Test Report: PMP22648

High-Power Density Reference Design for Automotive Vehicle-to-Everything (V2X) Power

1 Description

This reference design provides the system rails for automotive vehicle-to-everything power. A 5-V bus is generated by the off-battery buck converter (LM63625-Q1), and this supplies all the point-of-load devices. The bus converter switches at 2.1 MHz, and the load converters (TPS628501-Q1) switch at 2.2 MHz. Easily-configurable jumpers allow users to enable and disable each device on the board and toggle the bus converter operational modes. A front-end EMI filter is included.

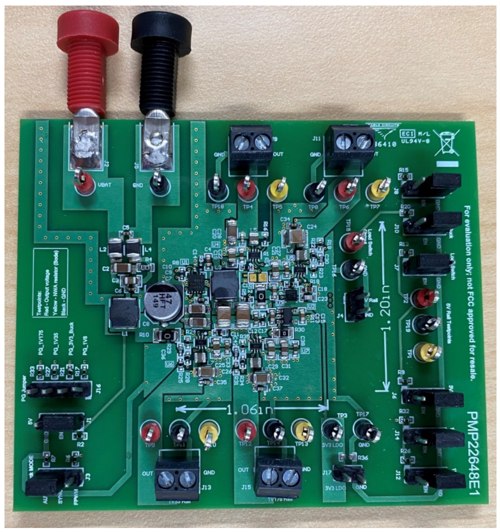


Figure 1-1. Board Top

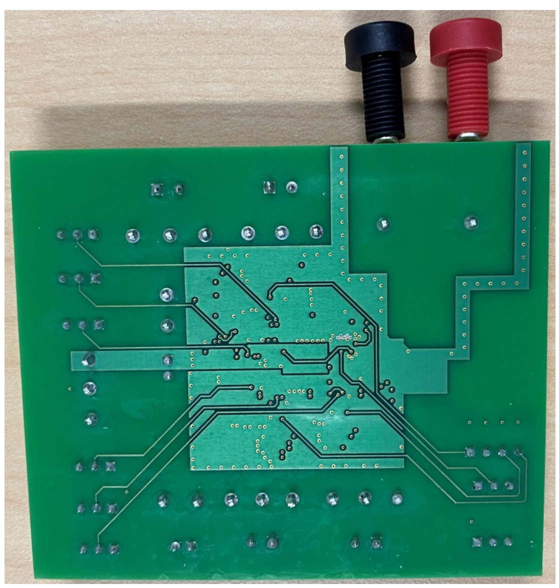


Figure 1-2. Board Bottom

2 Test Prerequisites

2.1 Voltage and Current Requirements

Table 2-1. Voltage and Current Requirements for 5-V Output (DC/DC)

PARAMETER	SPECIFICATIONS
Input Voltage	6 to 16 V (13.5 V nominal)
Output Voltage	5 V
Output Current	2.4 A
Switching Frequency	2.1 MHz

Table 2-2. Voltage and Current Requirements for 3.3-V Output (DC/DC)

PARAMETER	SPECIFICATIONS
Input Voltage	5 V
Output Voltage	3.3 V
Output Current	0.2 A
Switching Frequency	2.2 MHz

Table 2-3. Voltage and Current Requirements for 1.8-V Output (DC/DC)

PARAMETER	SPECIFICATIONS
Input Voltage	5 V
Output Voltage	1.8 V
Output Current	0.3 A
Switching Frequency	2.2 MHz

Table 2-4. Voltage and Current Requirements for 1.35-V Output (DC/DC)

PARAMETER	SPECIFICATIONS
Input Voltage	5 V
Output Voltage	1.35 V
Output Current	0.2 A
Switching Frequency	2.2 MHz

Table 2-5. Voltage and Current Requirements for 1.175-V Output (DC/DC)

PARAMETER	SPECIFICATIONS
Input Voltage	5 V
Output Voltage	1.175 V
Output Current	2 A
Switching Frequency	2.2 MHz

Table 2-6. Voltage and Current Requirements for 3.3-V Output (LDO)

PARAMETER	SPECIFICATIONS
Input Voltage	5 V
Output Voltage	3.3 V
Output Current	10 mA
Switching Frequency	N/A

2.2 Considerations

Unless stated otherwise, tests were performed with a 13.5-V input. The input supply was connected to the input of the EMI filter (instead of being directly connected to the input of the converter). For all tests, an electronic load was used, unless stated otherwise.

2.3 Dimensions

The board dimensions are 2.75 in × 3.30 in. The solution size dimensions are 1.20 in × 1.06 in.

3 Testing and Results

3.1 Efficiency Graphs

Efficiency was taken with the converter operating with 13.5-V input, 5-V output. The input supply was connected directly at the input of the converter. All other converters on the board were disabled. Peak efficiency is over 91%.

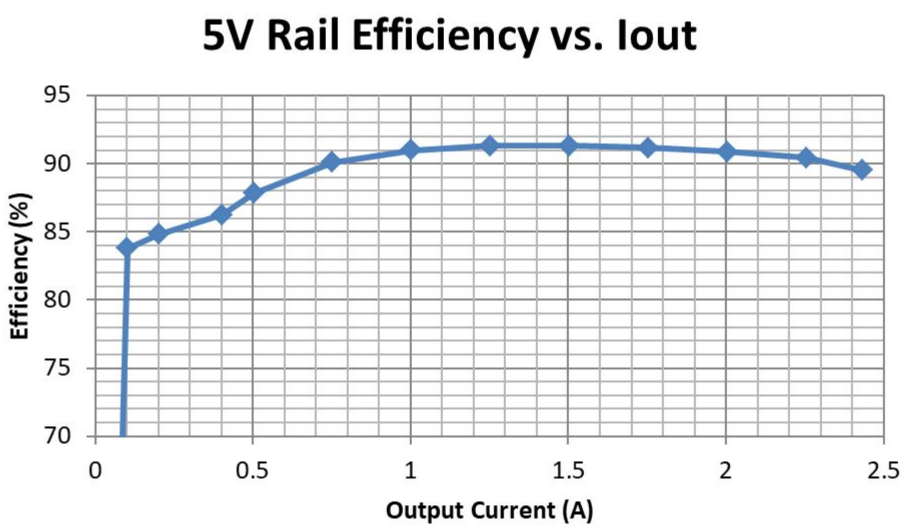


Figure 3-1. Efficiency vs I_{OUT} (5-V Output)

Efficiency was taken with the converter operating with 5-V input, 3.3-V output. The input supply was connected directly at the input of the converter. All other converters on the board were disabled. Peak efficiency is over 90%.

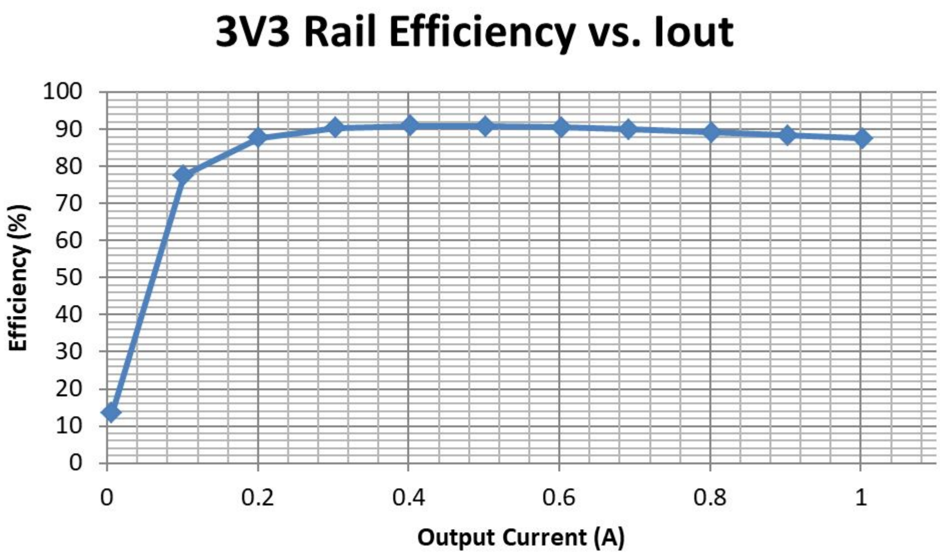


Figure 3-2. Efficiency vs I_{OUT} (3.3-V Output – DC/DC)

Efficiency was taken with the converter operating with 5-V input, 1.8-V output. The input supply was connected directly at the input of the converter. All other converters on the board were disabled. Peak efficiency is over 89%.

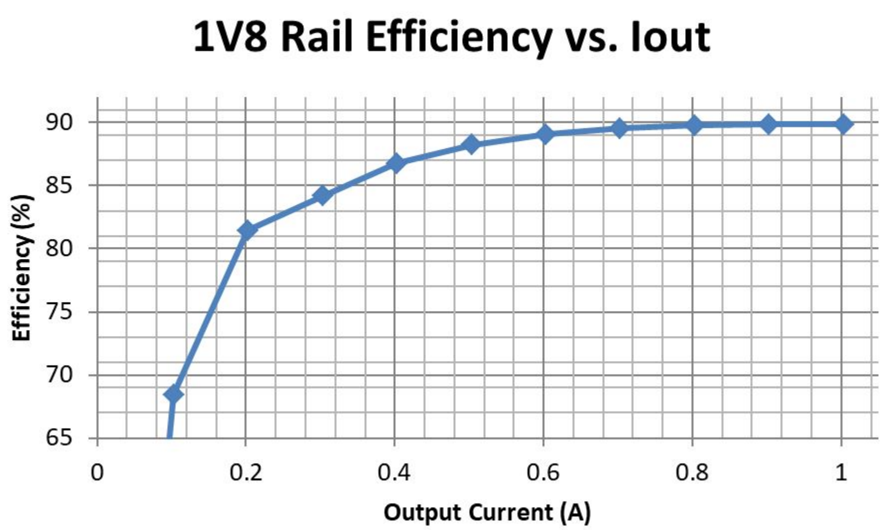


Figure 3-3. Efficiency vs I_{OUT} (1.8-V Output)

Efficiency was taken with the converter operating with 5-V input, 1.35-V output. The input supply was connected directly at the input of the converter. All other converters on the board were disabled. Peak efficiency is over 88%.

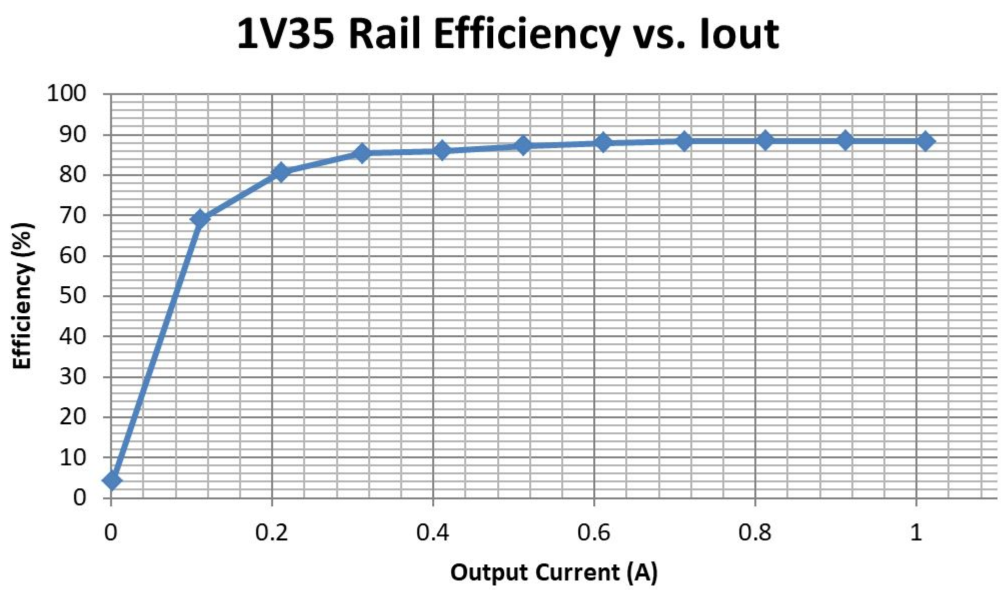


Figure 3-4. Efficiency vs I_{OUT} (1.35-V Output)

Efficiency was taken with the converter operating with 5-V input, 1.175-V output. The input supply was connected directly at the input of the converter. All other converters on the board were disabled. Peak efficiency is over 86%.

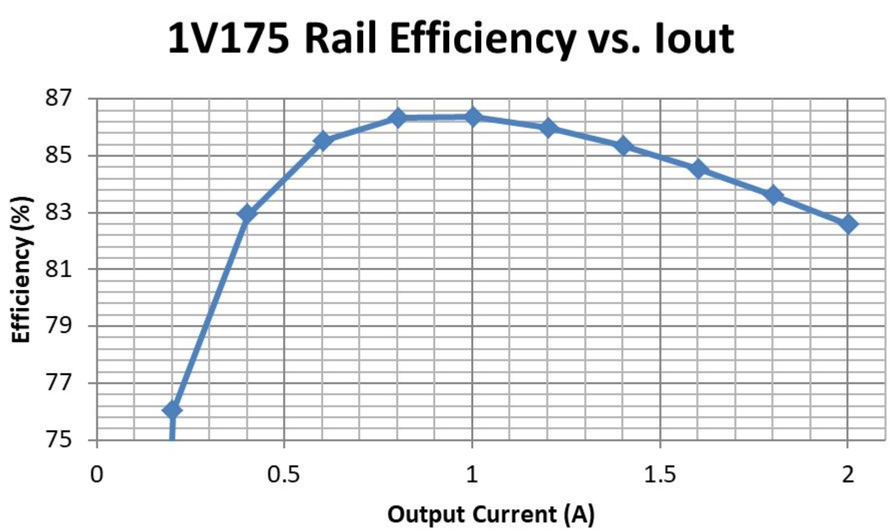


Figure 3-5. Efficiency vs I_{OUT} (1.175-V Output)

3.2 Efficiency Data

Efficiency data is shown in the following tables.

Table 3-1. Efficiency Raw Data (5-V Output)

V_{IN} (V)	Iin (A)	Vout (V)	Iout (A)	Pin (W)	Pout (W)	Efficiency	Efficiency (%)
13.503	0.0000302	5.03751	0.0097	0.000408	0.048864	0.04204	4.204027
13.248	0.046132	5.0103	0.102234	0.611157	0.512223	0.838121	83.81205
12.993	0.091725	4.99825	0.20226	1.191783	1.010946	0.848264	84.82636
13.407	0.17367	4.99017	0.40255	2.328394	2.008793	0.862738	86.27377
13.386	0.213298	4.98947	0.5027	2.855207	2.508207	0.878467	87.84675
13.332	0.31253	4.98797	0.75274	4.16665	3.754645	0.901118	90.11183
13.276	0.41397	4.98635	1.00282	5.495866	5.000412	0.90985	90.98497
13.219	0.51744	4.98481	1.2529	6.840039	6.245468	0.913075	91.30749
13.161	0.62307	4.98342	1.5029	8.200224	7.489582	0.913339	**91.33387**
13.101	0.73125	4.98205	1.7532	9.580106	8.73453	0.911736	91.17362
13.04	0.84219	4.98071	2.0035	10.98216	9.978852	0.908642	90.86423
12.976	0.9562	4.97935	2.2533	12.40765	11.21997	0.904278	90.42783
12.926	1.047	4.97823	2.4336	13.53352	12.11502	0.895186	89.51861

Table 3-2. Efficiency Raw Data (3.3-V Output)

Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (W)	Pout (W)	Efficiency	Efficiency (%)
5.037	0.014756	3.32044	0.006	0.074326	0.019923	0.268044	13.45425
5.0211	0.086783	3.31939	0.101925	0.435746	0.338329	0.776436	77.64357
5.0074	0.15183	3.31823	0.20102	0.760274	0.667031	0.877356	87.73561
5.0016	0.22187	3.31695	0.30247	1.109705	1.003278	0.904094	90.40942
4.9925	0.2938	3.31577	0.40243	1.466797	1.334365	0.909714	**90.9714**
4.9894	0.36729	3.31463	0.50234	1.832557	1.665071	0.908606	90.86056
4.9861	0.44253	3.31364	0.60258	2.206499	1.996733	0.904933	90.49328
4.9831	0.51155	3.31259	0.69244	2.549105	2.29377	0.899833	89.98335
4.9792	0.59828	3.31143	0.80261	2.978956	2.657787	0.892187	89.21874
4.9757	0.67936	3.31032	0.90271	3.380292	2.988259	0.884024	88.4024
4.972	0.7623	3.3092	1.00235	3.790156	3.316977	0.875156	87.51558

Table 3-3. Efficiency Raw Data (1.8-V Output)

Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (W)	Pout (W)	Efficiency	Efficiency (%)
4.9117	0.018022	1.79348	0.0031	0.088519	0.00556	0.062809	6.280922
4.6946	0.057267	1.7924	0.10266	0.268846	0.184008	0.684437	68.44365
4.4559	0.100045	1.79132	0.20266	0.445791	0.363029	0.814349	81.43487
4.9403	0.13039	1.79022	0.30287	0.644166	0.542204	0.841715	84.1715
4.9194	0.16885	1.78913	0.40285	0.830641	0.720751	0.867705	86.77049
4.898	0.20816	1.78812	0.50302	1.019568	0.89946	0.882198	88.21976
4.8761	0.24826	1.78699	0.60334	1.210541	1.078163	0.890646	89.06455
4.854	0.28895	1.78595	0.70309	1.402563	1.255684	0.895278	89.52777
4.8313	0.33049	1.78488	0.80321	1.596696	1.433633	0.897875	89.78748
4.8082	0.37288	1.78379	0.90325	1.792882	1.611208	0.89867	**89.86697**
4.7847	0.41589	1.78277	1.00299	1.989909	1.7881	0.898584	89.85841

Table 3-4. Efficiency vs I_{OUT} (1.35-V Output)

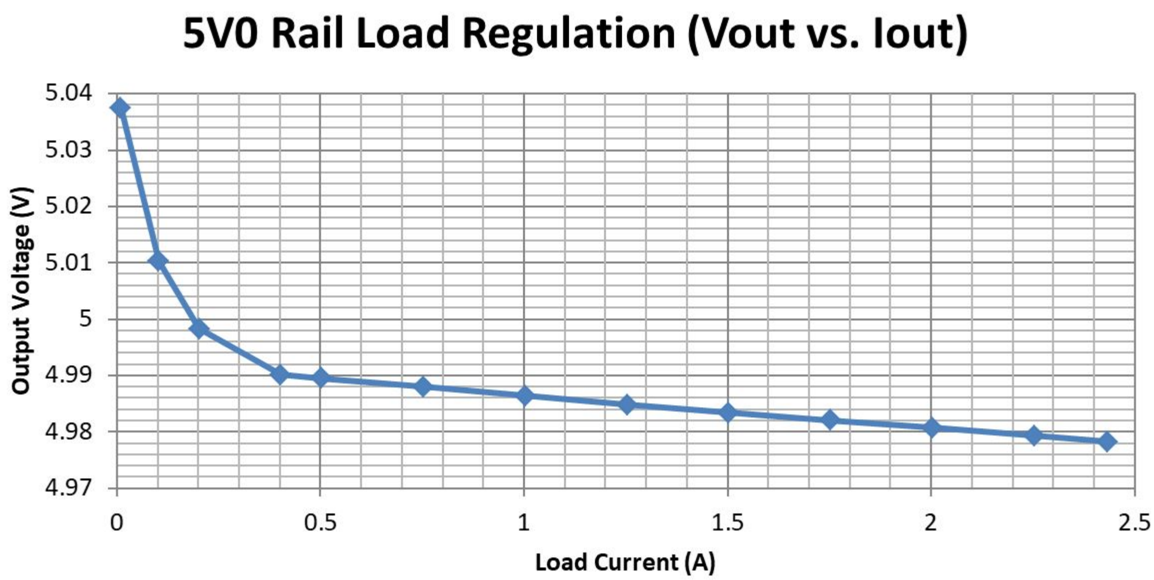
Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (W)	Pout (W)	Efficiency	Efficiency (%)
4.9341	0.013965	1.3641	0.0022	0.068905	0.003001	0.043553	4.355319
4.7559	0.046222	1.36308	0.111264	0.219827	0.151662	0.689913	68.99134
4.5785	0.077938	1.36214	0.21133	0.356839	0.287861	0.806697	80.6697
4.383	0.11345	1.36123	0.31168	0.497251	0.424268	0.853227	85.32268
4.9394	0.13182	1.36031	0.41144	0.651112	0.559686	0.859585	85.95851
4.9227	0.162	1.35941	0.51179	0.797477	0.695732	0.872417	87.24165
4.9059	0.19268	1.35851	0.61174	0.945269	0.831055	0.879173	87.91731
4.8887	0.22385	1.35763	0.71173	1.094335	0.966266	0.882971	88.29705
4.8711	0.25571	1.35676	0.81232	1.245589	1.102123	0.884821	**88.4821**
4.8533	0.28792	1.35583	0.91182	1.397362	1.236273	0.884719	88.47191
4.8352	0.32088	1.35496	1.01175	1.551519	1.370881	0.883573	88.35733

Table 3-5. Efficiency Raw Data (1.175-V Output)

Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (W)	Pout (W)	Efficiency	Efficiency (%)
4.9272	0.015235	1.192374	0.0016	0.075066	0.001908	0.025415	2.541498
4.6321	0.068488	1.189767	0.20269	0.317243	0.241154	0.760154	76.01544
4.9479	0.11662	1.18721	0.40306	0.577024	0.478517	0.829284	82.9284
4.9189	0.16994	1.184679	0.60346	0.835918	0.714906	0.855235	85.52352
4.889	0.22502	1.18216	0.80343	1.100123	0.949783	0.863343	86.33426
4.858	0.28209	1.179615	1.00337	1.370393	1.18359	0.863687	**86.36866**
4.8257	0.34137	1.177089	1.2032	1.647349	1.416273	0.859729	85.97288
4.7908	0.4032	1.174562	1.4034	1.931651	1.64838	0.853353	85.33533
4.7557	0.46752	1.172023	1.6037	2.223385	1.879573	0.845366	84.53657
4.719	0.53479	1.169419	1.804	2.523674	2.109632	0.835937	83.59368
4.6804	0.60502	1.16685	2.0041	2.831736	2.338484	0.825813	82.5813

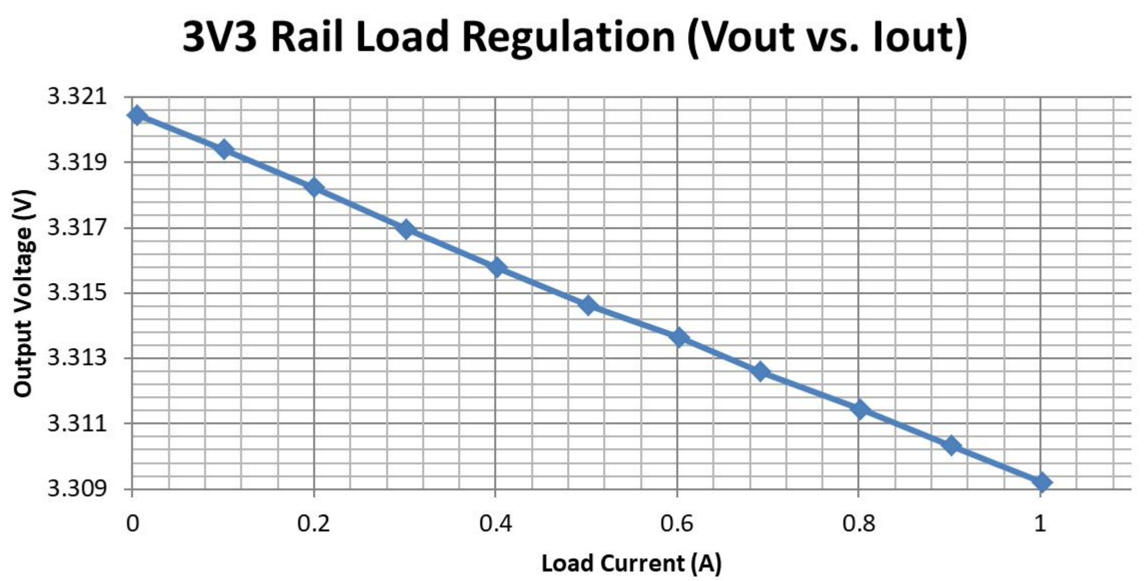
3.3 Load Regulation

Load regulation data was extracted from the efficiency measurements.



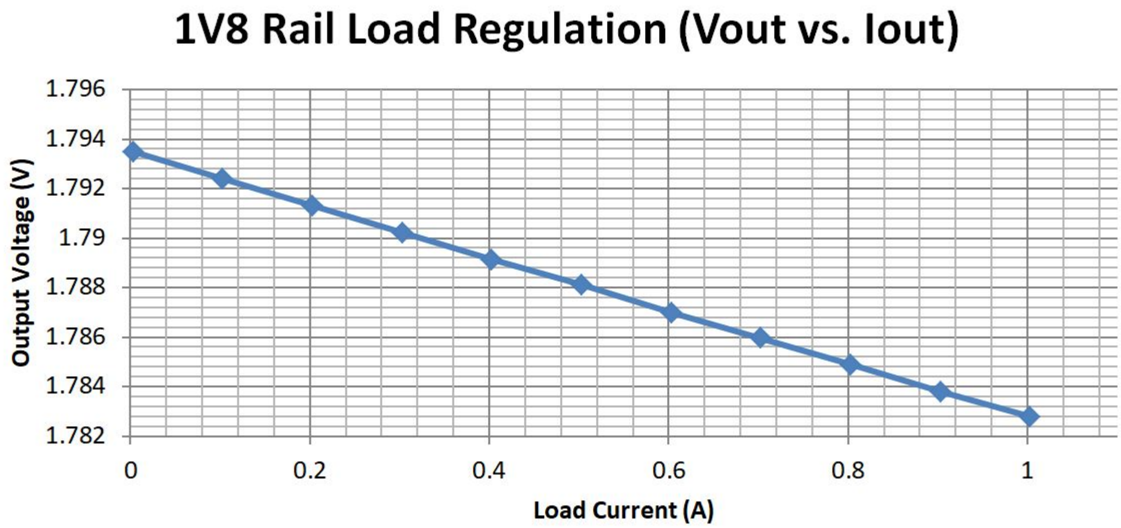
The output voltage is regulated to within 0.76% of the nominal 5 V.

Figure 3-6. Output Voltage vs I_{OUT} (5-V Output)



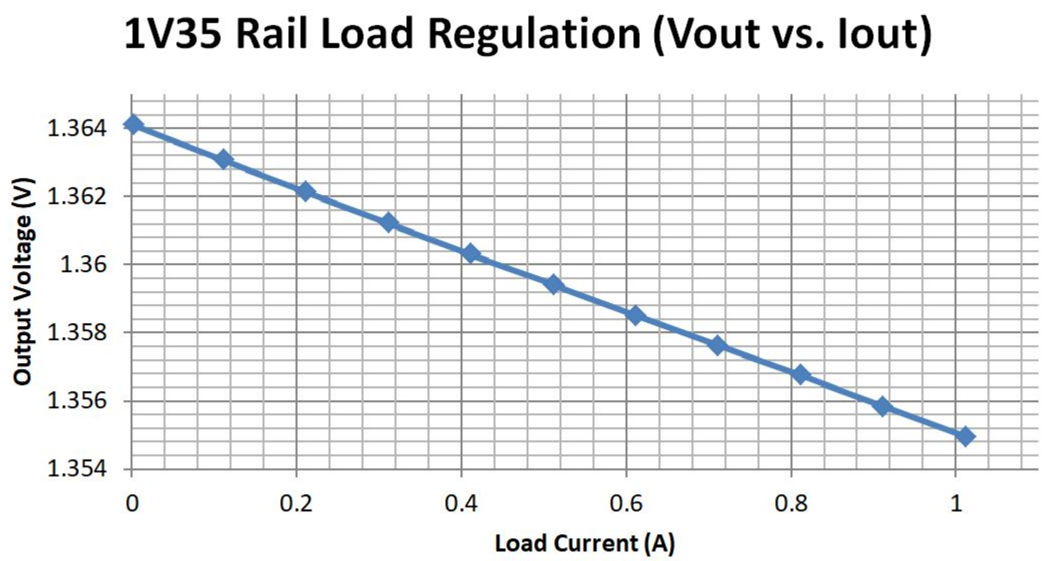
The output voltage is regulated to within 0.62% of the nominal 3.3 V.

Figure 3-7. Output Voltage vs I_{OUT} (3.3-V Output)



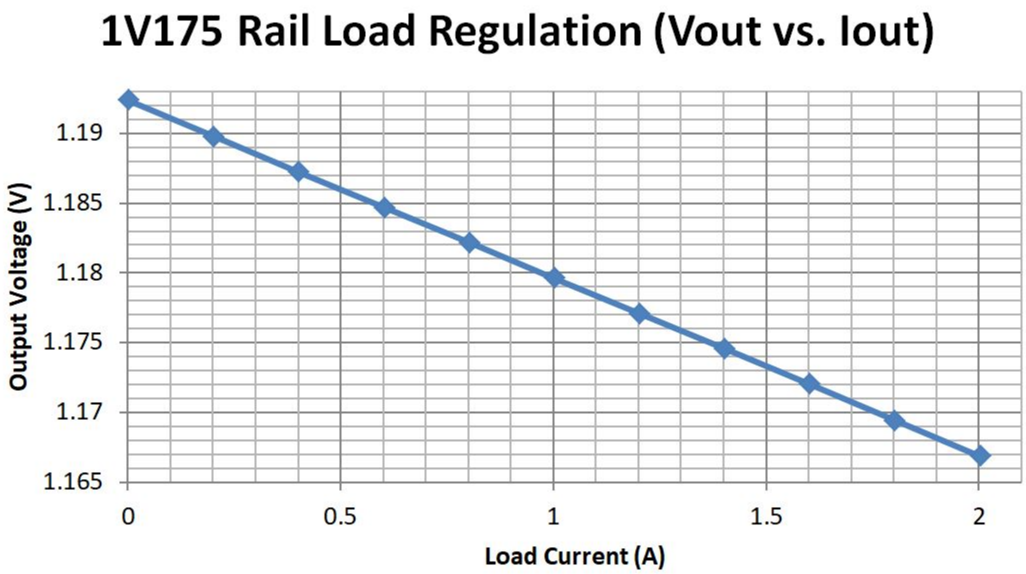
The output voltage is regulated to within 0.96% of the nominal 1.8 V.

Figure 3-8. Output Voltage vs I_{OUT} (1.8-V Output)



The output voltage is regulated to within 1.04% of the nominal 1.35 V.

Figure 3-9. Output Voltage vs I_{OUT} (1.35-V Output)



The output voltage is regulated to within 1.48% of the nominal 1.175 V.

Figure 3-10. Output Voltage vs. IOUT (1.175-V Output)

3.4 Thermal Image

The thermal image (with no airflow) was taken with all rails enabled and loaded to their maximum loads. Power resistors were soldered onto the 3V3 LDO, 1V8, 3V3 buck, and 1V35 rails for their loads, and the 1V175 rail was loaded using an electronic load.

Note

Load each converter using their output testpoints and not the output terminal blocks. The testpoints cut into the plane that the current is traveling through, decreasing the effective area that the current is flowing through on the way to the load connector. If the converters are loaded using the terminal blocks, you may see inaccurate thermal results.

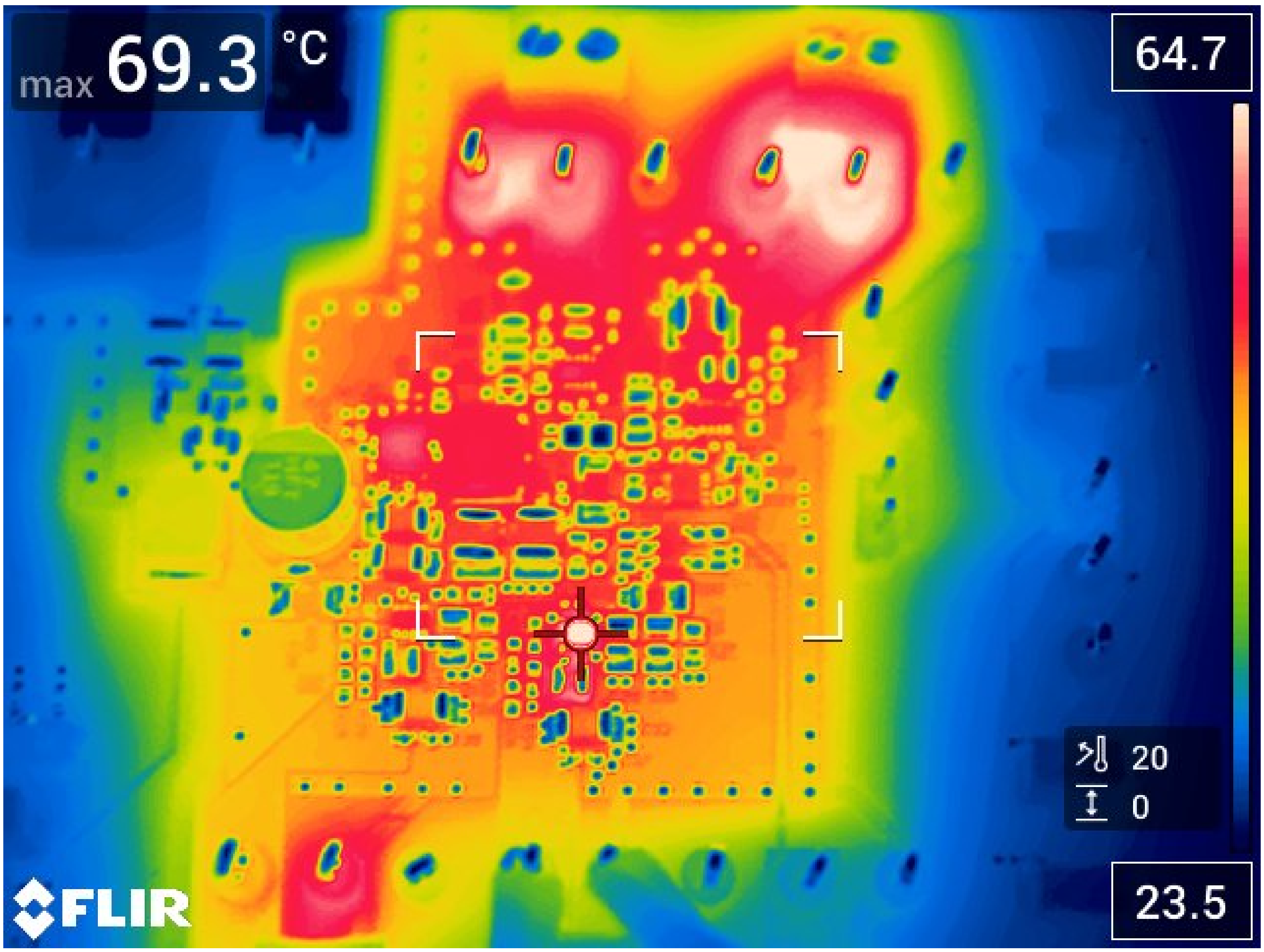
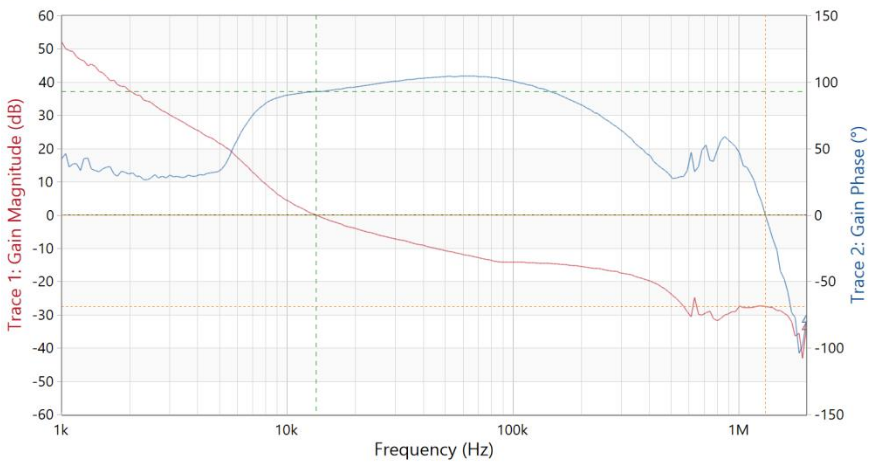


Figure 3-11. Board Top Thermal Image (V_{IN} = 13.5 V, All Rails at Maximum Load)

3.5 Bode Plots

Bode plots are shown in the following figures.

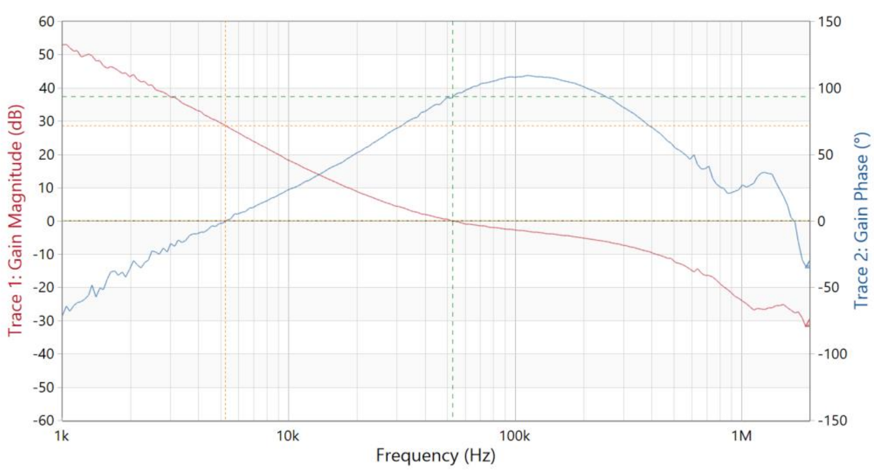
	Frequency	Trace 1	Trace 2
Cursor 1	13.446 kHz	0 dB	93.037 °
Cursor 2	1.313832 MHz	-27.454 dB	0 °
Delta C2-C1	1.300386 MHz	-27.454 dB	-93.037 °



V_{IN} = 13.5 V, V_{OUT} = 5 V, with a 2.43-A load current.
Phase Margin: 93.037 degrees, Gain Margin: –27.454 dB

Figure 3-12. 5-V Rail Bode Plot (V_{IN} = 13.5 V, I_{OUT} = 2.43 A)

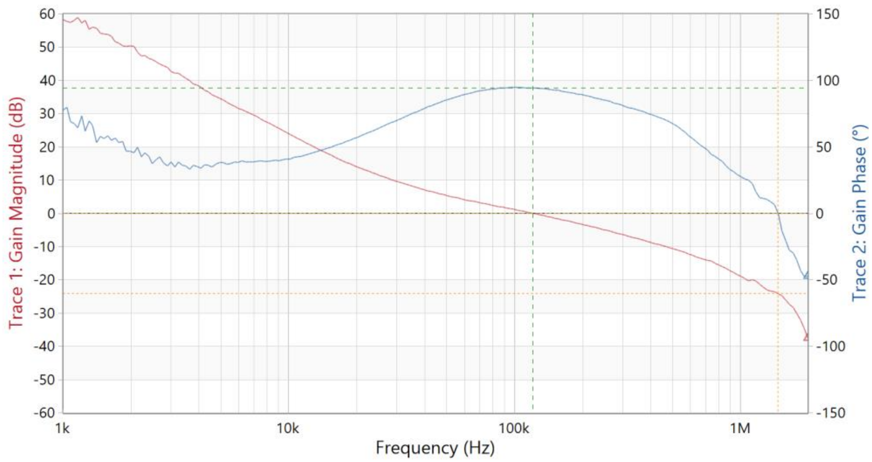
	Frequency	Trace 1	Trace 2
Cursor 1	53.204 kHz	0 dB	93.661 °
Cursor 2	5.255 kHz	28.757 dB	0 °
Delta C2-C1	-47.94943 kHz	28.757 dB	-93.661 °



V_{IN} = 5 V, V_{OUT} = 3.3 V, with a 0.18-A load current.
Phase Margin: 93.661 degrees, Gain Margin: –28.757 dB

Figure 3-13. 3.3-V Rail Bode Plot (V_{IN} = 5 V, I_{OUT} = 0.18 A)

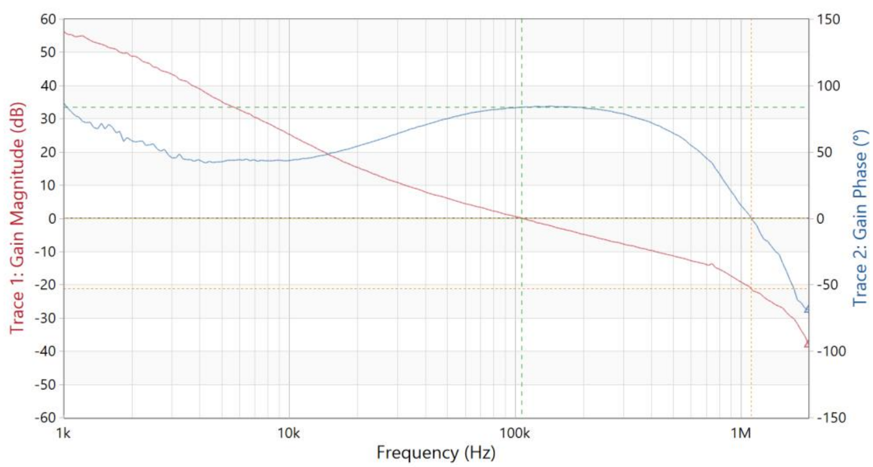
	Frequency	Trace 1	Trace 2
Cursor 1	121.053 kHz	0 dB	94.161 °
Cursor 2	1.470709 MHz	-24.116 dB	0 °
Delta C2-C1	1.349656 MHz	-24.116 dB	-94.161 °



V_{IN} = 5 V, V_{OUT} = 1.8 V, with a 0.28-A load current.
Phase Margin: 94.161 degrees, Gain Margin: 24.116 dB

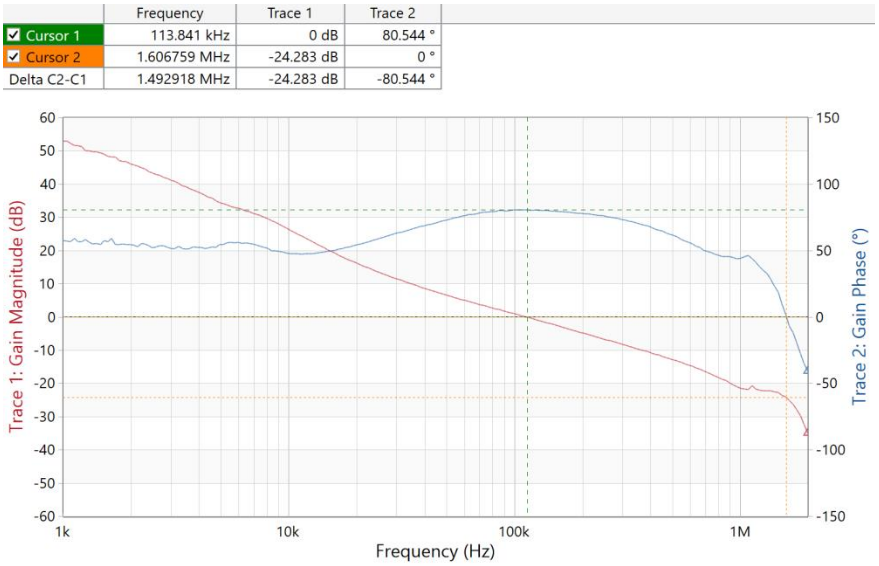
Figure 3-14. 1.8-V Rail Bode Plot (V_{IN} = 5 V, I_{OUT} = 0.28 A)

	Frequency	Trace 1	Trace 2
Cursor 1	107.203 kHz	0 dB	83.759 °
Cursor 2	1.113736 MHz	-21.223 dB	0 °
Delta C2-C1	1.006533 MHz	-21.223 dB	-83.759 °



V_{IN} = 5 V, V_{OUT} = 1.35 V, with a 0.22-A load current.
Phase Margin: 83.759 degrees, Gain Margin: 21.223 dB

Figure 3-15. 1.35-V Rail Bode Plot (V_{IN} = 5 V, I_{OUT} = 0.18 A)



V_{IN} = 5 V, V_{OUT} = 1.175 V, with a 2-A load current.
Phase Margin: 80.544 degrees, Gain Margin: 24.283 dB

Figure 3-16. 1.175-V Rail Bode Plot (V_{IN} = 5 V, I_{OUT} = 2 A)

3.6 Conducted Emissions Testing (CISPR 25, Class 5)

The test was carried out with all the rails loaded. The design passes CISPR 25 Class 5 with all the rails loaded. The frequency sweep is from 150 kHz to 108 MHz.

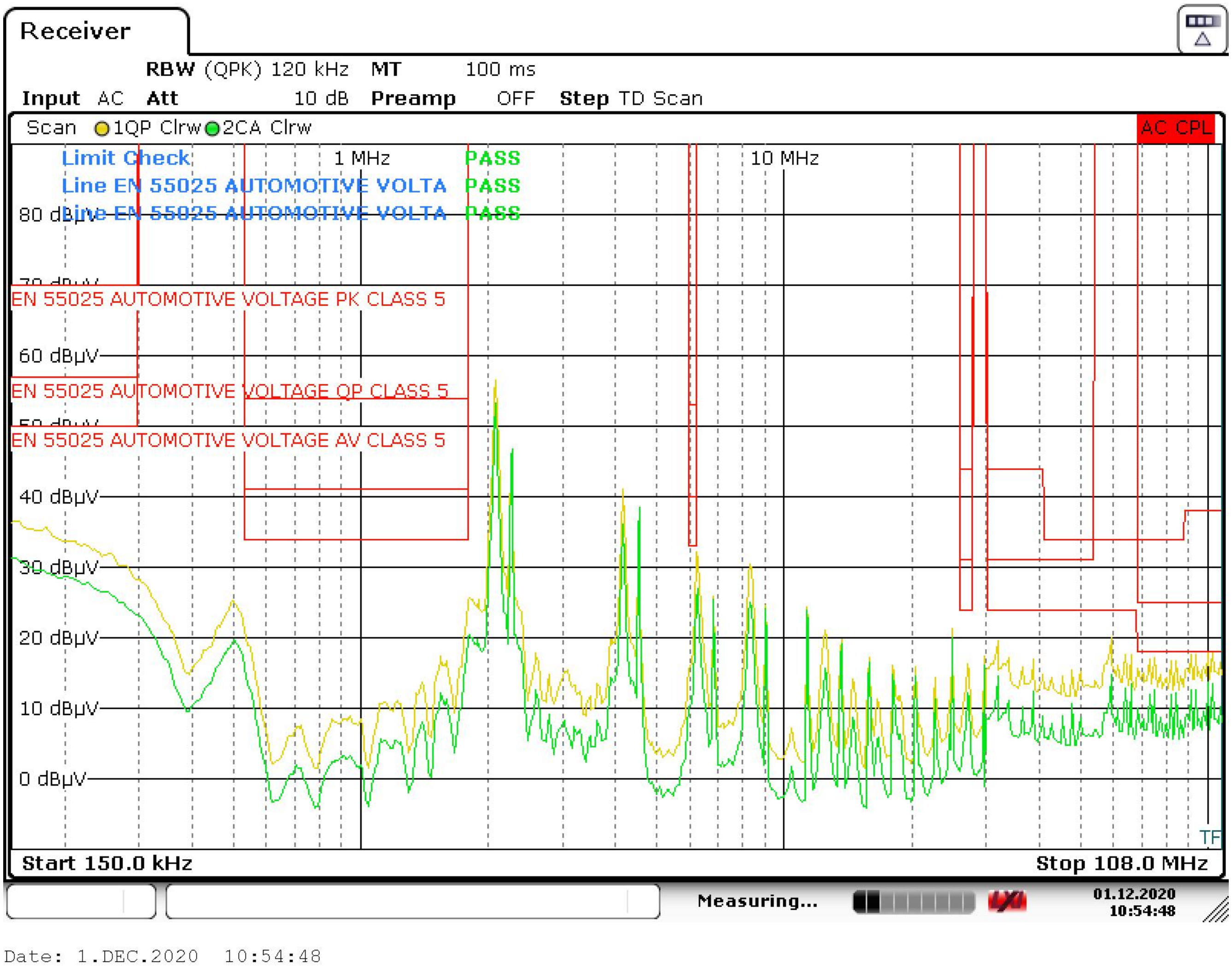


Figure 3-17. Conducted Emissions (CISPR25, Class 5) Results

4 Waveforms

4.1 Switching

The switch node measurements are shown in the follwing images. The board was supplied with 13.5 V_{IN} in all cases.

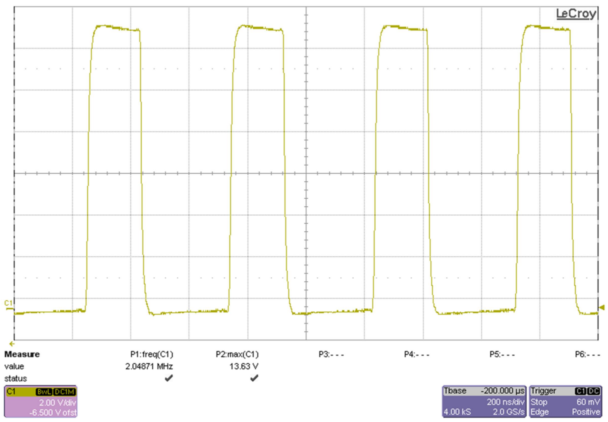


Figure 4-1. 5-V Rail Switch Node

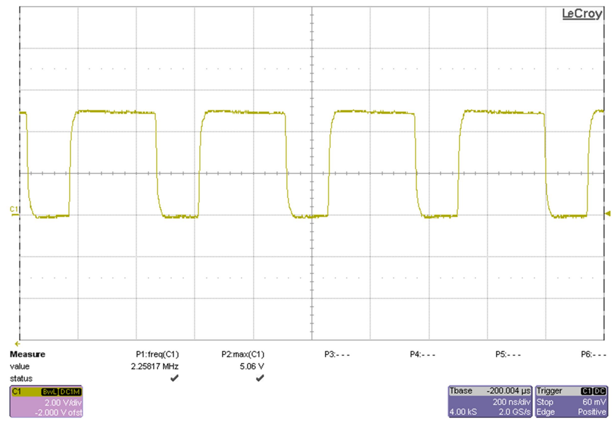


Figure 4-2. 3.3-V Rail Switch Node

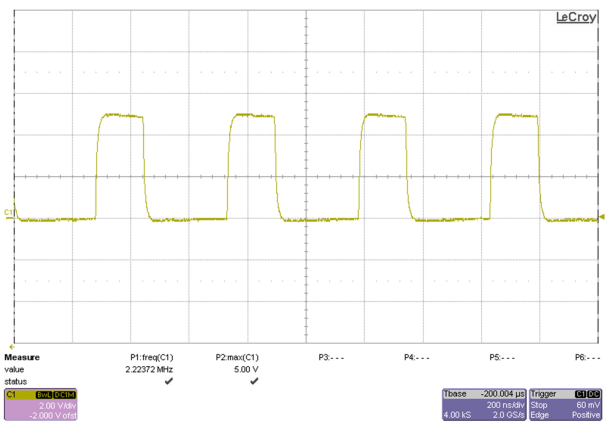


Figure 4-3. 1.8-V Rail Switch Node

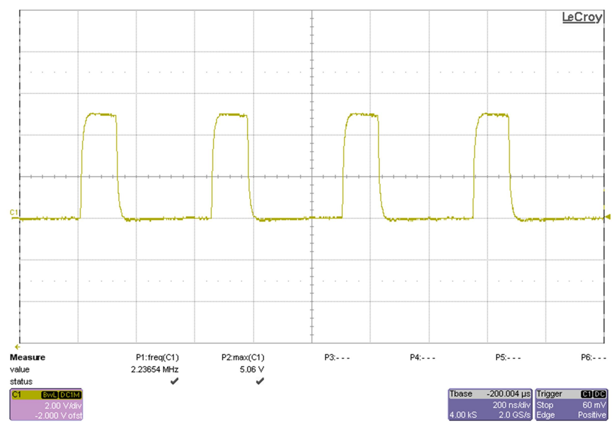


Figure 4-4. 1.35-V Rail Switch Node

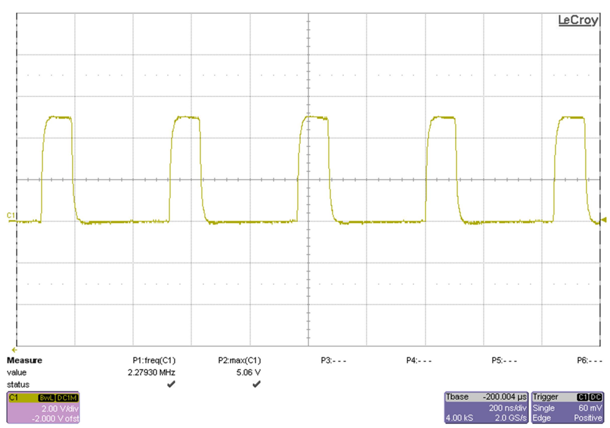


Figure 4-5. 1.175-V Rail Switch Node

4.2 Output Voltage Ripple

All converters are operating with an output ripple of 2% or less under full load.

Output ripple was measured at full load (2.43 A). The ripple is around 0.16% of the output voltage.

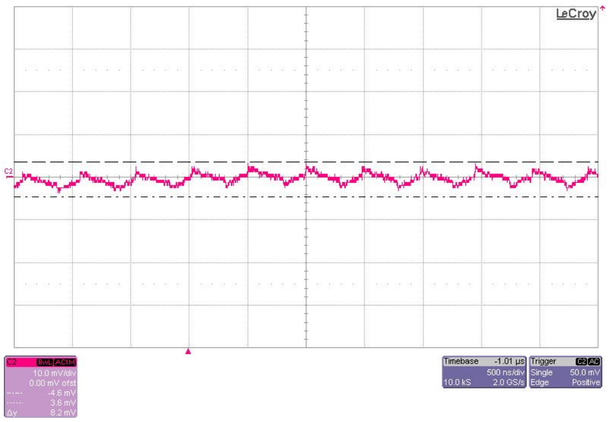


Figure 4-6. 5-V Rail Output Ripple (V_{IN} = 13.5 V, I_{OUT} = 2.43 A)

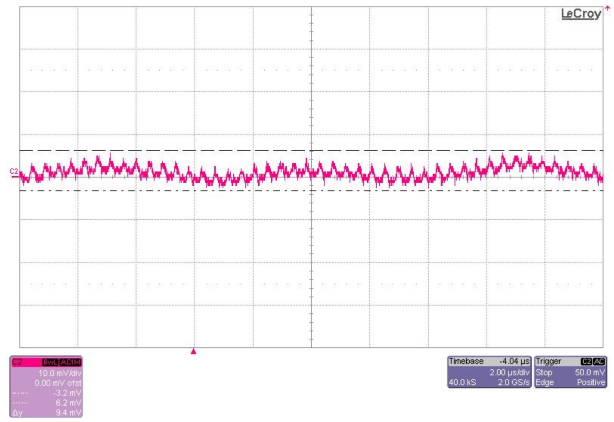


Figure 4-7. 3.3-V Rail Output Ripple (V_{IN} = 5 V, I_{OUT} = 0.18 A)

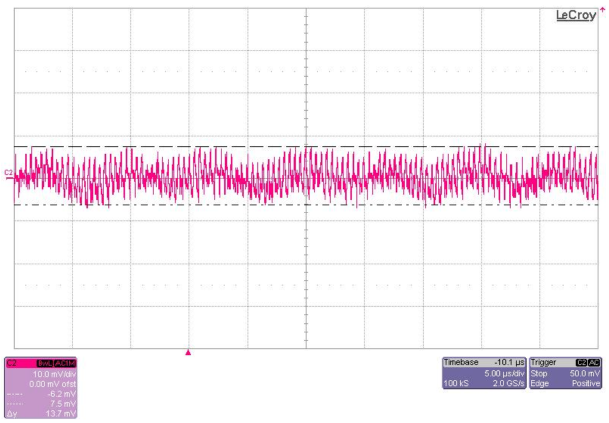


Figure 4-8. 1.8-V Rail Output Ripple (V_{IN} = 5 V, I_{OUT} = 0.28 A)

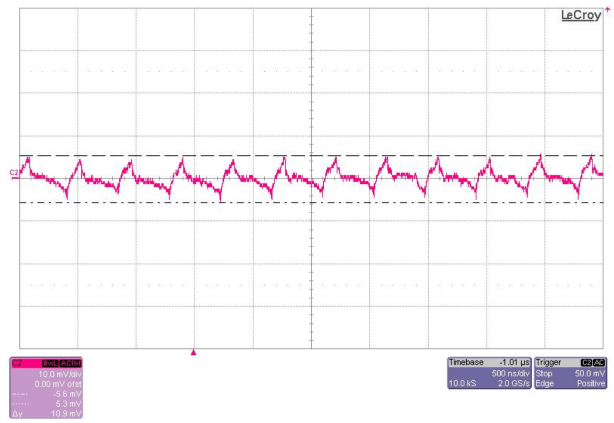


Figure 4-9. 1.35-V Rail Output Ripple (V_{IN} = 5 V, I_{OUT} = 0.22 A)

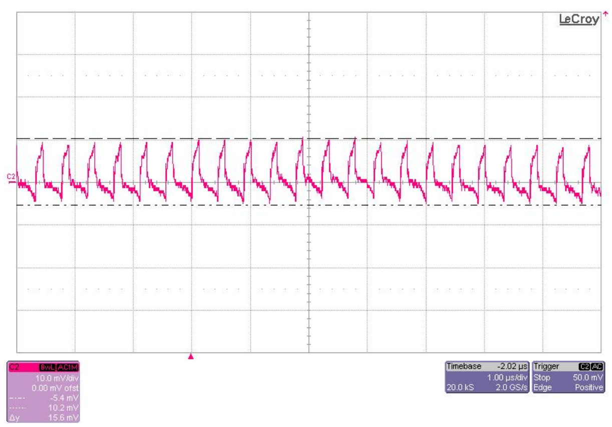


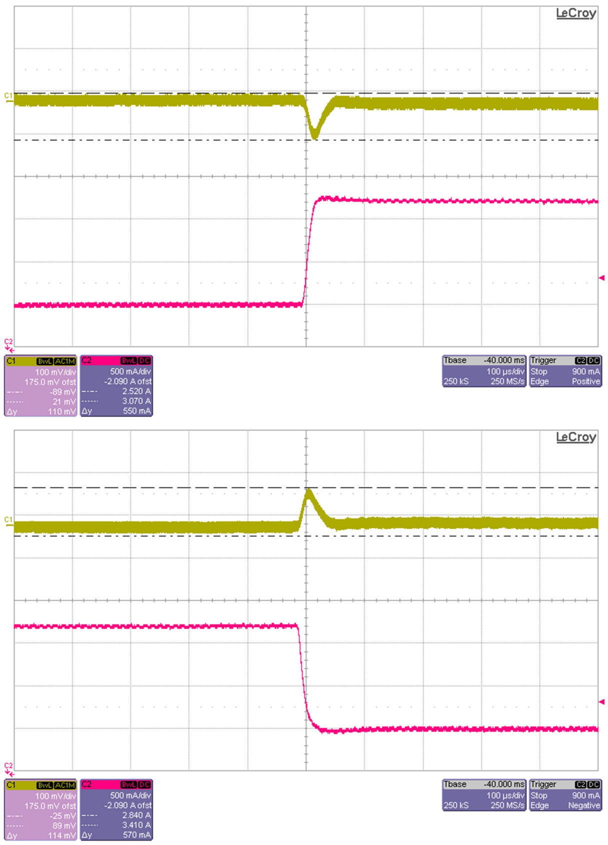
Figure 4-10. 1.175-V Rail Output Ripple (V_{IN} = 5 V, I_{OUT} = 2 A)

4.3 Load Transients

An electronic load was used for all testing.

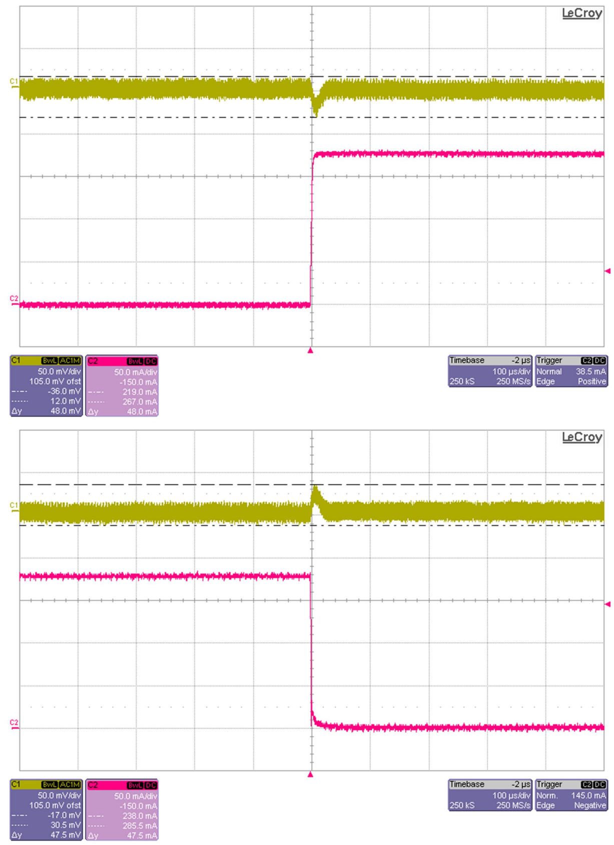
CH 1 (Pink trace) Load Current

CH 3 (Yellow trace): Output Voltage



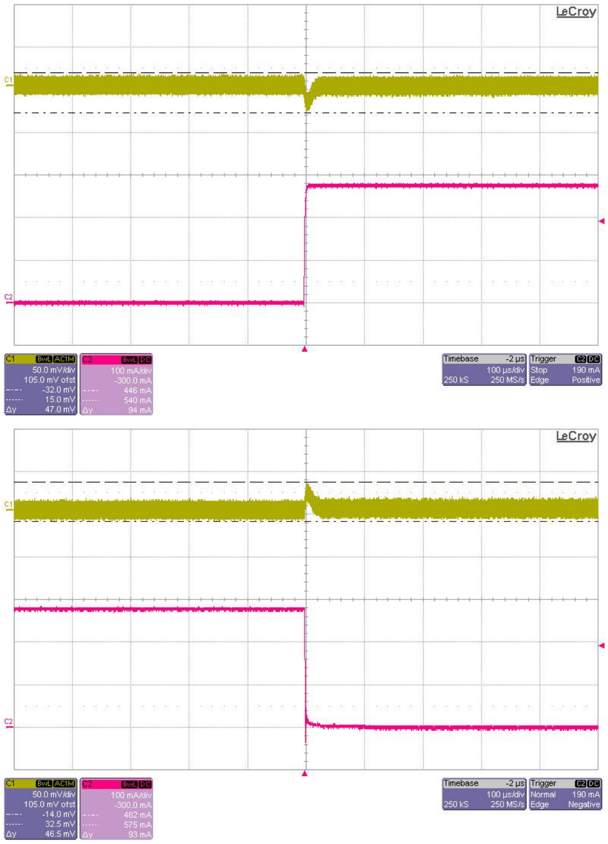
A 25% (0.61 A) to 75% (1.82 A) load step was run using an e-load with a 2.5 A/µs slew rate. The overshoot is 114 mV (2.28%), and the undershoot is 110 mV (2.20%).

Figure 4-11. Load Transient (V_{OUT} = 5 V, I_{OUT} = 0.61 A to 1.82 A)



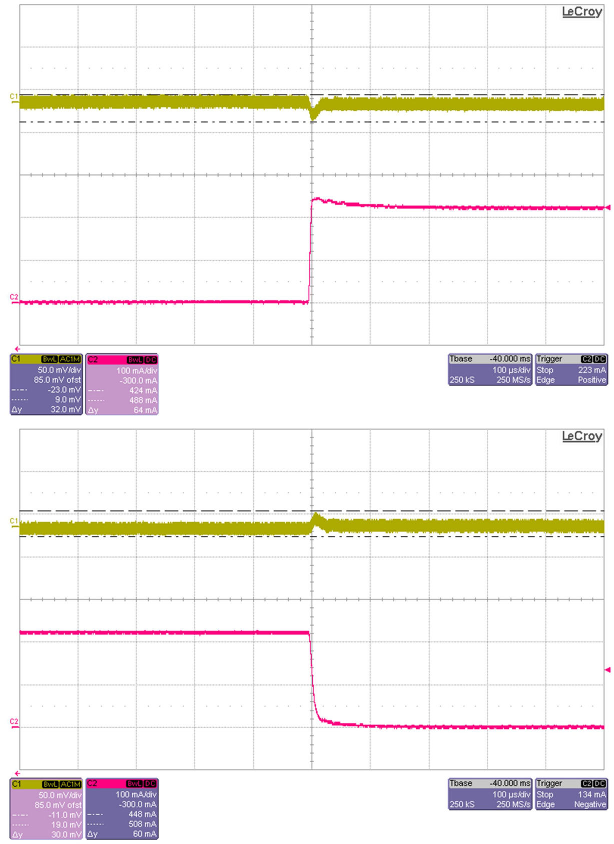
A 0% (0 A) to 100% (0.18 A) load step was run using an e-load with a 500 mA/us slew rate. The overshoot is 47.5 mV (1.44%), and the undershoot is 48 mV (1.45%).

Figure 4-12. Load Transient (V_{OUT} = 3.3 V, I_{OUT} = 0 A to 0.18 A)



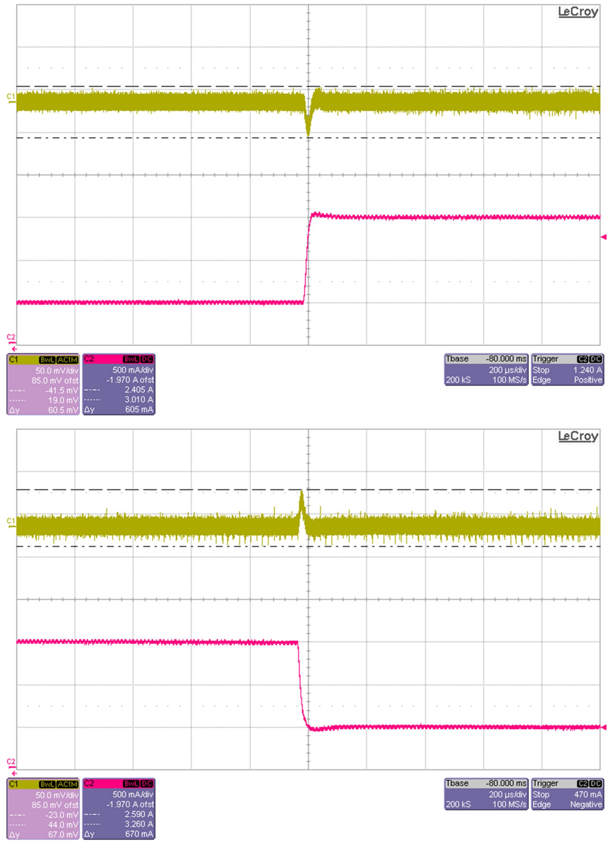
A 0% (0 A) to 100% (0.28 A) load step was run using an e-load with a 500 mA/µs slew rate. The overshoot is 46.5 mV (2.58%), and the undershoot is 47 mV (2.61%).

Figure 4-13. Load Transient (V_{OUT} = 1.8 V, I_{OUT} = 0 A to 0.28 A)



A 0% (0 A) to 100% (0.22 A) load step was run using an e-load with a 250 mA/µs slew rate. The overshoot is 30 mV (2.22%), and the undershoot is 32 mV (2.37%).

Figure 4-14. Load Transient (V_{OUT} = 1.35 V, I_{OUT} = 0 A to 0.22 A)



A 25% (0.5 A) to 75% (1.5 A) load step was run using an e-load with a 2.5 A/µs slew rate. The overshoot is 67 mV (5.70%), and the undershoot is 60.5 mV (5.15%).

Figure 4-15. Load Transient (V_{OUT} = 1.175 V, I_{OUT} = 0.5 A to 1.5 A)

4.4 Start-up Sequence

The following images show the start-up profiles of each converter. Smooth start-up is observed for each converter.

CH 2 (Pink trace) Input Voltage

CH 3 (Blue trace): Output Voltage

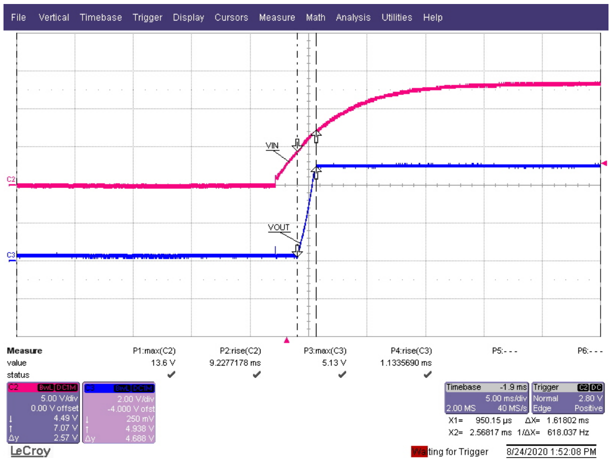


Figure 4-16. Start-up (V_{OUT} = 5 V)

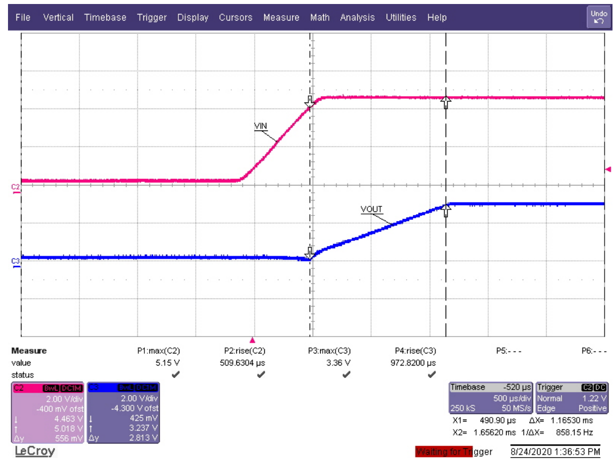


Figure 4-17. Start-up (V_{OUT} = 3.3 V)

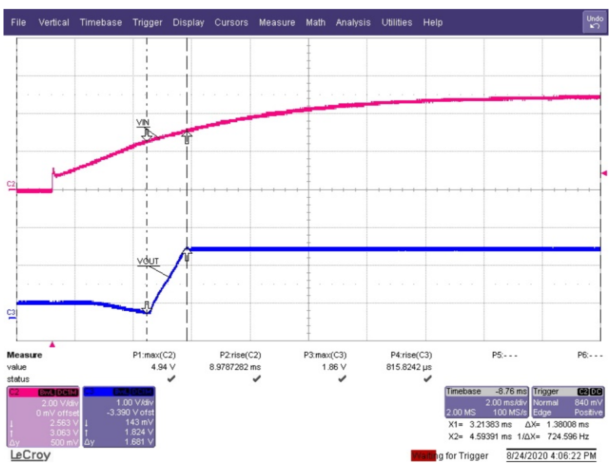


Figure 4-18. Start-up (V_{OUT} = 1.8 V)

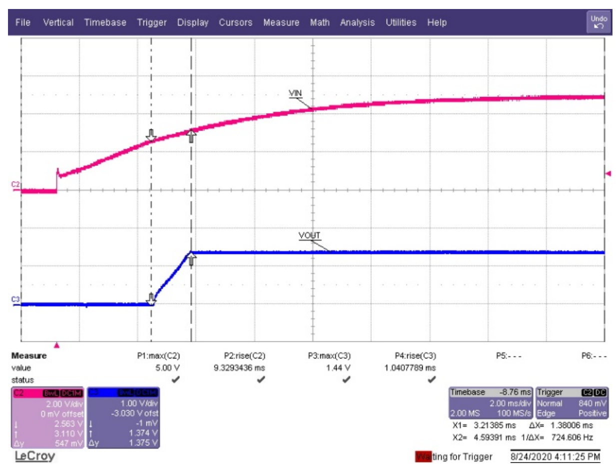


Figure 4-19. Start-up (V_{OUT} = 1.35 V)

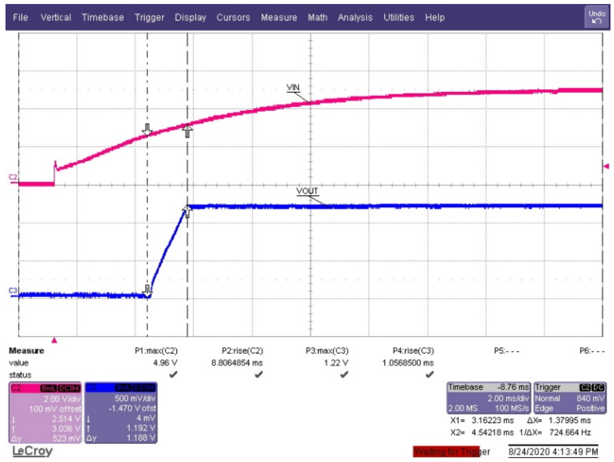


Figure 4-20. Start-up (V_{OUT} = 1.175 V)

4.5 Termination Sequence

The following images show the termination profiles of each converter.

CH 2 (Pink trace) Input Voltage

CH 3 (Blue trace): Output Voltage

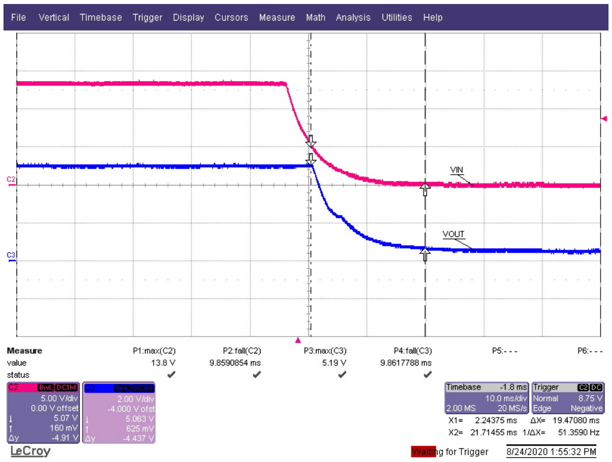


Figure 4-21. Termination (V_{OUT} = 5 V)

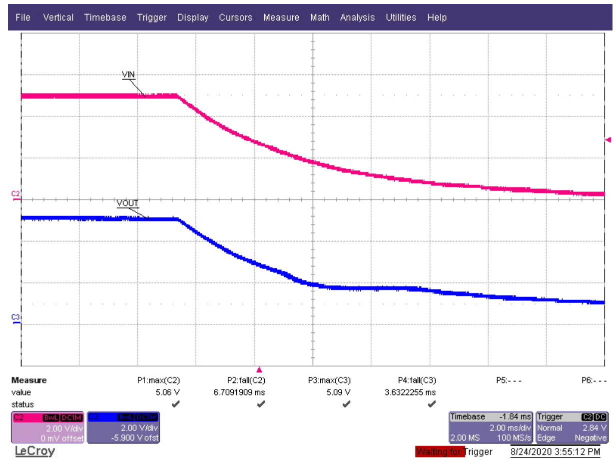


Figure 4-22. Termination (V_{OUT} = 3.3 V)

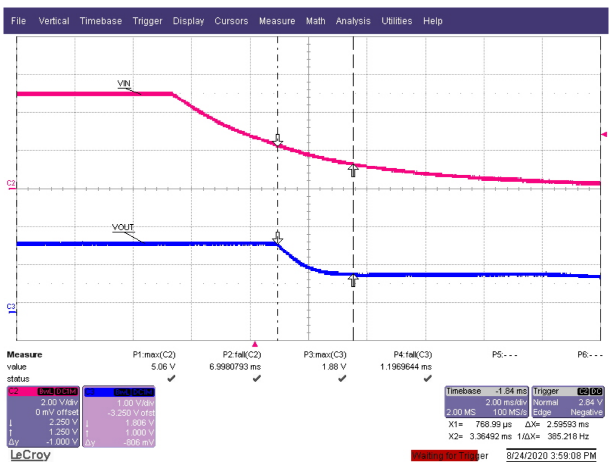


Figure 4-23. Termination (V_{OUT} = 1.8 V)

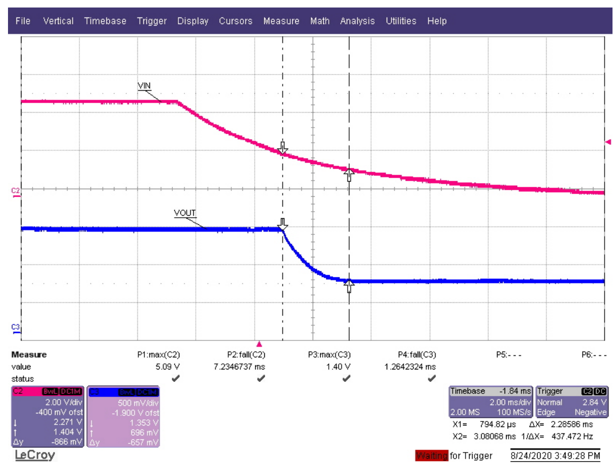


Figure 4-24. Termination (V_{OUT} = 1.35 V)

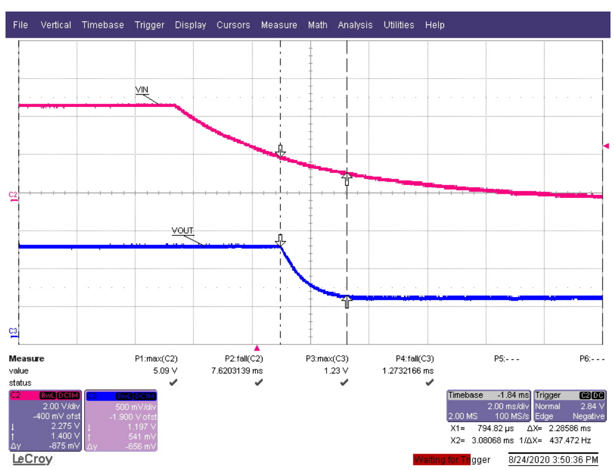


Figure 4-25. Termination (V_{OUT} = 1.175 V)

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265