Test Report: PMP23591

20V_{IN} to 60V_{IN}, 600W, Automotive Two-Phase Buck Converter With GaN Switches Reference Design

Description

This reference design generates a regulated 12V output from a nominal 48V input. This design can handle up to 50A maximum current and 25A maximum current per phase. The LM5137F-Q1 controller provides switching signals to the LMG2100R026 half-bridge Gallium Nitride (GaN) field-effect transistor (FET) with an integrated gate driver.

Resources

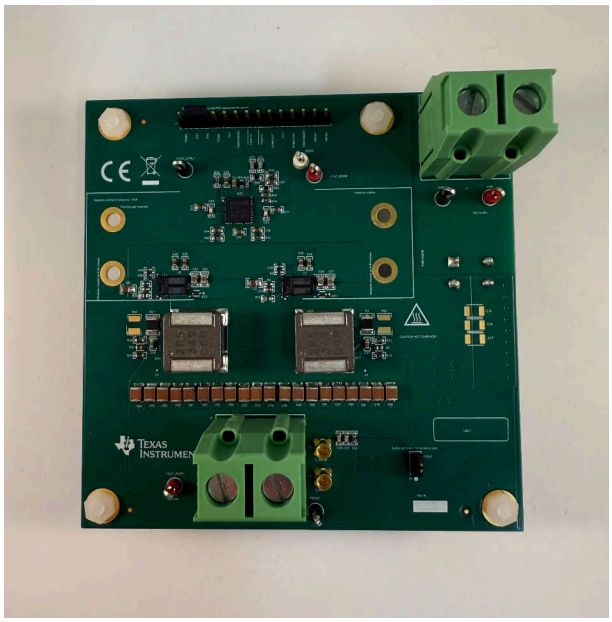
PMP23591	Design Folder
LM5137F-Q1	Product Folder
LMG2100R026	Product Folder

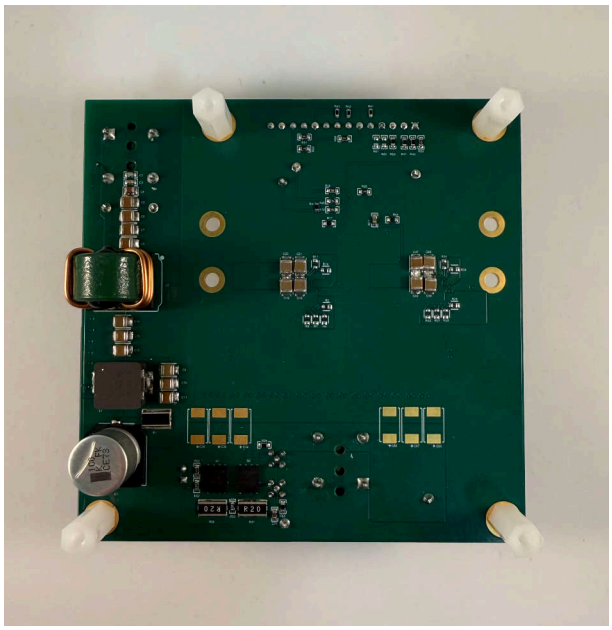
Features

- High current for body electronics and lighting applications
- Peak conversion efficiency of 95% to 97% in 36V to 60V input voltage range
- LM5137F-Q1 provides two-phase control and a gate driver in a single integrated circuit
- GaN switches with top-side cooling and heatsink
- Input electromagnetic interference (EMI) filter

Applications

- Zone control module





1 Test Prerequisites

This section provides the details of testing this reference design.

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input Voltage	20V to 60V
Output Voltage	12V
Output Current	50A (max)
Switching Frequency	440kHz

1.2 Required Equipment

- V_{IN} power supply 20V to 60V
- Electronic load to step for efficiency graphs, and for dynamic load testing such as Kikusui PLZ334WL, at least 660W
- Oscilloscope such as Tektronix MDO34 with TPP0500B 10 × voltage probes and 50A 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 50A and 25A current shunts for efficiency measurements

1.3 Safety Considerations

- Hot surface.
- Contact can cause burn.
- Do not touch.
- When testing for steady state load above 25A, please use a fan blowing on the board.

1.4 Dimensions

The size of the board is 100mm × 100mm. The board consists of six layers. Two internal GND layers, a power layer, and a signal layer with top and bottom layers. The board has six copper layers with 70um of copper thickness on each layer.

2 Testing and Results

2.1 Efficiency Graphs

When operating at full-load at 50A, the efficiency varies from 95% to 97% in different input voltage ranges.

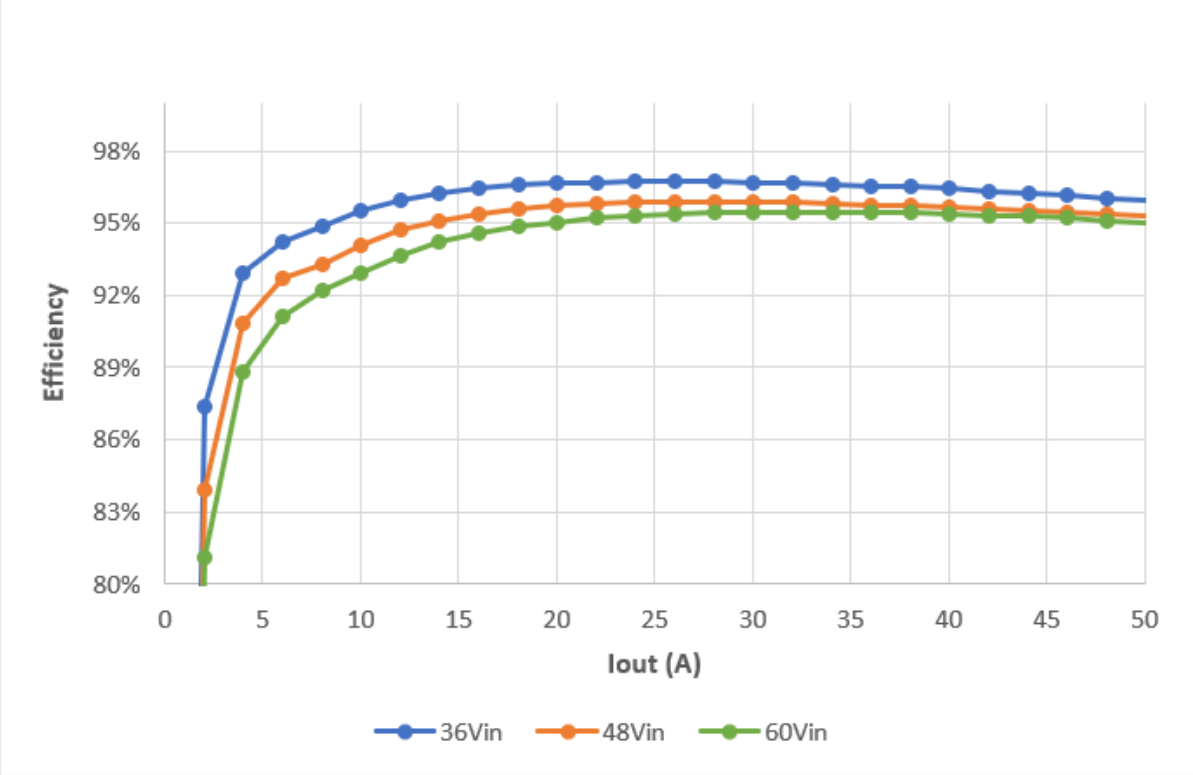


Figure 2-1. Efficiency Versus Output Current (A)

2.2 Efficiency Data

Efficiency data is shown in Table 2-1 through Table 2-3.

Table 2-1. Efficiency Data for 36V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
36.541	0.096	12.003	0.000	3.524	0.000	3.524	-0.004
36.506	0.759	12.003	2.017	27.711	24.214	3.497	87.379
36.471	1.424	12.002	4.019	51.920	48.234	3.685	92.902
36.434	2.105	12.002	6.019	76.689	72.240	4.449	94.199
36.398	2.787	12.002	8.019	101.450	96.244	5.206	94.869
36.362	3.462	12.002	10.021	125.885	120.277	5.608	95.545
36.326	4.140	12.002	12.024	150.370	144.317	6.053	95.975
36.289	4.820	12.002	14.026	174.897	168.344	6.553	96.253
36.251	5.503	12.002	16.029	199.494	192.385	7.109	96.437
36.212	6.189	12.002	18.032	224.124	216.424	7.701	96.564
36.173	6.878	12.002	20.035	248.804	240.459	8.345	96.646
36.133	7.570	12.002	22.038	273.542	264.503	9.040	96.695
36.093	8.265	12.002	24.040	298.316	288.533	9.783	96.721
36.052	8.963	12.002	26.041	323.125	312.551	10.574	96.728

Table 2-1. Efficiency Data for 36V Input (continued)

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
36.009	9.665	12.002	28.045	348.032	336.604	11.428	96.716
35.967	10.370	12.003	30.048	372.984	360.654	12.330	96.694
35.927	11.078	12.003	32.050	397.984	384.687	13.297	96.659
35.884	11.791	12.002	34.057	423.108	408.763	14.345	96.610
35.842	12.506	12.003	36.059	448.249	432.808	15.441	96.555
35.802	13.225	12.003	38.062	473.463	456.861	16.602	96.493
35.765	13.946	12.003	40.065	498.757	480.895	17.862	96.419
35.728	14.670	12.003	42.068	524.131	504.936	19.195	96.338
35.692	15.397	12.003	44.069	549.569	528.960	20.608	96.250
35.657	16.129	12.003	46.072	575.123	552.997	22.126	96.153
35.623	16.865	12.003	48.074	600.775	577.042	23.733	96.050
35.584	17.608	12.003	50.077	626.560	601.093	25.467	95.935

Table 2-2. Efficiency Data for 48V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
48.722	0.096	12.000	0.000	4.694	-0.003	4.697	-0.056
48.690	0.594	12.000	2.021	28.907	24.251	4.656	83.895
48.659	1.092	12.000	4.022	53.117	48.265	4.853	90.864
48.626	1.604	12.000	6.023	77.979	72.272	5.707	92.681
48.593	2.123	12.000	8.023	103.168	96.275	6.894	93.318
48.560	2.632	12.000	10.025	127.828	120.300	7.528	94.111
48.528	3.140	12.000	12.026	152.401	144.316	8.085	94.695
48.496	3.650	12.000	14.028	177.027	168.340	8.687	95.093
48.463	4.162	12.000	16.031	201.723	192.380	9.343	95.368
48.430	4.676	12.000	18.035	226.465	216.421	10.044	95.565
48.398	5.191	12.001	20.037	251.246	240.451	10.795	95.703
48.365	5.709	12.001	22.039	276.100	264.488	11.612	95.794
48.331	6.228	12.001	24.042	301.014	288.516	12.498	95.848
48.298	6.749	12.001	26.043	325.963	312.525	13.438	95.877
48.266	7.273	12.001	28.046	351.024	336.582	14.441	95.886
48.234	7.798	12.001	30.048	376.128	360.611	15.517	95.875
48.203	8.325	12.001	32.050	401.288	384.639	16.649	95.851
48.171	8.856	12.002	34.056	426.596	408.730	17.866	95.812
48.141	9.387	12.002	36.059	451.923	432.761	19.162	95.760
48.111	9.921	12.002	38.061	477.313	456.807	20.506	95.704
48.080	10.457	12.002	40.065	502.778	480.857	21.921	95.640
48.053	10.994	12.002	42.068	528.278	504.899	23.380	95.574
48.027	11.531	12.002	44.070	553.808	528.945	24.863	95.511
48.000	12.070	12.002	46.072	579.352	552.974	26.378	95.447
47.974	12.610	12.002	48.075	604.963	577.014	27.949	95.380

Table 2-2. Efficiency Data for 48V Input (continued)

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
47.946	13.153	12.002	50.080	630.643	601.076	29.567	95.312

Table 2-3. Efficiency Data for 60V Input

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
60.901	0.092	0.000	0.000	5.591	0.000	5.591	-0.006
60.860	0.490	0.004	2.015	29.822	0.008	29.814	81.089
60.818	0.892	0.008	4.017	54.272	0.032	54.240	88.830
60.776	1.304	0.012	6.017	79.256	0.072	79.184	91.122
60.733	1.718	0.016	8.017	104.329	0.128	104.201	92.236
60.689	2.132	0.020	10.020	129.418	0.201	129.217	92.931
60.646	2.540	0.024	12.022	154.070	0.289	153.781	93.662
60.602	2.949	0.028	14.025	178.718	0.393	178.325	94.193
60.558	3.359	0.032	16.028	203.424	0.513	202.911	94.573
60.516	3.771	0.036	18.030	228.187	0.650	227.537	94.842
60.473	4.184	0.040	20.032	252.990	0.802	252.188	95.043
60.429	4.598	0.044	22.035	277.846	0.971	276.876	95.197
60.385	5.014	0.048	24.037	302.760	1.155	301.605	95.301
60.336	5.431	0.052	26.038	327.704	1.355	326.349	95.375
60.274	5.852	0.056	28.041	352.723	1.572	351.151	95.428
60.241	6.272	0.060	30.043	377.815	1.804	376.011	95.452
60.197	6.693	0.064	32.044	402.912	2.052	400.860	95.466
60.163	7.117	0.068	34.050	428.176	2.317	425.858	95.458
60.134	7.540	0.072	36.052	453.440	2.598	450.842	95.442
60.107	7.965	0.076	38.055	478.754	2.895	475.859	95.417
60.054	8.395	0.080	40.058	504.172	3.207	500.965	95.377
60.027	8.824	0.084	42.060	529.669	3.536	526.133	95.326
60.000	9.253	0.088	44.062	555.206	3.880	551.325	95.268
59.972	9.686	0.092	46.064	580.909	4.241	576.668	95.193
59.946	10.120	0.096	48.066	606.661	4.618	602.043	95.113
59.909	10.559	0.100	50.071	632.554	5.011	627.543	95.024

2.3 Thermal Images

Temperature rise for Figure 2-2 at 48V input voltage, 12V output voltage with 25A load without fan is 98.5ºC. This picture was taken once the device reached the steady state at room temperature (around 25ºC).

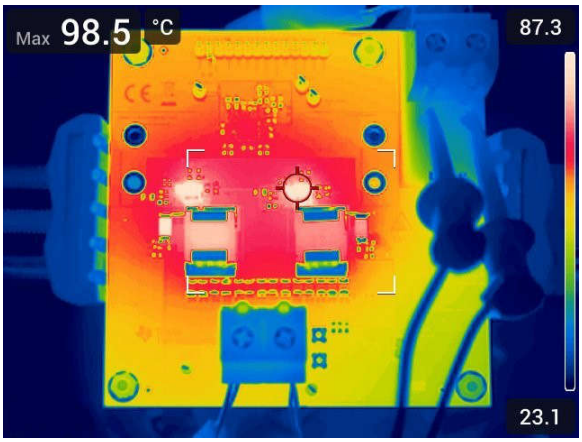


Figure 2-2. 48V_{IN}, 25A Thermal Image With No Fan

Figure 2-3 and Figure 2-4 are taken with a fan blowing on the board. With an efficient cooling system or with a strong airflow in place, the board can perform a lot better thermally when operating at any load (50A maximum) in a steady-state. Both of the following measurements are also taken at room temperature (around 25ºC).

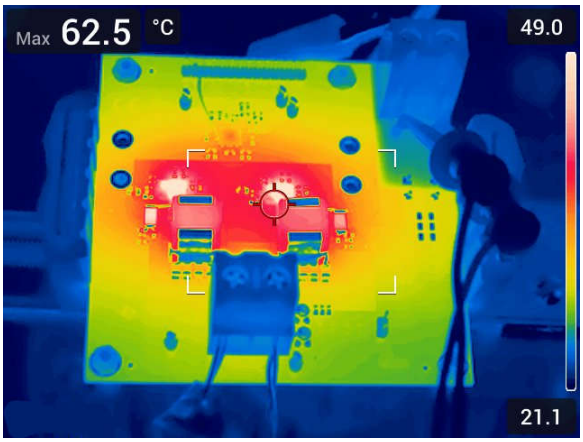


Figure 2-3. 48V_{IN}, 25A Thermal Image With Fan

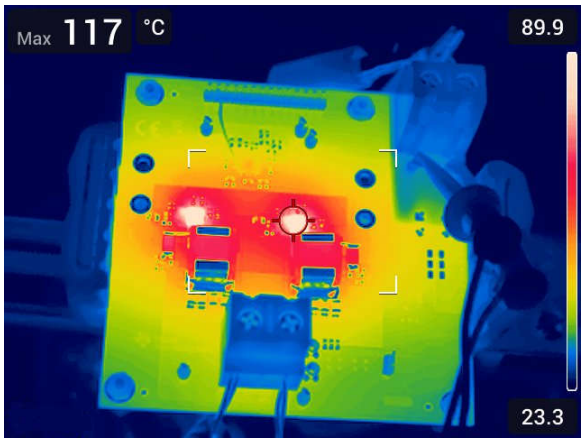


Figure 2-4. 48V_{IN}, 50A Thermal Image With Fan

2.4 Bode Plots

All of the bode-plots are shown at 12V output and at 25A load. Bode plots at different loads tends to be very similar with slight changes of noise level, increase in crossover frequency at higher load, and so on. Both the phase margin and gain margin tend to be the same at various loads.

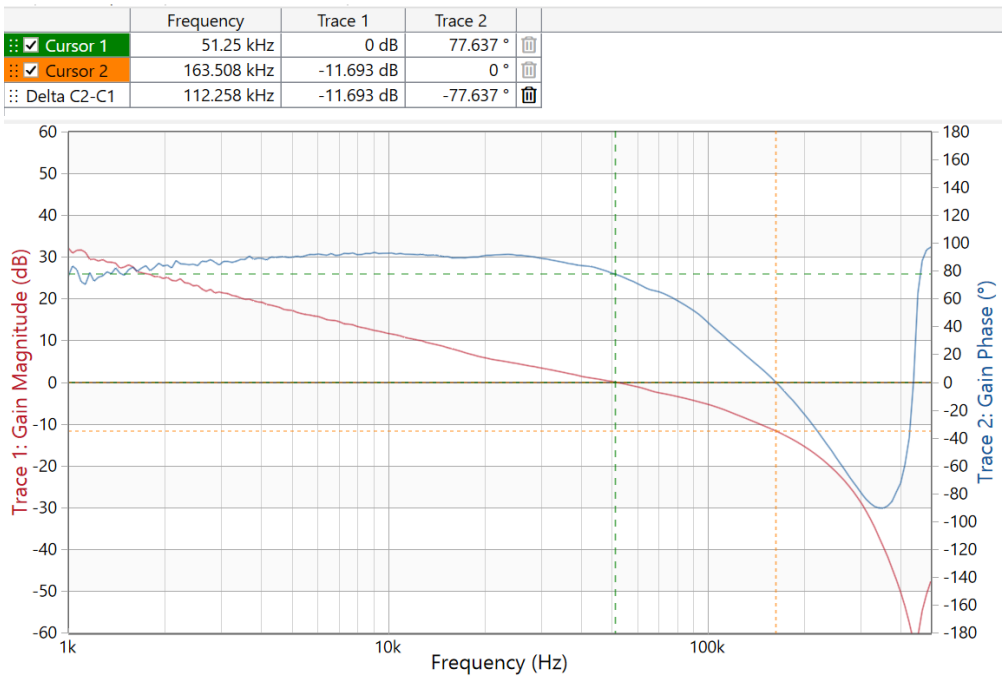


Figure 2-5. 36V_{IN}, 25A Load Current, Crossover Frequency 51.25kHz, 77.64° Phase Margin, 11.69dB Gain Margin

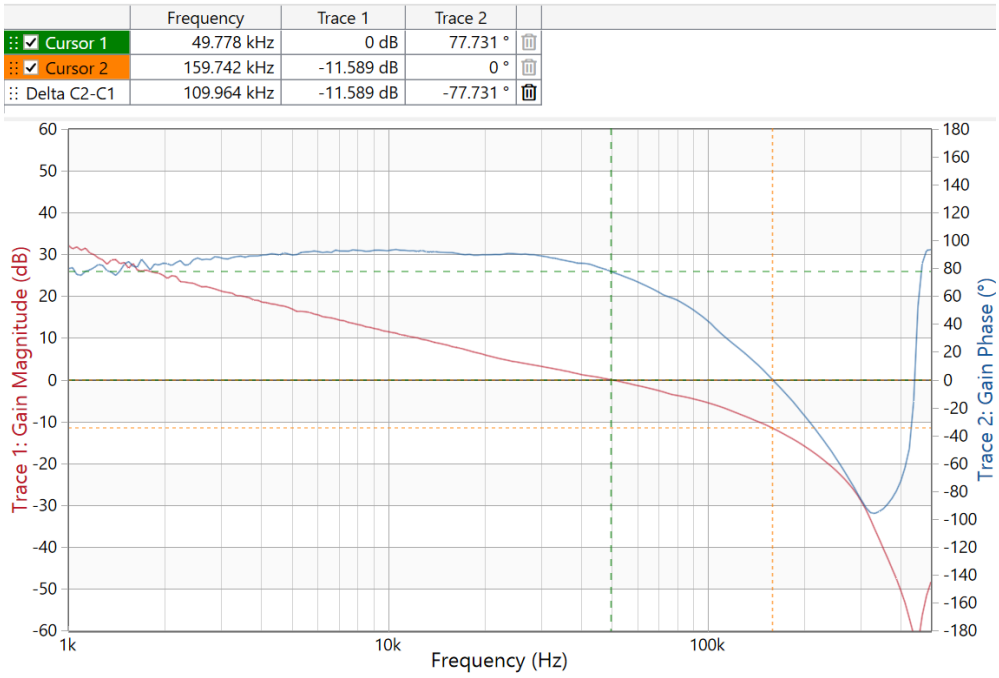


Figure 2-6. 48V_{IN}, 25A Load Current, Crossover Frequency 49.78kHz, 77.73° Phase Margin, 11.59dB Gain Margin

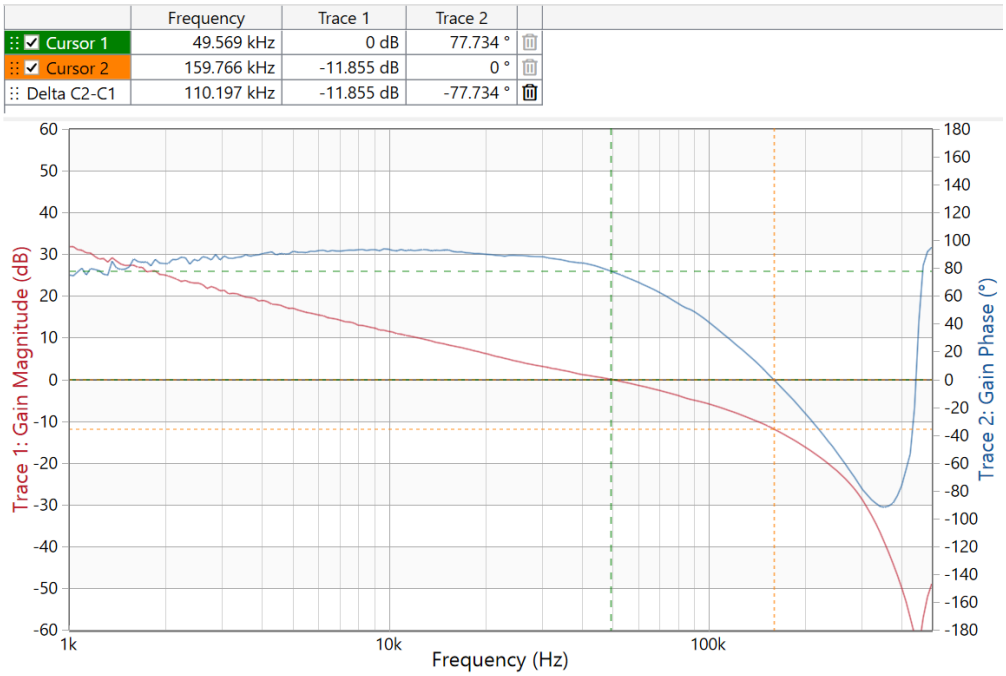


Figure 2-7. 60V_{IN}, 25A Load Current, Crossover Frequency 49.57kHz, 77.73° Phase Margin, 11.86dB Gain Margin

3 Waveforms

3.1 Switching

Both switching waveforms are taken at maximum load at 50A (25A per phase). Figure 3-1 and Figure 3-2 show frequency around 450kHz. Both phases are 120º out of phase with each other.

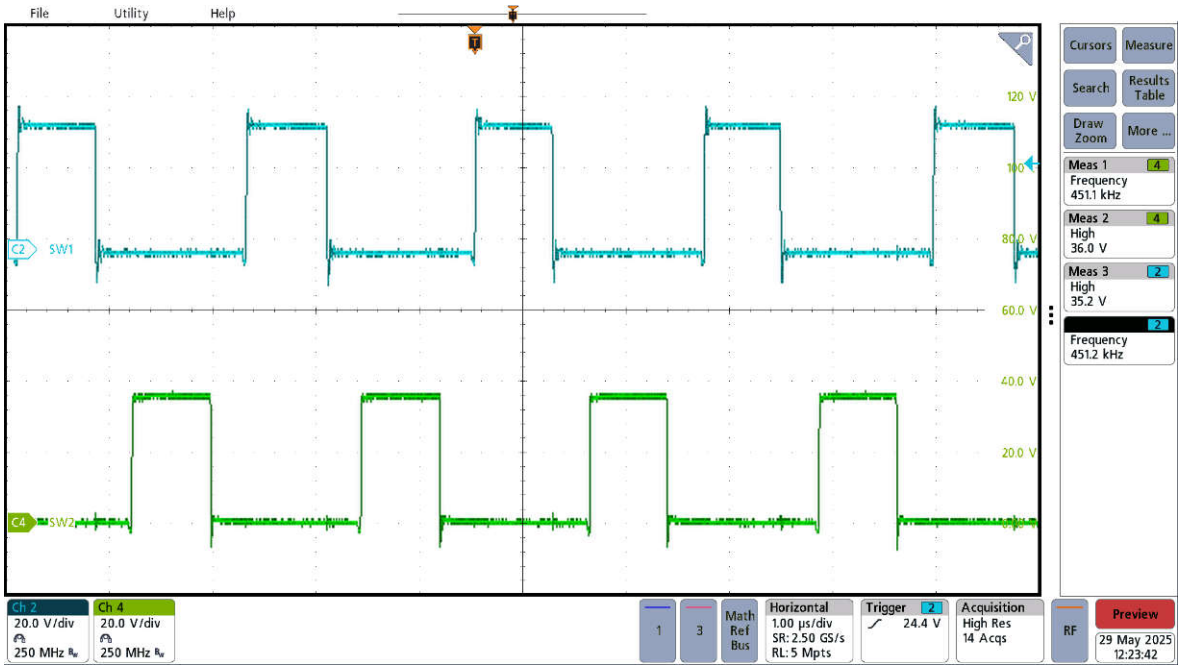


Figure 3-1. 36V_{IN} Switching Waveform

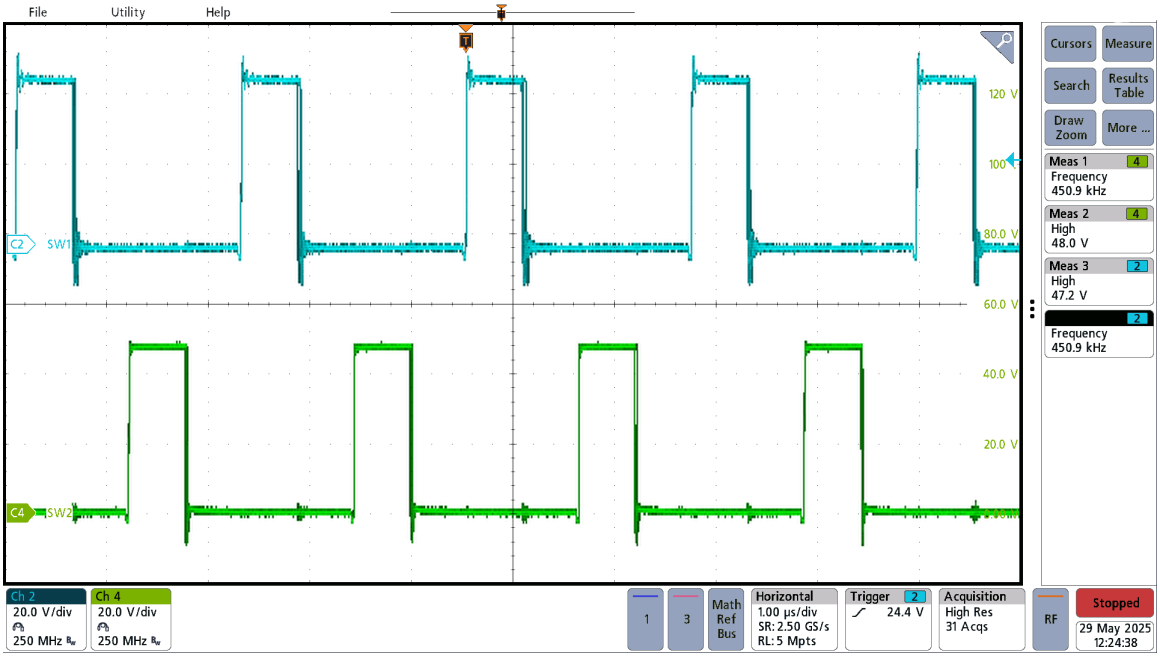


Figure 3-2. 48V_{IN} Switching Waveforms

3.2 Output Voltage Ripple

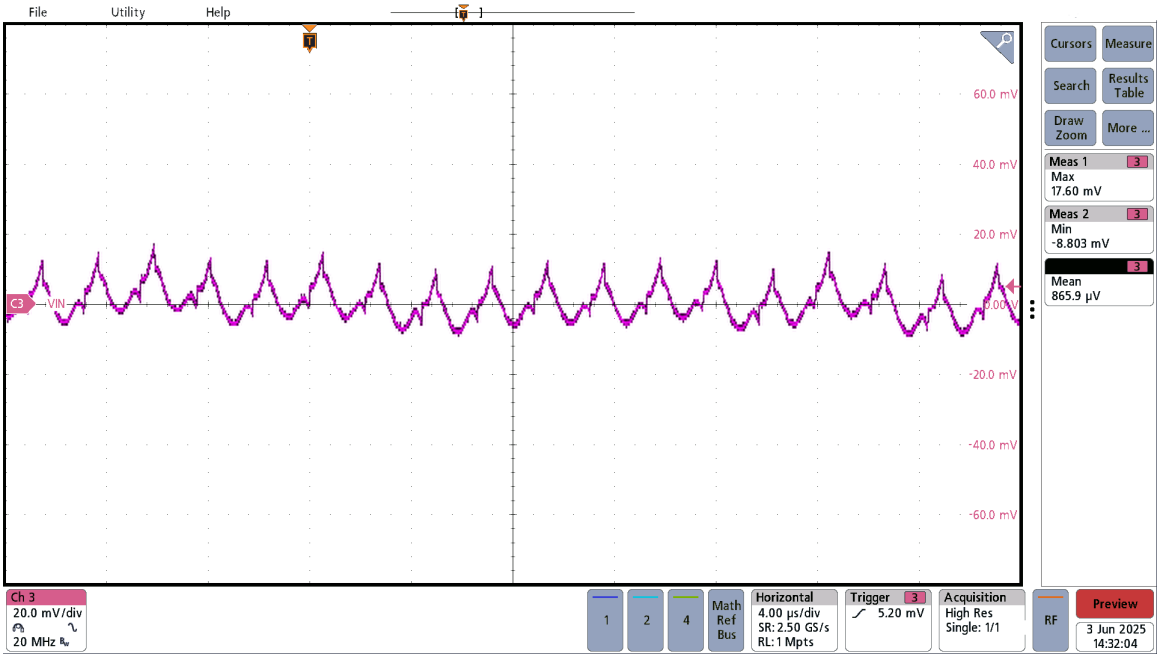


Figure 3-3. AC Coupled Output Voltage Ripple

3.3 Input Voltage Ripple

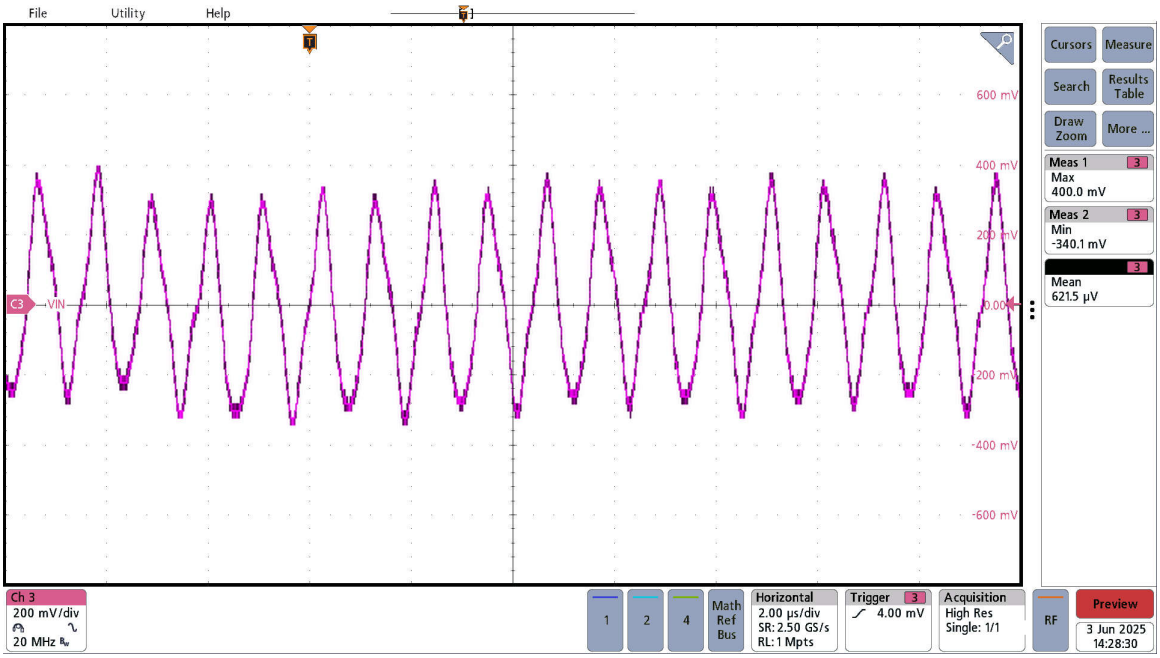


Figure 3-4. AC Coupled Input Voltage Ripple

3.4 Load Transients

Figure 3-5 represents load transient response between 0A to 25A load step. Output voltage is about 580mV, around 5%. Output voltage overshoot is about 620mV, around 5% as well. For this testing, slew rate is set to be 5A/µs. Rise time is 6.820µs and fall time is 7.967µs.

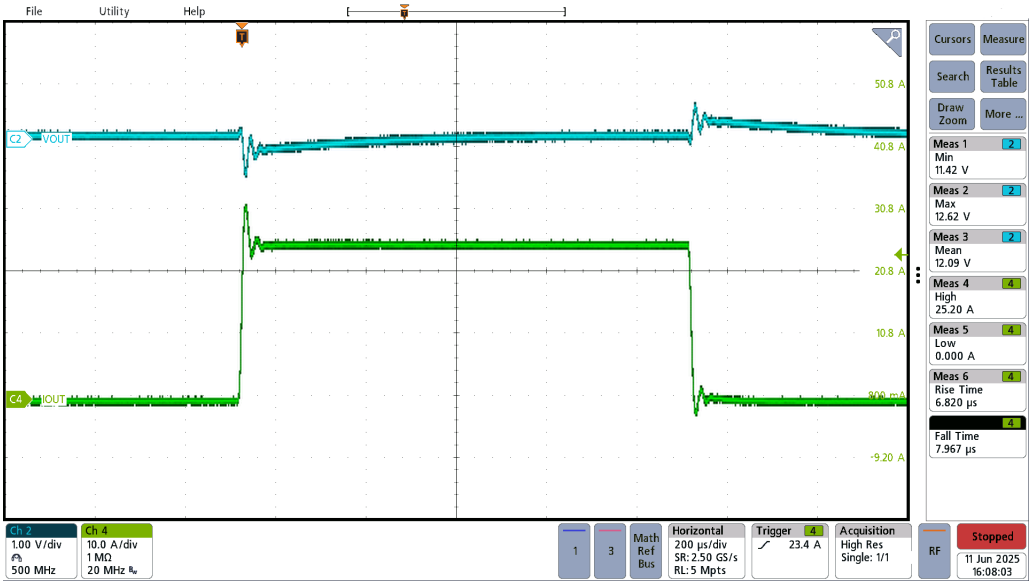


Figure 3-5. Load Transient 0A to 25A

Figure 3-6 represents load transient response between 25A to 50A load step. Output voltage is about 580mV, around 5%. Output voltage overshoot is about 620mV, around 5% as well. For this testing, slew rate is set to be 5A/µs. Rise time is 6µs and fall time is 6.273µs.

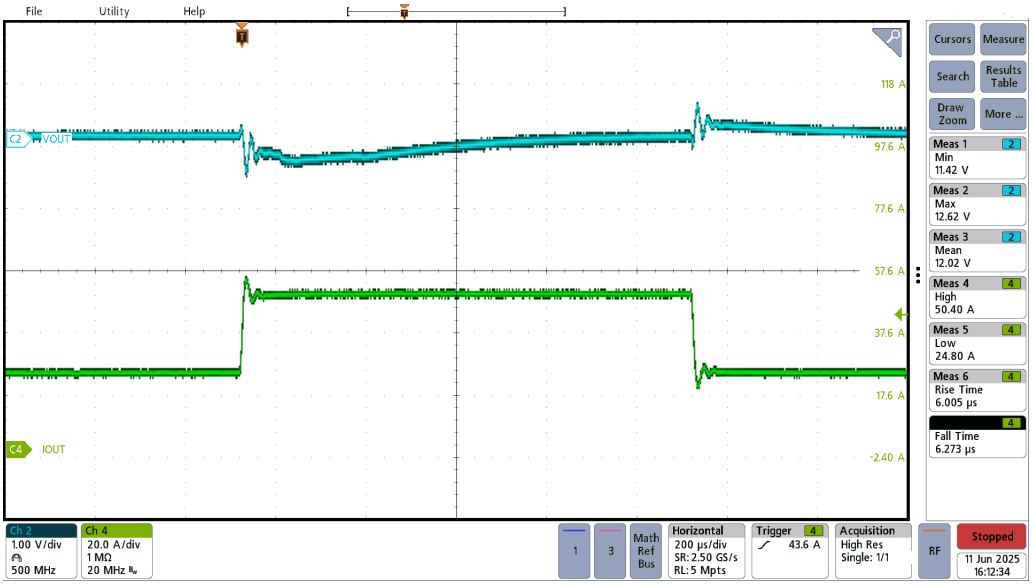


Figure 3-6. Load Transient 25A to 50A

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