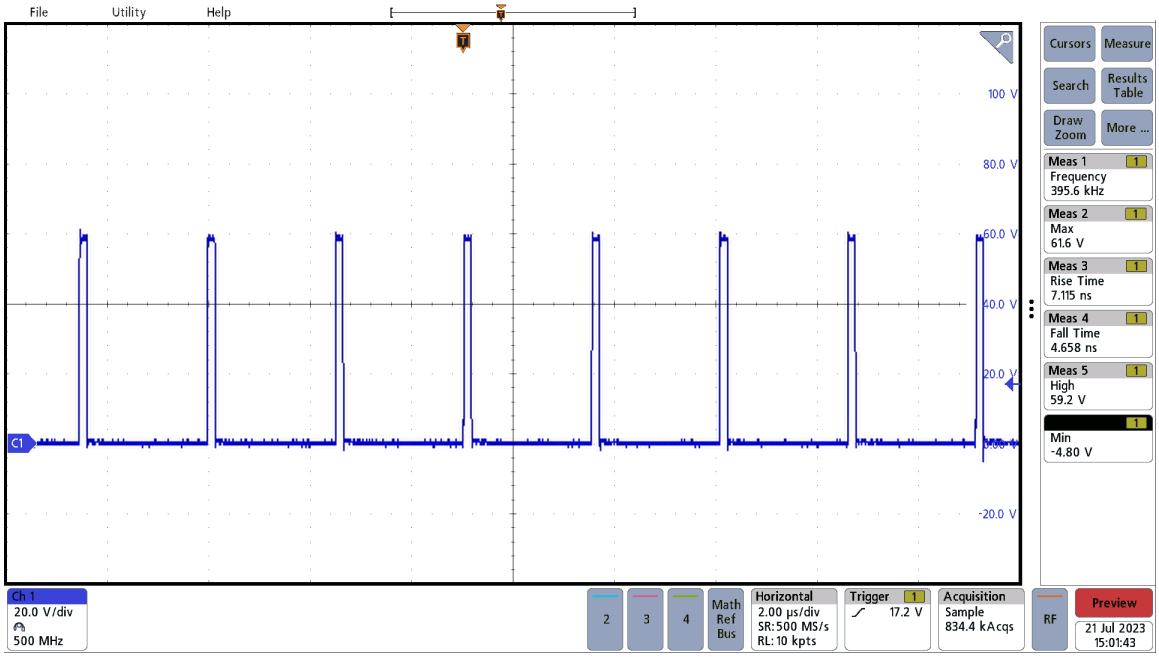


Figure 3-1. 60-V Switching Waveform

3.2 Load Transients

Figure 3-2 represents load transient 1 at 24 V_{IN} with a 15-A steady-state load in parallel (not captured by the current probe), thus the image shows a step and dump between 0 A and 30 A. Load transient 1 exhibits a step response, starting from a load of 15 A to 45 A, followed by a load dump from 45 A to 15 A. The load change time is approximately 2 µs. The undershoot and overshoot for each is around 2.7% or 90 mV. For all images, the top trace represents V_{OUT}, while the bottom represents I_{OUT}.

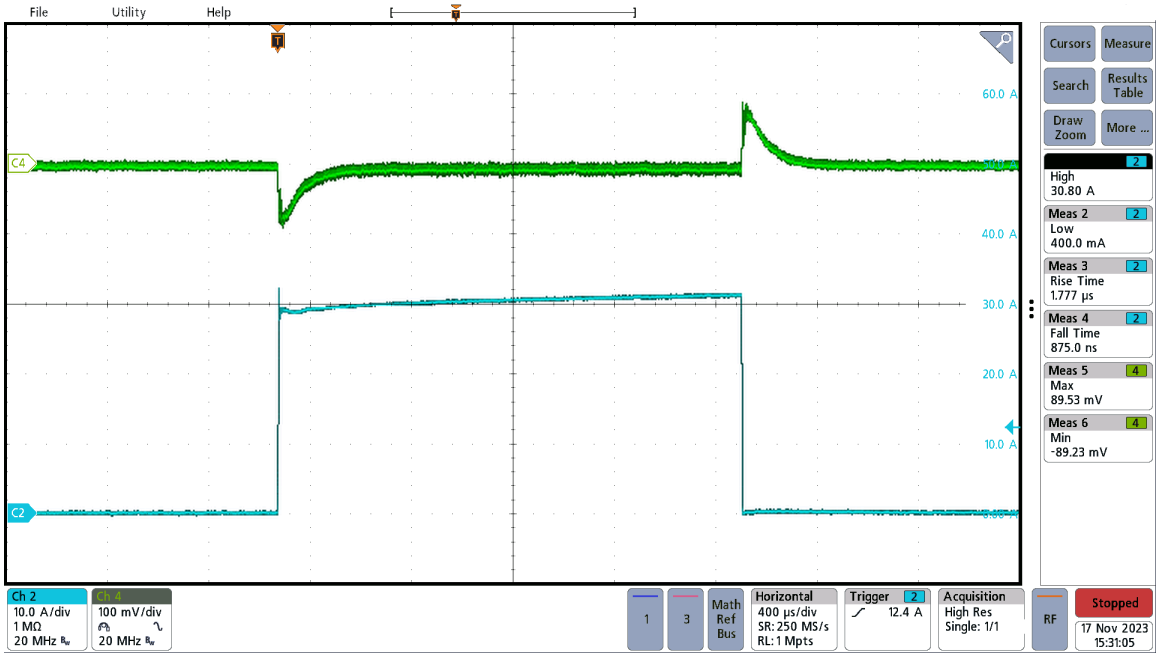


Figure 3-2. Load Transient 1

Figure 3-3 illustrates the load transient 2 at 48 V_{IN} with a 15-A load in parallel, thus the image shows a step and dump between 0 A and 30 A. Load transient 2 exhibits a step response, starting from a load of 15 A to 45 A, followed by a load dump from 45 A to 15 A. The load change time is approximately 2 µs. Both the overshoot and undershoot measure to be about 90 mV.

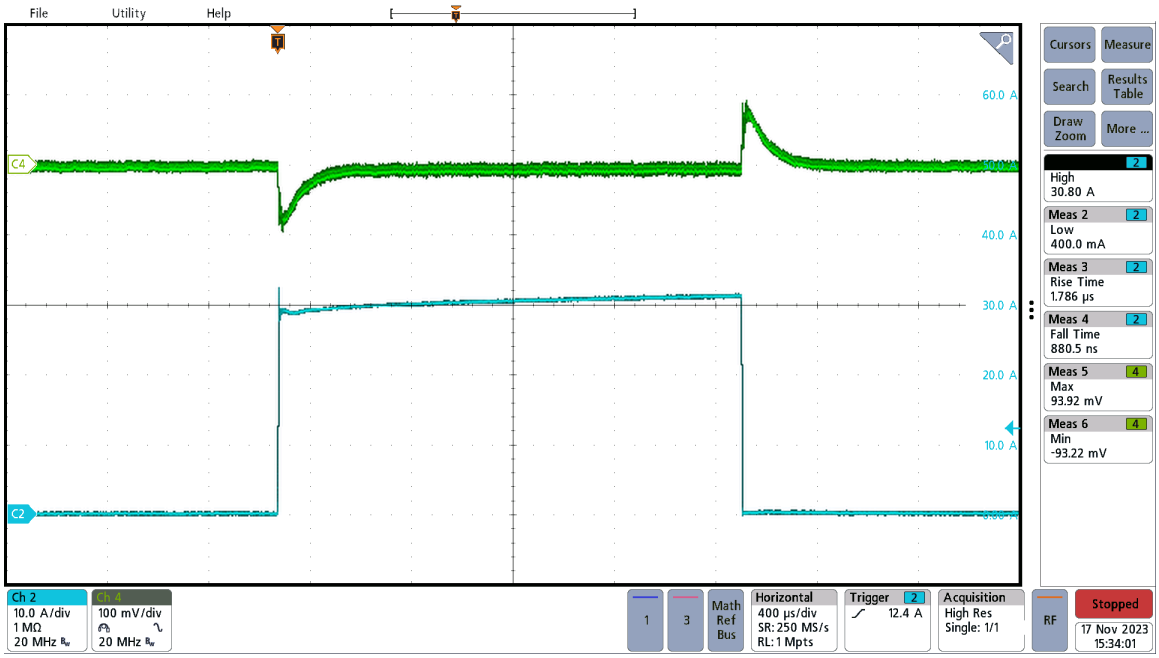


Figure 3-3. Load Transient 2

3.3 Start-Up and Shutdown Sequences

Start-up behavior for a 24-V input is shown in Figure 3-4, while the shutdown behavior is shown in Figure 3-5.

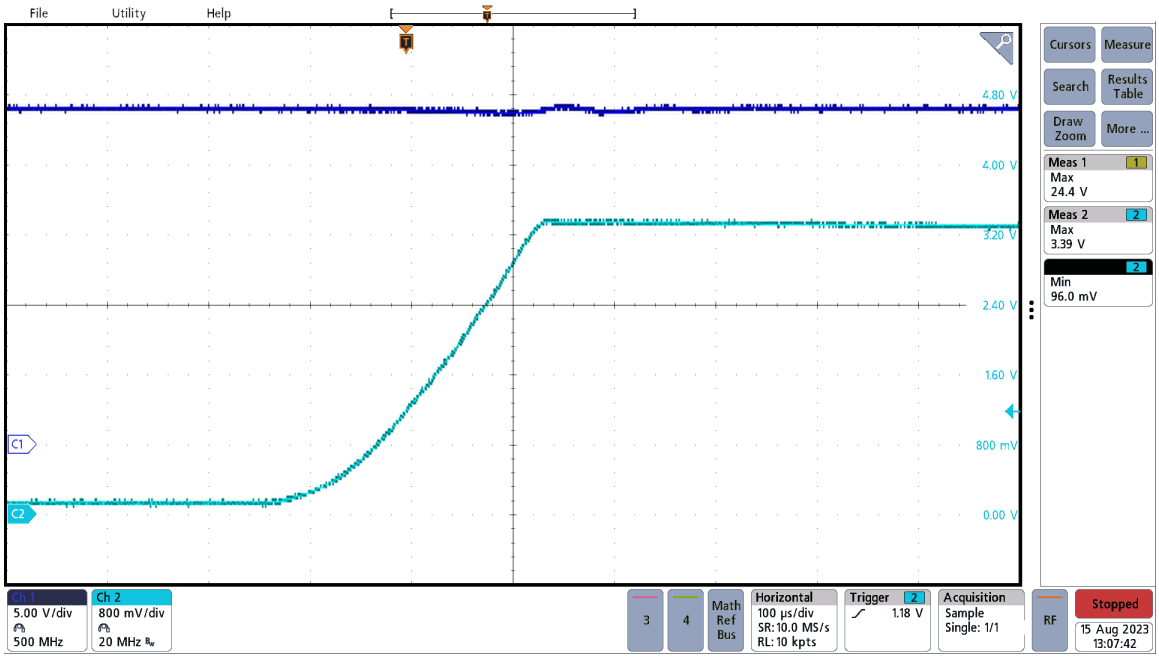


Figure 3-4. 24-V_{IN} Start-Up

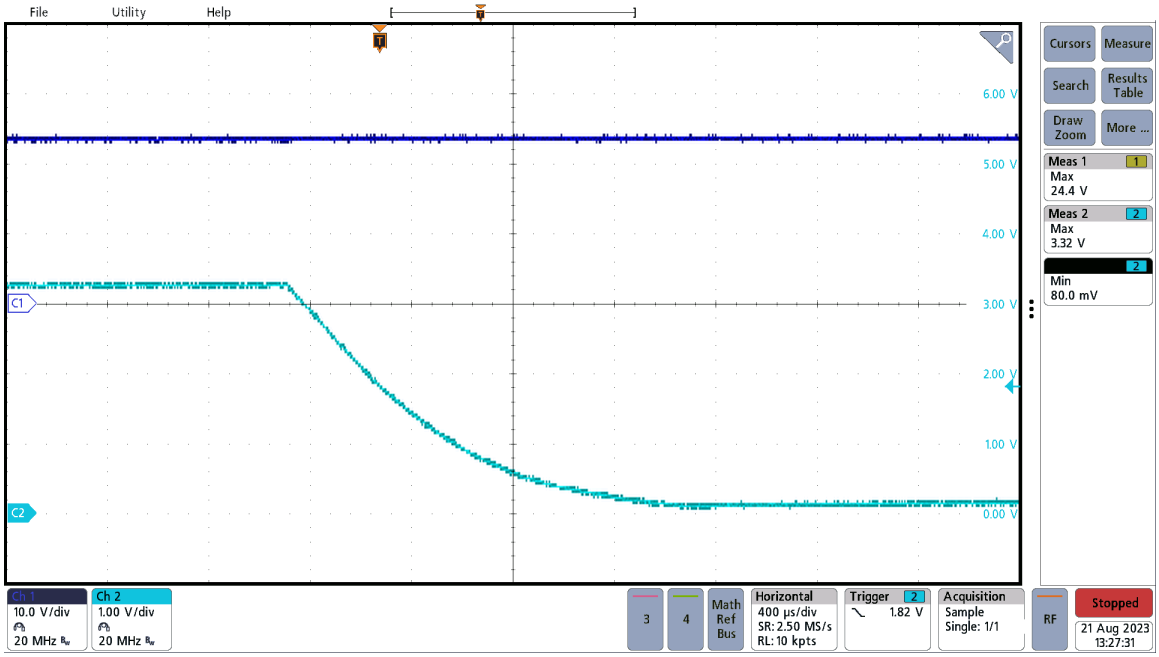


Figure 3-5. 24-V_{IN} Shutdown

The start-up waveform for a 48 V input is displayed in Figure 3-6 and the shutdown waveform is seen in Figure 3-7.

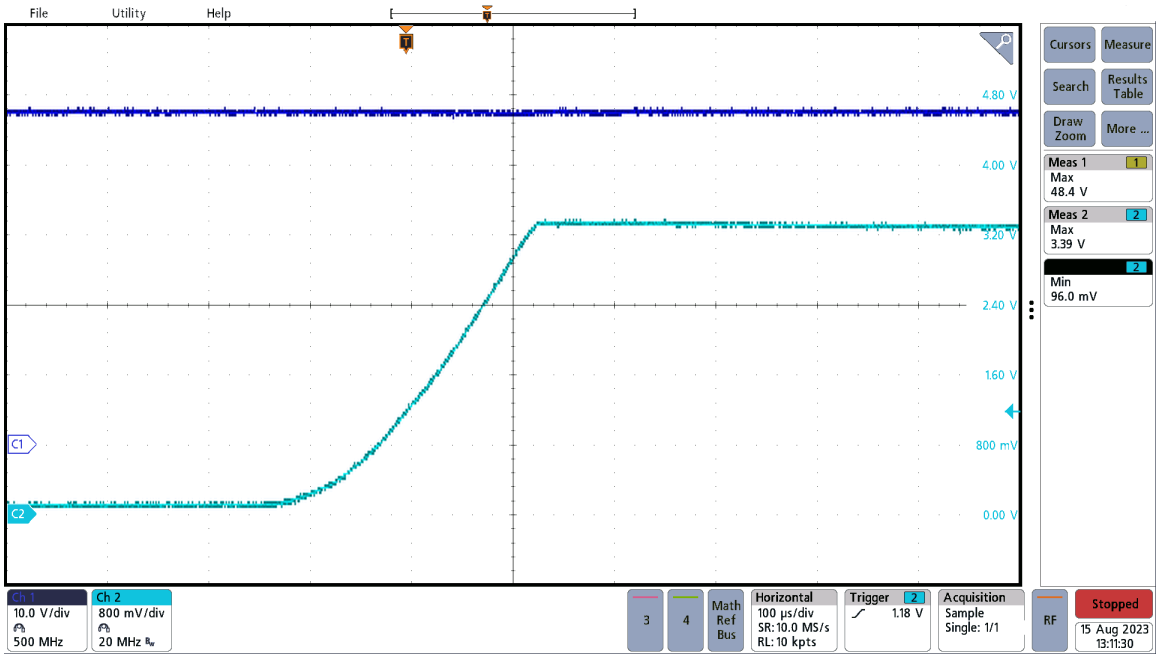


Figure 3-6. 48-V_{IN} Start-Up

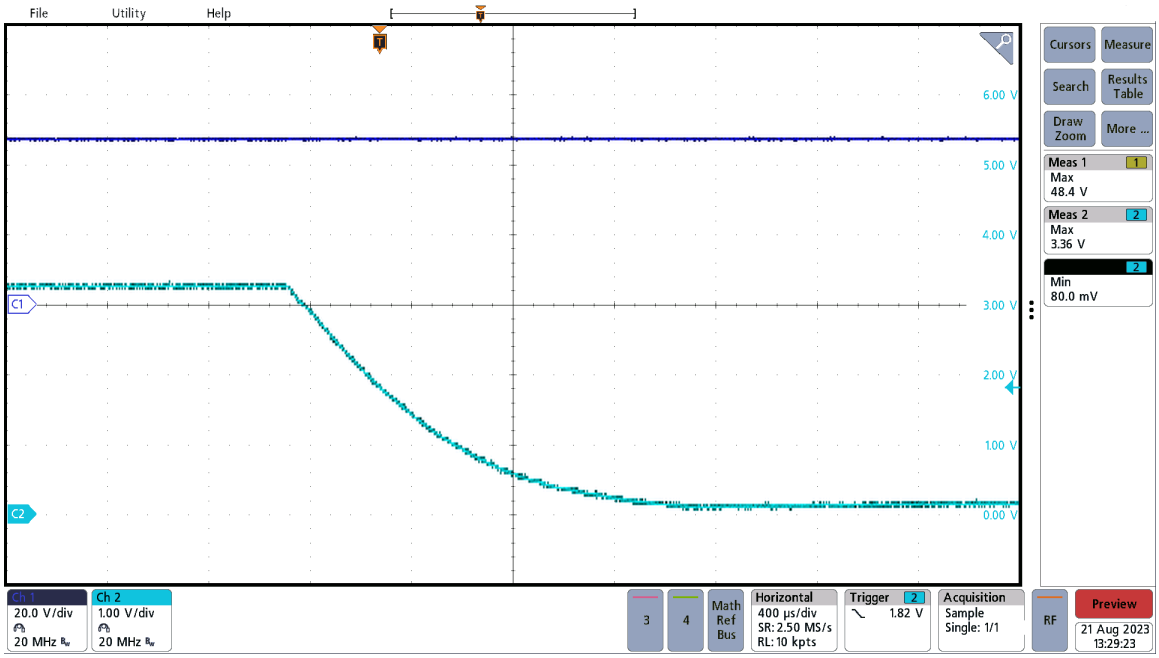


Figure 3-7. 48-V_{IN} Shutdown

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