Test Report: PMP23404

24-V_{IN} to 60-V_{IN}, 300-W, Automotive 2-Phase Converter Reference Design

Description

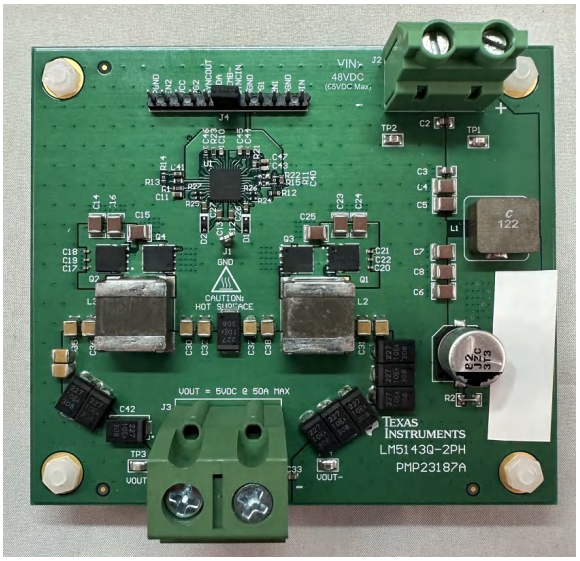
This reference design offers power for automotive advanced driver assistance systems (ADAS), infotainment, and cluster applications. Operation is over the full automotive range up to 60 V. The design exhibits a peak conversion efficiency of 91% to 96% in the 24-V_{IN} to 60-V_{IN} range. Results demonstrate a 2% output voltage undershoot and overshoot for a 30-A step and dump. The 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

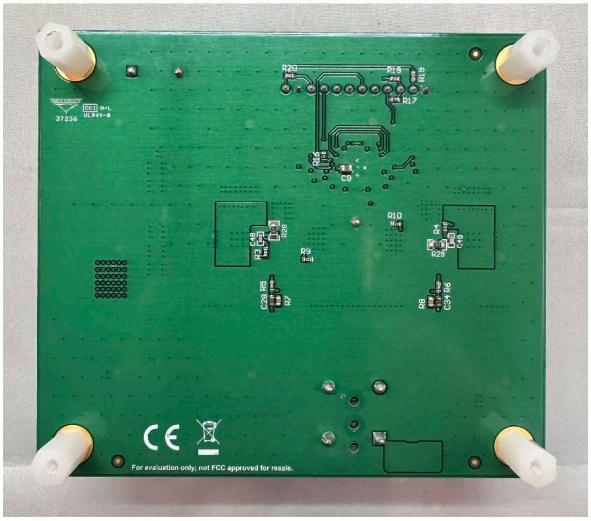
- High current for advanced driver assistance systems (ADAS), infotainment, and cluster applications
- Peak conversion efficiency of 91% to 96% in the 24- to 60-V_{IN} range
- LM5143-Q1 provides two-phase control and gate drive in a single IC
- Output voltage undershoot and overshoot 2% for 30-A step 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



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1 Test Prerequisites

This section provides the testing guide used in the detailed testing of the 5-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)
5-V output	Load up to 60 A Use J3 terminal block Eaton EM292902
Various signals: J4	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 330 W at the input voltage under test, or 14 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 5-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 50-A and 25-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

The dimensions of the board are 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).

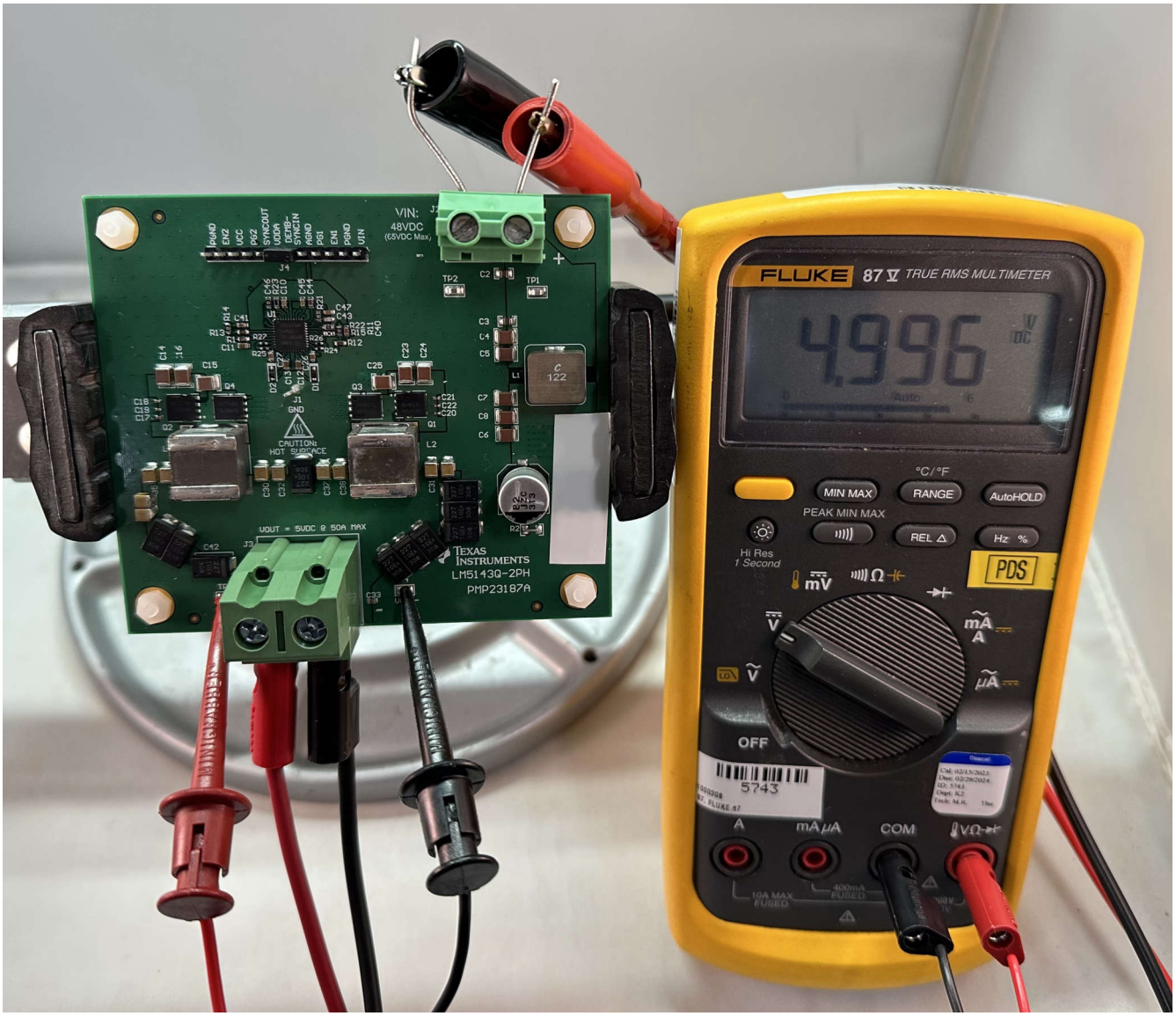

Figure 1-1. Test Setup

CAUTION

Caution Hot surface.
Contact with heatsinks may cause burns.
Do not touch.

2 Testing and Results

2.1 Efficiency Graphs

The efficiency of the system is demonstrated across an input voltage range of 24 V to 60 V.

According to Figure 2-1, when operating at full 60-A load, the efficiency is within the range of 89% to 92%.

The efficiency graph is derived from the conversion loss vs load current graph (Figure 2-2), which also spans over the same 24-V to 60-V input range. The no load loss varies from under 2 W when the input voltage is 24 V, increasing to just under 5 W when the input voltage reaches 60 V. The range of full load loss extends from 29.7 W at 36-V input to 36.4 W at 60-V input.

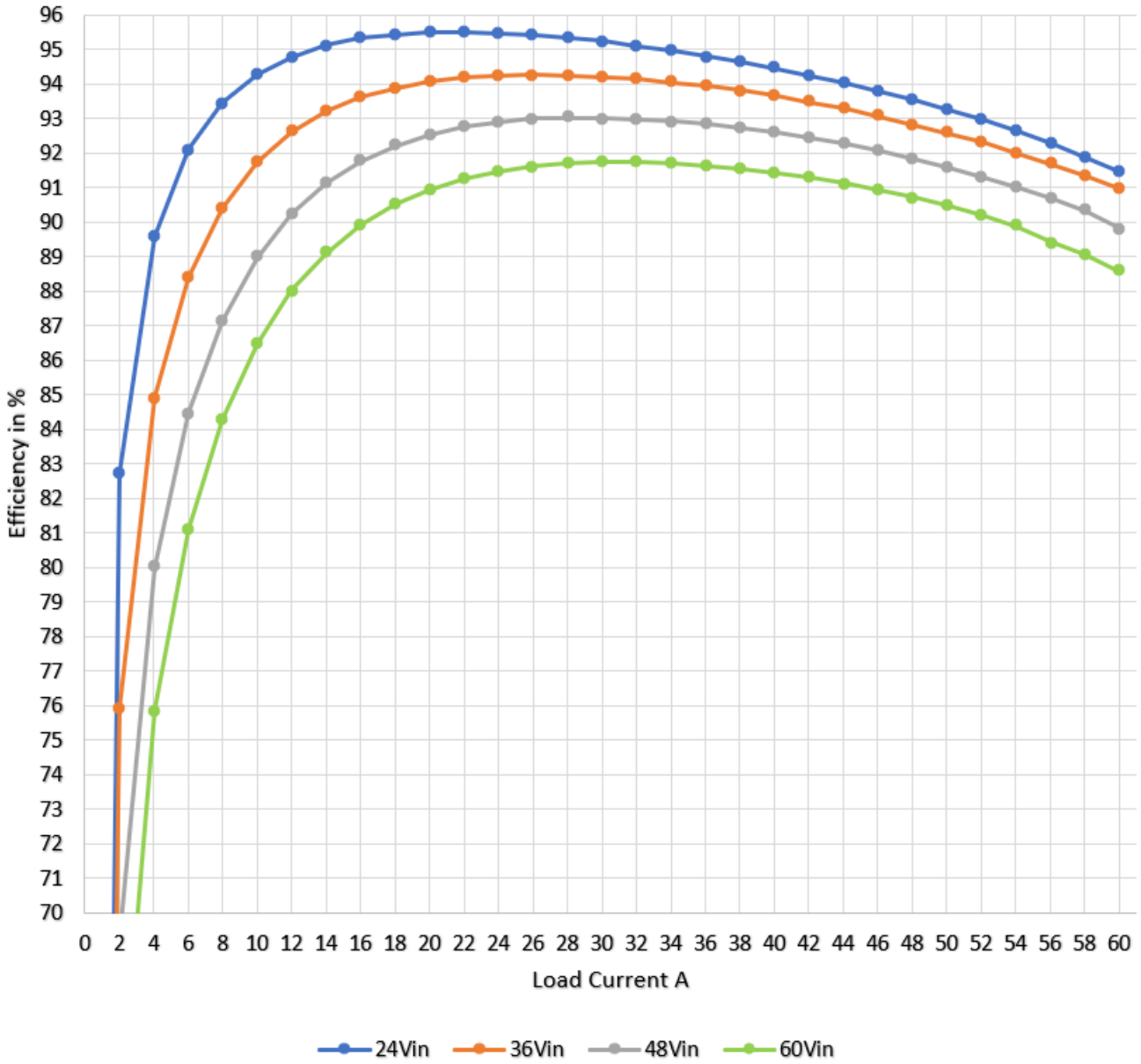

Figure 2-1. 5 V, 2-Phase Conversion Efficiency

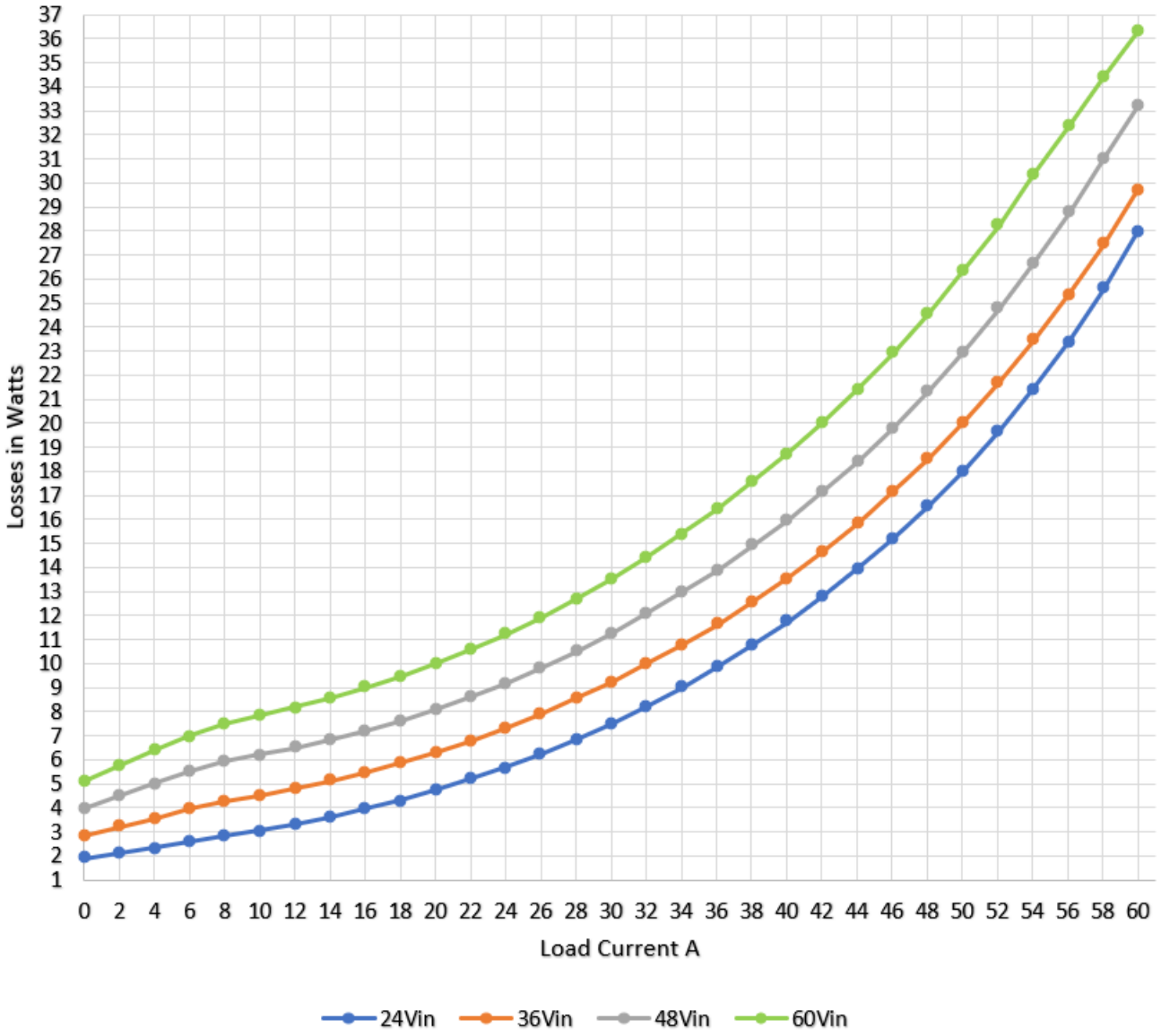

Figure 2-2. 5 V, 2-Phase Conversion Losses

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	0.079	4.996	0.000	1.894	0.000	1.894	0.000
23.998	0.509	4.996	2.02	12.204	10.095	2.109	82.719
23.998	0.934	4.996	4.02	22.42	20.084	2.336	89.582
23.998	1.361	4.995	6.02	32.652	30.072	2.58	92.100
23.998	1.786	4.995	8.02	42.872	40.06	2.812	93.441
23.998	2.212	4.995	10.02	53.091	50.049	3.042	94.271
23.998	2.64	4.995	12.022	63.352	60.044	3.308	94.779
23.998	3.068	4.995	14.023	73.637	70.038	3.599	95.113
23.998	3.499	4.995	16.026	83.976	80.042	3.934	95.315
23.998	3.931	4.994	18.026	94.339	90.025	4.314	95.427
23.998	4.365	4.994	20.028	104.744	100.018	4.726	95.488
23.998	4.801	4.994	22.03	115.206	110.009	5.197	95.489
23.998	5.238	4.994	24.031	125.69	120.002	5.688	95.474
23.998	5.676	4.993	26.03	136.22	129.974	6.246	95.415
23.998	6.118	4.993	28.033	146.829	139.983	6.846	95.337
23.998	6.562	4.993	30.035	157.469	149.968	7.501	95.236
23.997	7.007	4.993	32.035	168.162	159.936	8.226	95.108
23.997	7.457	4.992	34.041	178.943	169.941	9.002	94.970
23.997	7.908	4.992	36.042	189.782	179.917	9.865	94.802
23.997	8.363	4.992	38.044	200.677	189.912	10.765	94.635
23.997	8.819	4.992	40.046	211.637	199.892	11.745	94.451
23.997	9.279	4.991	42.047	222.669	209.861	12.808	94.248
23.997	9.743	4.991	44.048	233.805	219.84	13.965	94.027
23.997	10.21	4.991	46.049	245	229.811	15.189	93.800
23.997	10.681	4.99	48.051	256.319	239.776	16.543	93.546
23.997	11.158	4.99	50.053	267.764	249.744	18.02	93.270
23.997	11.642	4.989	52.056	279.377	259.731	19.646	92.968
23.997	12.131	4.989	54.057	291.098	269.67	21.428	92.639
23.996	12.628	4.988	56.057	303.037	279.63	23.407	92.276
23.996	13.134	4.988	58.056	315.165	289.562	25.603	91.876
23.996	13.649	4.987	60.055	327.515	299.502	28.013	91.447

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	0.079	4.996	0.000	2.856	0.000	2.856	0.000
35.998	0.370	4.995	2.023	13.312	10.104	3.208	75.905
35.998	0.658	4.995	4.023	23.670	20.098	3.571	84.911
35.998	0.945	4.995	6.023	34.031	30.084	3.947	88.401
35.998	1.231	4.995	8.022	44.323	40.070	4.254	90.403
35.998	1.516	4.994	10.024	54.573	50.064	4.509	91.738
35.998	1.801	4.994	12.024	64.838	60.052	4.786	92.618
35.998	2.088	4.994	14.025	75.154	70.046	5.108	93.203
35.998	2.375	4.994	16.028	85.507	80.042	5.466	93.608
35.998	2.664	4.993	18.029	95.892	90.028	5.864	93.885
35.998	2.954	4.994	20.031	106.326	100.023	6.303	94.072
35.998	3.245	4.993	22.033	116.806	110.012	6.794	94.184
35.998	3.537	4.993	24.034	127.322	120.004	7.318	94.252
35.998	3.831	4.993	26.034	137.892	129.979	7.913	94.262
35.998	4.126	4.993	28.036	148.523	139.977	8.546	94.246
35.998	4.422	4.992	30.037	159.180	149.957	9.223	94.206
35.997	4.720	4.992	32.038	169.900	159.928	9.972	94.131
35.997	5.020	4.992	34.043	180.701	169.946	10.755	94.048
35.997	5.321	4.992	36.045	191.539	179.927	11.612	93.937
35.997	5.624	4.992	38.046	202.445	189.907	12.538	93.807
35.997	5.929	4.991	40.048	213.436	199.889	13.546	93.653
35.997	6.237	4.991	42.050	224.512	209.856	14.655	93.472
35.997	6.547	4.991	44.050	235.678	219.839	15.839	93.279
35.997	6.860	4.990	46.051	246.944	229.806	17.138	93.060
35.997	7.176	4.990	48.053	258.310	239.774	18.536	92.824
35.997	7.495	4.989	50.055	269.782	249.745	20.037	92.573
35.996	7.817	4.989	52.057	281.394	259.717	21.677	92.296
35.996	8.143	4.988	54.058	293.107	269.662	23.444	92.001
35.996	8.473	4.988	56.057	304.987	279.602	25.385	91.677
35.996	8.806	4.987	58.057	316.974	289.521	27.453	91.339
35.996	9.145	4.986	60.055	329.185	299.458	29.727	90.969

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	0.083	4.996	0.000	3.973	0.000	3.973	0.000
47.996	0.304	4.996	2.024	14.609	10.109	4.500	69.199
47.996	0.524	4.996	4.024	25.132	20.104	5.029	79.991
47.996	0.742	4.995	6.023	35.626	30.090	5.536	84.460
47.996	0.958	4.995	8.022	45.983	40.072	5.912	87.144
47.996	1.172	4.995	10.024	56.273	50.069	6.204	88.975
47.996	1.387	4.995	12.025	66.549	60.058	6.490	90.247
47.996	1.602	4.994	14.026	76.870	70.049	6.821	91.127
47.996	1.818	4.994	16.028	87.237	80.050	7.187	91.762
47.996	2.035	4.994	18.030	97.655	90.039	7.615	92.202
47.996	2.253	4.994	20.031	108.113	100.035	8.078	92.529
47.996	2.471	4.994	22.033	118.620	110.021	8.599	92.751
47.996	2.691	4.993	24.035	129.177	120.008	9.169	92.902
47.996	2.912	4.993	26.033	139.787	129.985	9.802	92.988
47.995	3.135	4.993	28.036	150.469	139.973	10.495	93.025
47.995	3.359	4.992	30.037	161.219	149.944	11.275	93.007
47.995	3.584	4.992	32.038	172.018	159.918	12.100	92.966
47.995	3.811	4.991	34.043	182.896	169.927	12.970	92.909
47.995	4.038	4.991	36.044	193.797	179.903	13.894	92.831
47.995	4.267	4.991	38.046	204.776	189.883	14.893	92.727
47.995	4.497	4.991	40.048	215.850	199.868	15.982	92.596
47.995	4.730	4.990	42.050	226.995	209.839	17.156	92.442
47.995	4.963	4.990	44.049	238.197	219.801	18.396	92.277
47.994	5.200	4.989	46.051	249.572	229.769	19.804	92.065
47.994	5.439	4.989	48.052	261.052	239.727	21.325	91.831
47.994	5.681	4.989	50.055	272.675	249.725	22.951	91.583
47.994	5.926	4.988	52.057	284.425	259.665	24.759	91.295
47.993	6.173	4.988	54.058	296.281	269.622	26.659	91.002
47.993	6.424	4.987	56.058	308.316	279.567	28.750	90.675
47.993	6.678	4.986	58.057	320.476	289.487	30.990	90.330
47.993	6.936	4.986	60.001	332.896	299.166	33.730	89.810

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	0.085	4.996	0.000	5.093	0.000	5.093	0.000
59.995	0.264	4.996	2.017	15.815	10.075	5.740	63.704
59.995	0.441	4.995	4.018	26.460	20.072	6.388	75.857
59.995	0.618	4.995	6.018	37.062	30.060	7.001	81.109
59.995	0.792	4.995	8.017	47.520	40.046	7.474	84.271
59.995	0.965	4.995	10.018	57.872	50.042	7.830	86.470
59.995	1.137	4.994	12.019	68.204	60.026	8.178	88.010
59.994	1.310	4.994	14.021	78.583	70.025	8.558	89.109
59.994	1.484	4.994	16.024	89.002	80.020	8.982	89.908
59.994	1.658	4.994	18.025	99.458	90.011	9.447	90.502
59.994	1.833	4.994	20.026	109.975	100.000	9.975	90.930
59.994	2.009	4.993	22.028	120.551	109.985	10.566	91.235
59.994	2.187	4.993	24.031	131.189	119.976	11.213	91.453
59.994	2.364	4.992	26.030	141.855	129.948	11.907	91.606
59.994	2.544	4.992	28.033	152.619	139.940	12.679	91.692
59.994	2.724	4.991	30.034	163.433	149.914	13.519	91.728
59.994	2.906	4.991	32.035	174.322	159.901	14.421	91.728
59.994	3.089	4.991	34.040	185.313	169.903	15.410	91.684
59.993	3.272	4.991	36.041	196.323	179.872	16.451	91.620
59.993	3.457	4.990	38.042	207.425	189.850	17.575	91.527
59.993	3.644	4.990	40.045	218.592	199.830	18.762	91.417
59.993	3.831	4.990	42.046	229.842	209.799	20.042	91.280
59.993	4.020	4.989	44.047	241.199	219.763	21.436	91.113
59.992	4.211	4.989	46.048	252.643	229.725	22.918	90.929
59.992	4.405	4.988	48.049	264.247	239.682	24.565	90.704
59.992	4.600	4.988	50.052	275.989	249.654	26.335	90.458
59.992	4.798	4.987	52.054	287.844	259.611	28.234	90.191
59.991	4.999	4.987	54.055	299.889	269.558	30.331	89.886
59.991	5.195	4.987	56.054	311.624	279.533	32.090	89.409
59.991	5.403	4.986	58.004	324.123	289.220	34.903	89.034
59.990	5.597	4.986	60.052	335.740	299.412	36.328	88.569

2.3 Thermal Images

The thermal images presented in Figure 2-3 and Figure 2-4 were taken with a load of 60 A at steady-state and with a fan blowing on the hardware.

Figure 2-3 has an input voltage of 24 V, to which both the low-side FETs experienced a rise of about 74°C above the ambient room temperature of 21°C to 23°C. Figure 2-4 has an input voltage of 48 V, to which the low-side FET reaches a temperature of 112°C, measured relative to the ambient room temperature of 21°C to 23°C.

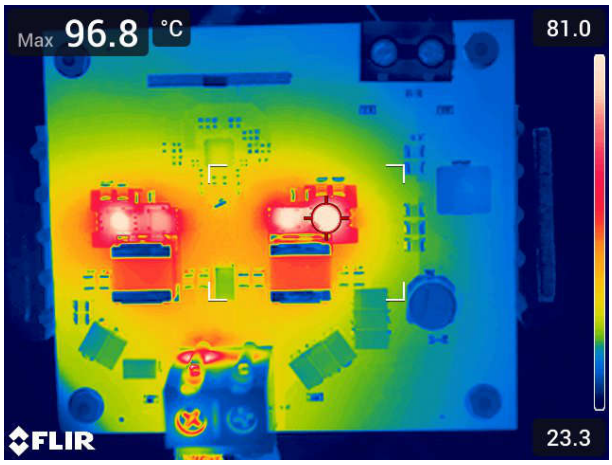

Figure 2-3. 24-V_{IN}, 60-A Thermal Image With Fan

Figure 2-4. 48-V_{IN}, 60-A Thermal Image With Fan

The thermal images shown in Figure 2-5 and Figure 2-6 were taken with a load of 40 A at steady-state and with a fan blowing on the hardware.

Figure 2-5 has an input voltage of 24 V, to which both the low-side FETs experienced a rise of about 32°C above the ambient room temperature of 21°C to 23°C. Figure 2-6 has an input voltage of 48 V, to which the low-side FET reaches a temperature of 69°C, measured relative to the ambient room temperature of 21°C to 23°C.

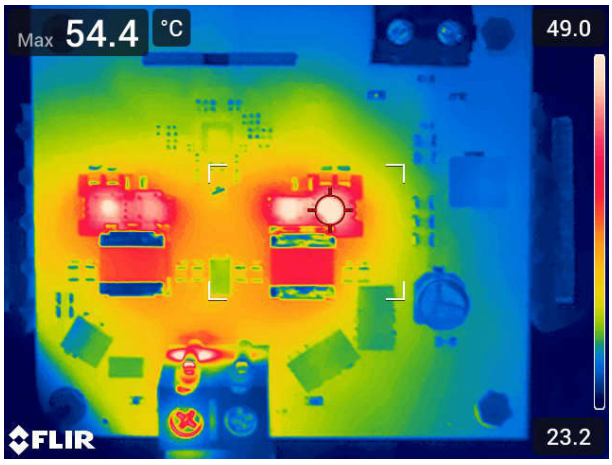

Figure 2-5. 24-V_{IN}, 40-A Thermal Image With Fan

Figure 2-6. 48-V_{IN}, 40-A Thermal Image With Fan

The thermal images shown in Figure 2-7 and Figure 2-8 were taken with a load of 30 A at steady-state and without a fan blowing on the hardware.

With an input voltage of 24 V, the thermal image displayed in Figure 2-7 shows the low-side FET reaching 76°C. With an input voltage of 48 V, the thermal image displayed in Figure 2-8 shows the low-side FET reaching 101°C. Both were measured relative to the ambient room temperature of 21°C to 23°C.

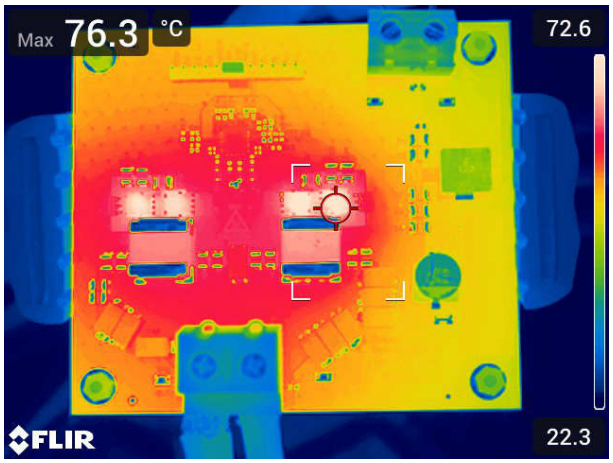

Figure 2-7. 24-V_{IN}, 30-A Thermal Image With No Fan

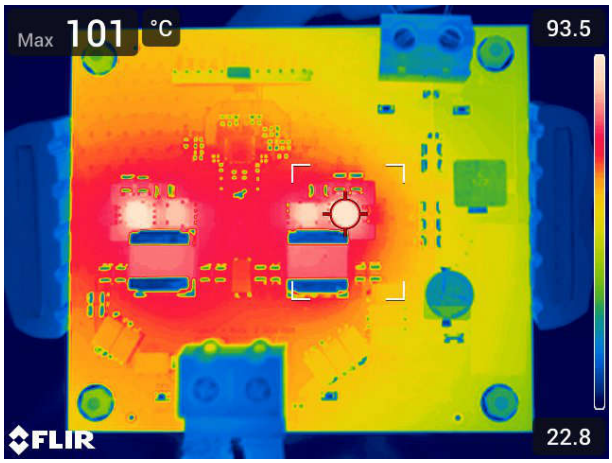

Figure 2-8. 48-V_{IN}, 30-A Thermal Image With No Fan

With strong airflow or an efficient cooling system in place, the board can perform when operating up to full load in steady-state.

2.4 Bode Plots

Each Bode plot is shown at a 5-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 23 kHz at no load to 28 kHz at the maximum 60-A load, but the phase margin is always at least 62 degrees and gain margin is more than 10 dB.

The Bode plots in Figure 2-9 and Figure 2-10 were created at a 30-A load with Figure 2-9 having a 24-V input and Figure 2-10 having a 48-V input.

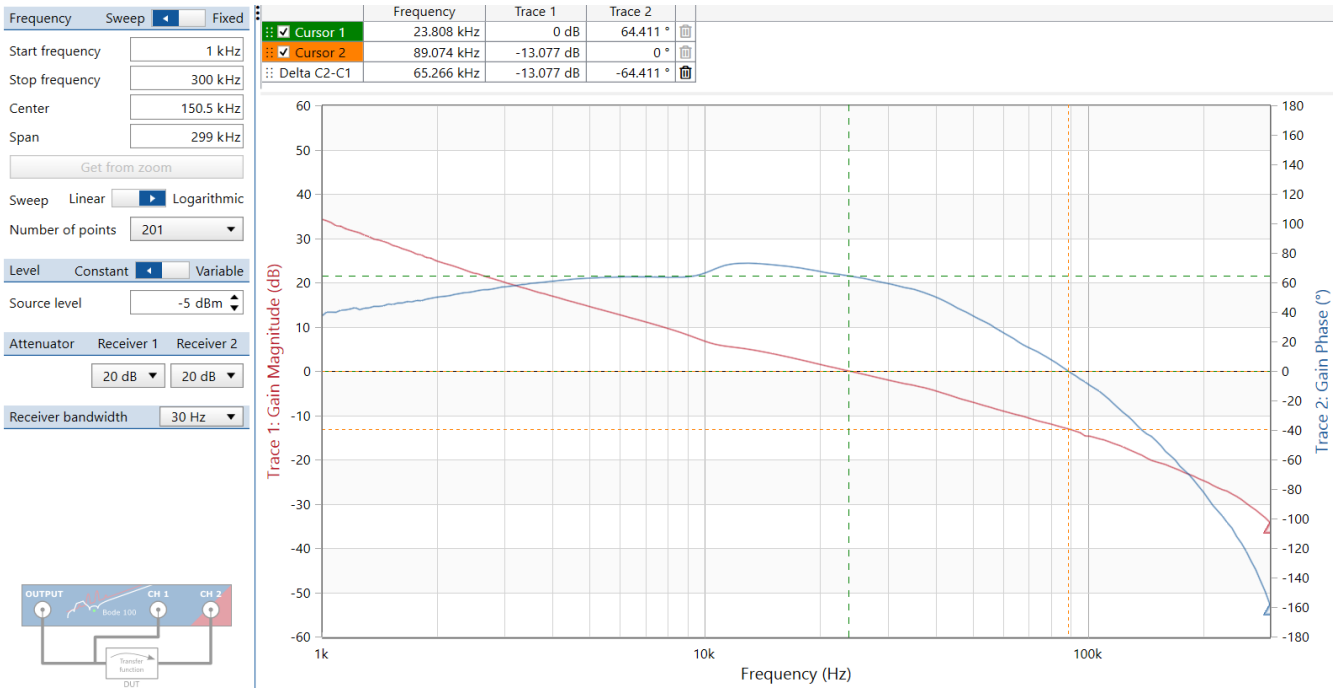

Figure 2-9. 24-V_{IN} Bode Plot

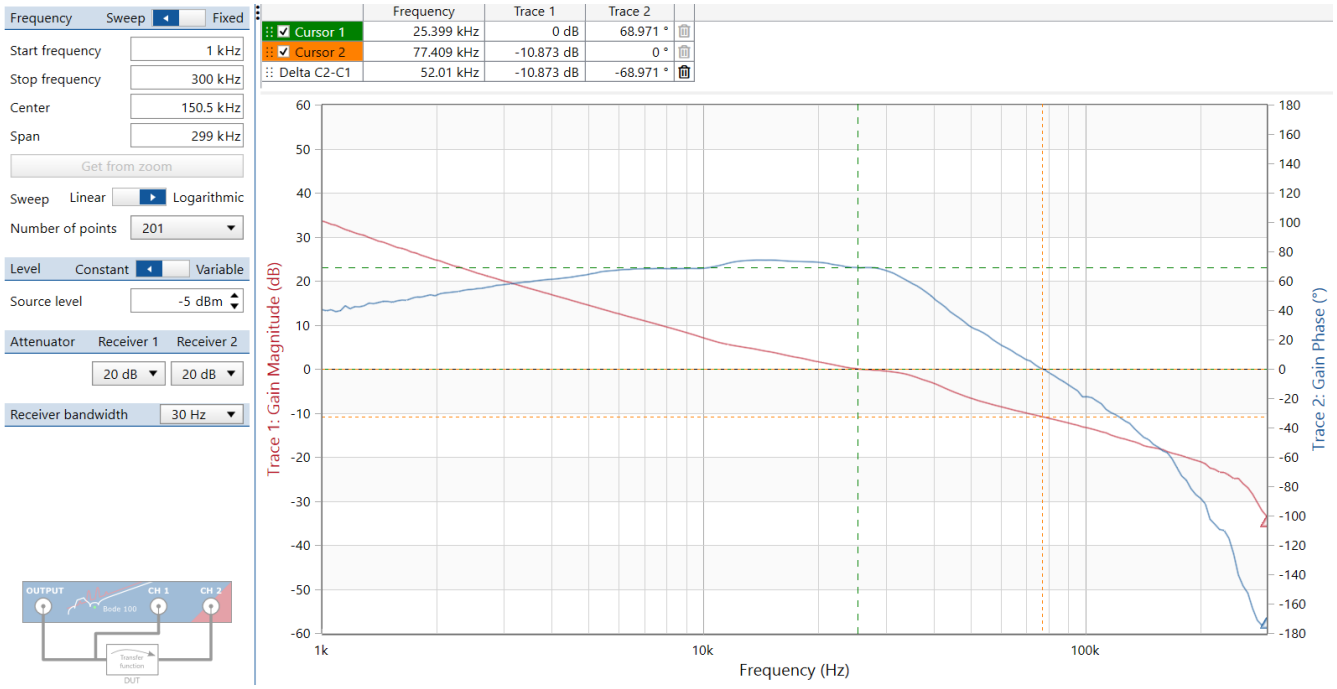

Figure 2-10. 48-V_{IN} Bode Plot

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 398 kHz, an overshoot of 2 V, a rise time of 8 ns, and a fall time of 4 ns.

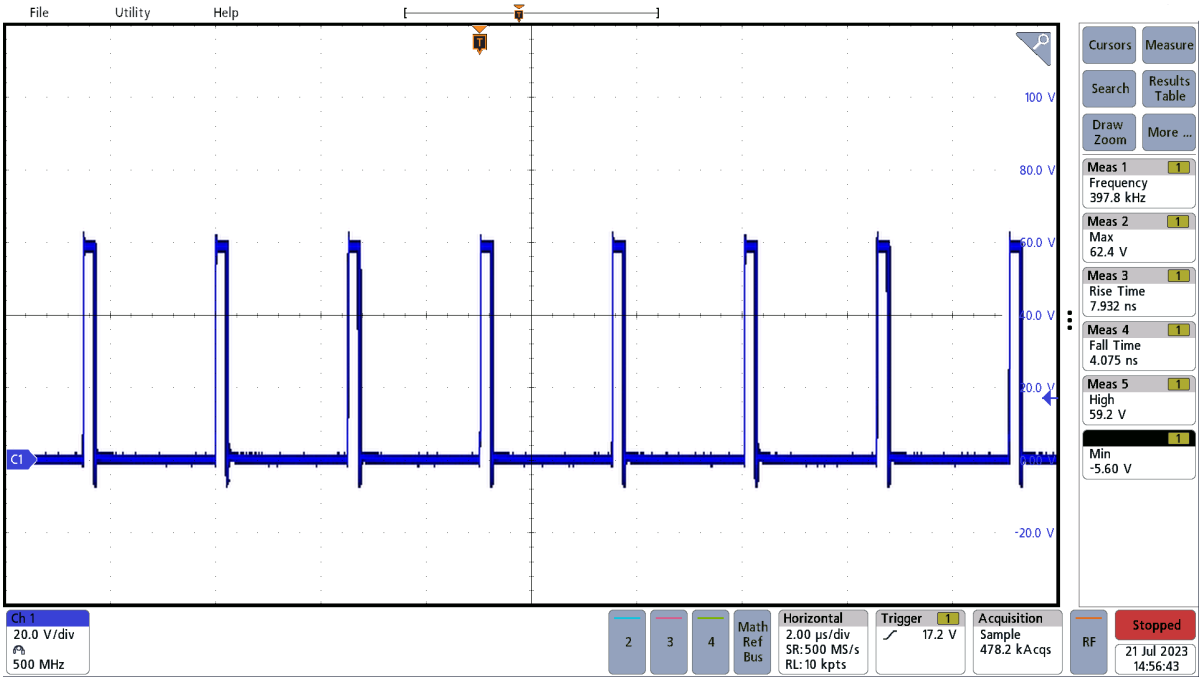

Figure 3-1. 60-V Switching Waveform

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 images show 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 for both transitions is approximately 2 µs. The undershoot and overshoot for each is around 2% or 100 mV. For all images, the top trace represents V_{OUT}, while the bottom represents I_{OUT}.

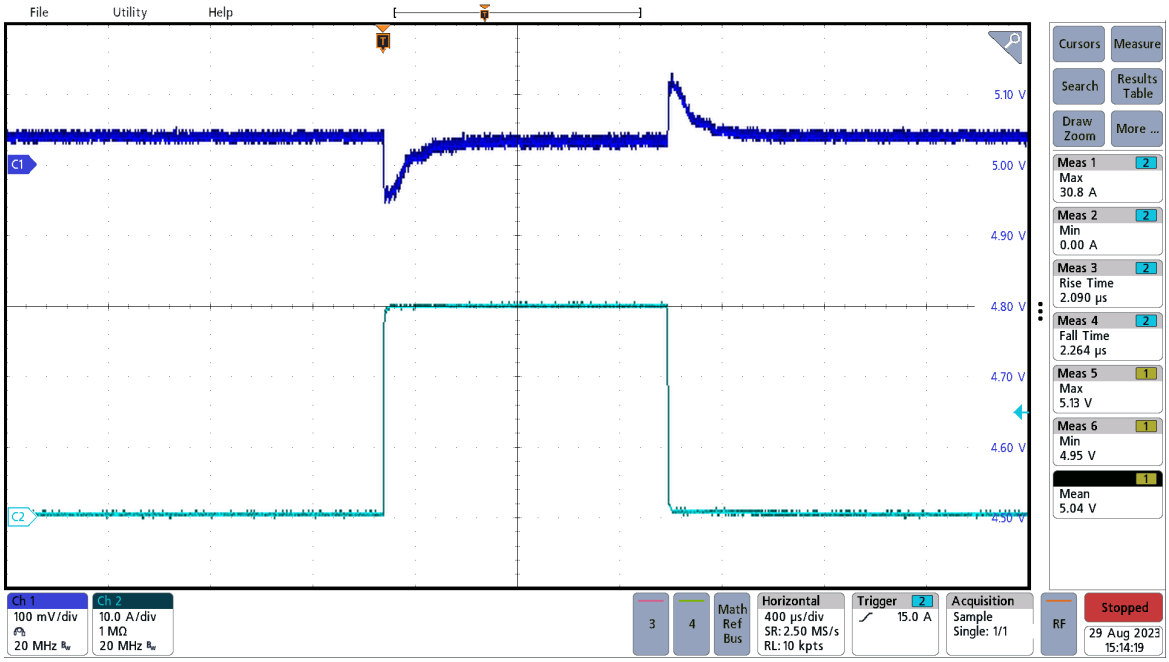

Figure 3-2. Load Transient 1

Figure 3-3 illustrates the load transient 2 at 48 V_{IN} with a 15-A load in parallel, thus the images show 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 for both transitions is approximately 2 µs. Both the overshoot and undershoot measure to be about 100 mV.

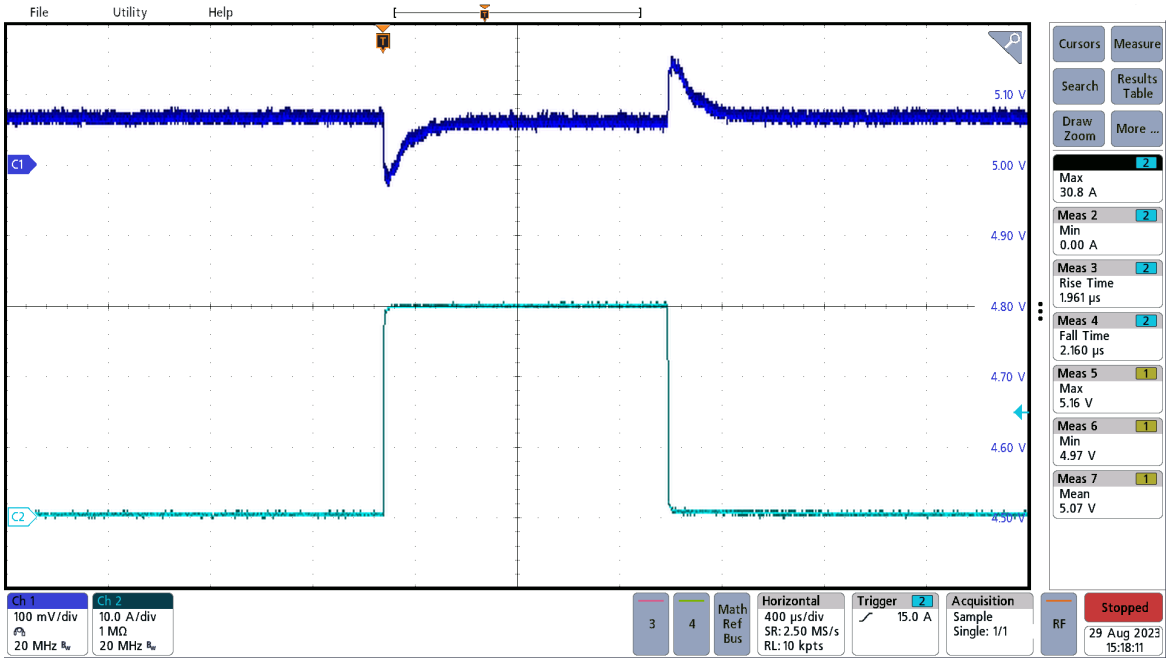

Figure 3-3. Load Transient 2

3.3 Start-Up and Shutdown Sequences

Figure 3-4 and Figure 3-5 display the start-up waveforms at 24-V and 48-V input into a ⅓-Ω constant-resistance load using an electronic load. The board Enable is pulled LOW, by connecting it to PGND, then turning ON the benchtop power supply to the desired input voltage, and then pulling the board Enable HIGH, by disconnecting it from PGND.

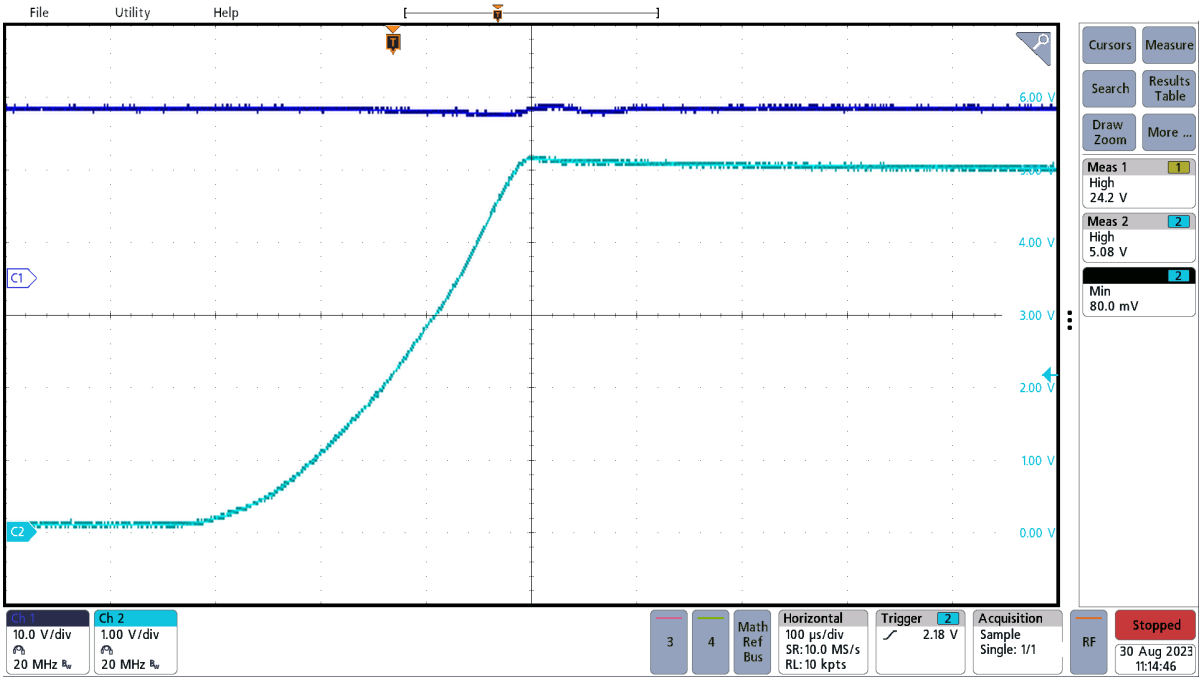

Figure 3-4. 24-V_{IN} Start-Up

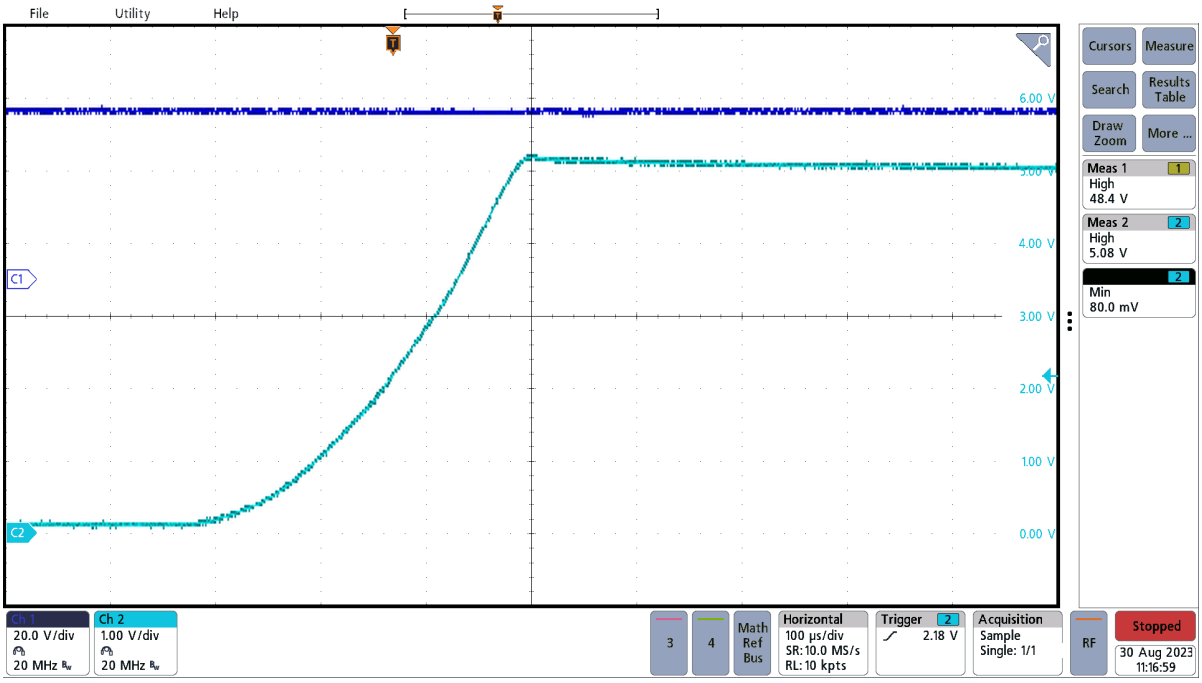

Figure 3-5. 48-V_{IN} Start-Up

Figure 3-6 and Figure 3-7 show the shutdown waveforms at 24-V and 48-V input into a ⅓-Ω constant-resistance load using an electronic load. While the benchtop power supply is ON and at the desired input voltage and the board Enable is HIGH, the board Enable is pulled LOW by connecting it to PGND.

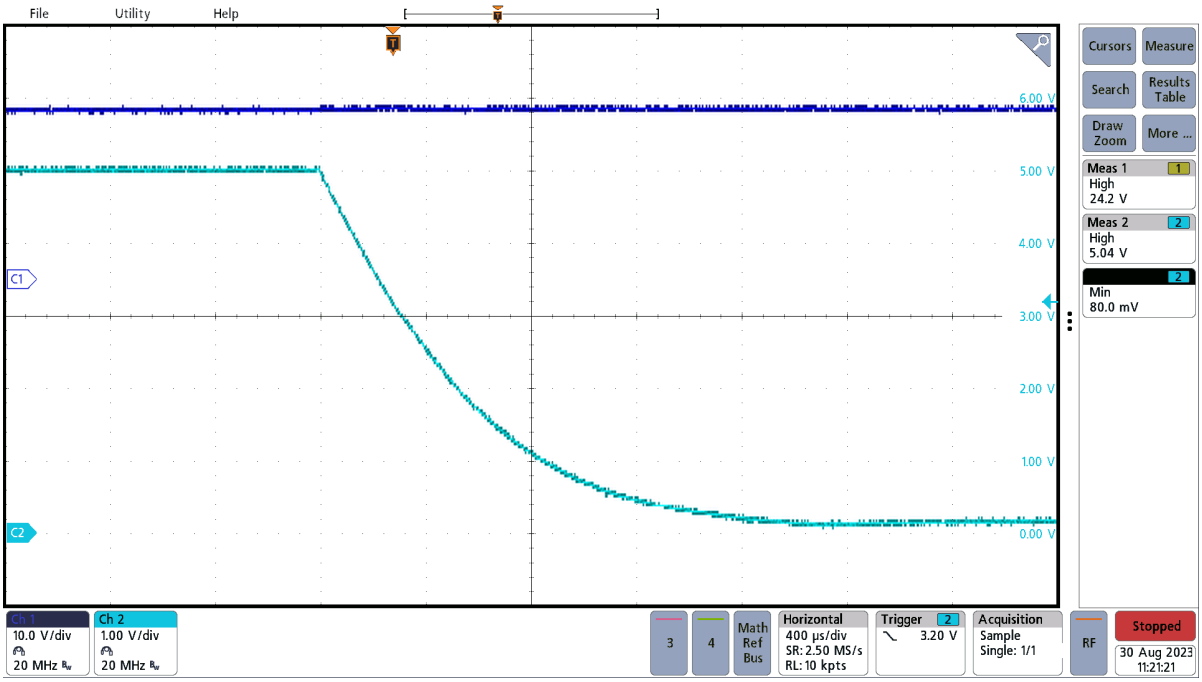

Figure 3-6. 24-V_{IN} Shutdown

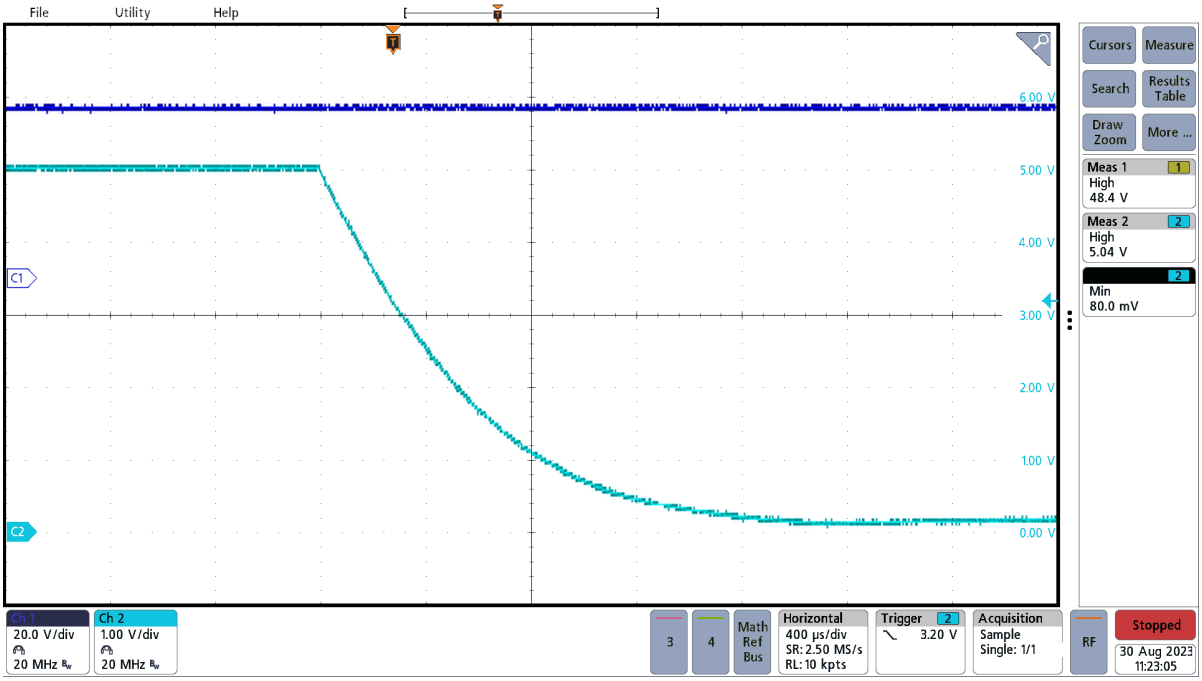

Figure 3-7. 48-V_{IN} Shutdown

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