Test Report: PMP23456

USB Type-C® and USB Power Delivery for 1S Li-Ion Battery Charger Reference Design

Description

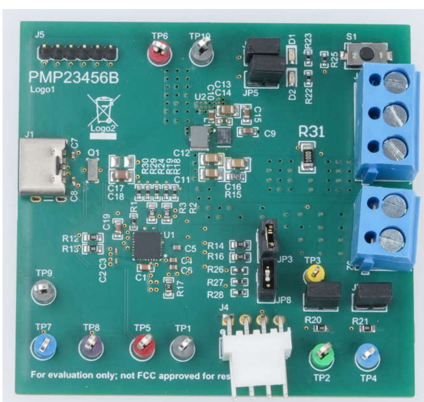
This reference design uses a TPS25730S sink-only USB Type-C power delivery (PD) controller in collaboration with a BQ25638 inter-intergrated circuit (I2C) controlled single-cell buck charger configured as a complete USB Type-C single-cell battery charger design targeted at portable personal electronic devices. The PD controller negotiates either a 5V-3A or 9V-3A contract from the USB-C input, and delivers this to the buck charger which generates a regulated 4.8V maximum to the system output and or the battery output. The maximum output load is designed for 3A total, which can be split between the system and battery outputs with charge enabled or disabled.

Features

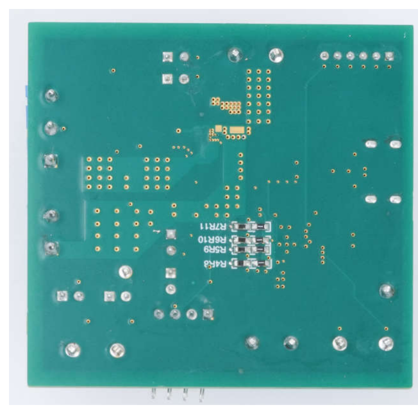
- Small design size
- 1.5MHz switching frequency
- Charge enabled or disabled option
- I2C configurations
- Thermistor sensing

Applications

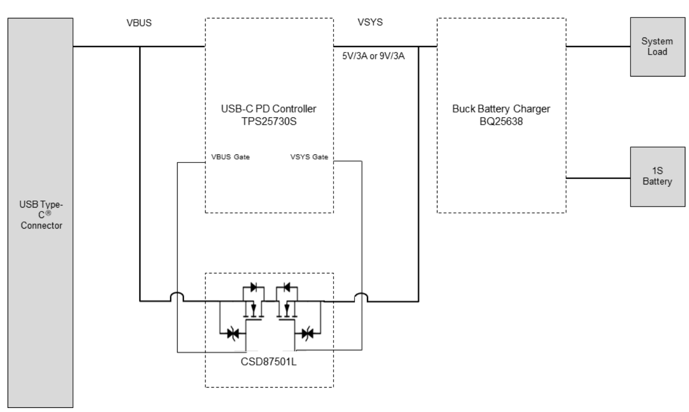
- Mobile projector
- Digital still camera
- Standard notebook PC



Top Photo



Bottom Photo



Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
Sink voltage and current contracts	5V-3A or 9V-3A
System voltage range	4.8V with charge enabled, 4.02V with charge disabled
Battery voltage range	4.8V
Maximum output current	3A
Switching frequency	1.5MHz

1.2 Required Equipment

- DC Source
- USB Type-C PD adapter
- USB Type-C cable
- Electronic load with constant voltage setting
- USB Type-C DUO EVM board (sink and source emulator)

1.3 Considerations

The reference design shows an example of how to implement a USB Type-C PD alongside a switching battery charger. This design can be used in small portable electronic devices as well as various other personal electronic systems. This design assists with different functions, from the ability to charge a battery as well as providing power to the system.

1.4 Dimensions

Board size: 59.7mm × 57.2mm × 13mm (including connectors).

1.5 Test Setup

Place a 1mF capacitor or battery simulator to VBAT output with electronic load in constant voltage mode during testing.

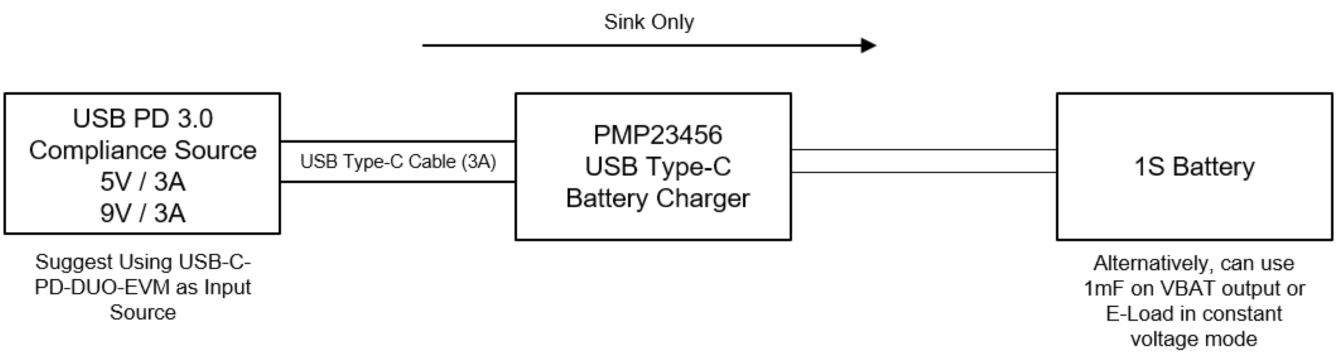


Figure 1-1. Test Setup

2 Testing and Results

2.1 Efficiency Graphs

Figure 2-1 shows the system efficiency from VBUS to VSYS with charge disabled. There was no battery connected to the VBAT terminal. VSYS is equal to 3.75V.

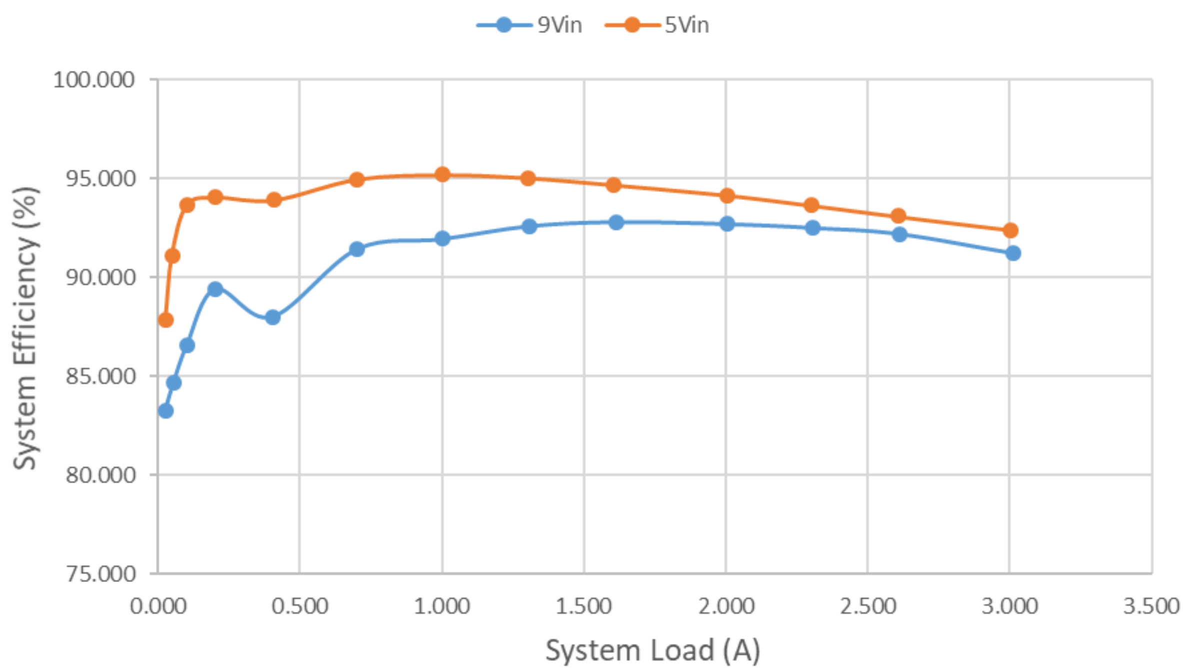


Figure 2-1. System Efficiency Graph - Charge Disabled

Charge efficiency is shown in Figure 2-2, from VBUS to VBAT with charge enabled. A 1mF capacitor with an e-load set to constant voltage mode at 3.8V was used to simulate a battery for these measurements.

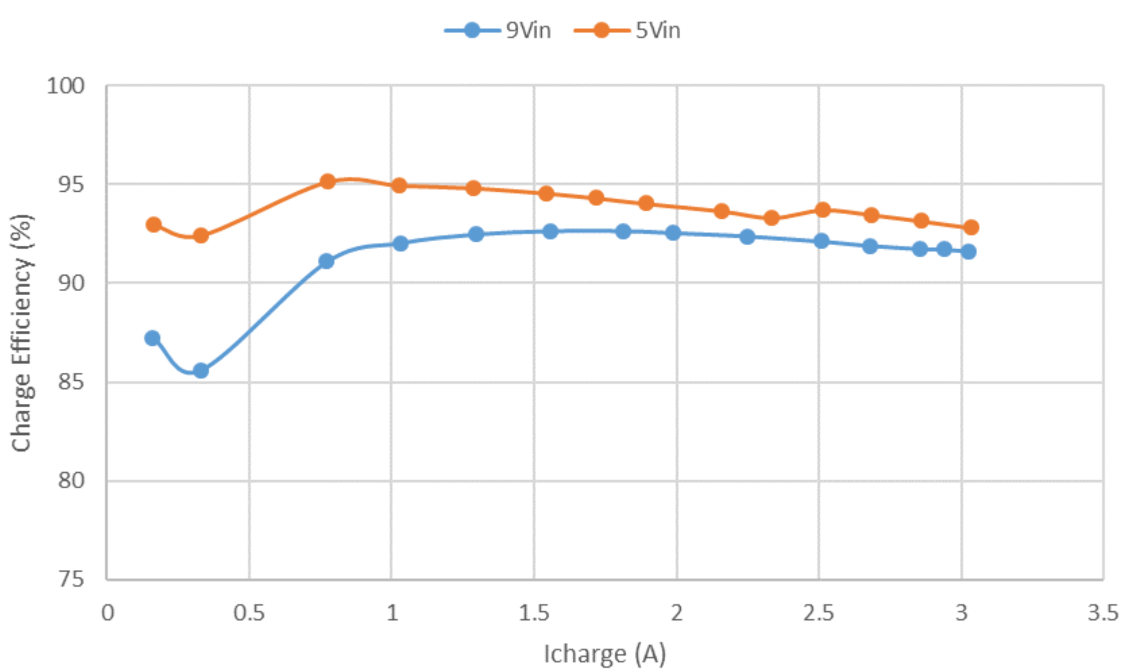


Figure 2-2. Charge Efficiency Graph - Charge Enabled

2.2 Efficiency Data

System efficiency is shown in Table 2-1 from VBUS to VSYS with charge disabled. There was no battery connected to the VBAT terminal. VSYS is equal to 3.75V.

Table 2-1. System Efficiency Data: V_{IN} = 5V

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{loss} (W)	Eff (%)
5.042	0.022	3.747	0.026	0.111	0.097	0.014	87.828
5.037	0.040	3.747	0.049	0.201	0.184	0.018	91.127
5.036	0.081	3.747	0.102	0.408	0.382	0.026	93.694
5.016	0.162	3.747	0.204	0.813	0.764	0.048	94.068
5.004	0.325	3.744	0.408	1.626	1.528	0.099	93.928
5.027	0.550	3.741	0.702	2.765	2.626	0.139	94.985
5.000	0.786	3.738	1.001	3.930	3.742	0.188	95.210
5.006	1.022	3.735	1.302	5.116	4.863	0.253	95.052
5.037	1.255	3.732	1.604	6.321	5.986	0.335	94.696
5.029	1.580	3.728	2.007	7.946	7.482	0.464	94.164
5.013	1.826	3.724	2.302	9.154	8.573	0.581	93.652
5.004	2.081	3.720	2.606	10.413	9.694	0.719	93.095
5.031	2.402	3.716	3.005	12.084	11.167	0.918	92.404

Table 2-2. System Efficiency Data: V_{IN} = 9V

V_{IN} (V)	I_{IN} (A)	V_{sys} (V)	I_{sys} (A)	P_{IN} (W)	P_{OUT} (W)	P_{loss} (W)	Eff (%)
9.000	0.013	3.747	0.026	0.117	0.097	0.020	83.267
9.018	0.027	3.748	0.055	0.243	0.206	0.037	84.662
9.012	0.049	3.748	0.102	0.442	0.382	0.059	86.573
9.003	0.094	3.746	0.202	0.846	0.757	0.090	89.414
9.002	0.190	3.744	0.402	1.710	1.505	0.205	87.997
9.049	0.318	3.743	0.703	2.878	2.631	0.246	91.442
9.010	0.452	3.737	1.002	4.073	3.744	0.328	91.945
9.016	0.585	3.734	1.308	5.274	4.884	0.390	92.600
9.000	0.721	3.729	1.615	6.489	6.022	0.467	92.808
9.018	0.894	3.724	2.007	8.062	7.474	0.588	92.706
9.041	1.026	3.718	2.308	9.276	8.581	0.695	92.508
9.019	1.165	3.712	2.610	10.507	9.688	0.819	92.207
9.011	1.357	3.705	3.011	12.228	11.156	1.072	91.232

Charge efficiency is shown in Table 2-3, from VBUS to VBAT with charge enabled. A 1mF capacitor with an e-load set to constant voltage mode at 3.8V was used to simulate a battery for these measurements.

Table 2-3. Charge Efficiency Data: V_{IN} = 5V

V_{IN} (V)	I_{IN} (A)	V_{bat} (V)	I_{chg} (A)	P_{IN} (W)	P_{charge} (W)	P_{loss} (W)	Efficiency (%)
5.007	0.133	3.823	0.162	0.666	0.619	0.047	93.002
5.025	0.274	3.857	0.330	1.377	1.273	0.104	92.444
5.042	0.636	3.947	0.773	3.207	3.051	0.156	95.145
5.020	0.863	4.002	1.028	4.332	4.114	0.218	94.963
5.035	1.091	4.054	1.285	5.493	5.209	0.284	94.834
5.017	1.336	4.108	1.543	6.703	6.339	0.364	94.568
5.055	1.493	4.146	1.717	7.547	7.119	0.428	94.323
5.011	1.681	4.185	1.893	8.423	7.922	0.501	94.049
5.068	1.928	4.243	2.157	9.771	9.152	0.619	93.665
5.014	2.138	4.283	2.336	10.720	10.005	0.715	93.332
5.006	2.314	4.322	2.512	11.584	10.857	0.727	93.724
5.007	2.500	4.358	2.685	12.518	11.701	0.816	93.479
5.006	2.700	4.401	2.861	13.516	12.591	0.925	93.157
5.021	2.885	4.43	3.035	14.486	13.445	1.041	92.817

Table 2-4. Charge Efficiency Data: V_{IN} = 9V

V_{IN} (V)	I_{IN} (A)	V_{bat} (V)	I_{chg} (A)	P_{IN} (W)	P_{charge} (W)	P_{loss} (W)	Efficiency (%)
9.052	0.078	3.826	0.161	0.706	0.616	0.090	87.243
9.011	0.164	3.856	0.328	1.478	1.265	0.213	85.584
9.002	0.371	3.941	0.772	3.340	3.042	0.297	91.098
9.003	0.498	3.995	1.033	4.483	4.127	0.357	92.045
9.024	0.627	4.044	1.294	5.658	5.233	0.425	92.487
9.024	0.762	4.097	1.555	6.876	6.371	0.505	92.649
9.005	0.903	4.151	1.815	8.132	7.534	0.597	92.653
9.025	0.997	4.187	1.989	8.998	8.328	0.670	92.554
9.001	1.147	4.241	2.249	10.324	9.538	0.786	92.385
9.059	1.291	4.294	2.509	11.695	10.774	0.922	92.120
9.029	1.399	4.330	2.681	12.632	11.609	1.023	91.903
9.008	1.508	4.367	2.854	13.584	12.463	1.121	91.750
9.031	1.552	4.371	2.941	14.016	12.855	1.161	91.717
9.008	1.611	4.392	3.027	14.512	13.295	1.217	91.612

2.3 Thermal Images

Thermal image when charge is disabled is shown in Figure 2-3.

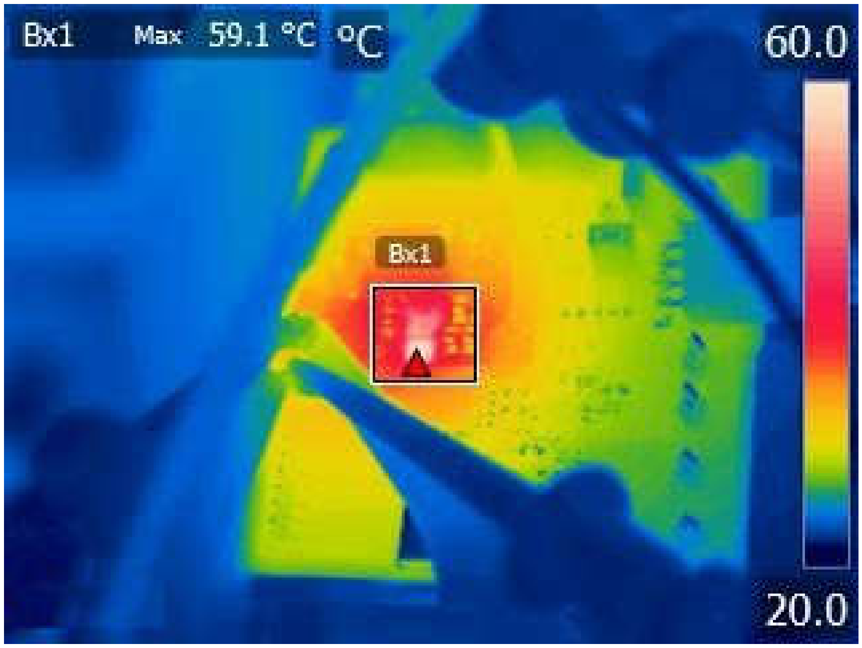


Figure 2-3. Thermal Image: VBUS = 9V, VSYS = 3.75V, ISYS = 3A, ICHG = 0A, 20 mins, Bx1 = U2

Thermal image when charge is enabled is shown in Figure 2-4.

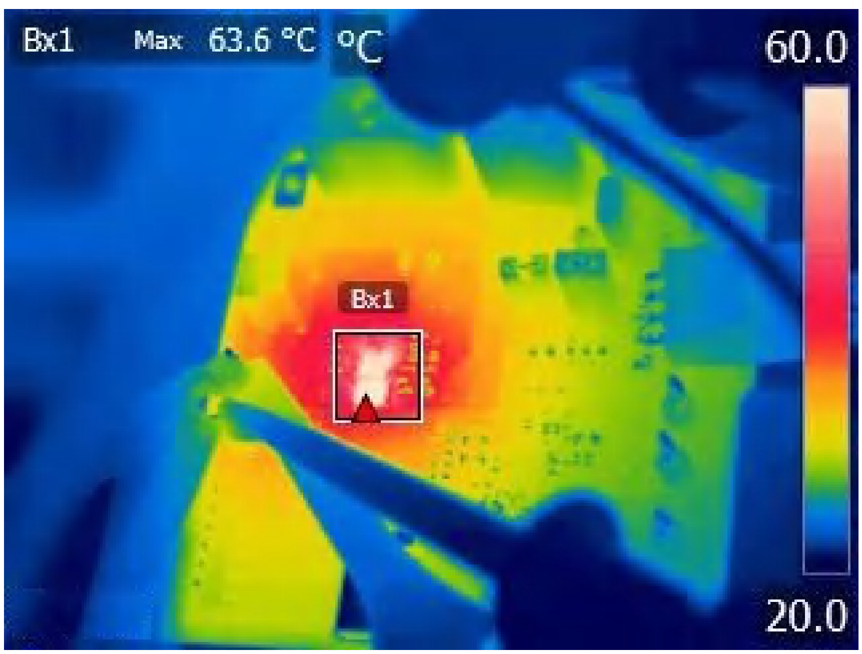


Figure 2-4. Thermal Image: VBUS = 9V, VBAT = VSYS = 4.2V, ISYS = 0A, ICHG = 3A, 20 mins, Bx1 = U2

Thermal image when charge is enabled is shown in Figure 2-5.

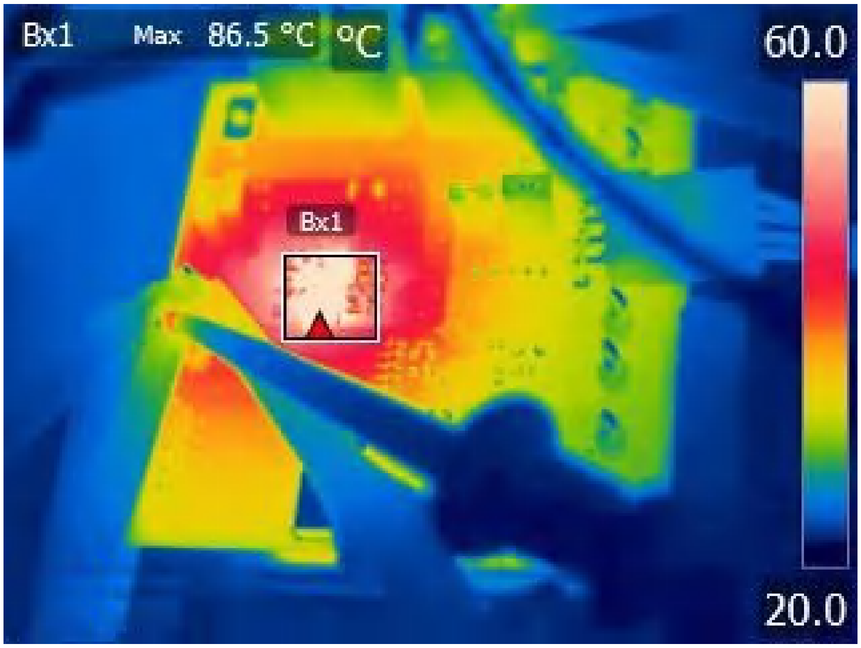


Figure 2-5. Thermal Image: VBUS = 9V, VBAT = VSYS = 4.2V, ISYS = 3.5A, ICHG = 0.5A, 20 mins, Bx1 = U2

3 Waveforms

3.1 Switching

Switching behavior is shown in Figure 3-1.

VBUS = 9V, VSYS = 3.75V, ISYS = 3A

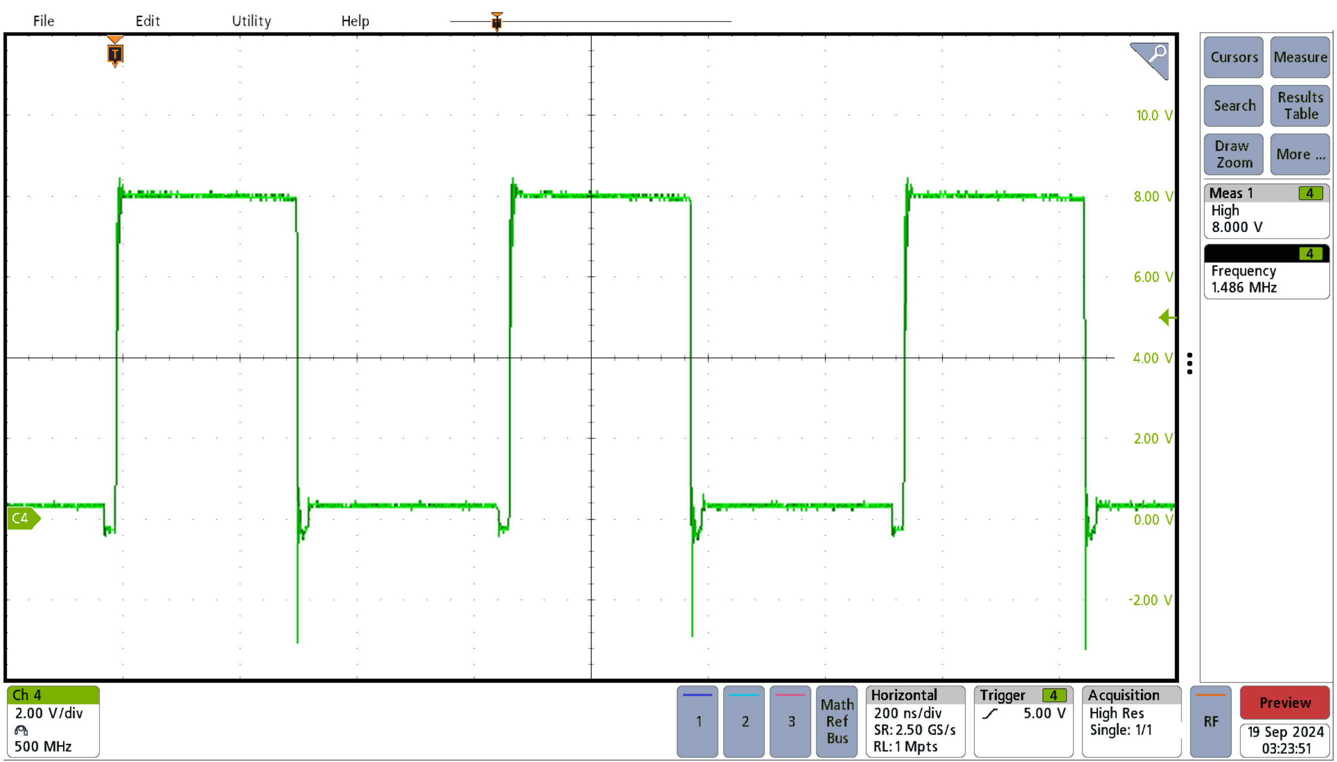


Figure 3-1. Switching

3.2 Output Voltage Ripple

Output voltage ripple is shown in Figure 3-2 and Figure 3-3, where VSYS equals 3.75V and ISYS equals 3A. Note that the oscillations in the output voltage ripple are inherent to the BQ25638 and the small inductor value. The device outputs a 3.75VDC within reason.

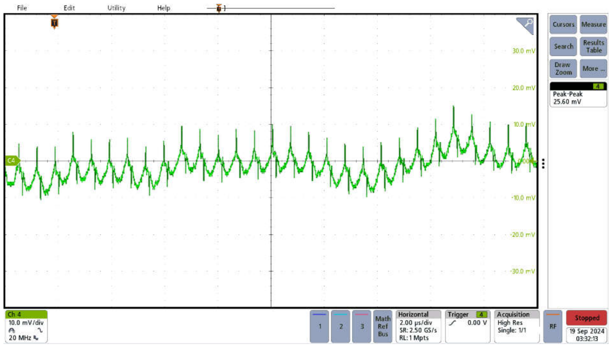


Figure 3-2. Output Voltage Ripple at VBUS = 5V

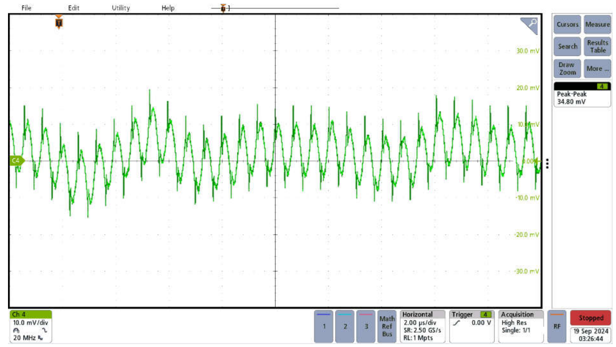


Figure 3-3. Output Voltage Ripple at VBUS = 9V

3.3 Load Transients

Load transient response is shown in Figure 3-4 and Figure 3-5.

VBUS = 9V, VSYS = 3.75V

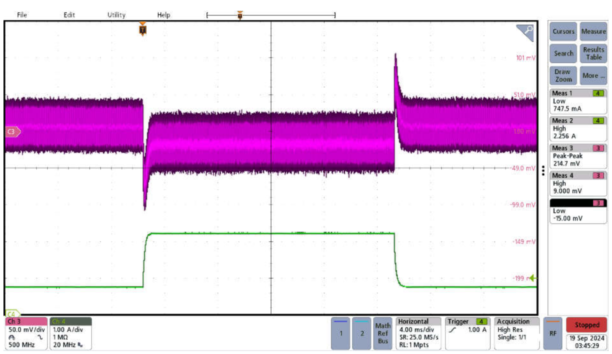


Figure 3-4. Load Transient From ISYS = 0.75A to 2.25A (25% to 75% load)

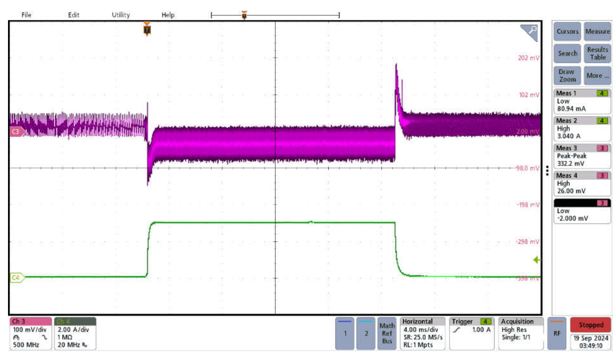


Figure 3-5. Load Transient From ISYS = 0A to 3A (0% to 100% load)

3.4 Start-up Sequence

Start-up behavior is shown in Figure 3-6 through Figure 3-9. Note that in the *dead battery scenario*, there is no battery connected to VBAT, and VSYS starts from 0V. This is a less realistic scenario compared to the *low battery scenario*, where there is a battery simulator connected to VBAT and set to 3.6V, where VSYS starts from.

In Figure 3-6, there is a soft-start ramp from 0V to about 2V resulting from a pull up in the connected EV2400. This behavior is not relevant in a real-world application. Step 1 in VSYS is due to the buck converter turning on and VSYS ramping up to default 3.75V. Step 2 is when the battery is connected to the system, and VSYS rises about VBAT. Step 3 is when charge starts resulting in a small change in VSYS. This is similar to the behavior shown in Figure 3-8, where VSYS jumps from 3.6V to 3.75V and starts to rise to VBAT.

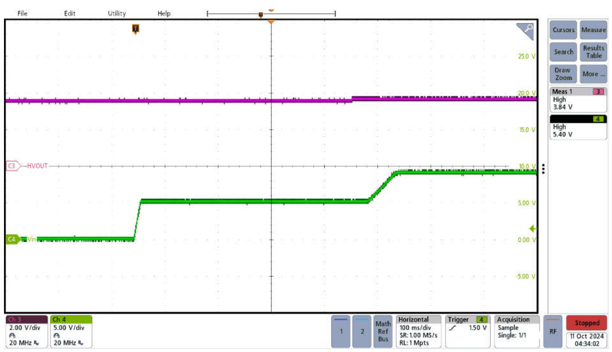


Figure 3-8. Start-Up With Charge Disabled, VBUS = 9V, VSYS = 3.75V, No Load, Low Battery Scenario

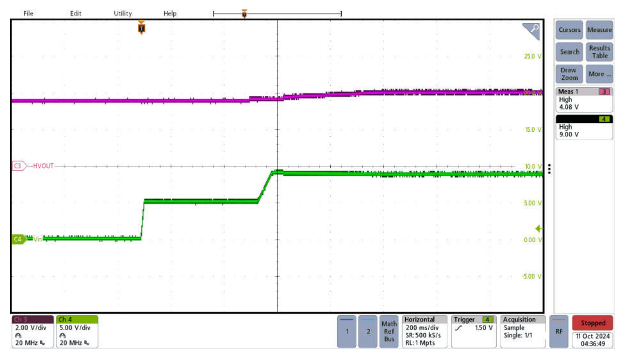


Figure 3-9. Start-Up With Charge Enabled, VBUS = 9V, VSYS = VBAT = 4.2V, No Load, Low Battery Scenario.