Test Report: PMP23300

60-W, USB Type-C® Buck Converter Reference Design

Description

This reference design is a 48-V input, 5-V to 20-V output, USB Power Delivery (PD) Source-only design. A wide VIN buck converter is employed to accept input voltage from 30 V to 60 V. The design uses a TPS65987DH USB PD controller to manage the USB PD communication and to control the feedback divider of the buck converter. A Tiva™ TM4C123GH6PM Arm® microcontroller and USB Micro-B connecter is included to provide compatibility with the TPS65987DH 6.1.X GUI tool. The design supports 5 V at 3 A, 9 V at 3 A, 15 V at 3 A, and 20 V at 3 A USB PD Source contracts.

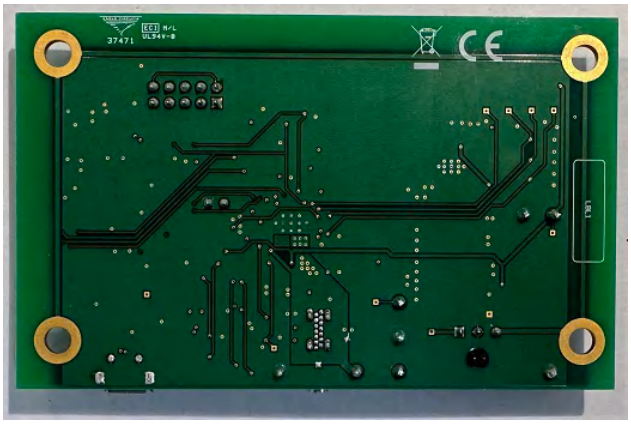
Features

- Wide input buck converter for delivering power from poorly-regulated supplies
- USB Type-C PD (Power Delivery) Source supporting 20-V at 3-A, 15-V at 3-A, 9-V at 3-A, or 5-V at 3-A outputs
- 96.8% maximum efficiency at 48-V input and full load
- External SPI Flash removes the need for microcontroller host device
- Optional microcontroller for easy programming of USB Type-C PD controller serial peripheral interface (SPI) Flash over USB Micro-B

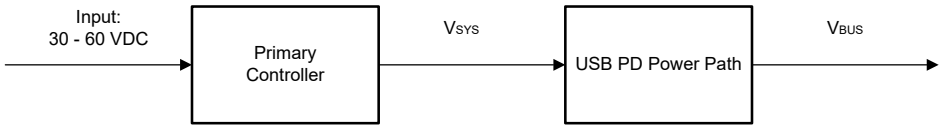
Applications

- Medical accessories - medical monitor
- Medical accessories - medical charger

Top of Board



Bottom of Board



Simple Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input Voltage	30 – 60 VDC
Bias Supply (P3V3)	3.3 VDC
Output Voltage (V_{SYS})	5, 9, 15, or 20 VDC
Output Current (V_{SYS})	3 A

1.2 Required Equipment

- Oscilloscope
- Power supply
- Load supply
- Multimeters
- Bode100

1.3 Dimensions

This reference design is 6.1 cm × 9.8 cm × 1.2 cm.

2 Testing and Results

2.1 Efficiency Graphs

Efficiency is shown in the following figures.

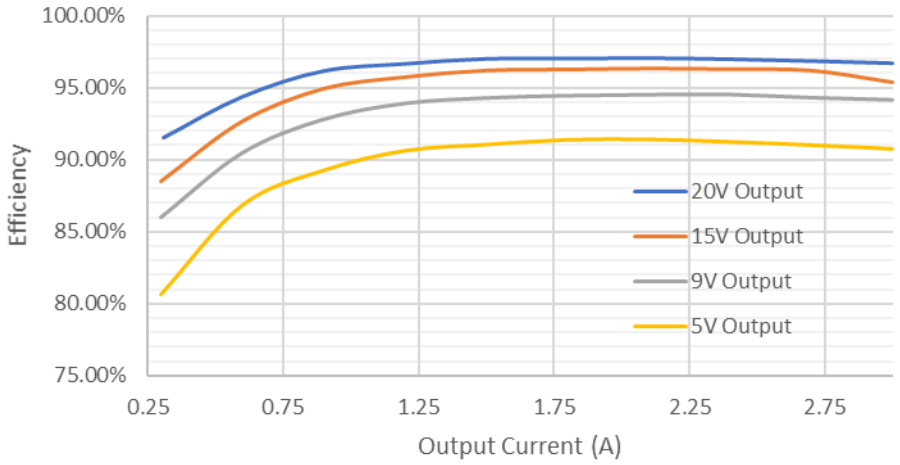


Figure 2-1. Efficiency Graph at 30-V Input

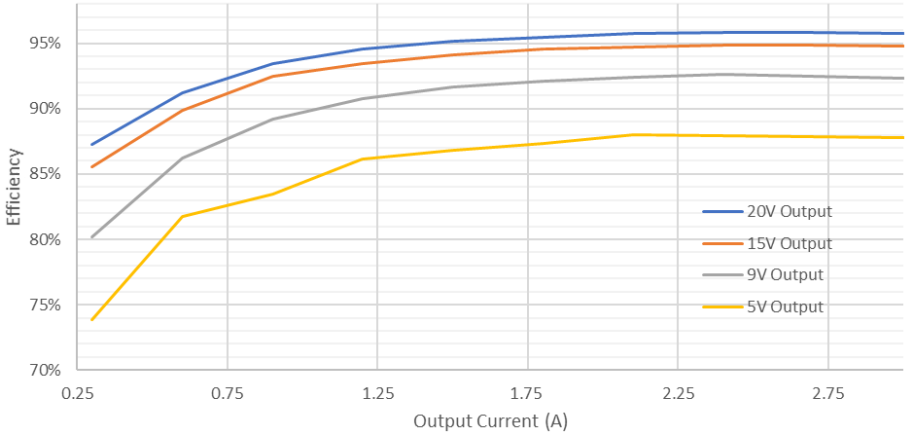


Figure 2-2. Efficiency Graph at 48-V Input

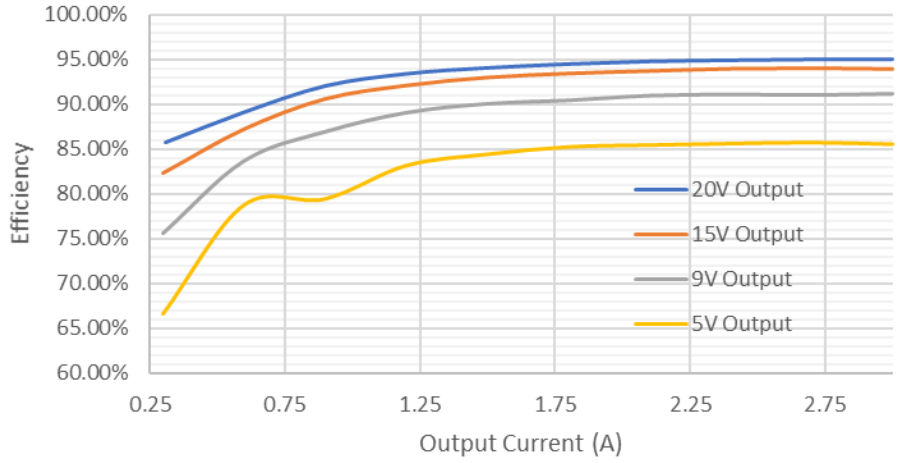


Figure 2-3. Efficiency Graph at 60-V Input

2.2 Efficiency Data

Efficiency data is shown in the following tables.

Table 2-1. 30-V Input, 20-V Output

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
30.01	0.229	6.87	20.29	20.28	0.31	6.29	6.29	91.53	91.48
30.01	0.427	12.81	20.15	20.14	0.60	12.09	12.08	94.35	94.30
30.01	0.638	18.85	20.13	20.10	0.90	18.12	18.09	96.13	95.99
30.01	0.833	25.00	20.13	20.09	1.20	24.16	24.11	96.63	96.44
30.00	1.038	31.14	20.13	20.09	1.50	30.20	30.14	96.97	96.77
30.03	1.244	37.36	20.13	20.08	1.80	36.23	36.14	96.99	96.75
30.03	1.451	43.57	20.13	20.07	2.10	42.27	42.15	97.02	96.73
30.02	1.660	49.83	20.13	20.06	2.40	48.31	48.14	96.95	96.61
30.02	1.870	56.14	20.13	20.05	2.70	54.35	54.14	96.82	96.43
30.02	2.081	62.47	20.13	20.04	3.00	60.39	60.12	96.67	96.24

Table 2-2. 48-V Input, 20-V Output

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
48.03	0.145	6.96	20.26	20.25	0.30	6.08	6.08	87.27%	87.23%
48.01	0.276	13.25	20.14	20.12	0.60	12.08	12.07	91.19%	91.10%
48.02	0.404	19.40	20.14	20.11	0.90	18.13	18.10	93.43%	93.29%
48.03	0.532	25.55	20.13	20.10	1.20	24.16	24.12	94.54%	94.40%
48.01	0.661	31.73	20.13	20.09	1.50	30.20	30.14	95.15%	94.96%
48.02	0.791	37.98	20.14	20.08	1.80	36.25	36.14	95.44%	95.16%
48.03	0.920	44.19	20.14	20.07	2.10	42.29	42.15	95.71%	95.38%
48.00	1.051	50.45	20.14	20.06	2.40	48.34	48.14	95.81%	95.43%
48.01	1.182	56.75	20.14	20.05	2.70	54.38	54.14	95.82%	95.40%
48.02	1.314	63.10	20.14	20.04	3.00	60.42	60.12	95.76%	95.28%

Table 2-3. 60-V Input, 20-V Output

V_{IN} (V)	I_{IN} (A)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{IN} (W)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
48.01	0.145	20.26	20.25	0.30	6.96	6.08	6.08	87.27	87.23
48.01	0.276	20.14	20.12	0.60	13.25	12.08	12.07	91.19	91.10
48.02	0.404	20.14	20.11	0.90	19.40	18.13	18.10	93.43	93.29
48.03	0.532	20.13	20.10	1.20	25.55	24.16	24.12	94.54	94.40
48.01	0.661	20.13	20.09	1.50	31.73	30.20	30.14	95.15	94.96
48.02	0.791	20.14	20.08	1.80	37.98	36.25	36.14	95.44	95.16
48.03	0.920	20.14	20.07	2.10	44.19	42.29	42.15	95.71	95.38
48.00	1.051	20.14	20.06	2.40	50.45	48.34	48.14	95.81	95.43
48.01	1.182	20.14	20.05	2.70	56.75	54.38	54.14	95.82	95.40
48.02	1.314	20.14	20.04	3.00	63.10	60.42	60.12	95.76	95.28

Table 2-4. 30-V Input, 15-V Output

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
30.01	0.172	5.16	15.22	15.21	0.30	4.57	4.56	88.46%	88.40%
30.02	0.326	9.79	15.11	15.09	0.60	9.07	9.05	92.64%	92.52%
30.02	0.477	14.32	15.10	15.07	0.90	13.59	13.56	94.91%	94.72%
30.00	0.631	18.93	15.10	15.06	1.20	18.12	18.07	95.72%	95.47%
30.00	0.785	23.55	15.10	15.05	1.50	22.65	22.58	96.18%	95.86%
30.01	0.941	28.24	15.10	15.04	1.80	27.18	27.07	96.25%	95.87%
30.01	1.097	32.92	15.10	15.03	2.10	31.71	31.56	96.32%	95.88%
30.02	1.254	37.65	15.10	15.02	2.40	36.24	36.05	96.27%	95.76%
30.02	1.412	42.39	15.10	15.01	2.70	40.77	40.53	96.18%	95.61%
30.00	1.573	47.19	15.00	15.00	3.00	45.00	45.00	95.36%	95.36%

Table 2-5. 48-V Input, 15-V Output

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
48.02	0.111	5.33	15.20	15.19	0.30	4.56	4.56	85.55%	85.49%
48.00	0.210	10.08	15.10	15.08	0.60	9.06	9.05	89.88%	89.76%
48.02	0.306	14.69	15.10	15.07	0.90	13.59	13.56	92.49%	92.30%
48.00	0.404	19.39	15.10	15.06	1.20	18.12	18.07	93.44%	93.19%
48.02	0.501	24.06	15.10	15.05	1.50	22.65	22.58	94.15%	93.84%
48.00	0.599	28.75	15.10	15.04	1.80	27.18	27.07	94.53%	94.16%
48.02	0.697	33.47	15.10	15.03	2.10	31.71	31.56	94.74%	94.30%
48.00	0.796	38.21	15.10	15.02	2.40	36.24	36.05	94.85%	94.35%
48.01	0.895	42.97	15.10	15.01	2.70	40.77	40.53	94.88%	94.32%
48.00	0.996	47.81	15.10	15.00	3.00	45.30	45.00	94.75%	94.13%

Table 2-6. 60-V Input, 15-V Output

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
60.01	0.092	5.52	15.16	15.15	0.30	4.55	4.55	82.38%	82.32%
60.02	0.173	10.38	15.10	15.08	0.60	9.06	9.05	87.25%	87.14%
60.01	0.250	15.00	15.10	15.07	0.90	13.59	13.56	90.58%	90.40%
60.00	0.328	19.68	15.10	15.06	1.20	18.12	18.07	92.07%	91.83%
60.02	0.406	24.37	15.10	15.05	1.50	22.65	22.58	92.95%	92.64%
60.00	0.485	29.10	15.10	15.05	1.80	27.18	27.09	93.40%	93.09%
60.02	0.564	33.85	15.10	15.04	2.10	31.71	31.58	93.67%	93.30%
60.01	0.643	38.59	15.10	15.02	2.40	36.24	36.05	93.92%	93.42%
60.00	0.723	43.38	15.10	15.01	2.70	40.77	40.53	93.98%	93.42%
60.01	0.804	48.25	15.10	15.00	3.00	45.30	45.00	93.89%	93.27%

Table 2-7. 30-V Input, 9-V Output

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
30.02	0.106	3.18	9.12	9.10	0.30	2.74	2.73	85.98%	85.79%
30.01	0.200	6.00	9.05	9.03	0.60	5.43	5.42	90.47%	90.27%
30.02	0.292	8.77	9.04	9.01	0.90	8.14	8.11	92.81%	92.51%
30.00	0.385	11.55	9.04	9.00	1.20	10.85	10.80	93.92%	93.51%
30.02	0.479	14.38	9.04	8.99	1.50	13.56	13.49	94.30%	93.78%
30.01	0.574	17.23	9.04	8.98	1.80	16.27	16.16	94.46%	93.84%
30.02	0.669	20.08	9.04	8.97	2.10	18.98	18.84	94.53%	93.79%
30.00	0.765	22.95	9.04	8.96	2.40	21.70	21.50	94.54%	93.70%
30.02	0.862	25.88	9.04	8.95	2.70	24.41	24.17	94.32%	93.38%
30.00	0.960	28.80	9.04	8.94	3.00	27.12	26.82	94.17%	93.13%

Table 2-8. 48-V Input, 9-V Output

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
48.00	0.071	3.41	9.11	9.10	0.30	2.73	2.73	80.19%	80.11%
48.02	0.131	6.29	9.04	9.02	0.60	5.42	5.41	86.22%	86.03%
48.01	0.190	9.12	9.04	9.01	0.90	8.14	8.11	89.19%	88.90%
48.00	0.249	11.95	9.04	9.00	1.20	10.85	10.80	90.76%	90.36%
48.02	0.308	14.79	9.04	8.99	1.50	13.56	13.49	91.68%	91.18%
48.01	0.368	17.67	9.04	8.98	1.80	16.27	16.16	92.10%	91.49%
48.00	0.428	20.54	9.04	8.97	2.10	18.98	18.84	92.41%	91.69%
48.02	0.488	23.43	9.04	8.96	2.40	21.70	21.50	92.58%	91.77%
48.01	0.550	26.41	9.04	8.95	2.70	24.41	24.17	92.44%	91.52%
48.00	0.612	29.38	9.04	8.94	3.00	27.12	26.82	92.32%	91.30%

Table 2-9. 60-V Input, 9-V Output

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
60.01	0.060	3.60	9.08	9.07	0.30	2.72	2.72	75.65%	75.57%
60.01	0.108	6.48	9.04	9.02	0.60	5.42	5.41	83.69%	83.50%
60.00	0.156	9.36	9.04	9.01	0.90	8.14	8.11	86.92%	86.63%
60.02	0.203	12.18	9.04	9.00	1.20	10.85	10.80	89.03%	88.64%
60.01	0.251	15.06	9.04	8.99	1.50	13.56	13.49	90.02%	89.53%
60.00	0.300	18.00	9.04	8.98	1.80	16.27	16.16	90.40%	89.80%
60.00	0.348	20.88	9.04	8.97	2.10	18.98	18.84	90.92%	90.22%
60.02	0.397	23.83	9.04	8.96	2.40	21.70	21.50	91.05%	90.25%
60.01	0.447	26.82	9.04	8.95	2.70	24.41	24.17	90.99%	90.09%
60.00	0.496	29.76	9.04	8.94	3.00	27.12	26.82	91.13%	90.12%

Table 2-10. 30-V Input, 5-V Output

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
30.00	0.063	1.89	5.08	5.07	0.30	1.52	1.52	80.63%	80.48%
30.02	0.116	3.48	5.04	5.02	0.60	3.02	3.01	86.84%	86.49%
30.01	0.169	5.07	5.03	5.00	0.90	4.53	4.50	89.26%	88.73%
30.00	0.222	6.66	5.03	5.00	1.20	6.04	6.00	90.63%	90.09%
30.02	0.276	8.29	5.03	4.99	1.50	7.55	7.49	91.06%	90.34%
30.02	0.330	9.91	5.03	4.98	1.80	9.05	8.96	91.39%	90.49%
30.01	0.385	11.55	5.03	4.97	2.10	10.56	10.44	91.42%	90.33%
30.00	0.441	13.23	5.03	4.96	2.40	12.07	11.90	91.25%	89.98%
30.02	0.497	14.92	5.03	4.95	2.70	13.58	13.37	91.03%	89.58%
30.01	0.554	16.63	5.03	4.94	3.00	15.09	14.82	90.76%	89.14%

Table 2-11. 48-V Input, 5-V Output

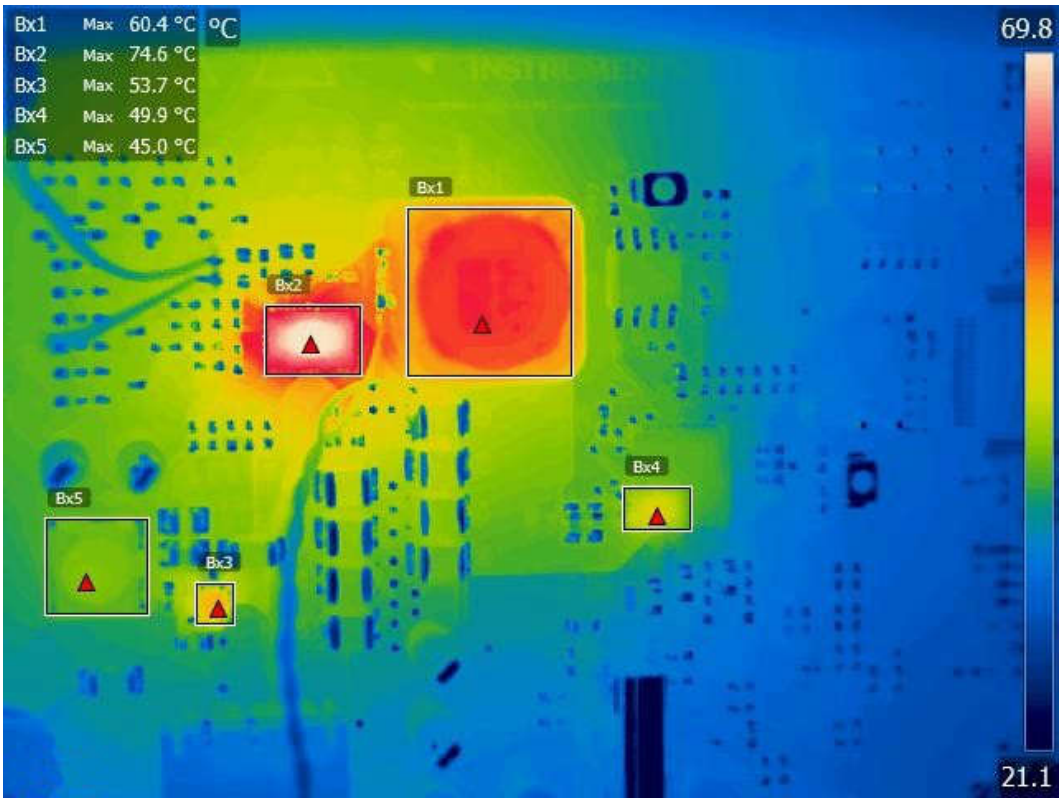
V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
48.00	0.043	2.06	5.08	5.07	0.30	1.52	1.52	73.84%	73.69%
48.02	0.077	3.70	5.04	5.02	0.60	3.02	3.01	81.78%	81.46%
48.02	0.113	5.43	5.03	5.00	0.90	4.53	4.50	83.43%	82.93%
48.01	0.146	7.01	5.03	5.00	1.20	6.04	6.00	86.11%	85.60%
48.01	0.181	8.69	5.03	4.99	1.50	7.55	7.49	86.83%	86.14%
48.00	0.216	10.37	5.03	4.98	1.80	9.05	8.96	87.33%	86.46%
48.00	0.250	12.00	5.03	4.97	2.10	10.56	10.44	88.03%	86.98%
48.02	0.286	13.73	5.03	4.96	2.40	12.07	11.90	87.90%	86.68%
48.02	0.322	15.46	5.03	4.95	2.70	13.58	13.35	87.83%	86.37%
48.01	0.358	17.19	5.03	4.94	3.00	15.09	14.81	87.80%	86.14%

Table 2-12. 60-V Input, 5-V Output

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{SYS} (V)	V_{BUS} (V)	I_{OUT} (A)	P_{SYS} (W)	P_{BUS} (W)	Eff_{SYS} (%)	Eff_{BUS} (%)
60.02	0.038	2.28	5.06	5.05	0.30	1.52	1.52	66.56%	66.43%
60.01	0.064	3.84	5.04	5.01	0.60	3.02	3.01	78.74%	78.27%
60.01	0.095	5.70	5.03	5.01	0.90	4.53	4.51	79.41%	79.09%
60.00	0.121	7.26	5.03	5.00	1.20	6.04	6.00	83.14%	82.64%
60.00	0.149	8.94	5.03	4.99	1.50	7.55	7.49	84.40%	83.72%
60.02	0.177	10.62	5.03	4.98	1.80	9.05	8.96	85.23%	84.38%
60.02	0.206	12.36	5.03	4.97	2.10	10.56	10.44	85.43%	84.41%
60.01	0.235	14.10	5.03	4.96	2.40	12.07	11.90	85.60%	84.41%
60.01	0.264	15.84	5.03	4.94	2.70	13.58	13.34	85.72%	84.19%
60.01	0.294	17.64	5.03	4.93	3.00	15.09	14.79	85.53%	83.83%

2.3 Thermal Images

Figure 2-4 shows a thermal image of the top view of the board. Ambient temperature is 22.5°C. The board is open frame with no active air flow. Input is 48 V and output is loaded with 20 V and 3 A at V_{BUS} for 30 minutes.

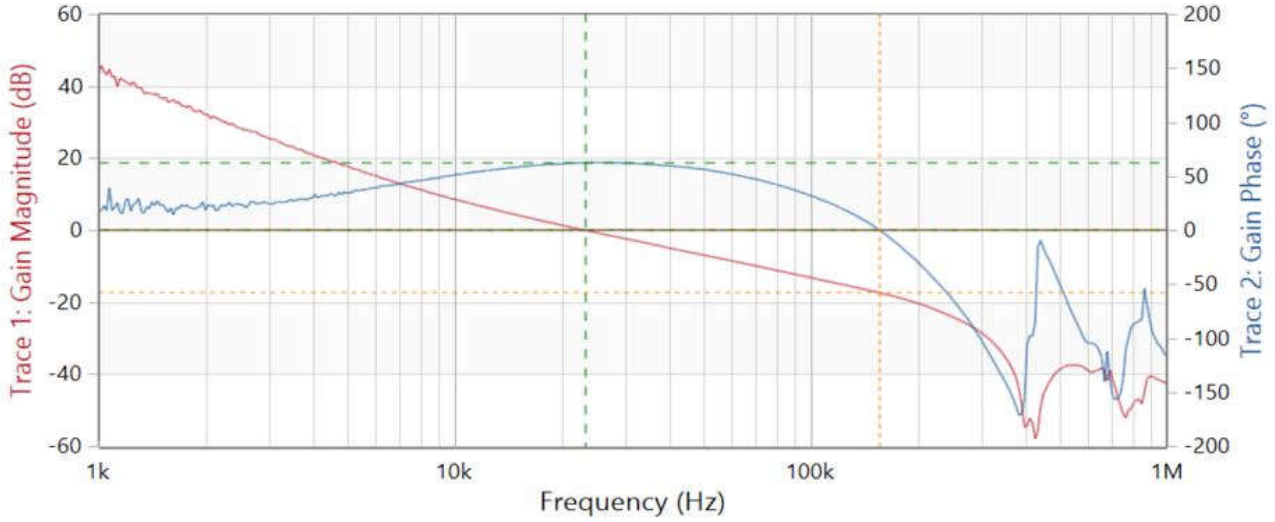


Bx1 = L1 – 20-V buck inductor
Bx2 = U1 – 20-V buck converter
Bx3 = U2 – 3.3-V buck converter
Bx4 = U4 – PD controller
Bx5 = L2 – 3.3-V buck inductor

Figure 2-4. Thermal Image

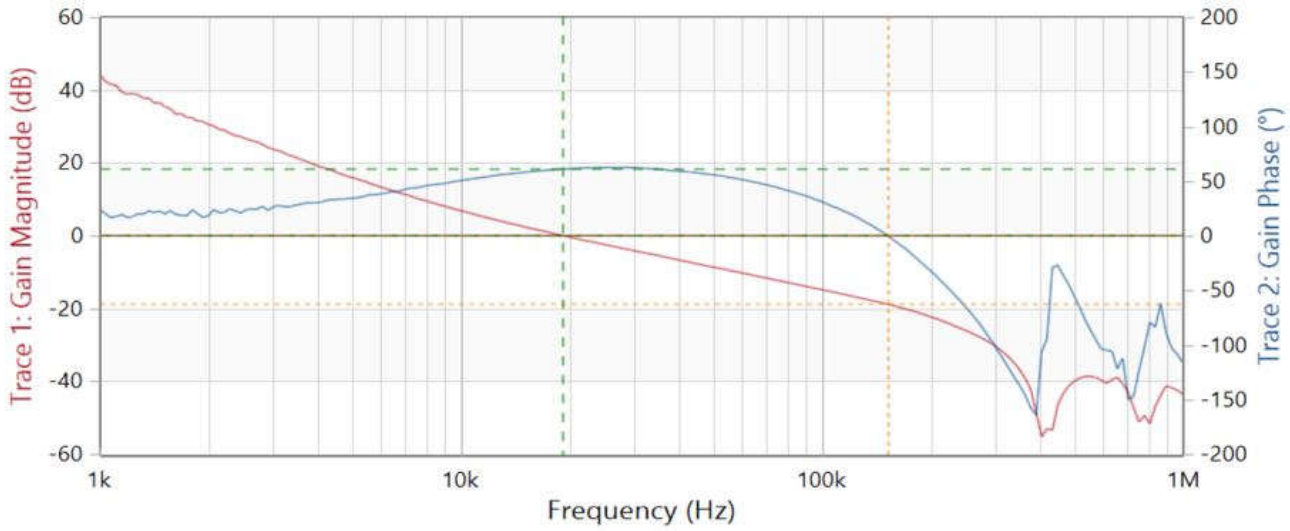
2.4 Bode Plots

Bode plots are shown in the following figures.



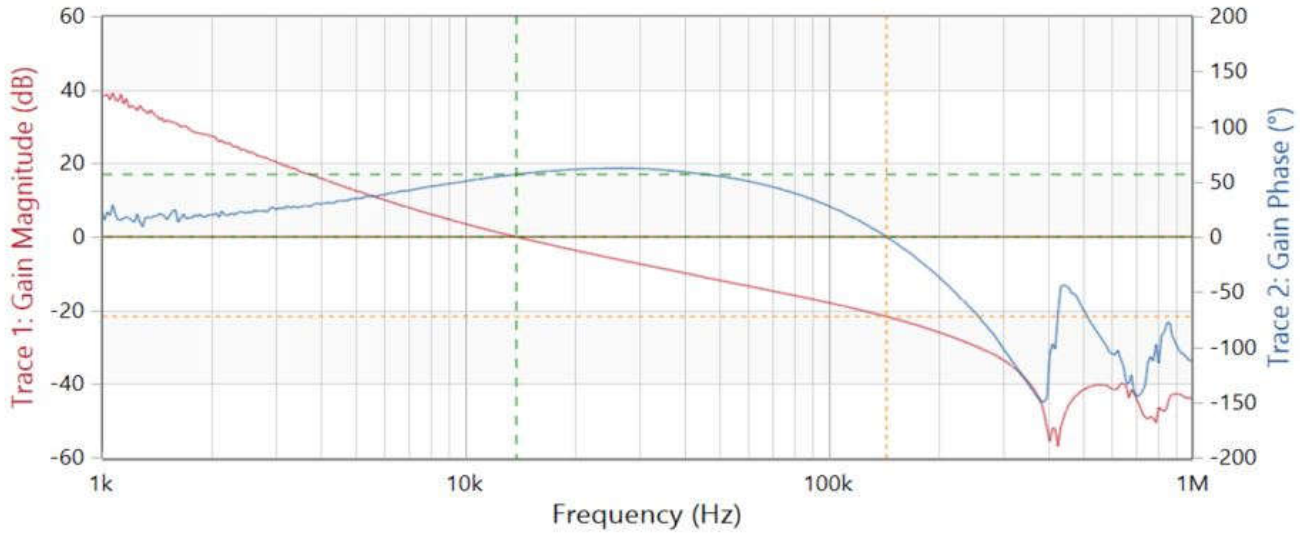
	Cursor 1	Cursor 2	Delta C2-C1
Frequency	23.182 kHz	156.162 kHz	132.98 kHz
Trace 1	**Magnitude (dB)**	**Magnitude (dB)**	**Magnitude (dB)**
Measurement	0 dB	-17.398 dB	-17.398 dB
Trace 2	**Phase (°)**	**Phase (°)**	**Phase (°)**
Measurement	62.226 °	0 °	-62.226 °

Figure 2-5. Bode Plot at 48-V Input, 20-V Output



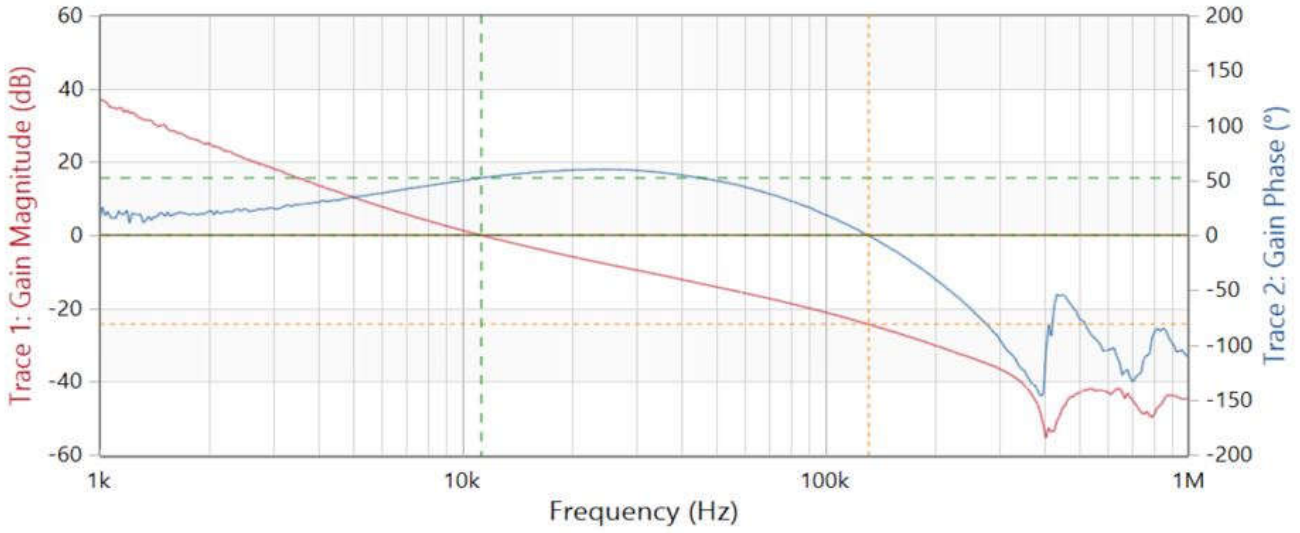
	Cursor 1	Cursor 2	Delta C2-C1
Frequency	19.193 kHz	152.221 kHz	133.029 kHz
Trace 1	**Magnitude (dB)**	**Magnitude (dB)**	**Magnitude (dB)**
Measurement	0 dB	-18.827 dB	-18.827 dB
Trace 2	**Phase (°)**	**Phase (°)**	**Phase (°)**
Measurement	60.931 °	0 °	-60.931 °

Figure 2-6. Bode Plot at 48-V Input, 15-V Output



	Cursor 1	Cursor 2	Delta C2-C1
Frequency	13.828 kHz	144.498 kHz	130.67 kHz
Trace 1	**Magnitude (dB)**	**Magnitude (dB)**	**Magnitude (dB)**
Measurement	0 dB	-21.666 dB	-21.666 dB
Trace 2	**Phase (°)**	**Phase (°)**	**Phase (°)**
Measurement	56.593 °	0 °	-56.593 °

Figure 2-7. Bode Plot at 48-V Input, 9-V Output



	Cursor 1	Cursor 2	Delta C2-C1
Frequency	11.252 kHz	131.175 kHz	119.923 kHz
Trace 1	**Magnitude (dB)**	**Magnitude (dB)**	**Magnitude (dB)**
Measurement	0 dB	-24.309 dB	-24.309 dB
Trace 2	**Phase (°)**	**Phase (°)**	**Phase (°)**
Measurement	52.063 °	0 °	-52.063 °

Figure 2-8. Bode Plot at 48-V Input, 5-V Output

3 Waveforms

3.1 Switching

Switching behavior is shown in the following figures.

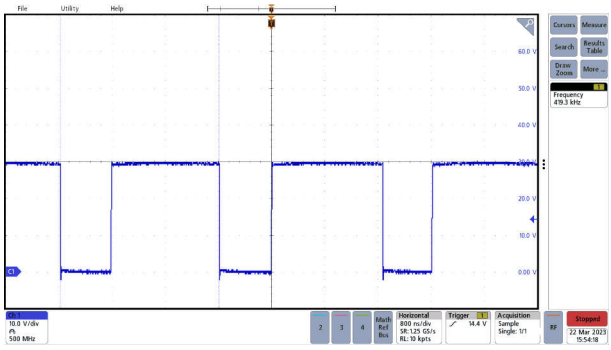


Figure 3-1. Switching at 30-V Input, 20-V Output

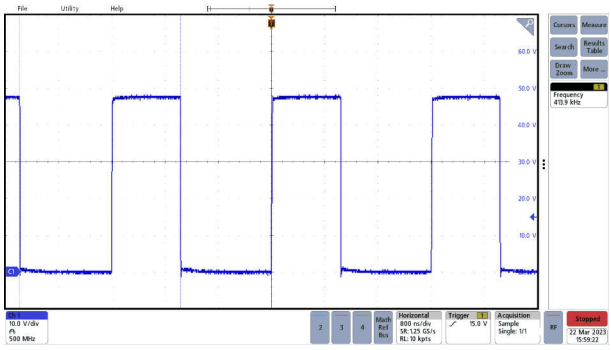


Figure 3-2. Switching at 48-V Input, 20-V Output

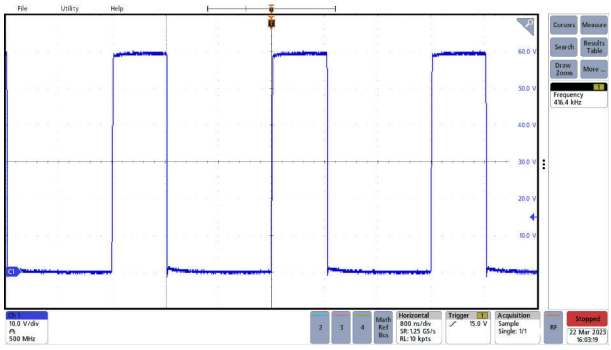


Figure 3-3. Switching at 60-V Input, 20-V Output

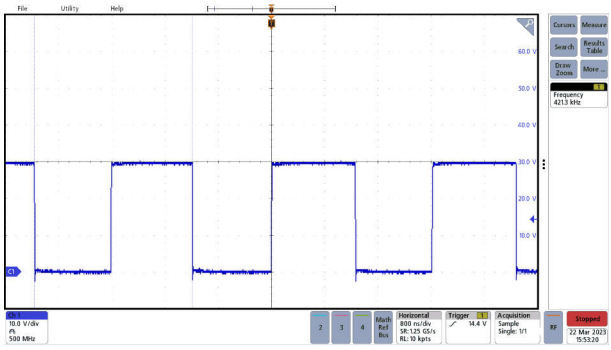


Figure 3-4. Switching at 30-V Input, 15-V Output

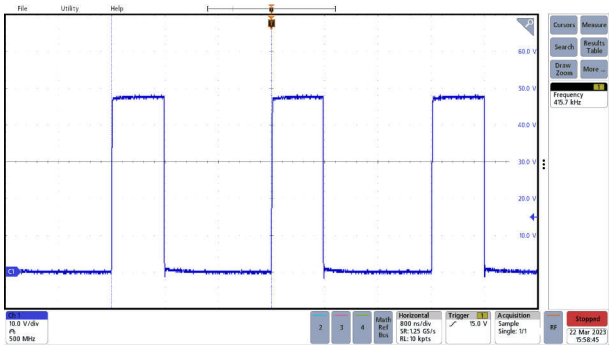


Figure 3-5. Switching at 48-V Input, 15-V Output

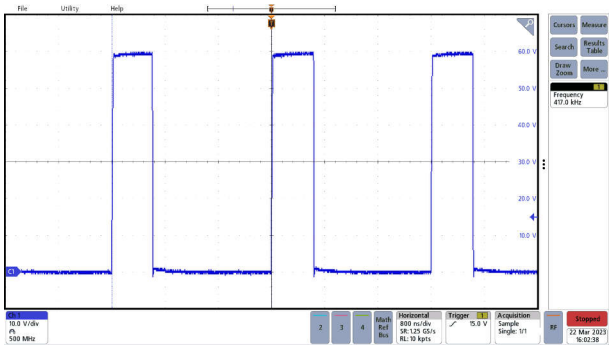


Figure 3-6. Switching at 60-V Input, 15-V Output

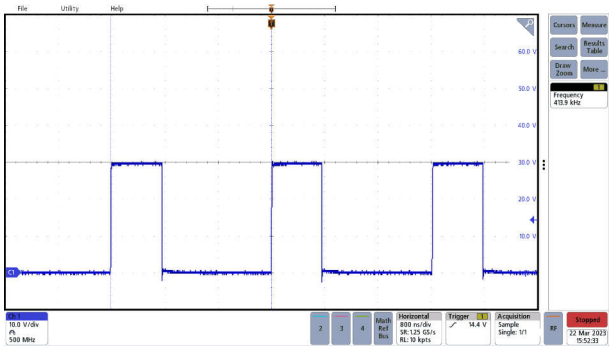


Figure 3-7. Switching at 30-V Input, 9-V Output

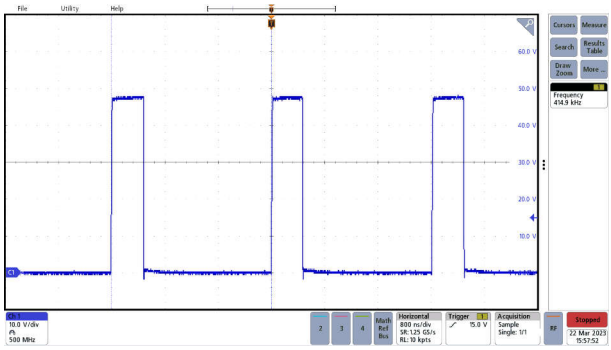


Figure 3-8. Switching at 48-V Input, 9-V Output

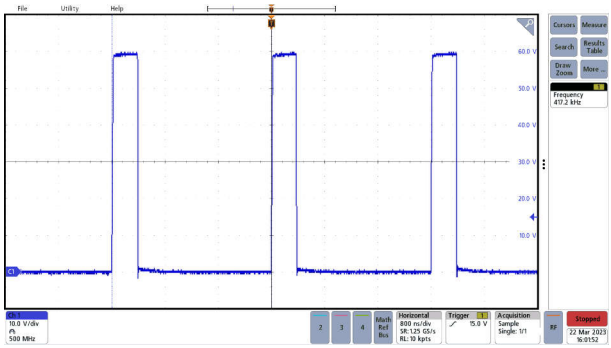


Figure 3-9. Switching at 60-V Input, 9-V Output

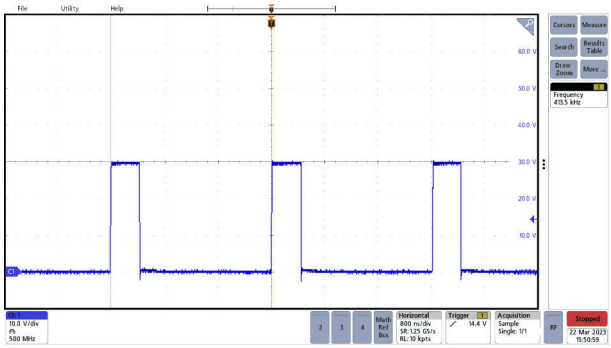


Figure 3-10. Switching at 30-V Input, 5-V Output

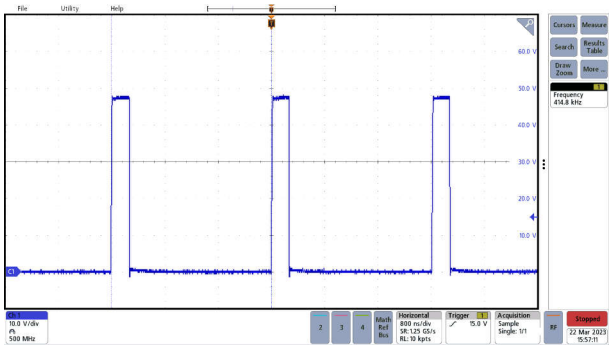


Figure 3-11. Switching at 48-V Input, 5-V Output

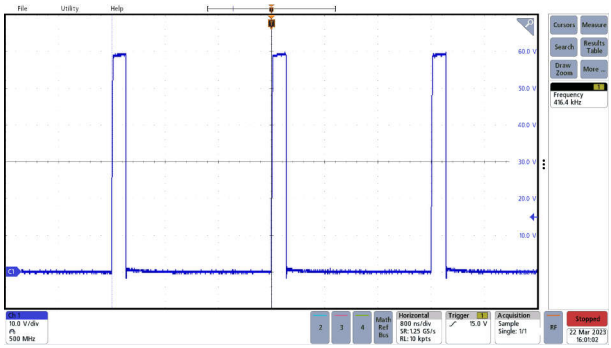


Figure 3-12. Switching at 60-V Input, 5-V Output

3.2 Output Voltage Ripple

Output voltage ripple waveforms are shown in the following figures.

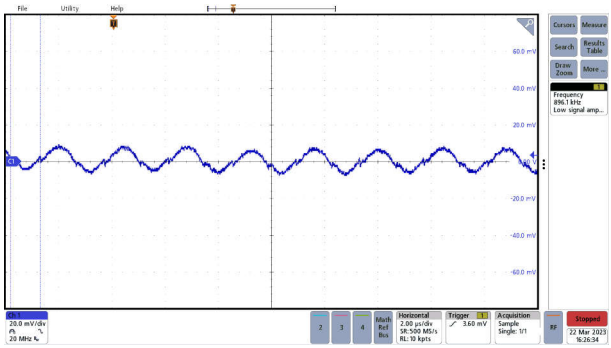


Figure 3-13. Output Voltage Ripple of 48-V Input, 20-V Output

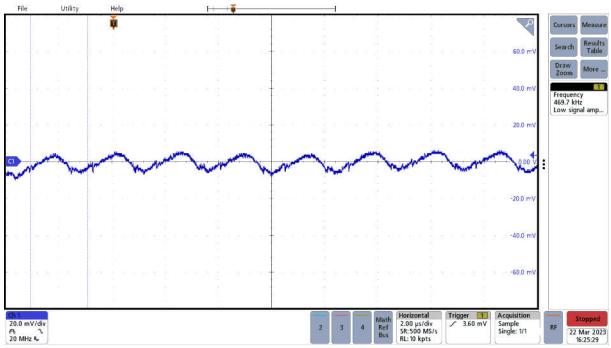


Figure 3-14. Output Voltage Ripple of 48-V Input, 15-V Output

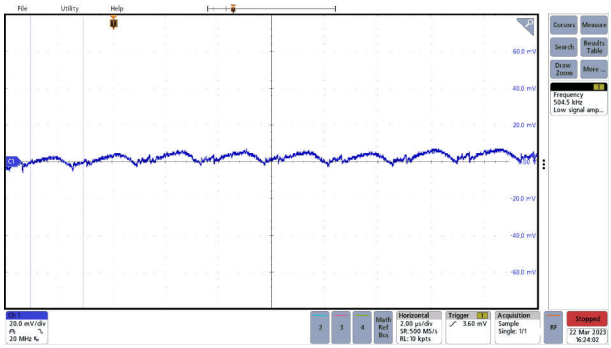


Figure 3-15. Output Voltage Ripple of 48-V Input, 9-V Output

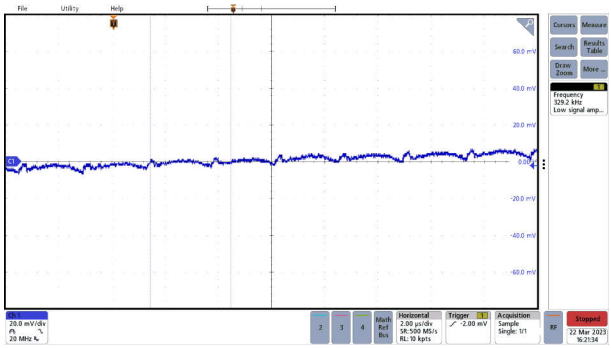


Figure 3-16. Output Voltage Ripple of 48-V Input, 5-V Output

3.3 Load Transients

Load transient response waveforms are shown in the following figures. The first response is from 0.75 A to 2.25 A and the next response is from 2.25 A to 0.75 A

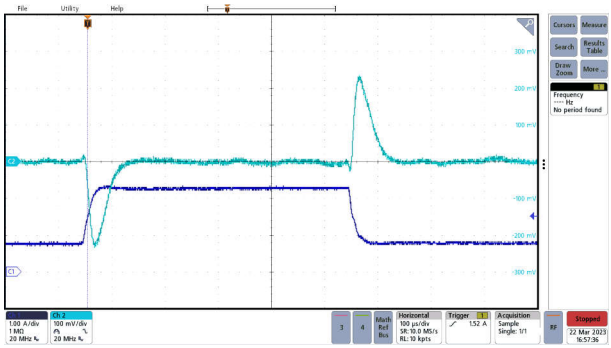


Figure 3-17. Load Transient at 48-V Input, 20-V Output

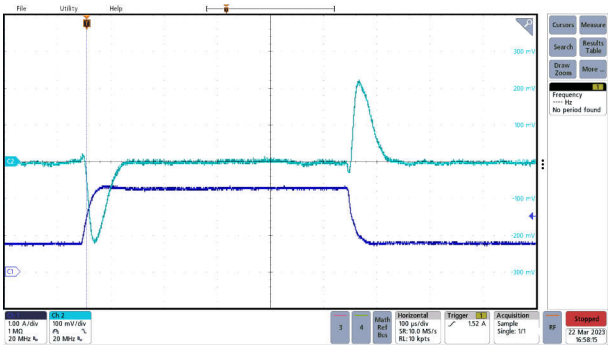


Figure 3-18. Load Transient at 48-V Input, 15-V Output

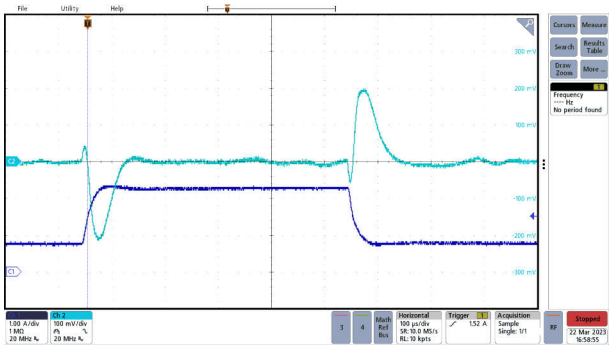


Figure 3-19. Load Transient at 48-V Input, 9-V Output

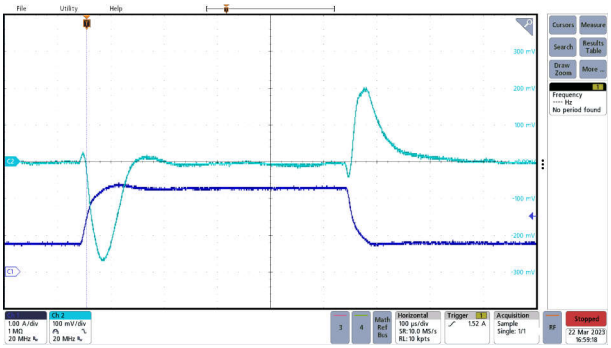
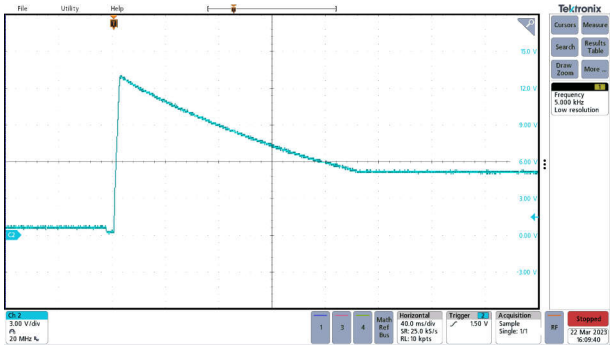


Figure 3-20. Load Transient at 48-V Input, 5-V Output

3.4 Start-Up Sequence

Start-up behavior is shown in the following figure, with 48-V input and no load.



PD control starts after settling to 5 V

Figure 3-21. Start-Up

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