Test Report: PMP21254

160-A, Four-Phase Reference Design Using the TPS546D24A Integrated FET Converter

1 Description

The PMP21254 is designed for powering high-current, low-voltage ASICs and FPGAs from a 5-V or 12-V rail. The design is optimized for high-density, and supports PMBus with current, voltage and temperature telemetry, if desired. A test report is included.

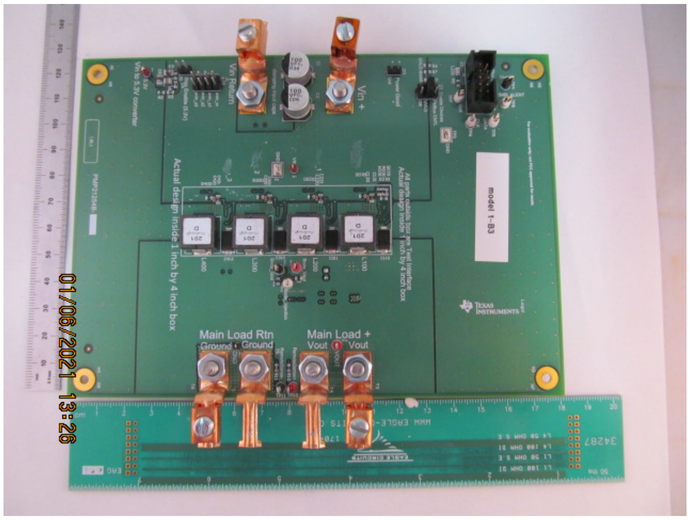


Figure 1-1. Top Photo

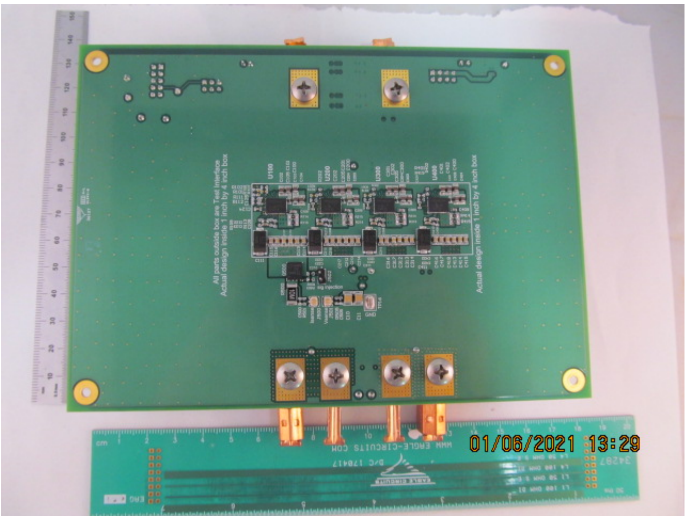


Figure 1-2. Bottom Photo

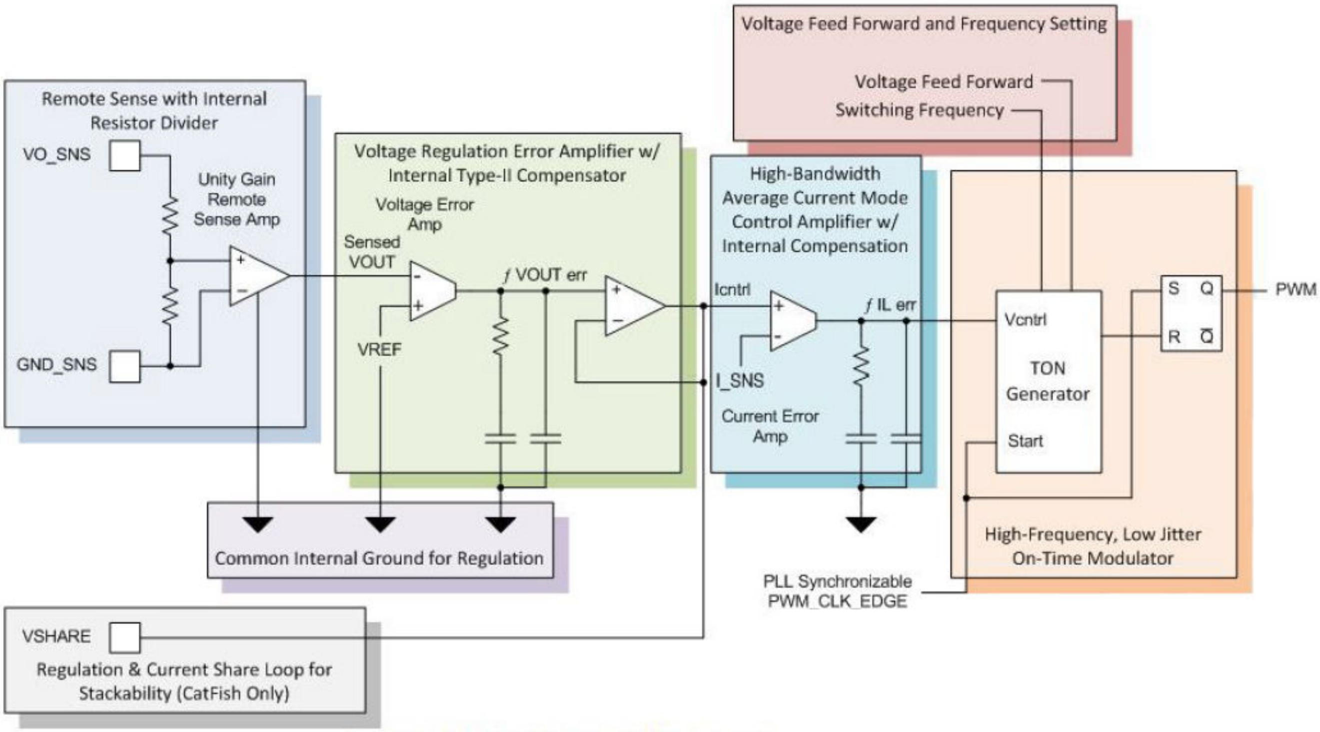


Figure 1-3. Control Scheme Block Diagram

2 Test Prerequisites

2.1 Voltage and Current Requirements

Table 2-1. Voltage and Current Requirements

Parameter	Specifications
V_{IN}	6 V–13.2 V
V_{OUT}	1.2 V
I_{OUT}	160-A steady state and 200-A peak

2.2 Required Equipment

- Lab Voltage Source (12 V, 250 W minimum)
- Load Bank (160 A capability)
- Oscilloscope (200 MHz minimum, 500 MHz prefered)
- Calibrated Voltmeter
- Shunt resistors
- 2 coaxial cables for voltage and current sensing U.FL (UMCC) / IPEX MHF1 to SMA Female to Female plus SMA to BNC Male to Male such as CAB.011 / Taoglas Limited plus Amphenol RF 245101-01-36.00. Both parts available at Digikey & Mouser.

2.3 Considerations

WARNING

High Temperatures! Hot surfaces are present. Contact may cause burns. Do not touch. Please take the proper precautions when operating.

2.4 Dimensions

PMP21254 assembled board: Main conversion is 4 in × 1 in rectangle, the full board including test interface is 7 in × 5 in.

2.5 Test Setup

The following image shows the bottom of the board during testing. The two black cabels are used for current and voltage monitoring.

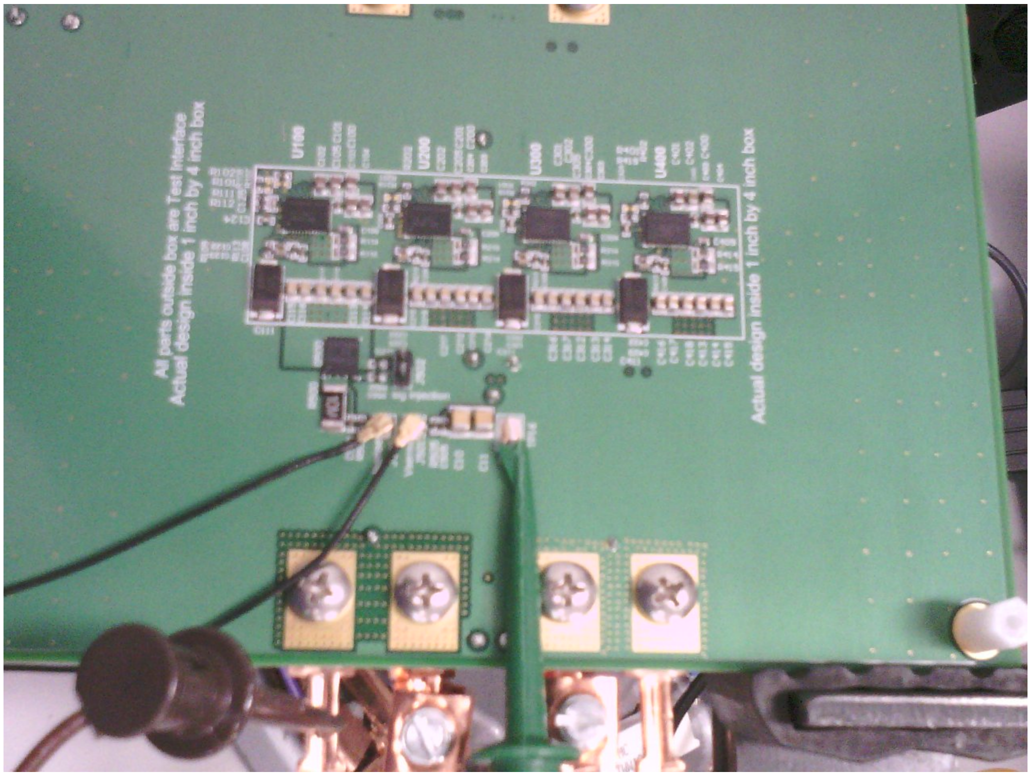


Figure 2-1. Test Setup

3 Testing and Results

3.1 Efficiency and Loss Graphs

The efficiency and loss vs current graphs follow.

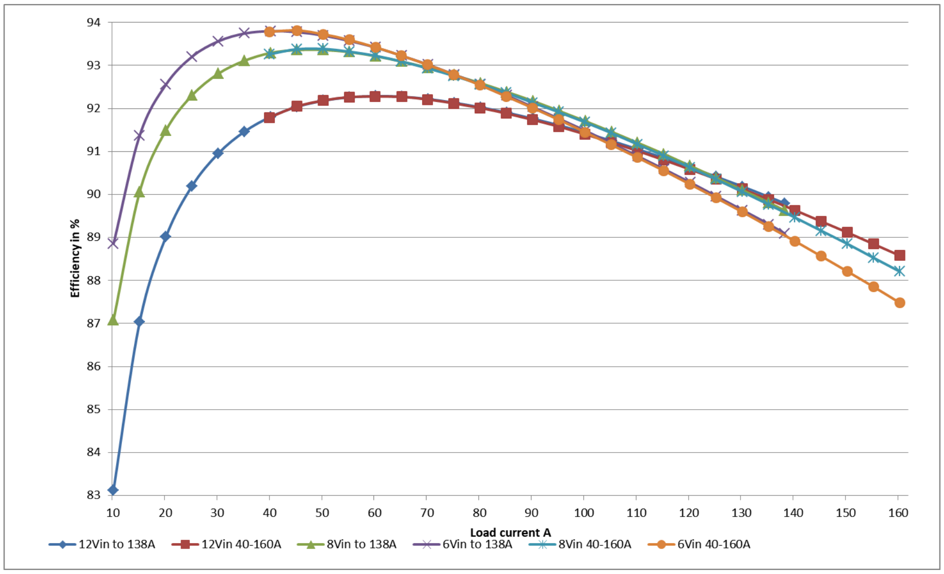


Figure 3-1. Efficiency Graph in Percentage

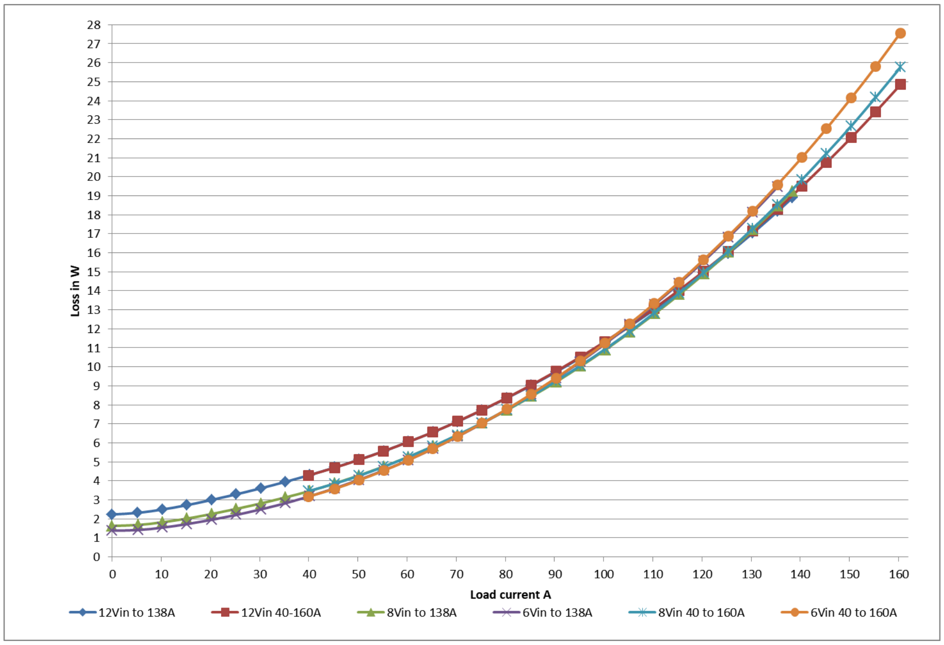


Figure 3-2. Loss in Watts

3.2 Efficiency Data

Efficiency data is shown in the following table with 1.2-V output model t1, 12 V_{IN}.

Table 3-1. 12 V_{IN}: 1.2 V, 0 A to 138 A With Approximately 1–2 mps Airflow

V_{IN} (V)	I_{IN} (A)	V_{OUT}	I_{OUT} (A)	Eff (%)	Loss (W)
11.999	0.186	1.200	0.000	0.000	2.234
11.999	0.717	1.200	5.234	73.033	2.320
11.999	1.233	1.200	10.240	83.115	2.497
11.999	1.752	1.200	15.241	87.031	2.726
11.999	2.275	1.200	20.241	89.010	3.000
11.999	2.801	1.200	25.250	90.199	3.294
11.999	3.328	1.201	30.253	90.954	3.612
11.999	3.857	1.201	35.255	91.463	3.951
11.999	4.388	1.201	40.260	91.807	4.314
11.999	4.922	1.201	45.265	92.038	4.702
11.999	5.457	1.201	50.271	92.181	5.120
11.999	5.995	1.201	55.273	92.261	5.567
11.999	6.537	1.201	60.280	92.286	6.050
11.999	7.081	1.201	65.292	92.273	6.565
11.999	7.628	1.201	70.296	92.220	7.121
11.999	8.179	1.201	75.299	92.134	7.720
11.999	8.733	1.201	80.306	92.028	8.353
11.999	9.291	1.201	85.312	91.904	9.024
11.999	9.851	1.201	90.318	91.763	9.736
11.999	10.415	1.201	95.326	91.608	10.487
11.999	10.983	1.201	100.335	91.433	11.290
11.999	11.555	1.201	105.340	91.246	12.137
11.999	12.129	1.201	110.348	91.052	13.023
11.999	12.710	1.201	115.353	90.847	13.959
11.999	13.294	1.201	120.362	90.632	14.943
11.999	13.880	1.201	125.369	90.410	15.970
11.999	14.471	1.201	130.371	90.183	17.046
11.999	15.066	1.201	135.375	89.944	18.179
11.999	15.426	1.201	138.383	89.794	18.891
11.999	15.674	1.201	140.354	89.633	19.497
11.999	16.280	1.201	145.358	89.374	20.756
11.999	16.889	1.201	150.358	89.116	22.055
11.999	17.504	1.201	155.372	88.846	23.426
11.999	18.125	1.201	160.383	88.577	24.843

Efficiency data is shown in the following table with 1.2-V output model t1, 8 V_{IN}.

Table 3-2. 8 V_{IN}: 1.2 V, 0 A to 138 A With Approximately 1–2 mps Airflow

V_{IN} (V)	I_{IN} (A)	V_{OUT}	I_{OUT} (A)	Eff (%)	Loss (W)
7.994	0.204	1.200	0.000	0.000	1.634
7.994	0.999	1.200	5.250	78.936	1.682
7.994	1.768	1.200	10.252	87.082	1.825
7.994	2.542	1.200	15.246	90.061	2.020
7.994	3.323	1.200	20.246	91.491	2.261
7.994	4.108	1.200	25.252	92.306	2.527
7.994	4.895	1.201	30.253	92.810	2.814
7.994	5.686	1.201	35.256	93.111	3.132
7.994	6.481	1.201	40.262	93.292	3.475
7.994	7.282	1.201	45.266	93.360	3.865
7.994	8.087	1.201	50.271	93.361	4.292
7.994	8.896	1.201	55.273	93.313	4.756
7.994	9.712	1.201	60.276	93.217	5.267
7.994	10.534	1.201	65.284	93.091	5.818
7.994	11.359	1.201	70.291	92.946	6.406
7.994	12.191	1.201	75.296	92.776	7.040
7.994	13.028	1.201	80.305	92.590	7.718
7.994	13.871	1.201	85.312	92.386	8.444
7.994	14.720	1.201	90.320	92.174	9.209
7.994	15.575	1.201	95.325	91.942	10.032
7.994	16.436	1.201	100.334	91.706	10.898
7.994	17.303	1.201	105.339	91.458	11.815
7.994	18.176	1.201	110.345	91.200	12.787
7.994	19.057	1.201	115.354	90.941	13.802
7.994	19.944	1.201	120.364	90.665	14.883
7.994	20.839	1.201	125.372	90.385	16.019
7.994	21.740	1.201	130.377	90.099	17.207
7.994	22.648	1.201	135.387	89.811	18.447
7.994	23.197	1.201	138.392	89.625	19.239
7.994	23.570	1.201	140.351	89.465	19.850
7.994	24.495	1.201	145.358	89.156	21.234
7.994	25.426	1.201	150.362	88.851	22.661
7.994	26.368	1.201	155.372	88.527	24.185
7.994	27.319	1.201	160.380	88.206	25.757

Efficiency data is shown in the following table with 1.2-V output model t1, 6 V_{IN}.

Table 3-3. 6 V_{IN}: 1.2 V, 0 A to 138 A With Approximately 1–2 mps Airflow

V_{IN} (V)	I_{IN} (A)	V_{OUT}	I_{OUT} (A)	Eff (%)	Loss (W)
5.999	0.231	1.200	0.000	0.000	1.384
5.999	1.287	1.200	5.255	81.698	1.413
5.999	2.309	1.200	10.254	88.853	1.544
5.999	3.339	1.200	15.249	91.372	1.728
5.999	4.377	1.200	20.249	92.553	1.956
5.999	5.422	1.200	25.254	93.205	2.210
5.999	6.471	1.201	30.255	93.562	2.499
5.999	7.527	1.201	35.258	93.743	2.825
5.999	8.590	1.201	40.261	93.798	3.196
5.999	9.660	1.201	45.266	93.777	3.607
5.999	10.738	1.201	50.270	93.697	4.060
5.999	11.823	1.201	55.275	93.572	4.559
5.999	12.915	1.201	60.283	93.419	5.099
5.999	14.017	1.201	65.288	93.225	5.697
5.999	15.126	1.201	70.296	93.019	6.335
5.999	16.243	1.201	75.297	92.789	7.027
5.999	17.369	1.201	80.306	92.556	7.756
5.999	18.502	1.201	85.314	92.303	8.543
5.999	19.645	1.201	90.320	92.033	9.389
5.999	20.795	1.201	95.327	91.760	10.280
5.999	21.956	1.201	100.337	91.482	11.220
5.999	23.126	1.201	105.344	91.188	12.226
5.999	24.304	1.201	110.348	90.890	13.283
5.999	25.491	1.201	115.357	90.588	14.394
5.999	26.692	1.201	120.368	90.280	15.564
5.999	27.902	1.201	125.374	89.958	16.809
5.999	29.121	1.201	130.380	89.633	18.111
5.999	30.351	1.201	135.388	89.306	19.472
5.999	31.098	1.201	138.393	89.094	20.347
5.999	31.602	1.201	140.353	88.915	21.016
5.999	32.858	1.201	145.359	88.564	22.542
5.999	34.126	1.201	150.361	88.210	24.137
5.999	35.407	1.201	155.367	87.852	25.805
5.999	36.702	1.201	160.378	87.479	27.568

3.3 Thermal Images

The following thermal image shows operation at 12-V input and 1.2- V at 100-A output, with no airflow. The board ran for 20 minutes with these conditions before the thermal image was taken.

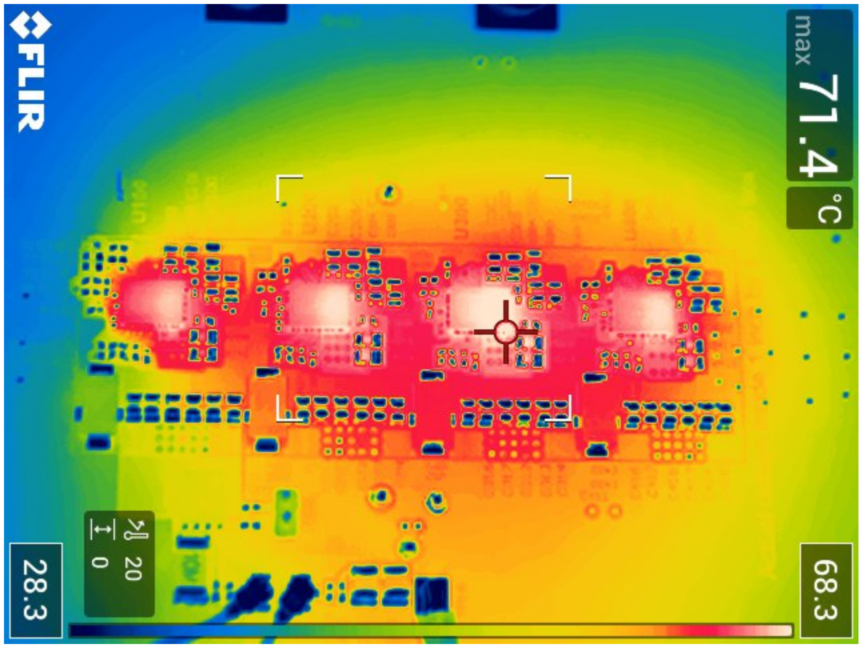


Figure 3-3. 100-A Output, No Airflow - Side With Converters

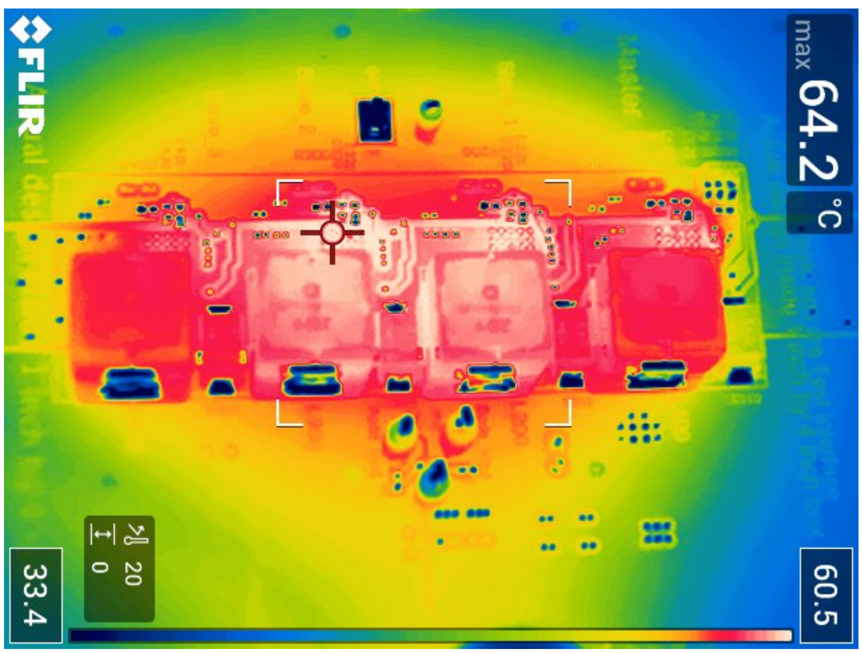


Figure 3-4. 100-A Output, No Airflow - Side With Inductors

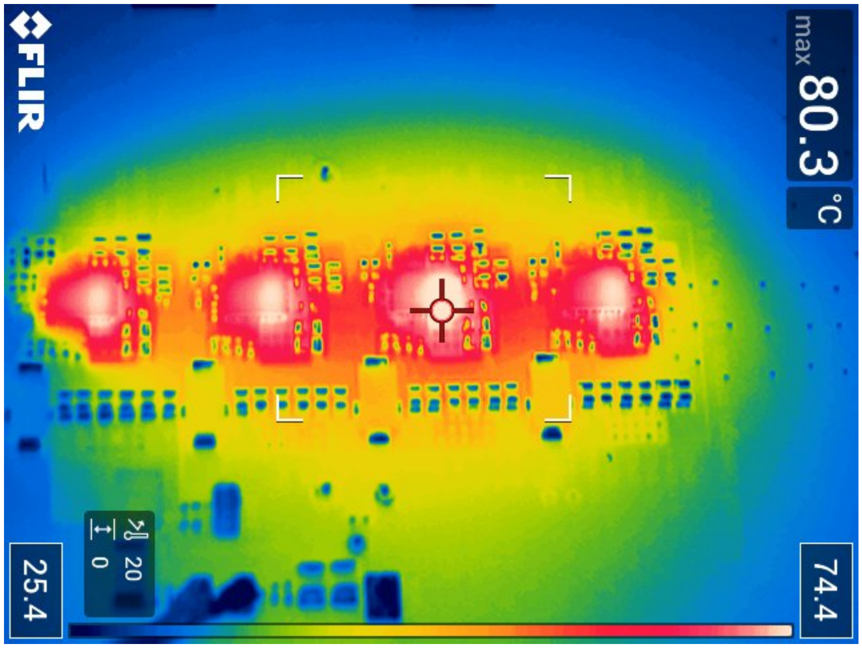


Figure 3-5. 160-A Output, 1–2 mps Airflow - Side With Converters

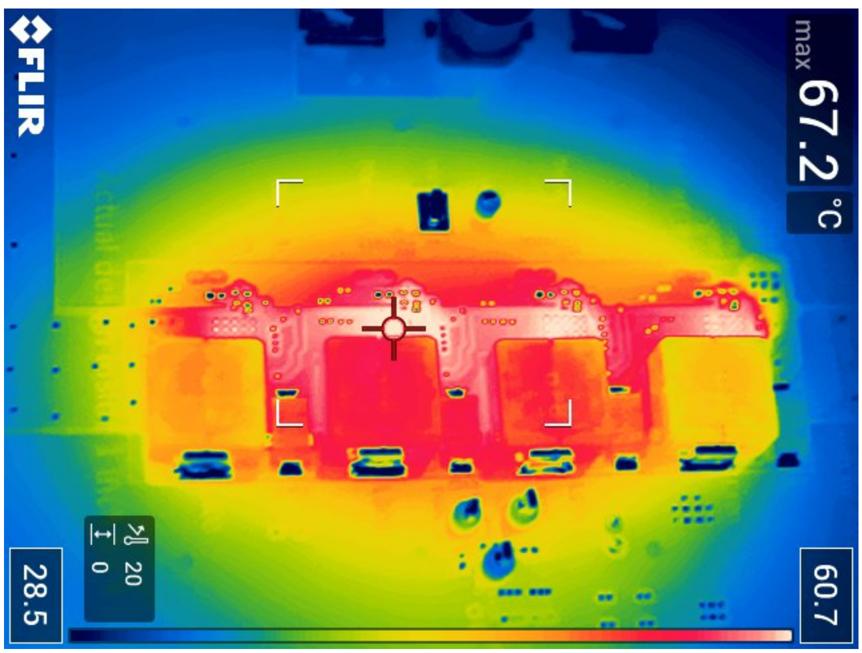


Figure 3-6. 160-A Output, 1–2 mps Airflow - Side With Inductors

3.4 Bode Plots

The following plot shows the loop gain and phase margin of the converter when loaded to 1.2 V at 40 A.

- V_{IN} = 12 V, Bandwidth = 23 kHz , Phase Margin = 68 degrees

The loop is set by pinstrap resistors using 550 kHz and compensation code 18 as the fastest loop allowed among the 32 pinstrap selections:

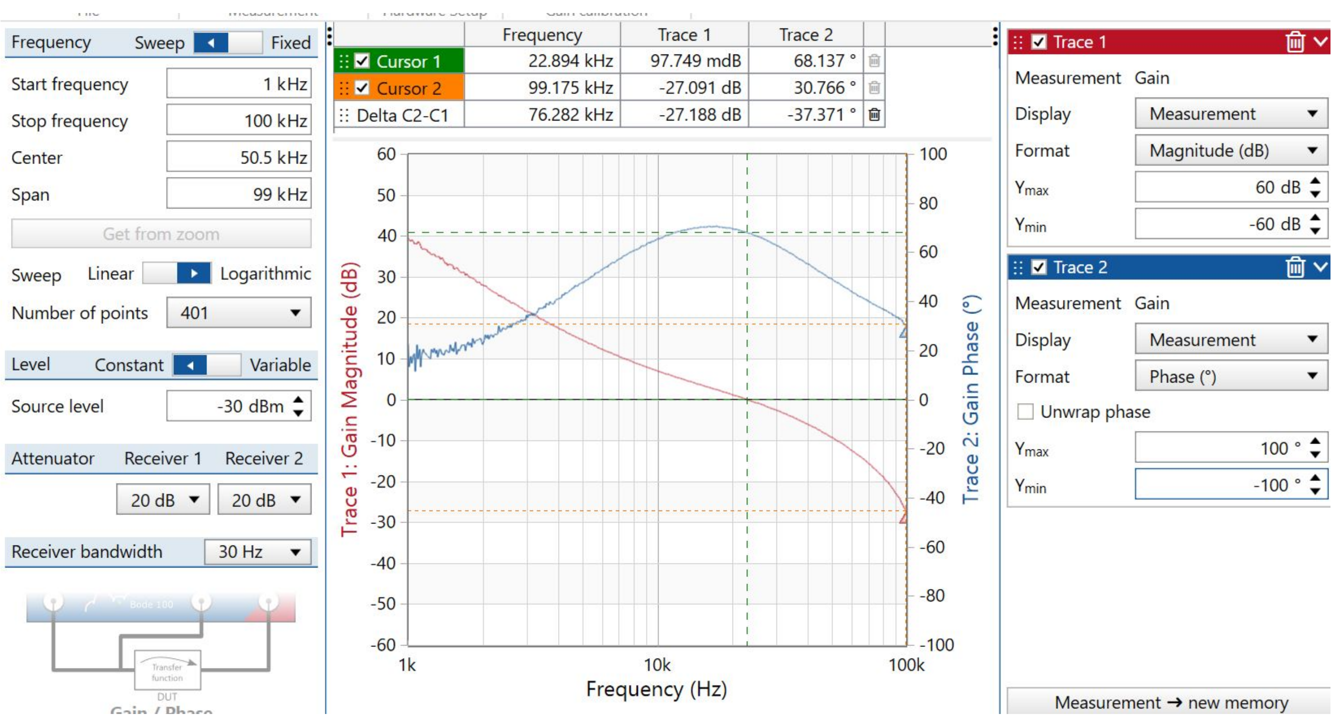


Figure 3-7. Bode Plot, Pinstrap Resistors

Loop set up using Nonvolatile Memory (NVM) programming which allows for many more than 32 compensation selections.

- Code11408458C2 used: 36-kHz bandwidth and 51 degrees of phase margin

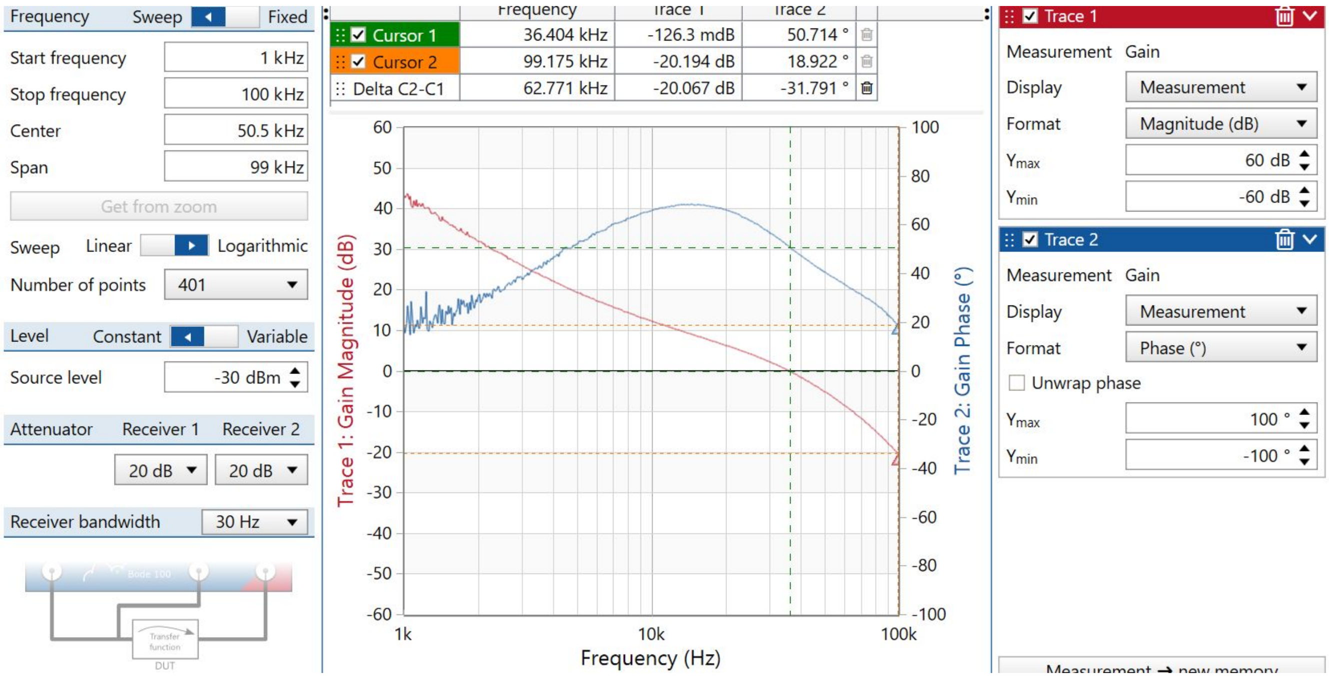


Figure 3-8. Bode Plot, NVM

4 Waveforms

4.1 Switching

The following images show the switch node voltage of the leader TPS546D24A and the main waveforms on each of the 3 followers. The input voltage is 12 V and the 1.2-V output is loaded to 160 A.

All scopes are taken at 5 V/DIV, 500 ns/DIV, full bandwidth which is 750 MHz for scope and 500 MHz for probe.

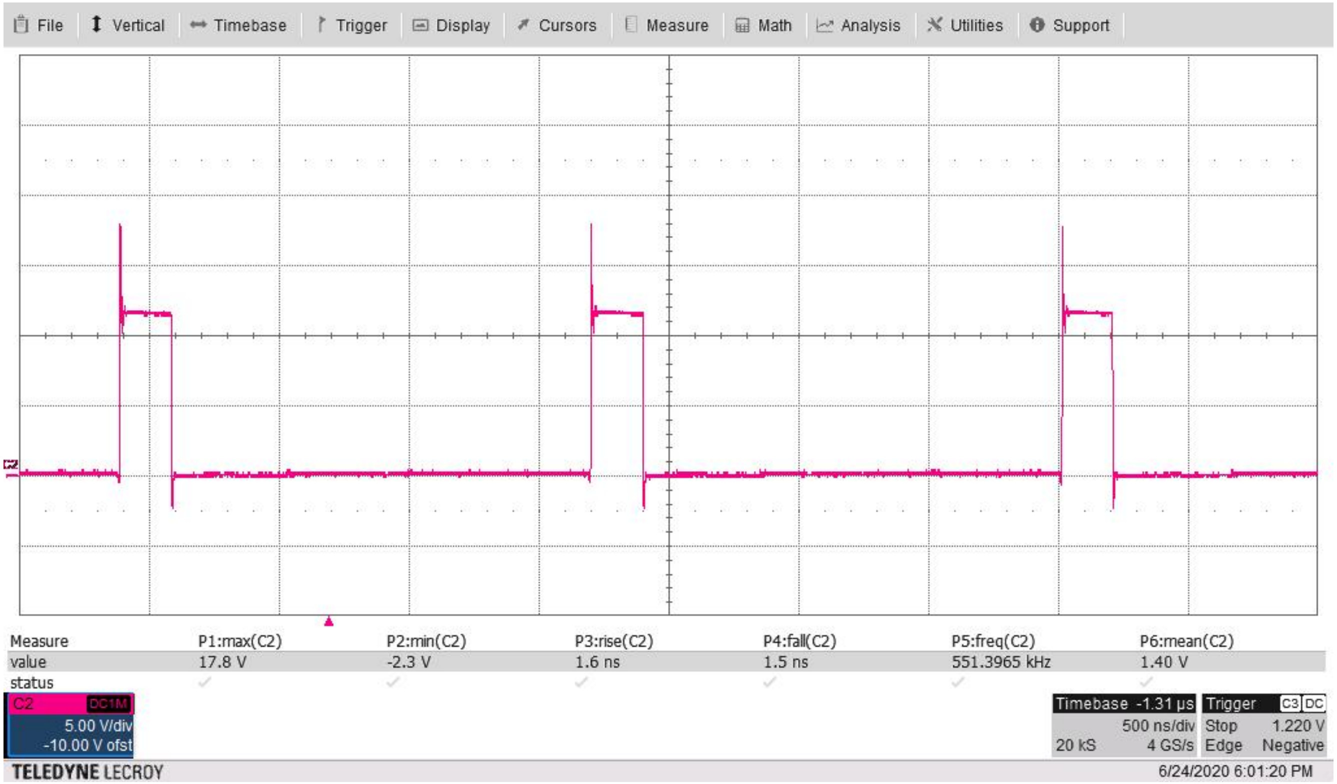


Figure 4-1. Leader

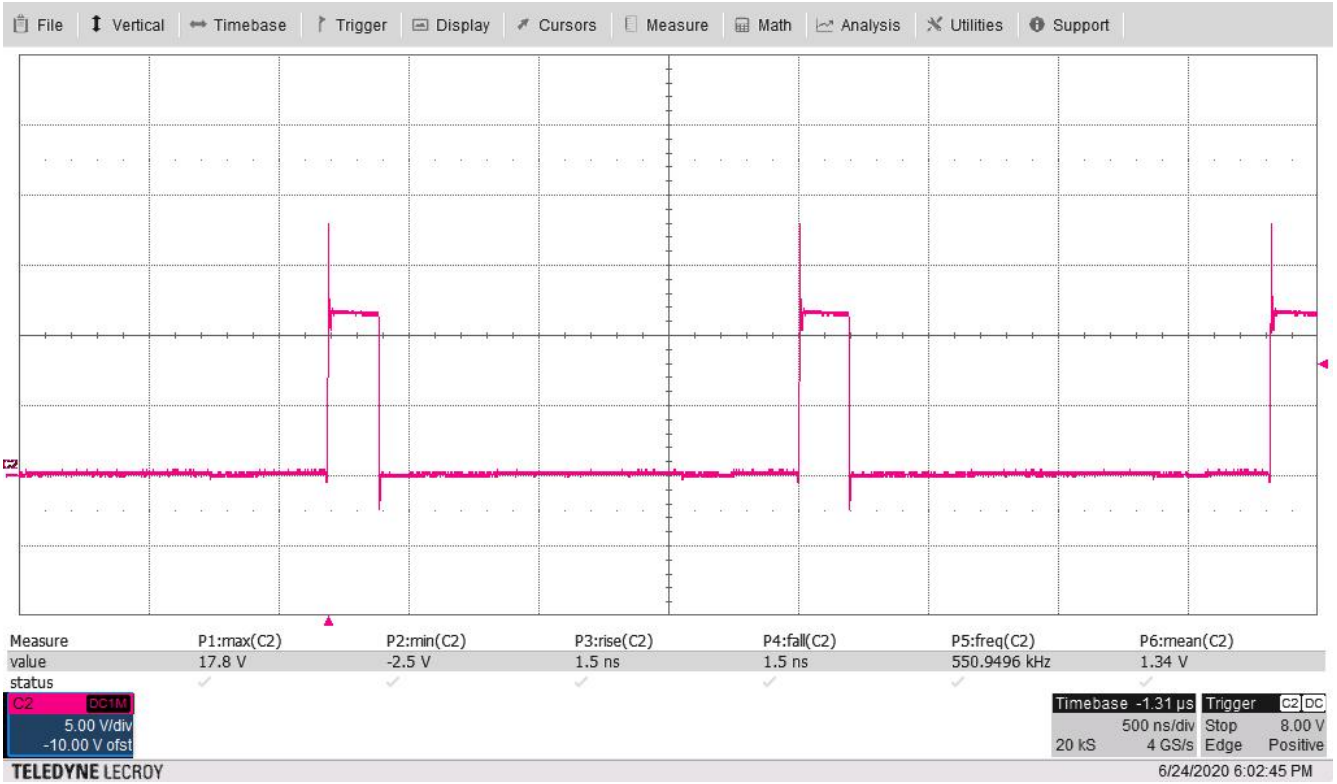


Figure 4-2. Follower 1

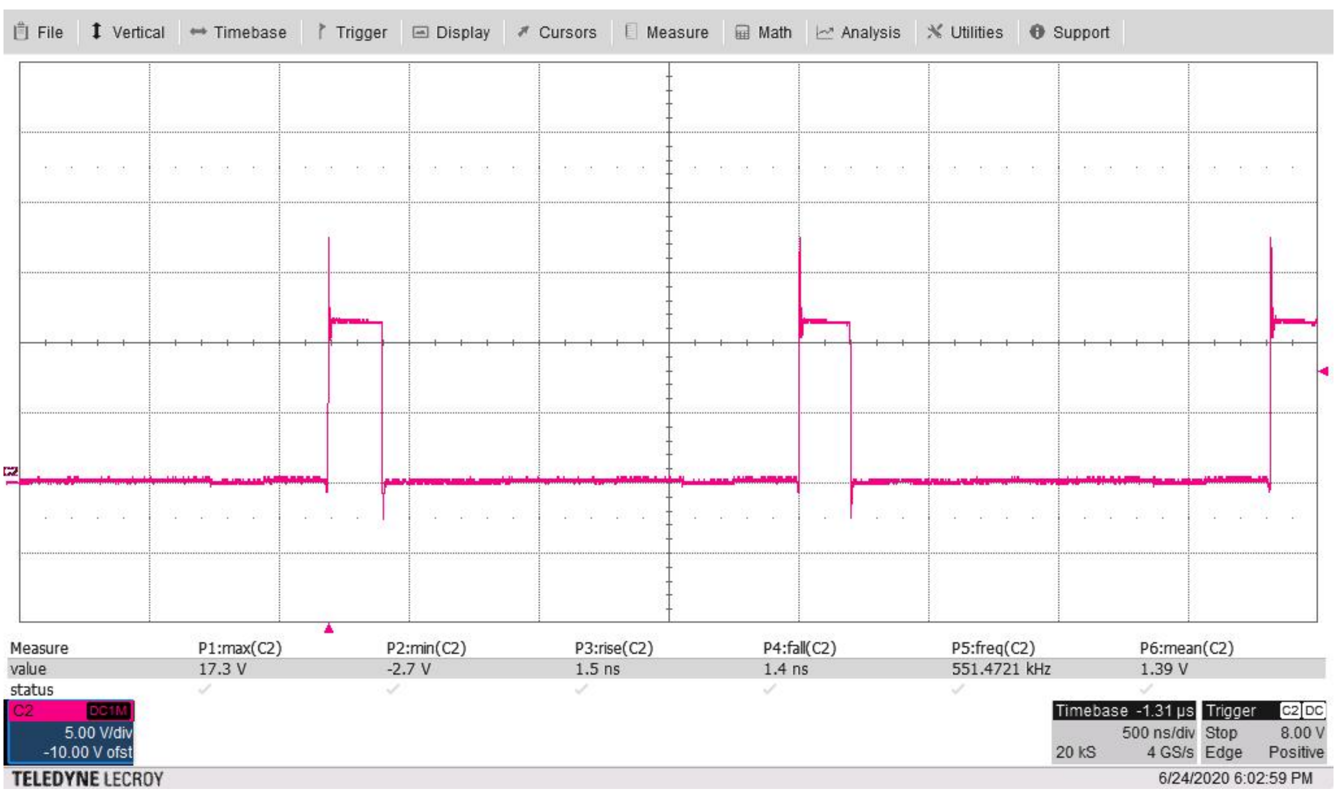


Figure 4-3. Follower 2

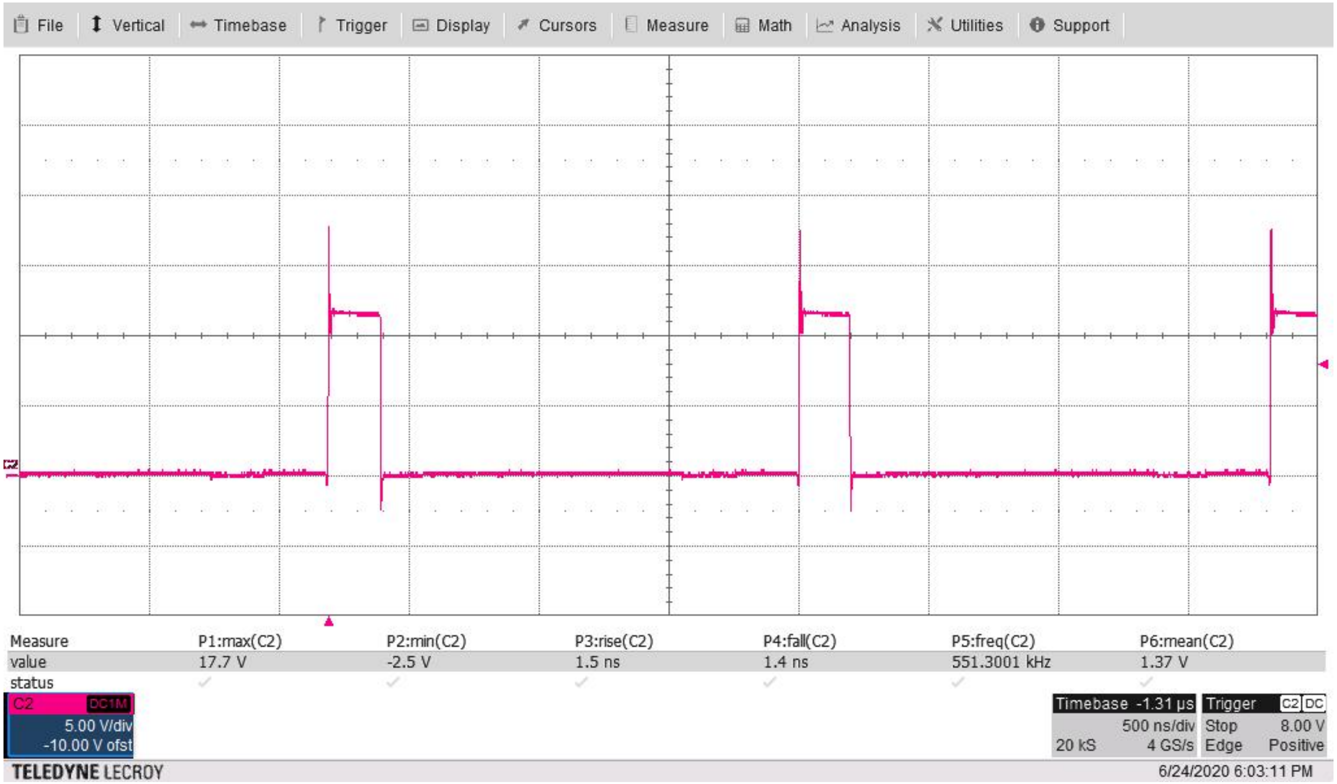


Figure 4-4. Follower 3

4.2 Output Voltage Ripple

The output ripple voltage is shown in the following figures. The images were taken with the 1.2-V output loaded to 160 A and the input voltage set to 12 V.

Both voltage ripple scopes were taken at 2 mV/DIV, 200 µs/DIV, 20-MHz bandwidth with onboard Vsense J501 and 1x probe. Ripple measurement was taken using connections on the bottom side of the board. Peak-to-peak ripple is 5.5 mV.

RMS of this ripple is based upon the same waveform and AC coupling was 745 µV.

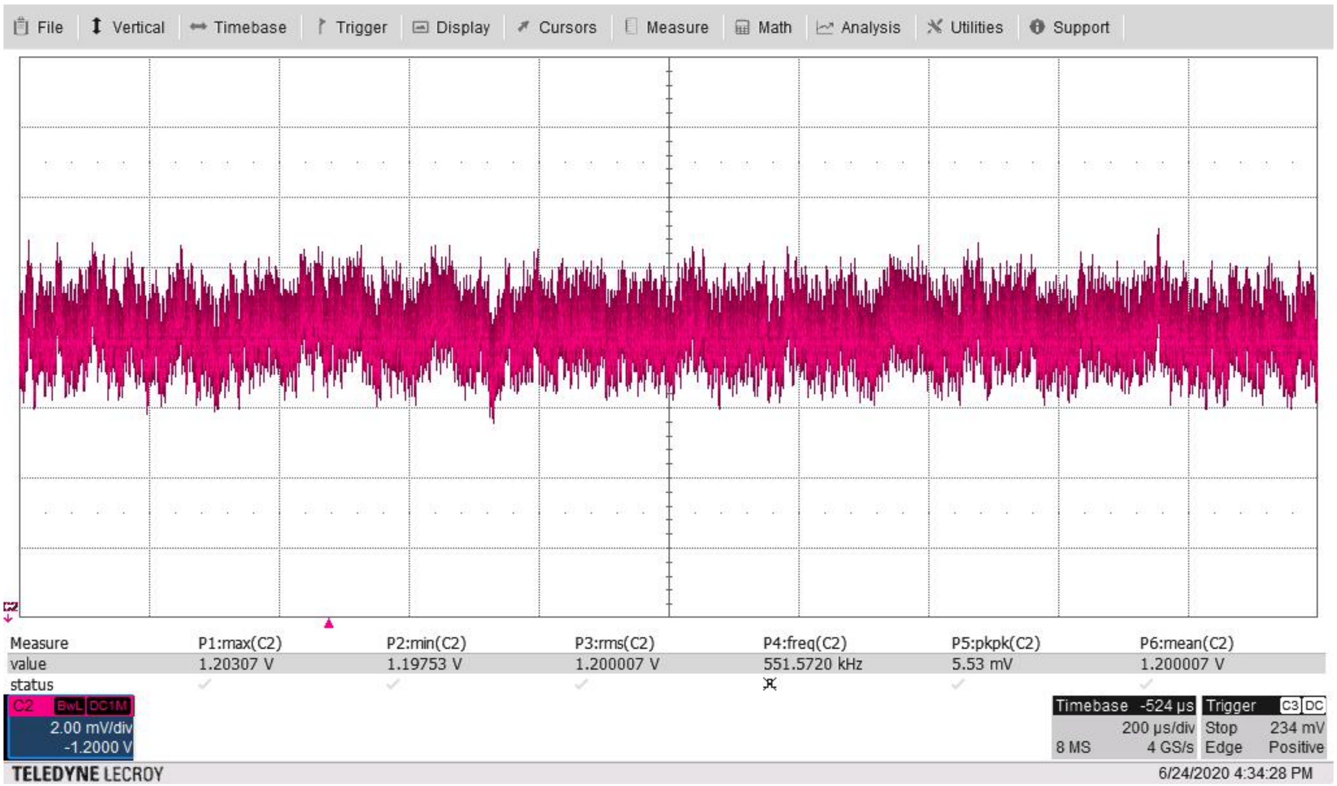


Figure 4-5. Output Voltage Ripple

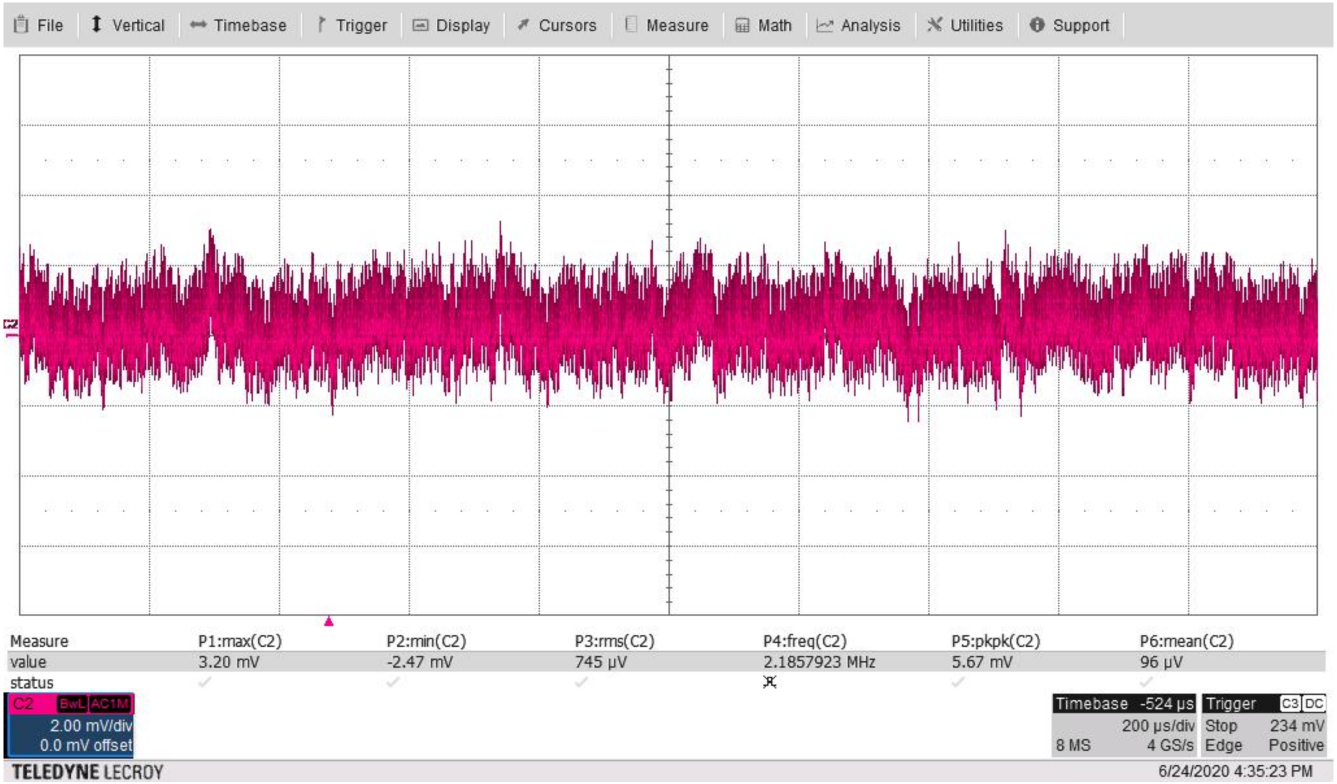


Figure 4-6. Output Voltage Ripple RMS, AC Coupling

4.3 Load Transients

Figure 4-7 shows the 1.2-V output voltage when the load current is stepped between 125 A and 200 A. An external static load of 125 A was used along with onboard dynamic load for 75-A pulses. The other parameters follow:

- V_{IN} = 12 V, rise 11.85 A/µs, fall 12.5 A/µs (10 mV/DIV, 10 A/DIV, 200 µs/DIV)

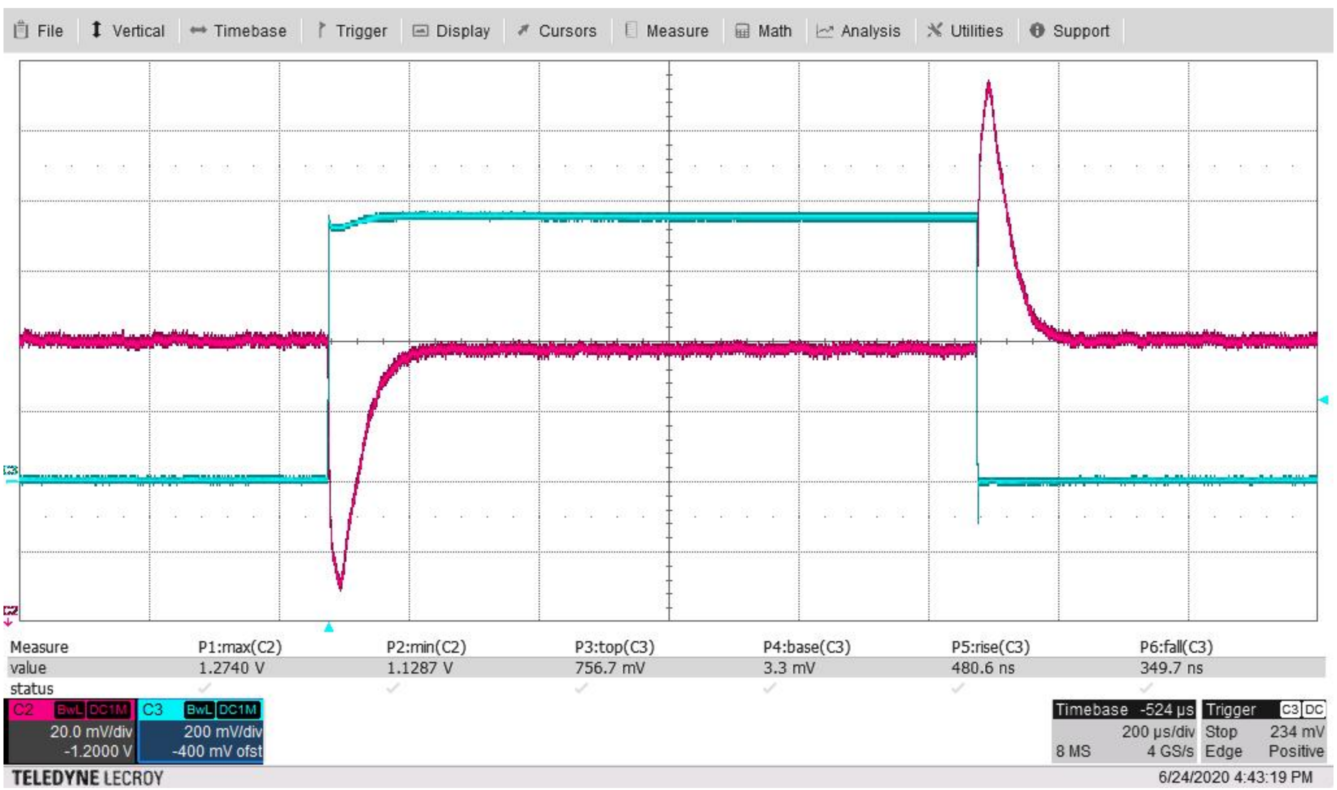
The dynamic load response measured at V_{OUT} is measured on the bottom side of the board using a coaxial connection: see *Test Setup*.

The measured maximum overshoot of 20.4 mV above nominal 1 V or 2.04% above nominal. The measured maximum undershoot of 23.9 mV below nominal 1 V or 2.39% below nominal.

- The current-sense waveform below is across a 10-mΩ resistor to ground on the dynamic load.
- Blue trace J500 on board

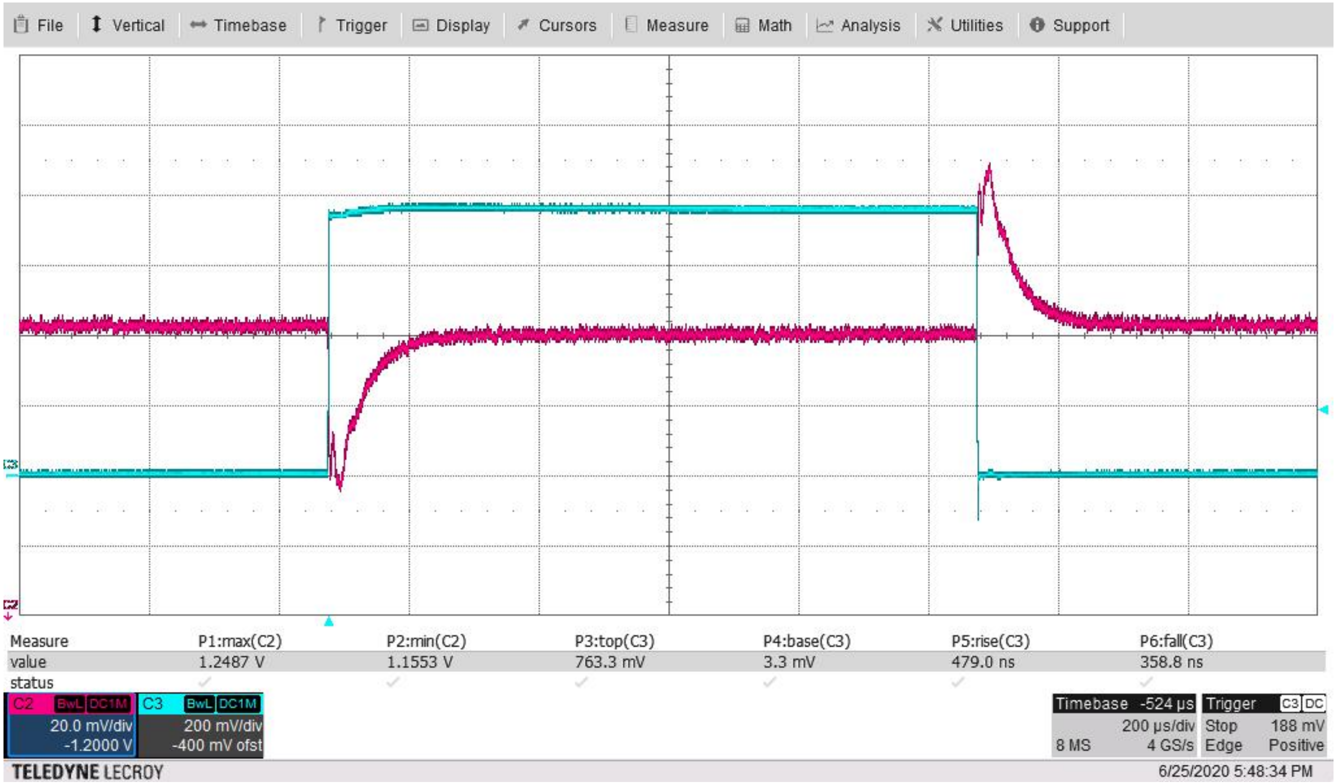
Hence, the “top” of this pulse of 750 mV above the base divided by 10 mΩ, corresponds to a 75-A pulse.

- dI/dT of rise is 80% of this 75 A (as rise time is defined for “10% to 90%” or 80%”) or 60 A divided by the rise time of 481 ns; or 60/0.48 or 125 A/µs. Rise time readings were 454–481 ns, 481 ns is used to estimate the dI/dT.
- dI/dT of fall is 80% of this 20 A (as fall time is defined for “90% to 10%” or 80%”) or 60 A divided by the fall time of 360 ns; or 60/0.36 or –165 A/µs. Fall time readings were 340 ns–360 ns, 360 ns is used to estimate the dI/dT.



Looking at both load step of 75 A from 125 A to 200 A, and load dump back to 125 A
Red trace being V_{OUT} on J501, blue trace dynamic I across 10 mΩ
Pinstrap set loop of 23-kHz crossover: minimum V_{OUT} at 71 mV below 1.2 V and max at 74 mV above 1.2 V

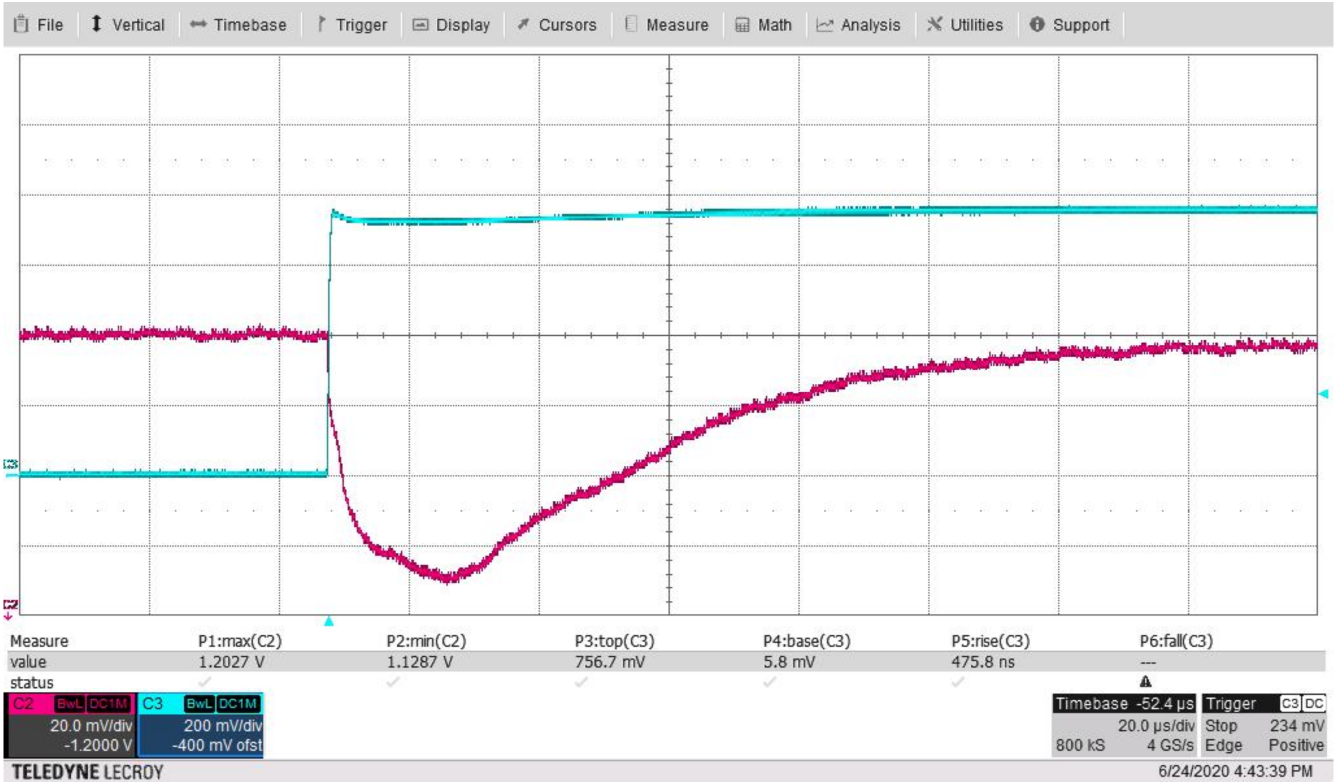
Figure 4-7. Load Step, Dump 125 A-200 A-125 A, 23-kHz Crossover



NVM loop Code11408458C2 for 36-kHz crossover: minimum V_{OUT} at 45 mV below 1.2 V and max at 49 mV above 1.2 V

Figure 4-8. Load Step, Dump 125 A-200 A-125 A, 36-kHz Crossover

Figure 4-9 through Figure 4-12 are the same pair of waveforms, adjusting the time scale to highlight the load step and load-dump responses.

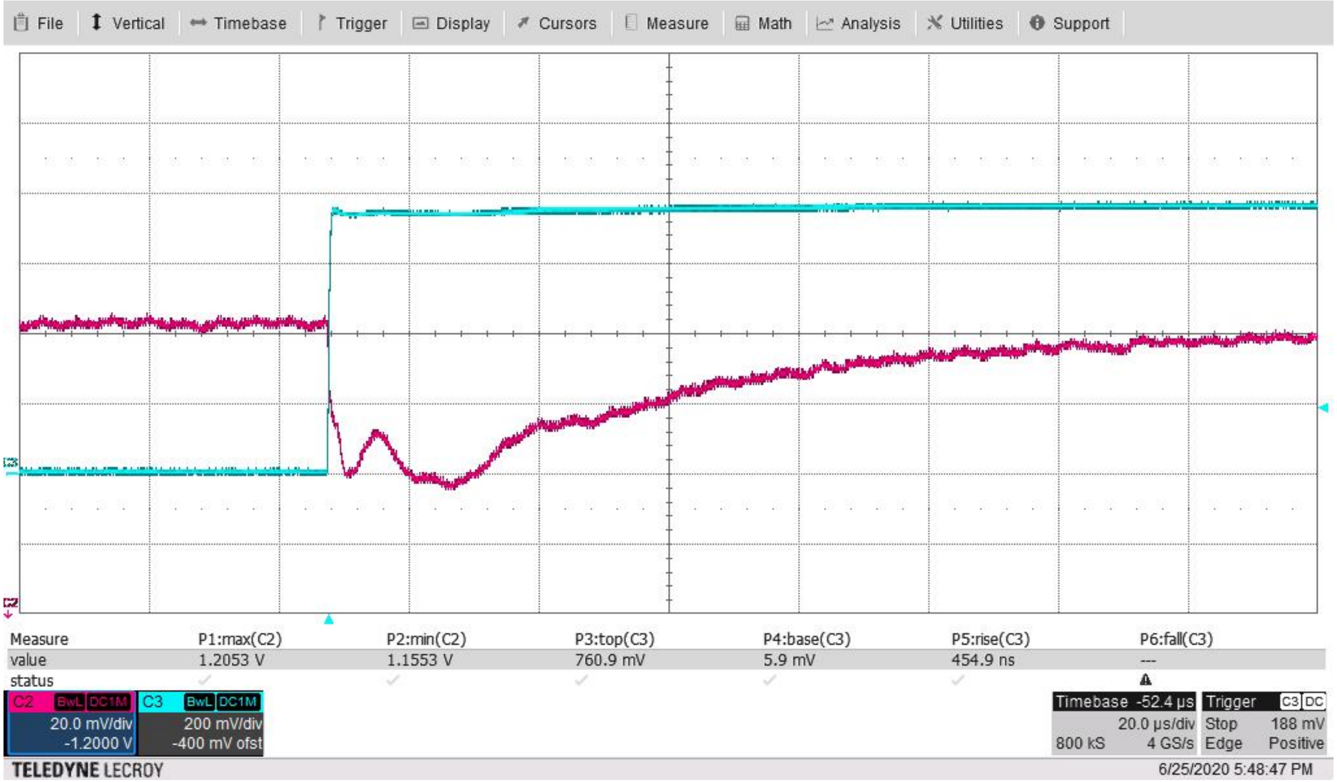


Focusing on load step of 75 A from 125 A to 200 A

Red trace being V_{OUT} on J501, blue trace J500 dynamic I across 10 mΩ (75-A step at 125 A/µs)

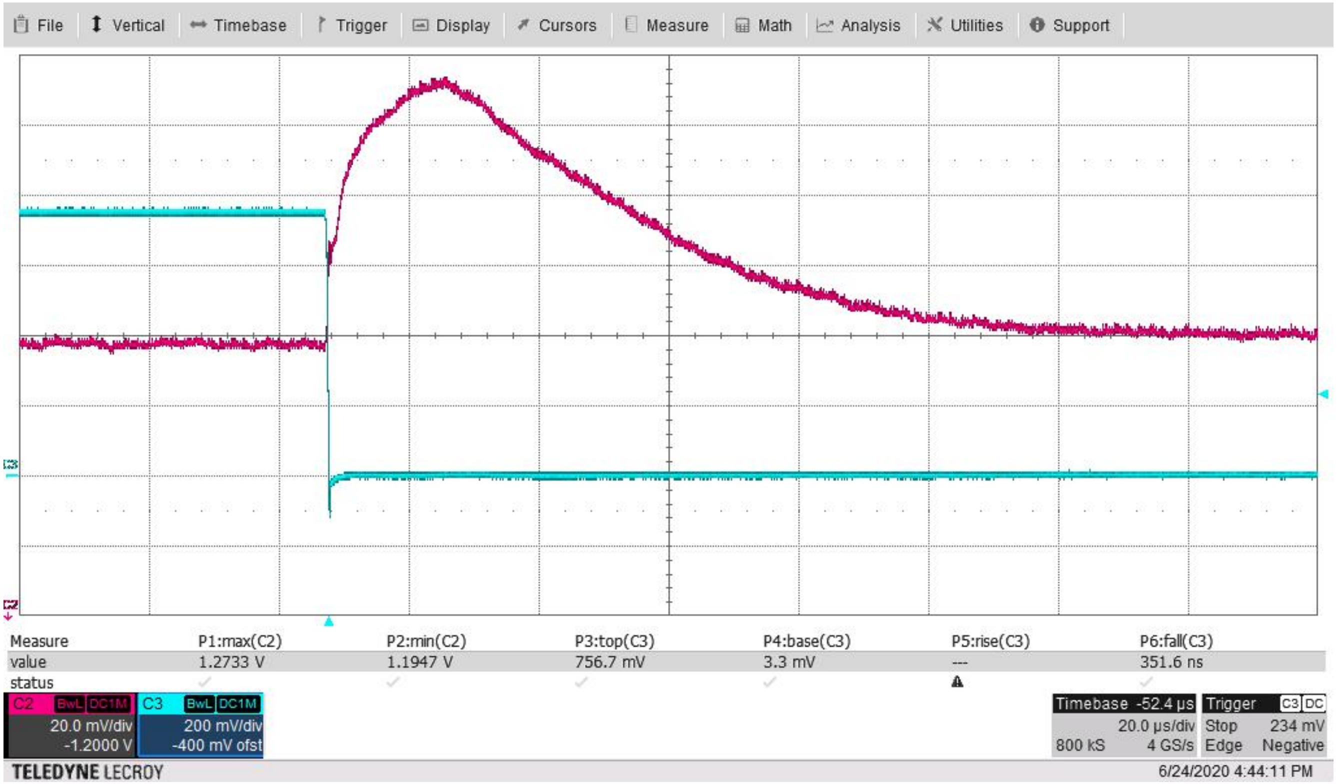
Pinstrap set loop of 23-kHz crossover: minimum V_{OUT} at 71 mV below 1.2 V

Figure 4-9. 125 A–200 A Load Step, 23-kHz Crossover



NVM loop Code11408458C2 for 36-kHz crossover: minimum V_{OUT} at 45 mV below 1.2 V

Figure 4-10. 125 A–200 A Load Step, 36-kHz Crossover

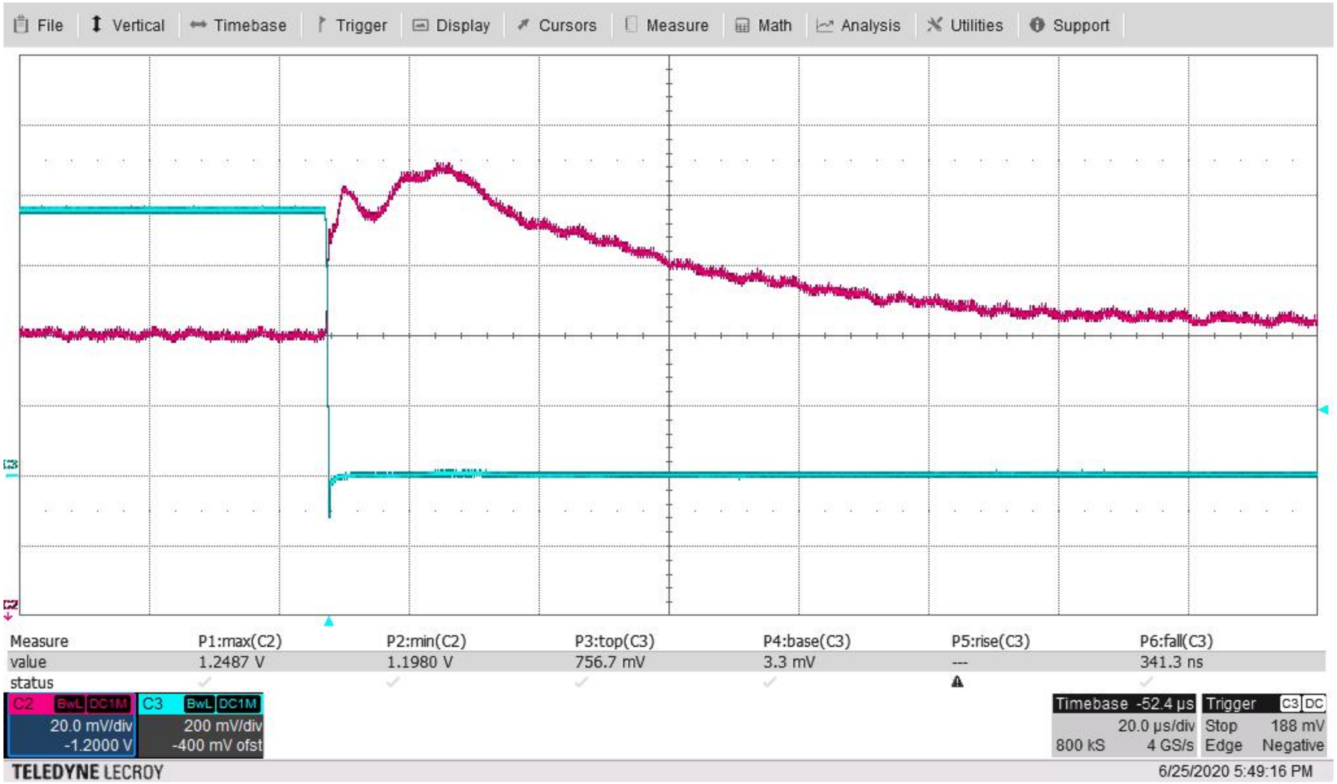


Focusing on load dump from 200 A back to 125 A.

Red trace being V_{OUT} on J501, blue trace J500 dynamic I across 10 mΩ for 75A dump at –165 A/µs

Pinstrap set loop of 23-kHz crossover: max at 73 mV above 1.2 V

Figure 4-11. 125 A–200 A Load Dump, 23-kHz Crossover



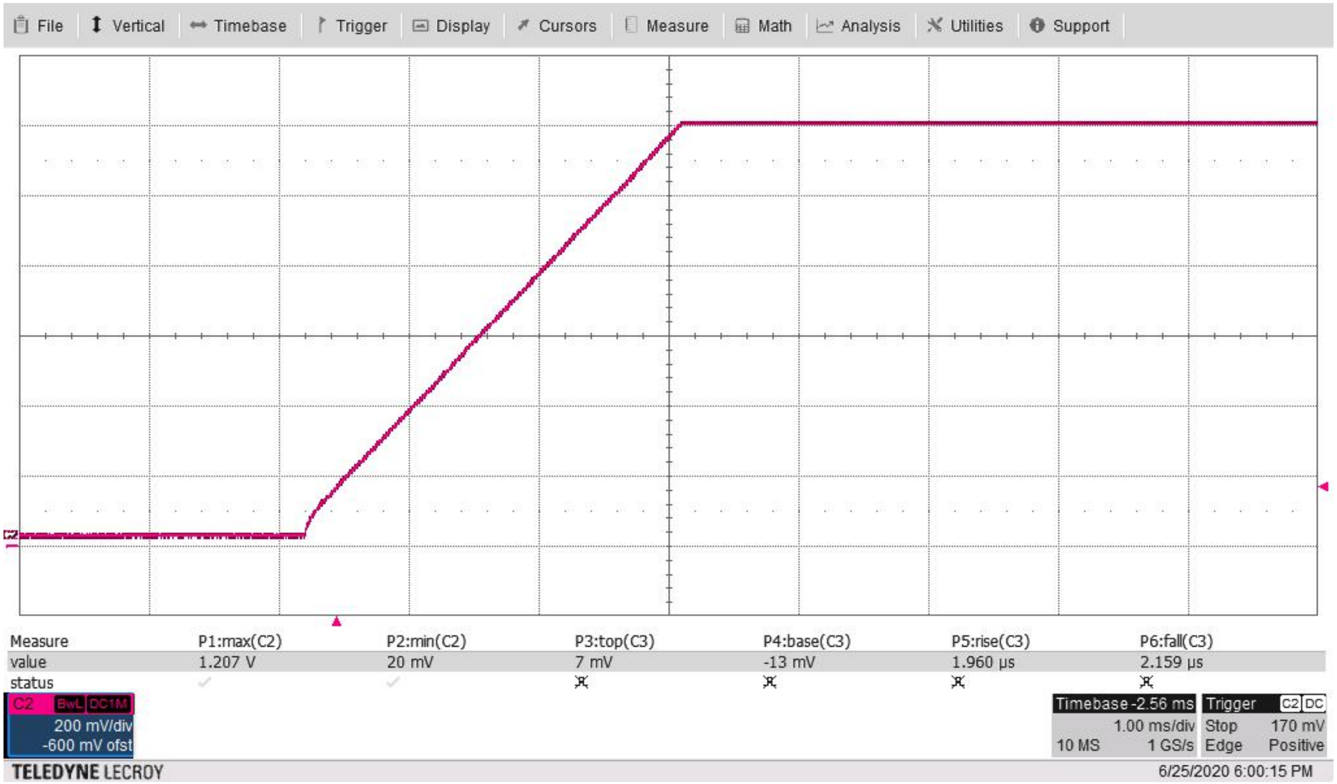
NVM loop code11408458C2 for 36-kHz crossover: maximum at 49 mV above 1.2 V

Figure 4-12. 125 A–200 A Load Dump, 36-kHz Crossover

4.4 Start-up Sequence

Figure 4-13 shows the output voltage startup waveform after the application of 12 V in and the Enable pin manually disconnected from GND with the 1.2-V output loaded to 0 A.

The faster 36-kHz bandwidth loop set by NVM is used here, as faster loops have greater risk of turn on overshoot.



200 mV/DIV, 1 ms/DIV

Figure 4-13. Start-Up Waveform

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