Test Report: PMP23452

Automotive, 20V to 60V Input, Dual-Output (3.3V, 20A and 5V, 20A) Converter Reference Design

Description

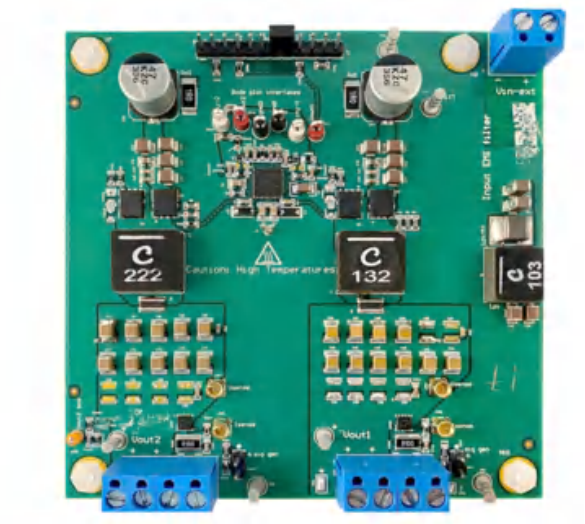
This reference design offers power for automotive advanced driver assistance systems (ADAS), infotainment, and cluster applications. Operation is over the full automotive range including battery voltage surges to 60V. Two outputs are provided, 3.3V and 5V each handling loads to 20A. The design exhibits a peak conversion efficiency of 95.5% with $24V_{IN}$ and 93.9% at $48V_{IN}$ for the 5V output. Results demonstrate 5% output voltage undershoot and overshoot for a 15A step and dump. The test report includes operational data spanning over the full input range and includes bode plots to verify stability with ample margins, thermal images, and precompliance conducted emissions scans versus CISPR25 Class 5 limits.

Features

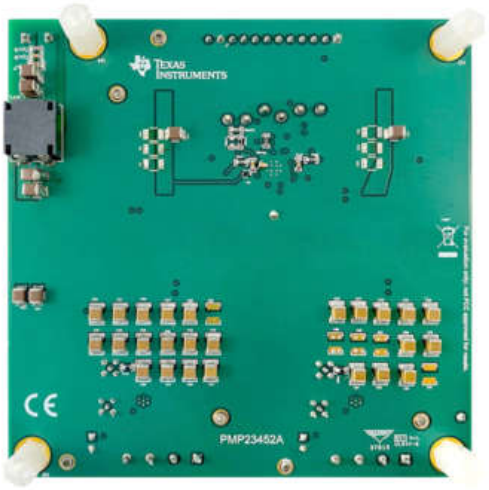
- High current for advanced driver assistance systems (ADAS), infotainment, and cluster applications
- Peak conversion efficiency of 95.5% with $24V_{IN}$ and 93.9% at $48V_{IN}$ for the 5V output
- LM5143-Q1 provides two-output control and gate drive in a single IC
- Output voltage undershoot and overshoot 5% for 15A step and dump
- Conducted emissions scans (precompliance) versus CISPR25 Class 5 limits provided for 48V input and near full loading on both outputs

Applications

- Driver monitoring
- ADAS domain controller
- Central compute unit multidomain
- Surround view system ECU
- Radar ECU
- Vehicle instrument cluster
- Digital cockpit processing unit



Top of Board



Bottom of Board

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
Input Power	20V to 60V steady-state. Use J11 onboard (On-Shore Technology ED120/2DS terminal block)
5V output and 3.3V outputs	Loads up to 20A each Various signals Use J33 for 3.3V and J50 for 5V terminal block On-Shore Technology ED120/4DS
Various signals	J4 Connect a conductor (jumper) from the J4 pin 7 (DEMB) to pin 6 (VDDA) for forced continuous conduction mode or to pin 8 (AGND) for diode-emulation mode

1.2 Required Equipment

- VIN power supply 20V to 60V, at least 200W at the input voltage of board under test, or 10A for the full load off a 20V input
- Electronic load to step for efficiency graphs such as Kikusui PLZ334WL.
- Oscilloscope such as Tektronix MDO34 with TPP0500B 10 × voltage probes
- Digital multimeters such as Fluke 87iii or 87V
- Vector Network Analyzer such as Bode 100 from OMICRON Lab for Bode plots
- Signal generator such as Tektronix AFG3000 series (older) or AFG31000 series (newer): Connect at J100 to apply dynamic loads to the 3.3V output, connect at J200 to apply dynamic loads to the 5V output.
- Mating connectors for J101 and J201 voltage senses and J102 and J202 current senses: Mate each with Amphenol 523-095-850-206-024 or equivalent which then mates with BNC male to male cable to scope input.
- Thermal camera such as FLIR E75
- Data acquisition & switch unit such as Keysight 34970, along with calibrated 10A and 25A current shunts for efficiency measurements
- CISPR 25 copper top table, 5uH line impedance stabilization networks LISNs, pre-compliance ESRP3 EMI receiver such as R and S ESRP3, "48V" battery for input power for conducted emissions measurements

1.3 Considerations

When testing for steady-state loads above 15A for more than a few seconds, use a fan blowing on the board.

1.4 Dimensions

The dimensions of the board are 4in × 4in.

1.5 Test Setup

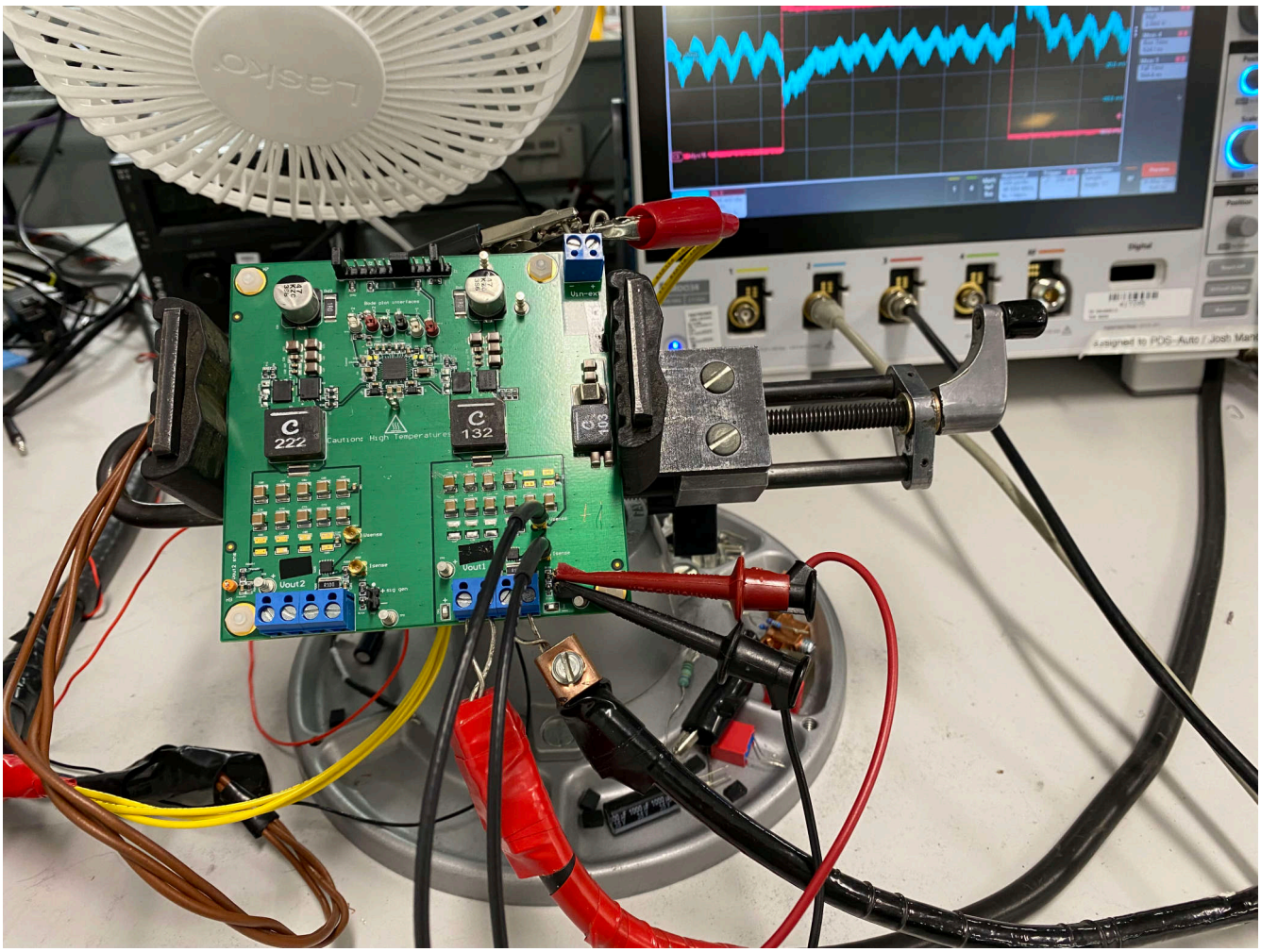


Figure 1-1. Test Setup

2 Testing and Results

2.1 Efficiency and Loss Graphs

Efficiency and Losses are shown in Figure 2-1 through Figure 2-4.

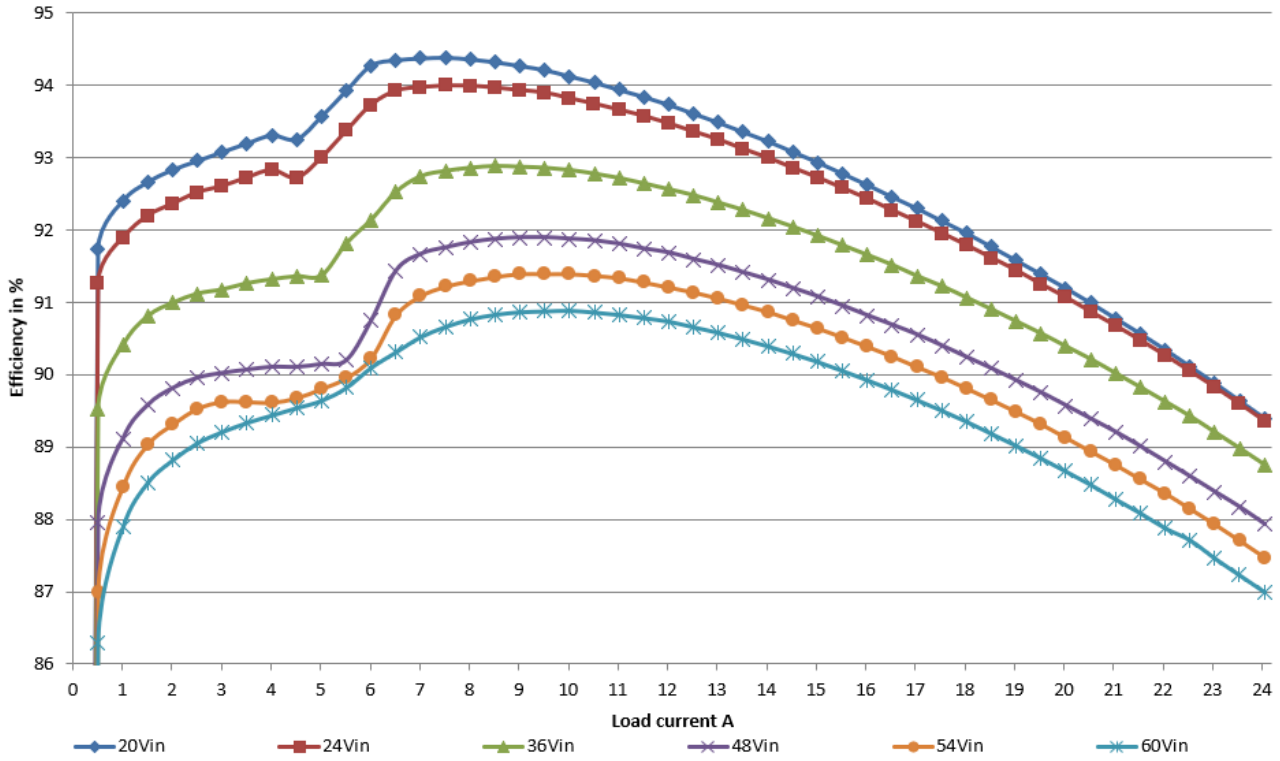


Figure 2-1. Efficiency: 3.3V Output

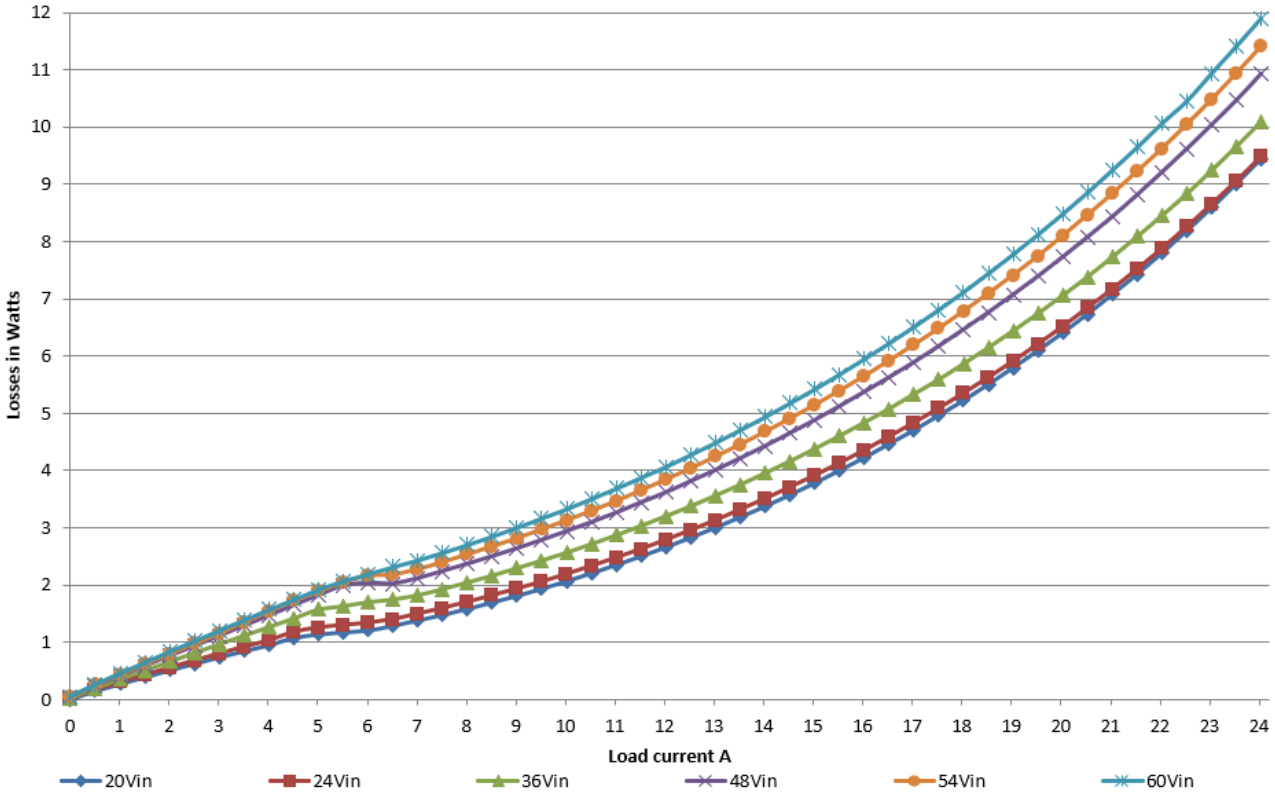


Figure 2-2. Losses: 3.3V Output

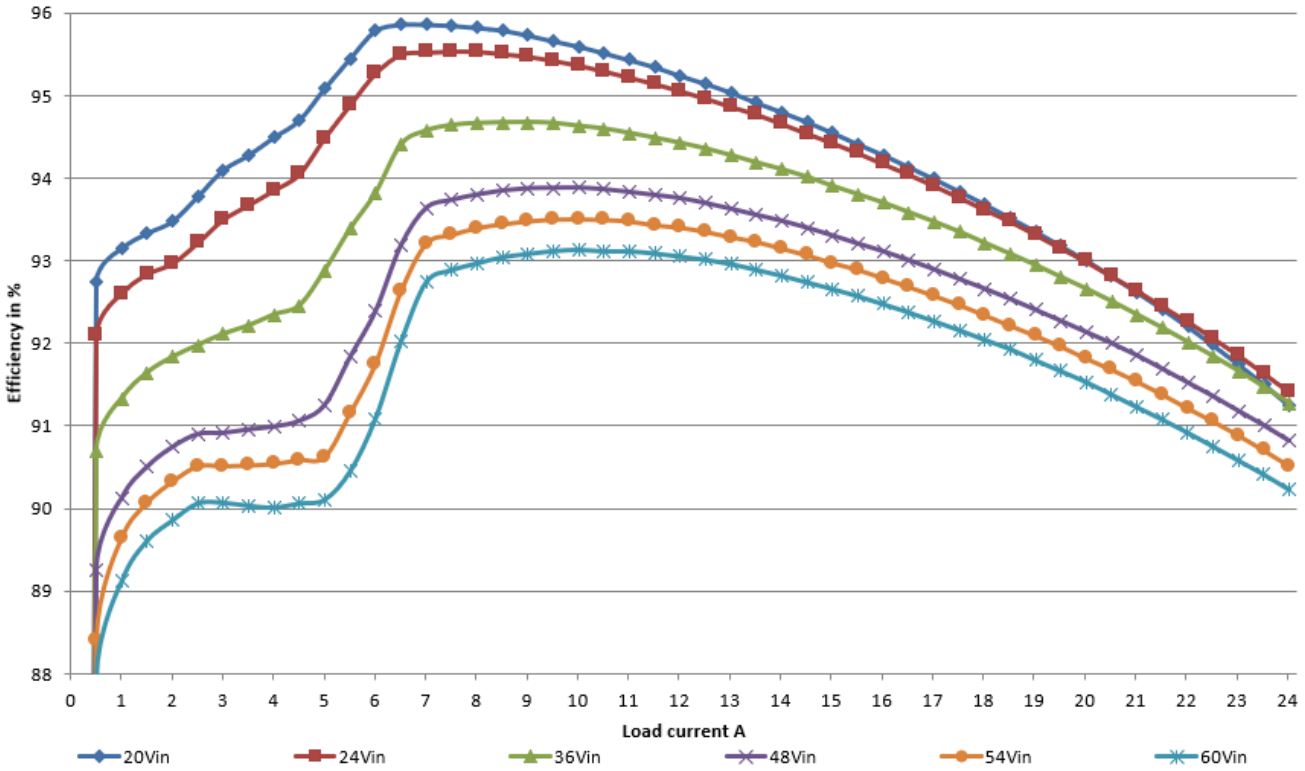


Figure 2-3. Efficiency: 5V Output

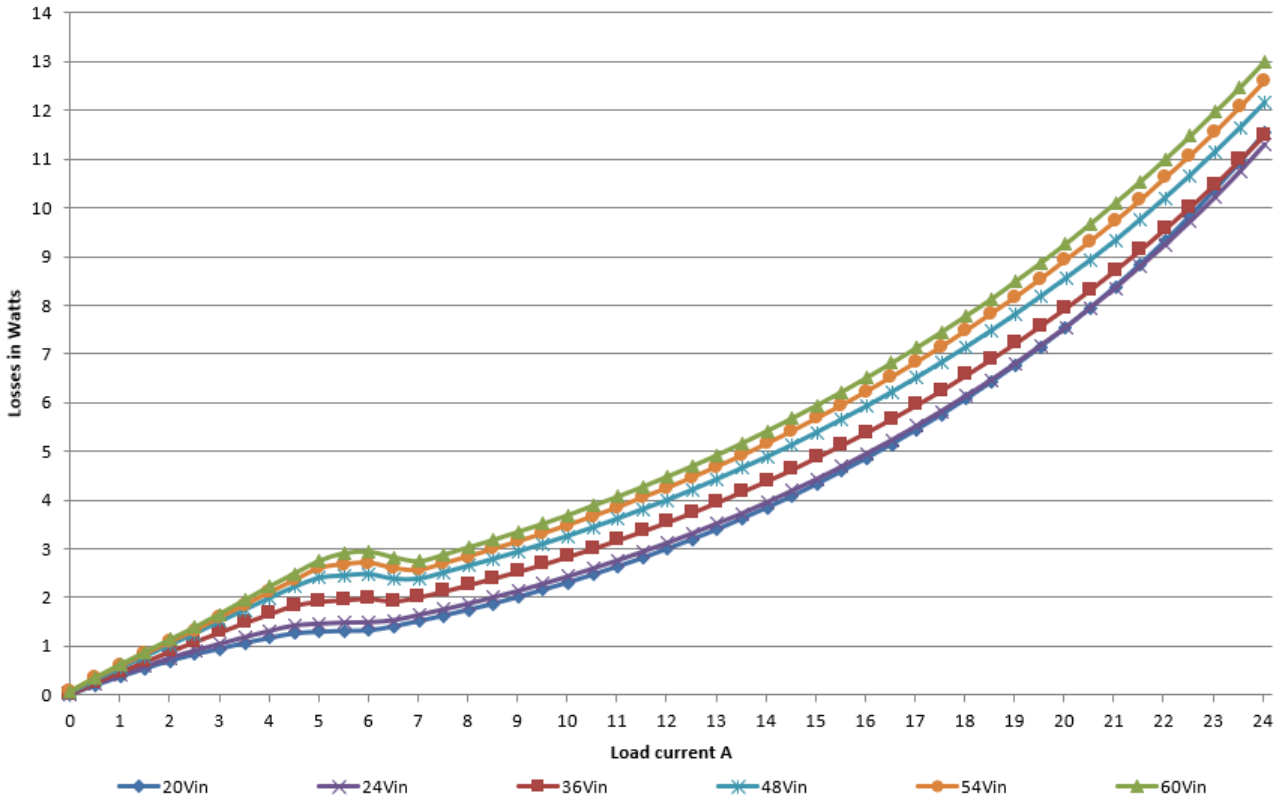


Figure 2-4. Losses: 5V Output

2.2 Efficiency Data

Efficiency and loss data is shown in Table 2-1 through Table 2-12. Both outputs were enabled and were in diode emulation mode. Each scan stepped load from 0A to 24A in 0.5A increments with a delay of 15 seconds before each reading. Model t4 with Cyntec inductors used. Runs were at room ambient with fan cooling at 1-2 meters per second airflow provided. This is the data from which the above graphs were generated. Shown first the 6 scans for the 3.3V wih V_{in} at 20V, 24V, 36V, 48V 54V and 60V. Then the 5V with same V_{in} at 20V, 24V, 36V, 48V 54V and 60V.

Table 2-1. $3.3V_{out}$ - $20V_{in}$

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
19.993	0.000	3.319	0.000	0.000	0.006
19.993	0.092	3.312	0.509	91.728	0.152
19.993	0.181	3.312	1.011	92.395	0.275
19.993	0.270	3.312	1.511	92.659	0.396
19.993	0.359	3.312	2.013	92.830	0.515
19.993	0.448	3.312	2.513	92.952	0.631
19.993	0.536	3.312	3.013	93.076	0.742
19.993	0.624	3.311	3.513	93.194	0.850
19.993	0.713	3.312	4.016	93.307	0.954
19.993	0.802	3.312	4.516	93.252	1.082
19.993	0.888	3.312	5.016	93.566	1.142
19.993	0.973	3.311	5.518	93.924	1.182
19.993	1.057	3.311	6.016	94.270	1.211

Table 2-1. 3.3V_{out} - 20V_{in} (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
19.993	1.144	3.311	6.517	94.344	1.294
19.993	1.231	3.311	7.016	94.368	1.386
19.993	1.319	3.311	7.518	94.379	1.483
19.993	1.407	3.312	8.018	94.356	1.588
19.993	1.496	3.312	8.519	94.317	1.700
19.993	1.585	3.311	9.021	94.265	1.817
19.993	1.674	3.312	9.520	94.207	1.939
19.993	1.764	3.312	10.022	94.122	2.073
19.993	1.853	3.312	10.522	94.034	2.211
19.993	1.944	3.312	11.023	93.933	2.358
19.993	2.034	3.312	11.523	93.836	2.507
19.993	2.125	3.312	12.023	93.727	2.665
19.993	2.216	3.311	12.525	93.604	2.834
19.993	2.308	3.311	13.025	93.481	3.007
19.993	2.400	3.311	13.525	93.350	3.191
19.993	2.492	3.312	14.026	93.221	3.378
19.992	2.586	3.311	14.529	93.075	3.579
19.992	2.679	3.311	15.029	92.931	3.786
19.992	2.772	3.311	15.529	92.775	4.005
19.992	2.867	3.312	16.030	92.620	4.230
19.992	2.962	3.311	16.530	92.453	4.468
19.992	3.057	3.312	17.031	92.295	4.709
19.992	3.152	3.312	17.530	92.121	4.966
19.992	3.249	3.312	18.033	91.951	5.228
19.992	3.346	3.312	18.533	91.763	5.510
19.992	3.443	3.312	19.032	91.575	5.798
19.992	3.541	3.312	19.532	91.385	6.098
19.992	3.640	3.312	20.035	91.191	6.410
19.992	3.739	3.312	20.535	90.988	6.735
19.992	3.839	3.312	21.035	90.775	7.080
19.992	3.939	3.312	21.537	90.563	7.432
19.992	4.041	3.312	22.038	90.343	7.801
19.992	4.143	3.312	22.538	90.112	8.190
19.992	4.246	3.312	23.037	89.881	8.590
19.992	4.350	3.312	23.539	89.637	9.014
19.992	4.455	3.312	24.039	89.396	9.445

Table 2-2. 3.3V_{out} - 24V_{in}

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
23.998	0.000	3.313	0.000	0.000	0.010
23.998	0.077	3.312	0.509	91.260	0.162
23.998	0.152	3.312	1.011	91.880	0.296
23.998	0.226	3.312	1.511	92.193	0.424
23.998	0.301	3.312	2.013	92.358	0.552
23.998	0.375	3.312	2.514	92.515	0.674
23.998	0.449	3.312	3.013	92.602	0.797
23.998	0.523	3.312	3.513	92.721	0.913
23.998	0.597	3.311	4.015	92.823	1.028
23.998	0.672	3.311	4.515	92.716	1.175
23.998	0.744	3.311	5.015	92.998	1.250
23.998	0.815	3.311	5.517	93.368	1.298
23.998	0.886	3.311	6.016	93.725	1.334
23.998	0.957	3.311	6.517	93.919	1.397
23.998	1.030	3.311	7.016	93.968	1.491
23.998	1.104	3.311	7.517	93.991	1.591
23.998	1.177	3.311	8.017	93.988	1.698
23.998	1.251	3.311	8.519	93.961	1.813
23.998	1.325	3.311	9.021	93.926	1.931
23.998	1.399	3.311	9.519	93.892	2.050
23.998	1.474	3.311	10.019	93.814	2.187
23.998	1.549	3.311	10.521	93.738	2.327
23.998	1.624	3.311	11.022	93.655	2.473
23.998	1.699	3.312	11.522	93.569	2.622
23.998	1.775	3.312	12.023	93.466	2.783
23.998	1.852	3.312	12.525	93.353	2.954
23.998	1.928	3.312	13.024	93.243	3.125
23.998	2.004	3.311	13.525	93.112	3.313
23.998	2.081	3.311	14.026	92.990	3.501
23.998	2.159	3.311	14.528	92.851	3.704
23.998	2.237	3.312	15.027	92.718	3.909
23.998	2.315	3.311	15.528	92.573	4.125
23.998	2.393	3.311	16.029	92.426	4.350
23.998	2.472	3.311	16.531	92.265	4.589
23.998	2.551	3.312	17.030	92.112	4.830
23.998	2.631	3.311	17.529	91.949	5.082
23.998	2.711	3.312	18.032	91.783	5.347
23.998	2.792	3.312	18.531	91.609	5.622
23.998	2.872	3.312	19.031	91.435	5.904
23.998	2.954	3.312	19.531	91.245	6.206

Table 2-2. $3.3V_{out}$ - $24V_{in}$ (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
23.998	3.036	3.312	20.033	91.062	6.512
23.998	3.118	3.312	20.533	90.863	6.838
23.998	3.201	3.312	21.033	90.672	7.166
23.998	3.285	3.312	21.536	90.469	7.514
23.998	3.369	3.312	22.036	90.261	7.875
23.998	3.454	3.312	22.536	90.042	8.254
23.998	3.539	3.312	23.035	89.821	8.645
23.998	3.626	3.312	23.538	89.592	9.056
23.998	3.713	3.312	24.037	89.354	9.485

Table 2-3. $3.3V_{out}$ - $36V_{in}$

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
35.998	0.001	3.326	0.000	0.000	0.021
35.998	0.052	3.312	0.510	89.517	0.198
35.998	0.103	3.312	1.011	90.402	0.356
35.998	0.153	3.312	1.511	90.806	0.507
35.998	0.204	3.312	2.014	90.989	0.660
35.998	0.254	3.312	2.513	91.116	0.812
35.998	0.304	3.312	3.013	91.174	0.966
35.998	0.354	3.312	3.513	91.260	1.114
35.998	0.405	3.312	4.016	91.314	1.265
35.998	0.455	3.312	4.516	91.356	1.415
35.998	0.505	3.311	5.017	91.367	1.570
35.998	0.553	3.311	5.518	91.812	1.630
35.998	0.601	3.312	6.017	92.135	1.701
35.998	0.648	3.311	6.518	92.522	1.744
35.998	0.696	3.312	7.016	92.738	1.820
35.998	0.745	3.311	7.518	92.812	1.928
35.998	0.794	3.311	8.019	92.855	2.043
35.998	0.844	3.312	8.519	92.879	2.163
35.998	0.894	3.312	9.022	92.868	2.294
35.998	0.943	3.311	9.521	92.855	2.426
35.998	0.993	3.311	10.021	92.824	2.565
35.998	1.043	3.311	10.522	92.773	2.714
35.998	1.094	3.312	11.024	92.713	2.869
35.998	1.144	3.311	11.522	92.638	3.032
35.998	1.195	3.312	12.023	92.558	3.201
35.998	1.246	3.312	12.526	92.475	3.375
35.998	1.297	3.312	13.026	92.373	3.561
35.998	1.348	3.311	13.525	92.271	3.751

Table 2-3. 3.3V_{out} - 36V_{in} (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
35.998	1.400	3.311	14.027	92.157	3.953
35.998	1.452	3.311	14.529	92.039	4.162
35.998	1.504	3.312	15.029	91.915	4.378
35.998	1.556	3.311	15.529	91.783	4.604
35.998	1.609	3.312	16.030	91.649	4.837
35.998	1.662	3.312	16.533	91.512	5.078
35.998	1.715	3.311	17.031	91.359	5.335
35.998	1.768	3.312	17.532	91.219	5.589
35.998	1.822	3.312	18.034	91.059	5.864
35.998	1.876	3.312	18.534	90.898	6.146
35.998	1.930	3.312	19.033	90.732	6.439
35.998	1.984	3.312	19.533	90.566	6.739
35.998	2.039	3.312	20.035	90.386	7.058
35.997	2.094	3.312	20.535	90.210	7.381
35.998	2.150	3.312	21.035	90.016	7.727
35.997	2.206	3.312	21.537	89.820	8.084
35.997	2.262	3.312	22.038	89.623	8.451
35.997	2.319	3.312	22.538	89.422	8.830
35.997	2.376	3.312	23.038	89.200	9.238
35.997	2.434	3.312	23.540	88.978	9.658
35.997	2.492	3.312	24.039	88.752	10.090

Table 2-4. 3.3V_{out} - 48V_{in}

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
47.996	0.001	3.321	0.000	0.000	0.035
47.996	0.040	3.312	0.510	87.953	0.232
47.996	0.078	3.312	1.011	89.111	0.409
47.996	0.116	3.312	1.511	89.577	0.582
47.996	0.155	3.312	2.014	89.809	0.757
47.996	0.193	3.312	2.514	89.951	0.930
47.995	0.231	3.312	3.014	90.017	1.107
47.996	0.269	3.312	3.514	90.062	1.284
47.996	0.308	3.312	4.016	90.101	1.461
47.996	0.346	3.312	4.517	90.099	1.644
47.995	0.384	3.312	5.017	90.140	1.817
47.996	0.422	3.312	5.518	90.194	1.987
47.995	0.458	3.312	6.017	90.742	2.033
47.995	0.492	3.312	6.517	91.433	2.022
47.995	0.528	3.312	7.016	91.663	2.113
47.995	0.565	3.312	7.518	91.752	2.238

Table 2-4. 3.3V_{out} - 48V_{in} (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
47.995	0.602	3.312	8.018	91.824	2.364
47.995	0.640	3.311	8.520	91.870	2.497
47.995	0.677	3.311	9.021	91.891	2.636
47.995	0.715	3.311	9.520	91.892	2.782
47.995	0.752	3.311	10.020	91.873	2.935
47.995	0.790	3.312	10.522	91.849	3.092
47.995	0.829	3.311	11.024	91.803	3.259
47.995	0.867	3.311	11.523	91.735	3.438
47.995	0.905	3.311	12.024	91.682	3.612
47.995	0.944	3.312	12.526	91.590	3.809
47.995	0.982	3.312	13.026	91.509	4.003
47.995	1.021	3.311	13.526	91.408	4.210
47.995	1.060	3.311	14.026	91.307	4.422
47.995	1.099	3.311	14.530	91.190	4.648
47.995	1.139	3.311	15.029	91.075	4.877
47.995	1.178	3.312	15.529	90.948	5.119
47.995	1.218	3.311	16.030	90.813	5.370
47.995	1.258	3.312	16.532	90.682	5.625
47.995	1.298	3.312	17.031	90.549	5.887
47.995	1.338	3.311	17.530	90.396	6.168
47.995	1.379	3.311	18.033	90.237	6.461
47.995	1.419	3.312	18.532	90.080	6.758
47.995	1.460	3.312	19.032	89.915	7.069
47.995	1.502	3.312	19.532	89.749	7.388
47.995	1.543	3.312	20.035	89.568	7.728
47.995	1.585	3.312	20.535	89.384	8.076
47.995	1.627	3.312	21.034	89.203	8.432
47.995	1.670	3.312	21.537	89.003	8.813
47.995	1.712	3.312	22.037	88.795	9.210
47.995	1.756	3.312	22.537	88.589	9.615
47.995	1.799	3.312	23.036	88.376	10.035
47.995	1.842	3.312	23.539	88.165	10.465
47.995	1.887	3.312	24.038	87.930	10.929

Table 2-5. 3.3V_{out} - 54V_{in}

Vin V	Iin A	Vout V	Iout A	eff %	loss W
53.995	0.001	3.321	0.000	0.000	0.044
53.995	0.036	3.312	0.514	86.995	0.255
53.995	0.070	3.312	1.015	88.442	0.439
53.995	0.104	3.312	1.515	89.032	0.618

Table 2-5. 3.3V_{out} - 54V_{in} (continued)

Vin V	Iin A	Vout V	Iout A	eff %	loss W
53.995	0.139	3.312	2.017	89.309	0.800
53.995	0.172	3.312	2.517	89.525	0.975
53.995	0.206	3.312	3.016	89.623	1.157
53.995	0.241	3.312	3.517	89.620	1.349
53.995	0.275	3.312	4.019	89.611	1.543
53.995	0.309	3.312	4.518	89.674	1.723
53.995	0.343	3.312	5.017	89.800	1.888
53.995	0.376	3.312	5.520	89.950	2.042
53.995	0.409	3.312	6.018	90.224	2.160
53.995	0.440	3.312	6.519	90.817	2.183
53.995	0.473	3.312	7.018	91.082	2.275
53.995	0.506	3.312	7.519	91.214	2.398
53.995	0.539	3.312	8.019	91.290	2.534
53.995	0.572	3.312	8.520	91.347	2.673
53.995	0.606	3.312	9.022	91.388	2.816
53.995	0.639	3.312	9.521	91.387	2.972
53.995	0.673	3.312	10.021	91.388	3.127
53.995	0.706	3.312	10.523	91.364	3.294
53.995	0.740	3.311	11.024	91.331	3.465
53.995	0.774	3.311	11.523	91.270	3.650
53.995	0.808	3.312	12.023	91.203	3.840
53.995	0.843	3.312	12.526	91.134	4.036
53.995	0.877	3.312	13.025	91.050	4.240
53.995	0.912	3.312	13.525	90.957	4.453
53.995	0.947	3.312	14.026	90.863	4.671
53.995	0.982	3.312	14.529	90.748	4.905
53.995	1.017	3.312	15.028	90.637	5.142
53.995	1.052	3.312	15.529	90.513	5.390
53.995	1.088	3.312	16.029	90.384	5.647
53.995	1.123	3.312	16.531	90.248	5.916
53.995	1.159	3.312	17.031	90.103	6.195
53.995	1.195	3.312	17.530	89.962	6.478
53.995	1.232	3.312	18.033	89.805	6.780
53.995	1.268	3.312	18.533	89.646	7.089
53.995	1.305	3.312	19.032	89.482	7.409
53.995	1.341	3.312	19.532	89.313	7.741
53.995	1.379	3.312	20.034	89.124	8.097
53.995	1.416	3.312	20.534	88.935	8.460
53.995	1.454	3.312	21.033	88.750	8.830
53.995	1.492	3.312	21.536	88.550	9.222

Table 2-5. 3.3V_{out} - 54V_{in} (continued)

Vin V	Iin A	Vout V	Iout A	eff %	loss W
53.995	1.530	3.312	22.038	88.356	9.619
53.994	1.568	3.312	22.537	88.142	10.041
53.994	1.607	3.312	23.036	87.928	10.474
53.994	1.646	3.312	23.539	87.702	10.932
53.994	1.686	3.312	24.038	87.472	11.403

Table 2-6. 3.3V_{out} - 60V_{in}

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
59.994	0.001	3.326	0.000	0.000	0.052
59.994	0.033	3.312	0.510	86.284	0.269
59.994	0.064	3.311	1.012	87.891	0.462
59.994	0.094	3.312	1.512	88.508	0.650
59.994	0.125	3.312	2.014	88.819	0.839
59.994	0.156	3.312	2.514	89.056	1.023
59.994	0.186	3.312	3.014	89.210	1.207
59.994	0.217	3.312	3.514	89.337	1.389
59.994	0.248	3.312	4.016	89.440	1.570
59.994	0.278	3.312	4.516	89.542	1.747
59.994	0.309	3.312	5.016	89.642	1.919
59.994	0.339	3.312	5.517	89.820	2.071
59.994	0.369	3.312	6.016	90.098	2.190
59.994	0.398	3.312	6.517	90.311	2.315
59.994	0.428	3.312	7.017	90.522	2.433
59.994	0.458	3.312	7.518	90.663	2.564
59.994	0.488	3.312	8.018	90.767	2.701
59.994	0.518	3.312	8.519	90.831	2.848
59.994	0.548	3.312	9.021	90.867	3.003
59.994	0.578	3.312	9.521	90.878	3.165
59.994	0.609	3.312	10.021	90.887	3.328
59.994	0.639	3.312	10.522	90.863	3.504
59.994	0.670	3.312	11.024	90.829	3.686
59.994	0.701	3.311	11.523	90.784	3.874
59.994	0.731	3.312	12.024	90.737	4.065
59.994	0.763	3.311	12.526	90.658	4.275
59.994	0.794	3.312	13.025	90.581	4.485
59.994	0.825	3.312	13.526	90.491	4.707
59.994	0.856	3.311	14.026	90.393	4.936
59.994	0.888	3.312	14.528	90.288	5.175
59.994	0.920	3.312	15.028	90.179	5.420
59.994	0.952	3.312	15.528	90.055	5.679

Table 2-6. 3.3V_{out} - 60V_{in} (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
59.994	0.984	3.312	16.029	89.925	5.947
59.994	1.016	3.312	16.531	89.791	6.224
59.994	1.049	3.312	17.031	89.651	6.511
59.994	1.081	3.312	17.530	89.504	6.808
59.994	1.114	3.312	18.032	89.351	7.117
59.994	1.147	3.312	18.533	89.184	7.443
59.994	1.180	3.312	19.032	89.018	7.776
59.994	1.214	3.312	19.532	88.845	8.122
59.994	1.247	3.312	20.035	88.663	8.484
59.994	1.281	3.312	20.534	88.479	8.855
59.994	1.315	3.312	21.033	88.280	9.248
59.994	1.350	3.312	21.536	88.086	9.647
59.994	1.384	3.312	22.037	87.879	10.067
59.994	1.418	3.312	22.537	87.714	10.455
59.994	1.454	3.312	23.036	87.463	10.937
59.994	1.490	3.312	23.538	87.228	11.415
59.994	1.526	3.312	24.038	86.997	11.900

Table 2-7. 5V_{out} - 20V_{in}

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
19.993	0.000	5.007	0.000	0.000	0.007
19.993	0.138	4.996	0.511	92.744	0.200
19.993	0.272	4.996	1.013	93.147	0.372
19.993	0.405	4.996	1.513	93.335	0.540
19.993	0.538	4.995	2.015	93.480	0.702
19.993	0.670	4.995	2.515	93.781	0.833
19.993	0.800	4.995	3.015	94.099	0.944
19.993	0.931	4.995	3.514	94.280	1.065
19.993	1.062	4.995	4.017	94.497	1.168
19.993	1.192	4.995	4.517	94.704	1.262
19.993	1.318	4.995	5.017	95.090	1.294
19.993	1.444	4.995	5.518	95.450	1.314
19.993	1.570	4.995	6.018	95.785	1.323
19.993	1.699	4.995	6.518	95.860	1.406
19.993	1.829	4.995	7.018	95.862	1.513
19.993	1.960	4.995	7.518	95.850	1.626
19.993	2.091	4.995	8.018	95.823	1.746
19.993	2.222	4.995	8.519	95.791	1.870
19.993	2.354	4.995	9.022	95.732	2.009
19.992	2.486	4.995	9.521	95.662	2.156

Table 2-7. $5V_{out}$ - $20V_{in}$ (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
19.992	2.619	4.995	10.021	95.598	2.305
19.992	2.752	4.995	10.523	95.517	2.467
19.992	2.886	4.995	11.025	95.433	2.635
19.992	3.020	4.996	11.523	95.348	2.808
19.992	3.155	4.996	12.024	95.243	3.000
19.992	3.290	4.996	12.527	95.145	3.193
19.992	3.425	4.996	13.025	95.041	3.396
19.992	3.561	4.996	13.526	94.918	3.618
19.992	3.698	4.996	14.027	94.804	3.841
19.992	3.835	4.996	14.531	94.684	4.076
19.992	3.973	4.996	15.030	94.552	4.327
19.992	4.111	4.997	15.530	94.415	4.590
19.992	4.250	4.997	16.032	94.284	4.857
19.992	4.389	4.997	16.533	94.139	5.144
19.992	4.529	4.997	17.032	93.995	5.438
19.992	4.670	4.997	17.533	93.843	5.748
19.992	4.812	4.998	18.035	93.687	6.073
19.992	4.954	4.998	18.534	93.522	6.416
19.992	5.097	4.998	19.034	93.359	6.767
19.992	5.241	4.998	19.534	93.183	7.143
19.992	5.386	4.998	20.037	93.007	7.530
19.992	5.532	4.998	20.536	92.817	7.943
19.992	5.679	4.999	21.036	92.623	8.375
19.992	5.828	4.999	21.538	92.418	8.833
19.992	5.977	5.000	22.039	92.207	9.313
19.992	6.128	5.000	22.539	91.980	9.825
19.992	6.280	5.000	23.038	91.750	10.358
19.992	6.435	5.001	23.541	91.507	10.927
19.992	6.591	5.001	24.041	91.248	11.533

Table 2-8. $5V_{out}$ - $24V_{in}$

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
23.998	0.000	5.001	0.000	0.000	0.009
23.998	0.116	4.994	0.512	92.093	0.219
23.998	0.228	4.994	1.013	92.602	0.404
23.998	0.339	4.994	1.514	92.841	0.583
23.998	0.451	4.994	2.016	92.971	0.761
23.998	0.562	4.994	2.515	93.222	0.913
23.998	0.671	4.994	3.016	93.501	1.047
23.998	0.781	4.994	3.516	93.677	1.185

Table 2-8. $5V_{out}$ - $24V_{in}$ (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
23.998	0.891	4.994	4.018	93.857	1.313
23.998	1.000	4.994	4.519	94.052	1.427
23.998	1.105	4.993	5.018	94.489	1.461
23.998	1.210	4.994	5.520	94.889	1.485
23.998	1.315	4.994	6.019	95.271	1.492
23.998	1.421	4.994	6.520	95.500	1.534
23.998	1.529	4.994	7.019	95.526	1.642
23.998	1.638	4.994	7.521	95.539	1.754
23.998	1.747	4.994	8.020	95.537	1.871
23.998	1.857	4.995	8.521	95.507	2.002
23.998	1.967	4.995	9.024	95.476	2.135
23.998	2.077	4.995	9.524	95.427	2.280
23.998	2.188	4.995	10.024	95.370	2.431
23.998	2.299	4.995	10.524	95.299	2.593
23.998	2.410	4.995	11.026	95.223	2.763
23.998	2.521	4.995	11.525	95.147	2.936
23.998	2.633	4.995	12.025	95.060	3.121
23.998	2.746	4.995	12.528	94.970	3.315
23.998	2.858	4.995	13.027	94.870	3.519
23.998	2.971	4.996	13.527	94.777	3.724
23.998	3.085	4.996	14.028	94.662	3.952
23.998	3.200	4.996	14.531	94.545	4.189
23.998	3.314	4.996	15.031	94.430	4.429
23.998	3.429	4.996	15.532	94.308	4.683
23.998	3.544	4.996	16.032	94.176	4.953
23.998	3.660	4.997	16.534	94.049	5.227
23.998	3.777	4.997	17.033	93.912	5.517
23.998	3.893	4.997	17.533	93.769	5.822
23.998	4.011	4.997	18.036	93.622	6.140
23.998	4.129	4.997	18.535	93.480	6.461
23.998	4.248	4.997	19.035	93.321	6.809
23.998	4.367	4.997	19.534	93.156	7.172
23.998	4.488	4.998	20.037	92.995	7.544
23.997	4.608	4.998	20.537	92.815	7.946
23.997	4.730	4.998	21.036	92.643	8.350
23.997	4.853	4.999	21.539	92.450	8.792
23.998	4.976	5.000	22.039	92.267	9.235
23.997	5.100	4.999	22.540	92.066	9.711
23.997	5.226	5.000	23.039	91.860	10.207
23.997	5.353	5.000	23.542	91.641	10.737

Table 2-8. $5V_{out}$ - $24V_{in}$ (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
23.997	5.480	5.001	24.040	91.415	11.289

Table 2-9. $5V_{out}$ - $36V_{in}$

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
35.998	0.001	5.005	0.000	0.000	0.022
35.998	0.078	4.994	0.511	90.696	0.262
35.998	0.154	4.994	1.012	91.324	0.480
35.998	0.229	4.994	1.512	91.641	0.689
35.998	0.304	4.994	2.014	91.831	0.895
35.998	0.379	4.994	2.514	91.974	1.096
35.998	0.454	4.994	3.014	92.110	1.289
35.998	0.529	4.994	3.514	92.210	1.483
35.998	0.603	4.995	4.016	92.345	1.663
35.998	0.678	4.994	4.516	92.454	1.841
35.998	0.749	4.994	5.015	92.878	1.921
35.998	0.820	4.994	5.517	93.382	1.953
35.998	0.890	4.994	6.016	93.814	1.981
35.998	0.958	4.994	6.516	94.400	1.930
35.998	1.029	4.994	7.016	94.570	2.012
35.998	1.102	4.995	7.518	94.638	2.128
35.998	1.175	4.995	8.018	94.662	2.258
35.998	1.248	4.994	8.519	94.671	2.395
35.998	1.322	4.995	9.022	94.674	2.535
35.998	1.395	4.995	9.521	94.663	2.681
35.998	1.469	4.994	10.021	94.628	2.841
35.998	1.543	4.994	10.523	94.594	3.003
35.998	1.618	4.995	11.025	94.541	3.179
35.998	1.692	4.995	11.524	94.484	3.361
35.998	1.767	4.995	12.024	94.423	3.548
35.998	1.842	4.995	12.526	94.354	3.744
35.998	1.917	4.995	13.026	94.272	3.953
35.997	1.993	4.995	13.526	94.185	4.172
35.997	2.069	4.996	14.027	94.103	4.391
35.997	2.145	4.996	14.530	94.010	4.625
35.997	2.221	4.995	15.030	93.900	4.878
35.997	2.298	4.996	15.530	93.800	5.128
35.997	2.375	4.996	16.031	93.698	5.387
35.997	2.452	4.996	16.533	93.582	5.665
35.997	2.529	4.996	17.032	93.468	5.947
35.997	2.607	4.997	17.533	93.346	6.245

Table 2-9. $5V_{out}$ - $36V_{in}$ (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
35.997	2.686	4.997	18.035	93.210	6.565
35.997	2.764	4.997	18.534	93.079	6.887
35.997	2.843	4.997	19.034	92.943	7.222
35.997	2.922	4.997	19.534	92.798	7.575
35.997	3.002	4.997	20.036	92.656	7.936
35.997	3.082	4.998	20.536	92.505	8.316
35.997	3.163	4.998	21.036	92.344	8.717
35.997	3.244	4.998	21.539	92.182	9.130
35.997	3.326	4.998	22.039	92.012	9.564
35.997	3.408	4.999	22.539	91.840	10.011
35.997	3.491	4.999	23.038	91.662	10.477
35.997	3.574	4.999	23.540	91.468	10.977
35.997	3.658	5.000	24.039	91.275	11.489

Table 2-10. $5V_{out}$ - $48V_{in}$

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
47.996	0.001	5.006	0.000	0.000	0.038
47.996	0.060	4.995	0.511	89.249	0.308
47.996	0.117	4.994	1.012	90.124	0.554
47.996	0.174	4.994	1.512	90.502	0.792
47.995	0.231	4.994	2.014	90.743	1.026
47.996	0.288	4.994	2.514	90.900	1.257
47.995	0.345	4.994	3.015	90.913	1.505
47.995	0.402	4.994	3.515	90.955	1.746
47.995	0.459	4.994	4.017	90.990	1.987
47.995	0.516	4.994	4.518	91.059	2.215
47.995	0.572	4.994	5.017	91.254	2.402
47.996	0.625	4.994	5.519	91.834	2.451
47.995	0.678	4.994	6.019	92.389	2.476
47.995	0.728	4.994	6.519	93.183	2.382
47.995	0.780	4.995	7.018	93.636	2.382
47.995	0.835	4.995	7.520	93.734	2.511
47.995	0.890	4.995	8.020	93.799	2.648
47.995	0.945	4.995	8.521	93.848	2.790
47.995	1.000	4.995	9.023	93.875	2.940
47.995	1.056	4.995	9.522	93.880	3.100
47.995	1.111	4.995	10.023	93.883	3.262
47.995	1.167	4.995	10.524	93.863	3.437
47.995	1.223	4.995	11.025	93.831	3.620
47.995	1.279	4.995	11.524	93.793	3.809

Table 2-10. $5V_{out}$ - $48V_{in}$ (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
47.995	1.335	4.995	12.026	93.756	4.000
47.995	1.392	4.995	12.528	93.696	4.210
47.995	1.448	4.995	13.027	93.627	4.429
47.995	1.505	4.995	13.527	93.554	4.656
47.995	1.562	4.995	14.028	93.482	4.885
47.995	1.619	4.995	14.531	93.398	5.131
47.995	1.677	4.996	15.031	93.304	5.389
47.995	1.734	4.995	15.531	93.206	5.656
47.995	1.792	4.996	16.032	93.112	5.925
47.995	1.850	4.996	16.533	93.006	6.211
47.995	1.909	4.996	17.033	92.895	6.508
47.995	1.967	4.996	17.532	92.776	6.820
47.995	2.026	4.996	18.035	92.659	7.139
47.995	2.085	4.996	18.535	92.535	7.471
47.995	2.145	4.997	19.035	92.405	7.818
47.995	2.204	4.996	19.535	92.270	8.177
47.995	2.264	4.997	20.038	92.133	8.548
47.995	2.324	4.997	20.537	91.999	8.925
47.995	2.385	4.997	21.037	91.852	9.325
47.995	2.446	4.997	21.539	91.689	9.756
47.995	2.507	4.997	22.040	91.523	10.201
47.995	2.569	4.998	22.540	91.357	10.657
47.995	2.631	4.998	23.039	91.180	11.138
47.995	2.694	4.998	23.542	91.004	11.632
47.995	2.757	4.999	24.040	90.817	12.151

Table 2-11. $5V_{out}$ - $54V_{in}$

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
53.995	0.001	5.006	0.000	0.000	0.056
53.995	0.054	4.995	0.513	88.395	0.336
53.995	0.105	4.995	1.013	89.642	0.585
53.995	0.155	4.995	1.513	90.072	0.833
53.995	0.206	4.994	2.015	90.327	1.078
53.995	0.257	4.993	2.516	90.514	1.317
53.995	0.308	4.993	3.015	90.514	1.578
53.995	0.359	4.993	3.515	90.524	1.837
53.995	0.410	4.993	4.018	90.542	2.096
53.995	0.461	4.993	4.518	90.589	2.343
53.995	0.512	4.993	5.018	90.627	2.592
53.995	0.560	4.993	5.520	91.158	2.673

Table 2-11. $5V_{out}$ - $54V_{in}$ (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
53.995	0.607	4.994	6.018	91.751	2.702
53.995	0.651	4.994	6.519	92.626	2.592
53.995	0.696	4.993	7.018	93.207	2.554
53.995	0.745	4.994	7.519	93.313	2.691
53.995	0.794	4.993	8.018	93.397	2.831
53.995	0.843	4.994	8.520	93.443	2.985
53.995	0.893	4.994	9.022	93.480	3.142
53.995	0.942	4.994	9.521	93.501	3.305
53.995	0.991	4.994	10.021	93.505	3.476
53.995	1.041	4.994	10.523	93.496	3.655
53.995	1.091	4.994	11.025	93.478	3.841
53.995	1.141	4.993	11.523	93.431	4.046
53.995	1.190	4.993	12.024	93.403	4.241
53.995	1.241	4.993	12.527	93.351	4.455
53.995	1.291	4.993	13.026	93.287	4.680
53.995	1.342	4.993	13.526	93.230	4.905
53.995	1.393	4.994	14.027	93.150	5.151
53.995	1.444	4.993	14.530	93.068	5.404
53.994	1.495	4.994	15.030	92.974	5.672
53.995	1.546	4.994	15.530	92.892	5.935
53.994	1.598	4.994	16.031	92.790	6.221
53.994	1.650	4.994	16.532	92.685	6.517
53.994	1.702	4.994	17.032	92.577	6.820
53.994	1.754	4.995	17.531	92.467	7.134
53.994	1.807	4.995	18.034	92.341	7.471
53.994	1.859	4.995	18.534	92.215	7.816
53.994	1.912	4.996	19.034	92.094	8.163
53.994	1.965	4.996	19.533	91.963	8.527
53.994	2.019	4.995	20.036	91.816	8.921
53.994	2.072	4.996	20.536	91.684	9.306
53.994	2.126	4.996	21.035	91.538	9.715
53.994	2.181	4.996	21.538	91.382	10.148
53.994	2.236	4.996	22.039	91.213	10.607
53.994	2.291	4.997	22.539	91.057	11.061
53.994	2.346	4.997	23.039	90.887	11.543
53.994	2.402	4.997	23.541	90.704	12.056
53.994	2.458	4.997	24.040	90.516	12.587

Table 2-12. $5V_{out}$ - $60V_{in}$

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
59.994	0.001	5.010	0.000	0.000	0.065
59.994	0.049	4.995	0.513	87.927	0.352
59.994	0.095	4.994	1.013	89.117	0.618
59.994	0.141	4.994	1.513	89.610	0.876
59.994	0.187	4.993	2.015	89.858	1.135
59.994	0.232	4.993	2.515	90.065	1.385
59.994	0.278	4.992	3.014	90.072	1.659
59.994	0.325	4.992	3.515	90.035	1.942
59.994	0.371	4.993	4.018	90.015	2.225
59.994	0.417	4.993	4.518	90.064	2.488
59.994	0.463	4.993	5.017	90.110	2.749
59.994	0.508	4.992	5.519	90.453	2.908
59.994	0.550	4.992	6.018	91.090	2.938
59.994	0.589	4.992	6.518	92.015	2.824
59.994	0.630	4.992	7.017	92.742	2.742
59.994	0.674	4.992	7.518	92.888	2.874
59.994	0.718	4.992	8.018	92.971	3.027
59.994	0.762	4.992	8.520	93.046	3.179
59.994	0.806	4.992	9.022	93.084	3.346
59.994	0.851	4.993	9.522	93.119	3.513
59.994	0.895	4.992	10.022	93.135	3.688
59.994	0.940	4.992	10.523	93.116	3.883
59.994	0.985	4.992	11.024	93.116	4.069
59.994	1.030	4.993	11.523	93.090	4.270
59.994	1.075	4.992	12.024	93.054	4.481
59.994	1.121	4.992	12.527	93.015	4.696
59.994	1.166	4.992	13.026	92.962	4.923
59.994	1.212	4.992	13.526	92.892	5.167
59.994	1.258	4.992	14.027	92.821	5.416
59.994	1.304	4.992	14.530	92.740	5.679
59.994	1.350	4.993	15.029	92.660	5.944
59.994	1.396	4.993	15.530	92.574	6.220
59.994	1.443	4.993	16.030	92.477	6.510
59.994	1.489	4.993	16.531	92.378	6.811
59.994	1.536	4.993	17.031	92.271	7.124
59.994	1.583	4.994	17.531	92.162	7.445
59.994	1.631	4.994	18.033	92.045	7.783
59.994	1.678	4.994	18.533	91.933	8.122
59.994	1.726	4.994	19.033	91.797	8.494
59.993	1.774	4.994	19.533	91.666	8.869

Table 2-12. $5V_{out}$ - $60V_{in}$ (continued)

V_{in} V	I_{in} A	V_{out} V	I_{out} A	eff %	loss W
59.994	1.823	4.995	20.035	91.533	9.258
59.993	1.871	4.995	20.535	91.382	9.673
59.993	1.920	4.995	21.034	91.230	10.100
59.993	1.969	4.995	21.537	91.079	10.538
59.993	2.018	4.995	22.038	90.920	10.994
59.993	2.068	4.996	22.537	90.754	11.471
59.993	2.118	4.996	23.037	90.583	11.965
59.993	2.168	4.997	23.540	90.414	12.471
59.993	2.219	4.996	24.040	90.230	13.006

2.3 Thermal Images

Thermal images are shown in Figure 2-5 through Figure 2-8.

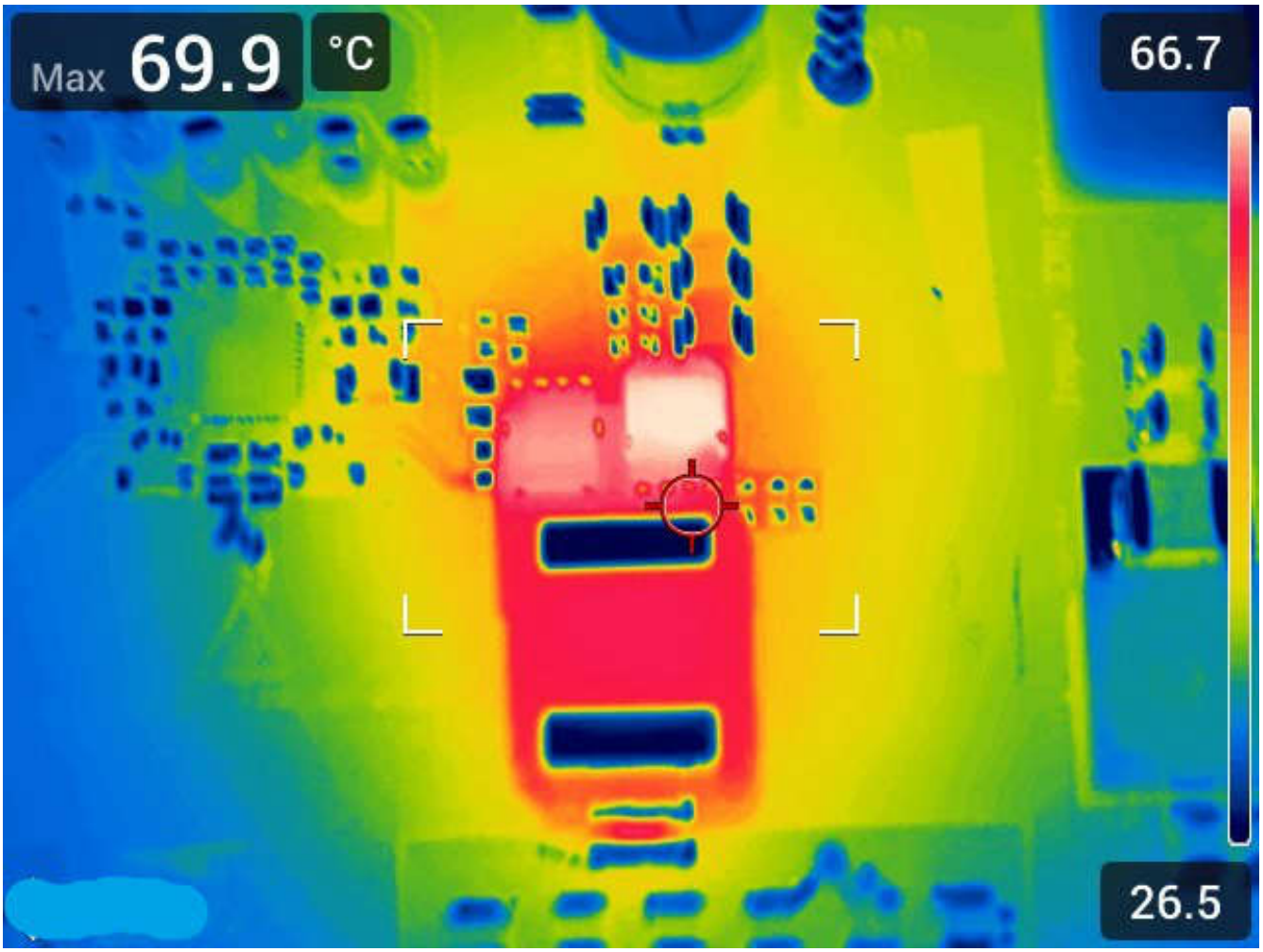


Figure 2-5. 48V_{in} 3.3V 15A Load No Fan - Stabilized

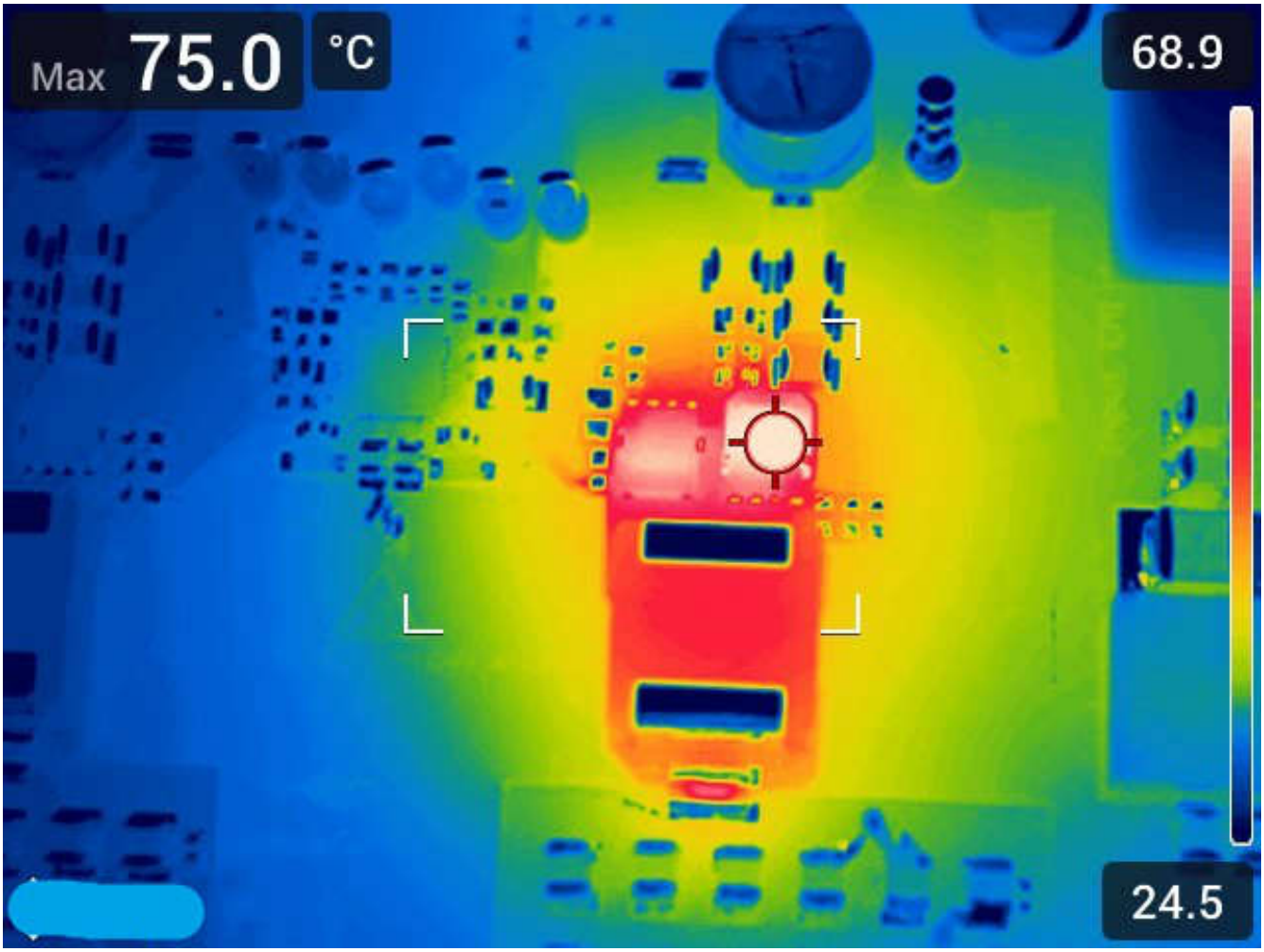


Figure 2-6. 48V_{in} 3.3V 20A Load with Fan - Stabilized

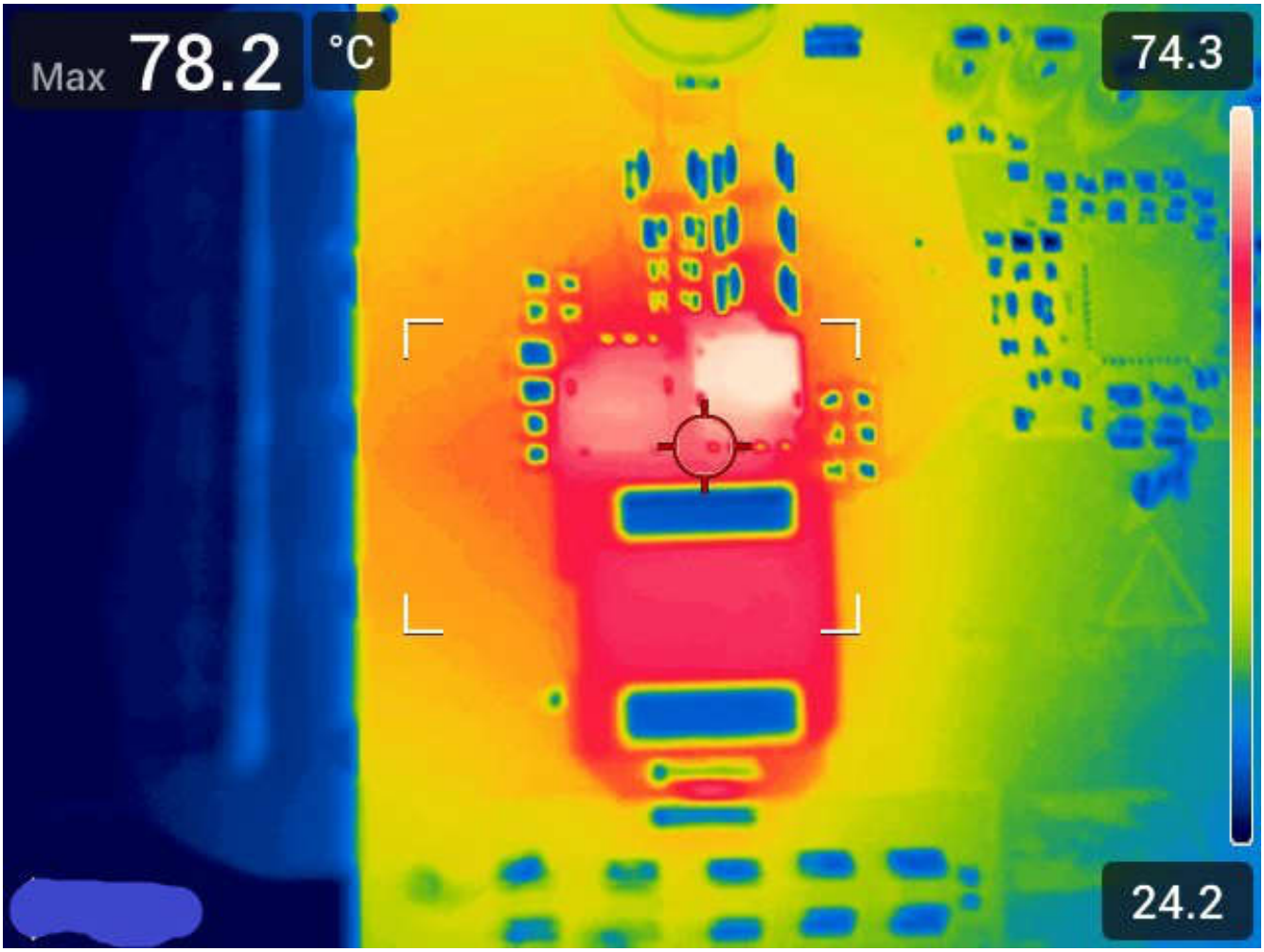


Figure 2-7. 48V_{in} 5V 15A Load No Fan - Stabilized

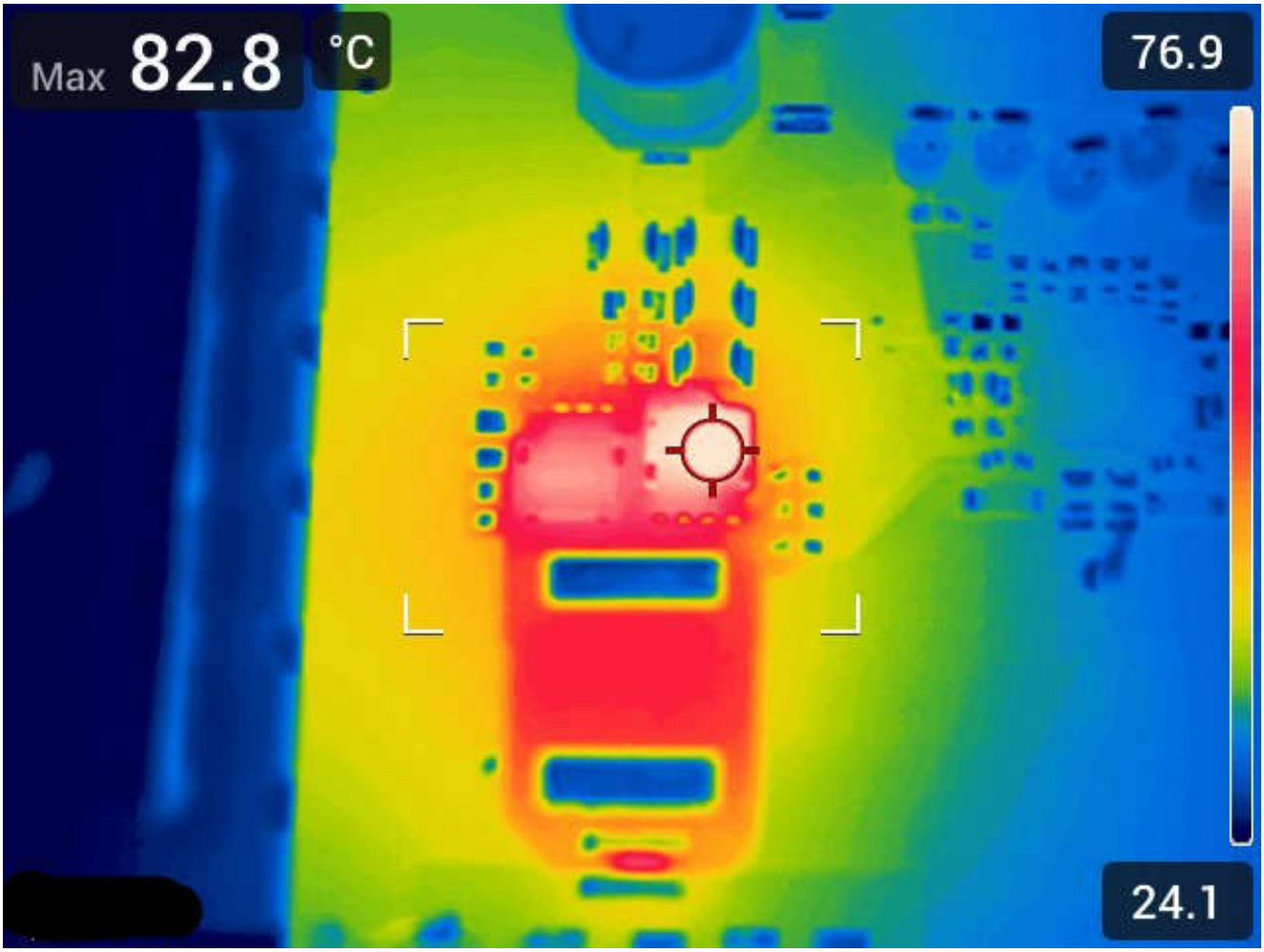


Figure 2-8. 48V_{in} 5V 20A Load With Fan - Stabilized

2.4 Bode Plots

Bode plots for 3.3V and 5V control loops shown in Figure 2-9 and Figure 2-10.

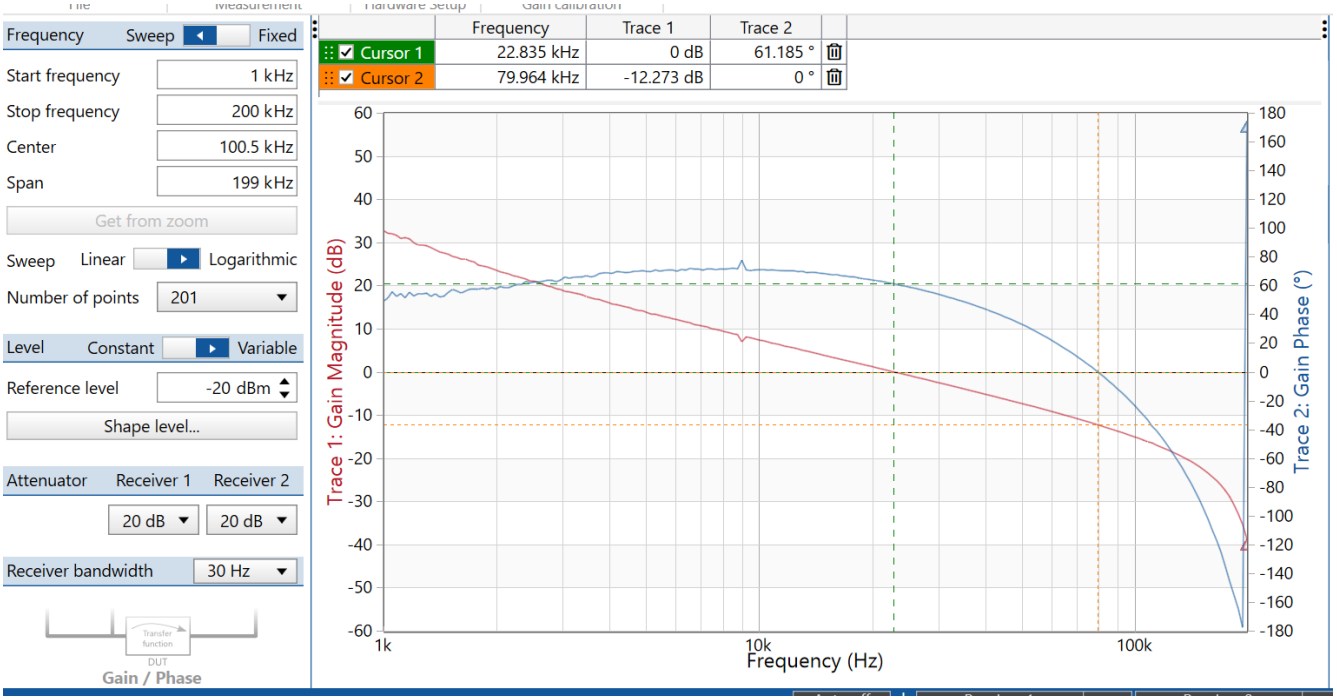


Figure 2-9. 3.3V Output Bode Plot

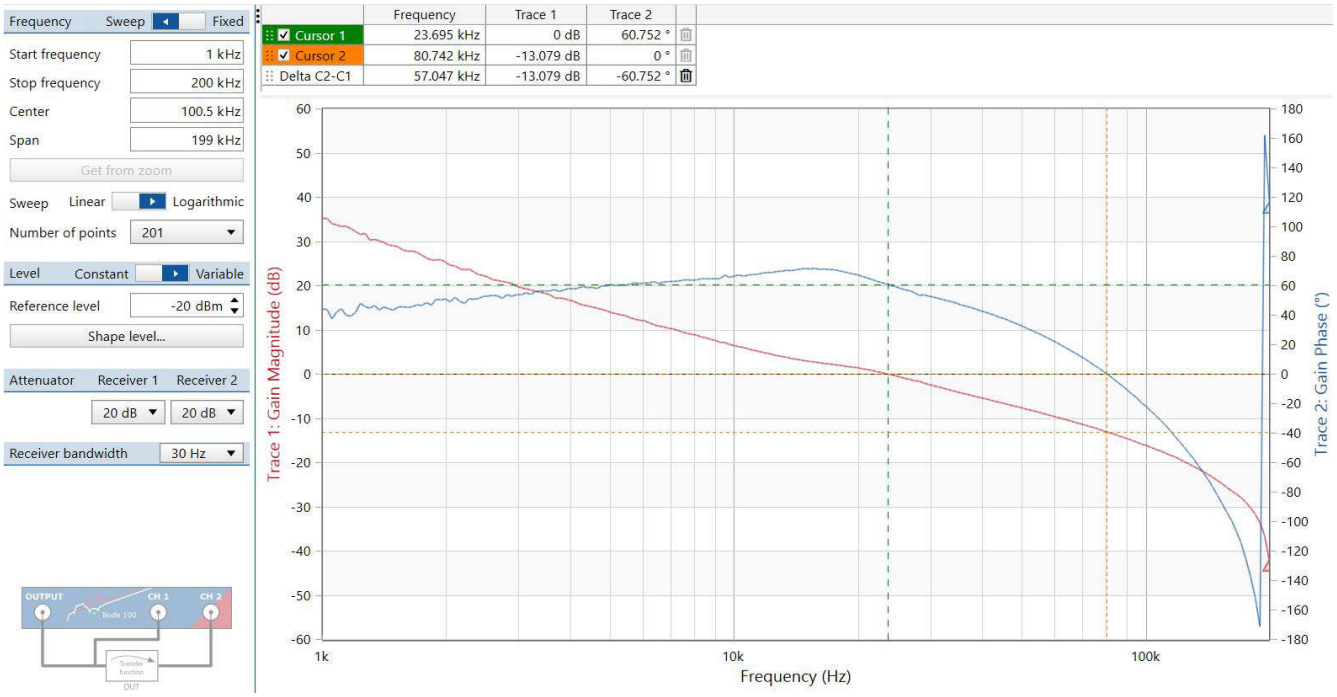
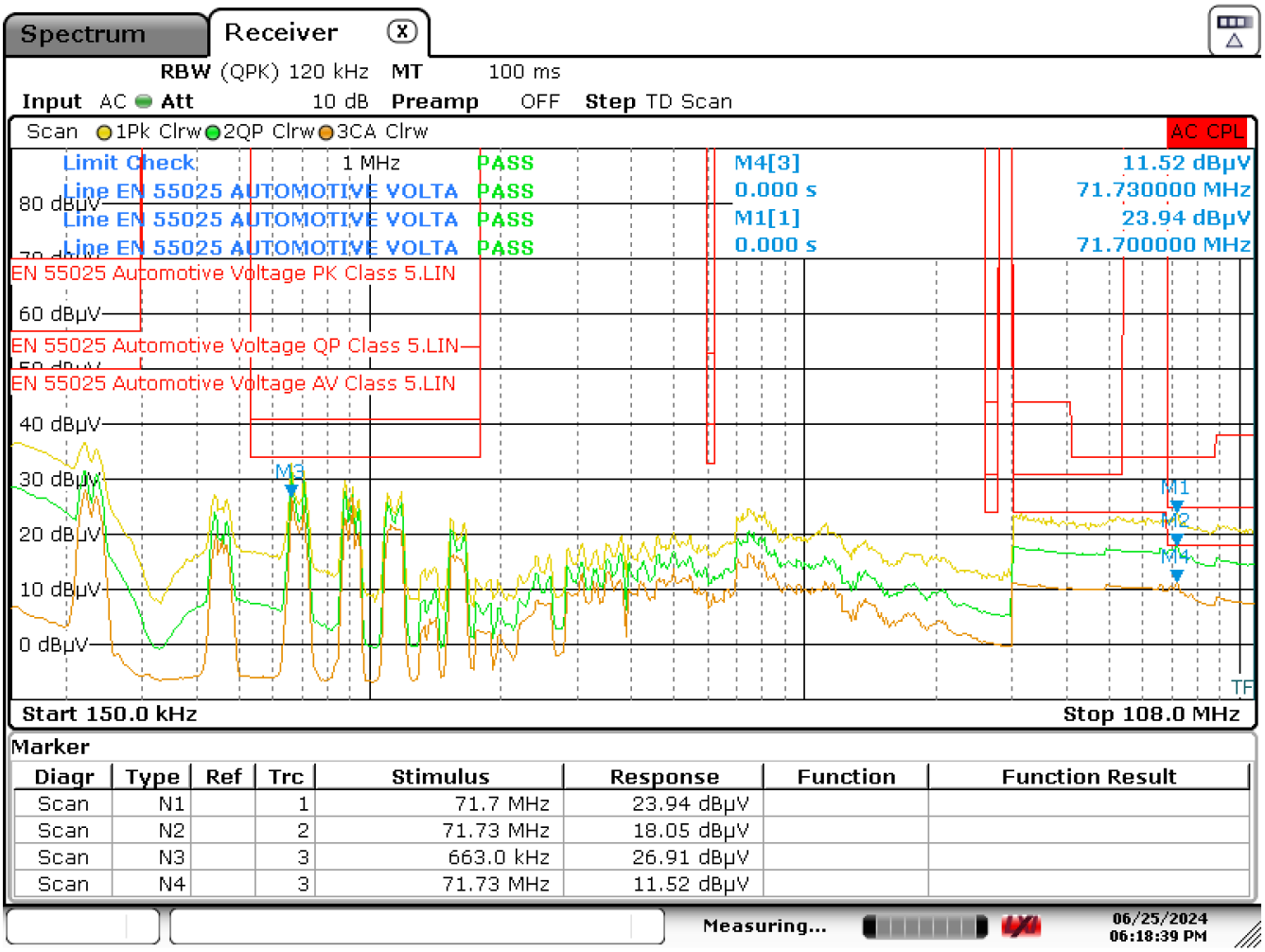


Figure 2-10. 5V Output Bode Plot

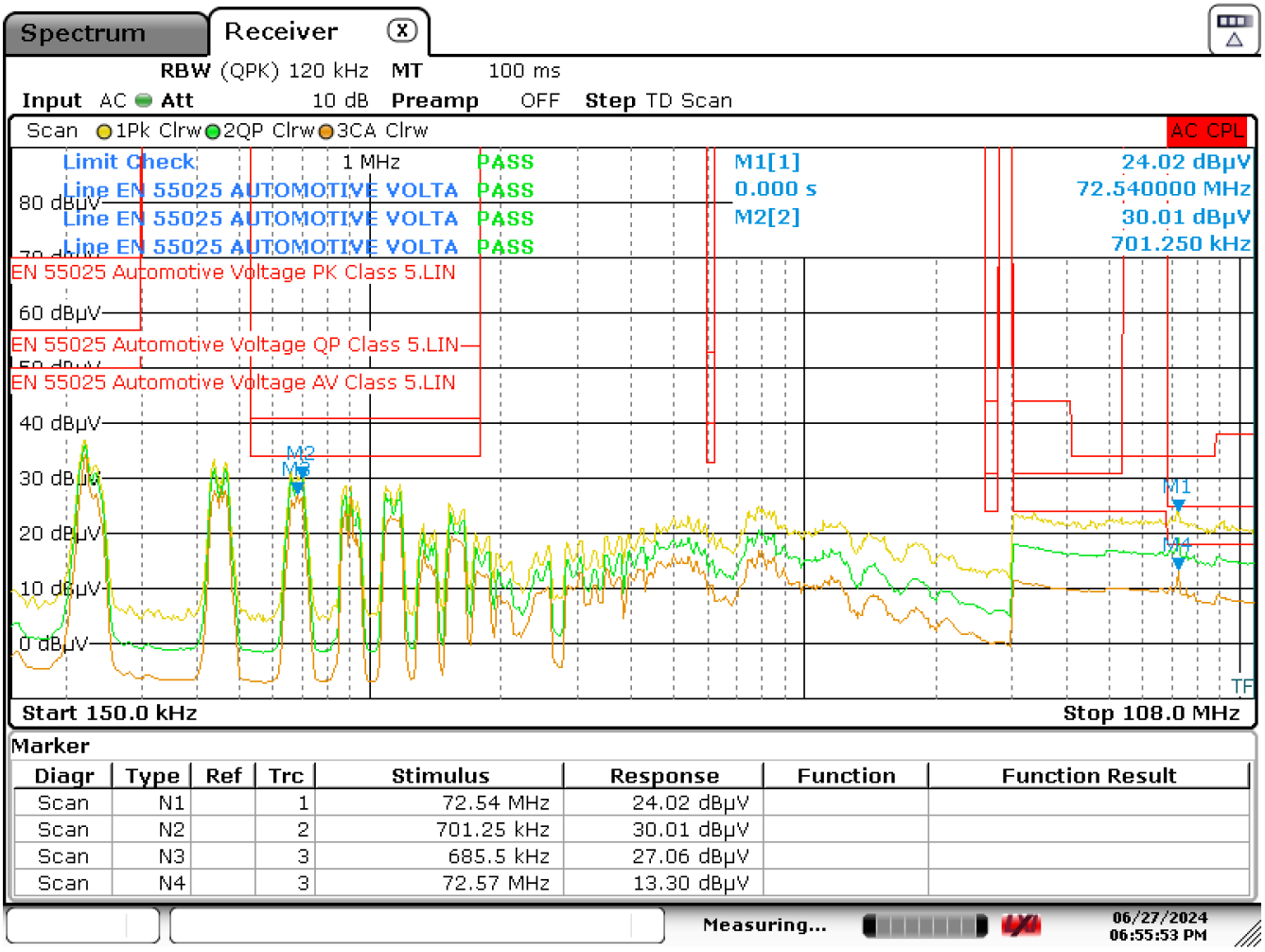
2.5 Conducted Emissions (CISPR 25) Pre-Compliance Scans

Conducted EMI is shown in Figure 2-11 and Figure 2-12.



Date: 25.JUN.2024 18:18:38

Figure 2-11. Precompliance Scan on Model t1 with Coilcraft XGL1350 Inductors



Date: 27.JUN.2024 18:55:54

Figure 2-12. Precompliance Scan on Model t4 with Cyntec VCUD128T Inductors

3 Waveforms

3.1 Output Voltage Ripple

Output voltage ripple is shown in Figure 3-1 and Figure 3-2. About half of the output ripple is due to the 10kHz switching frequency dithering activated to reduce conducted emissions. Overall output ripple is still well under 1% of V_{out}.

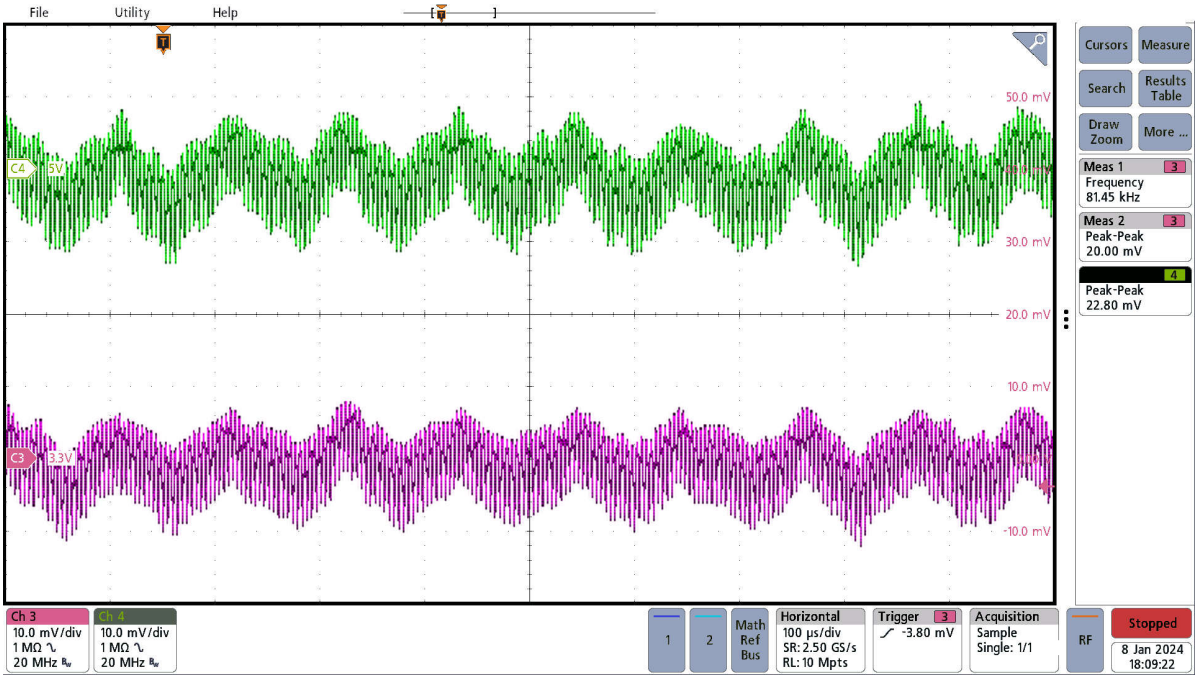


Figure 3-1. 3.3V Loaded to 20A

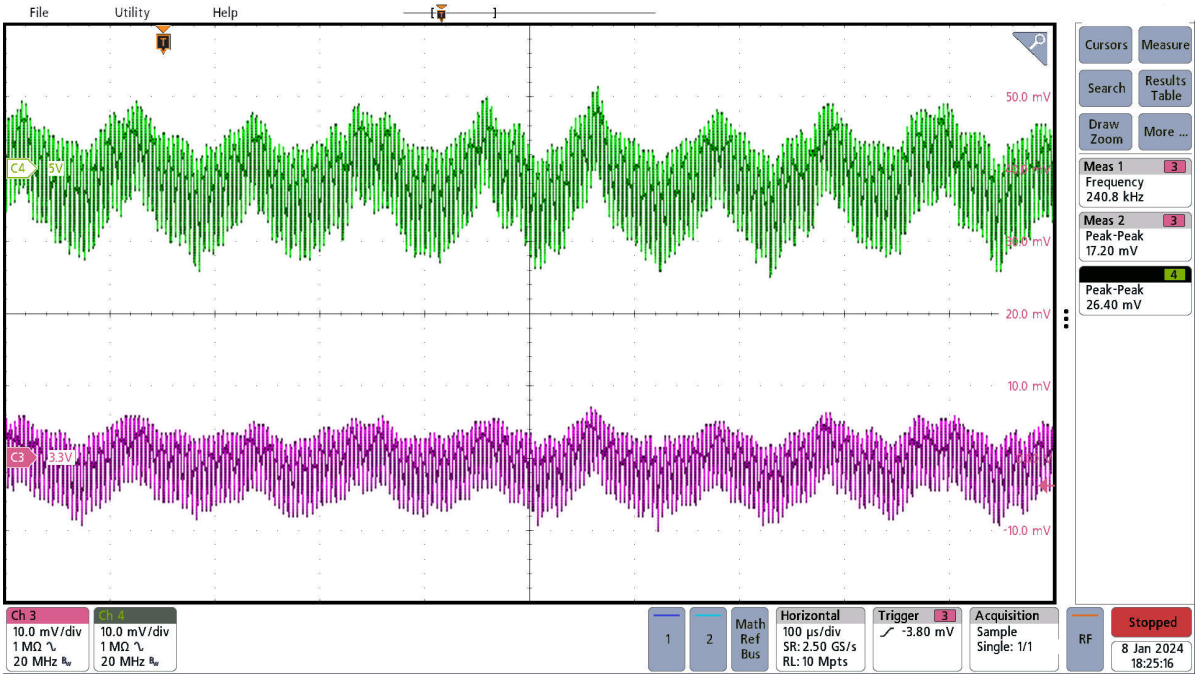


Figure 3-2. 5V Loaded to 15A

3.2 Load Transients

Load transient response is shown in Figure 3-3 and Figure 3-4. In these waveforms, the output ripple before and after the load changes show the 10kHz switching frequency dithering activated to reduce conducted emissions.

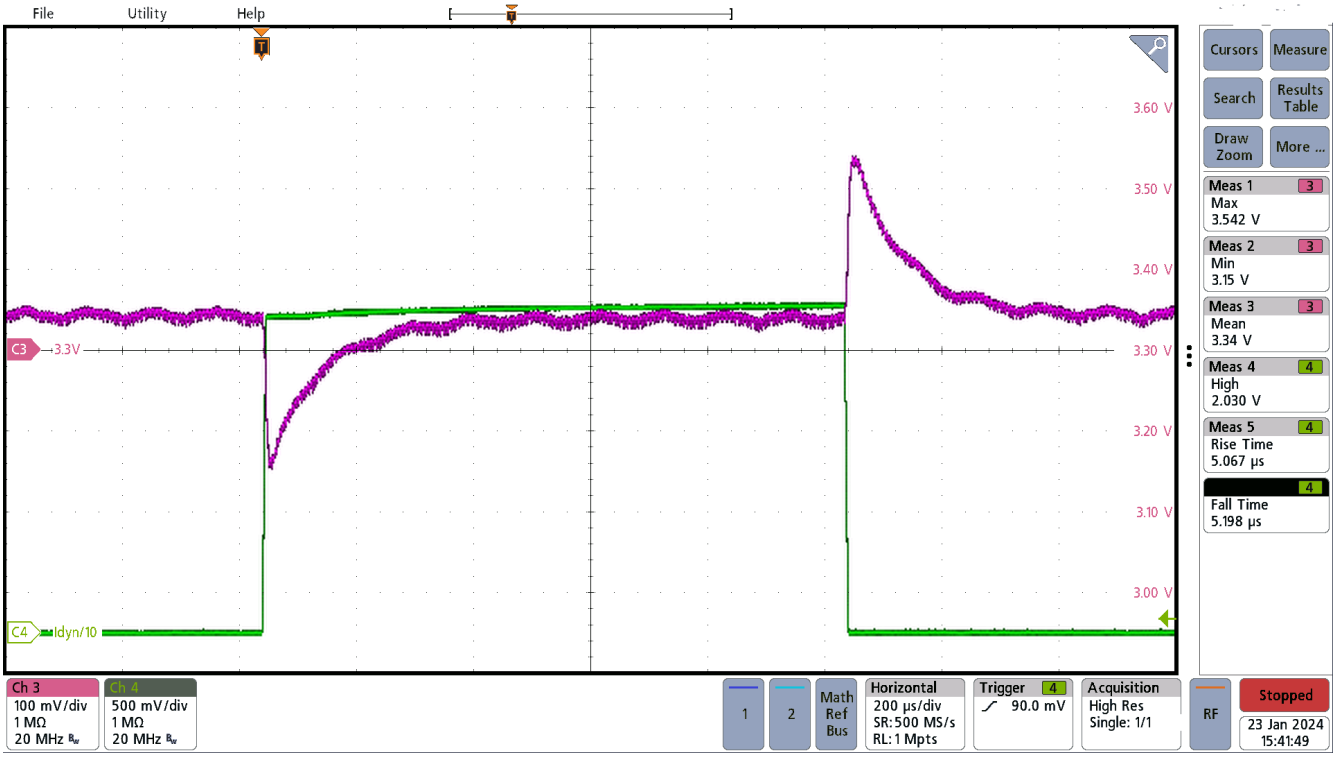


Figure 3-3. Load Dynamics: 3.3V 20A Step and Dump

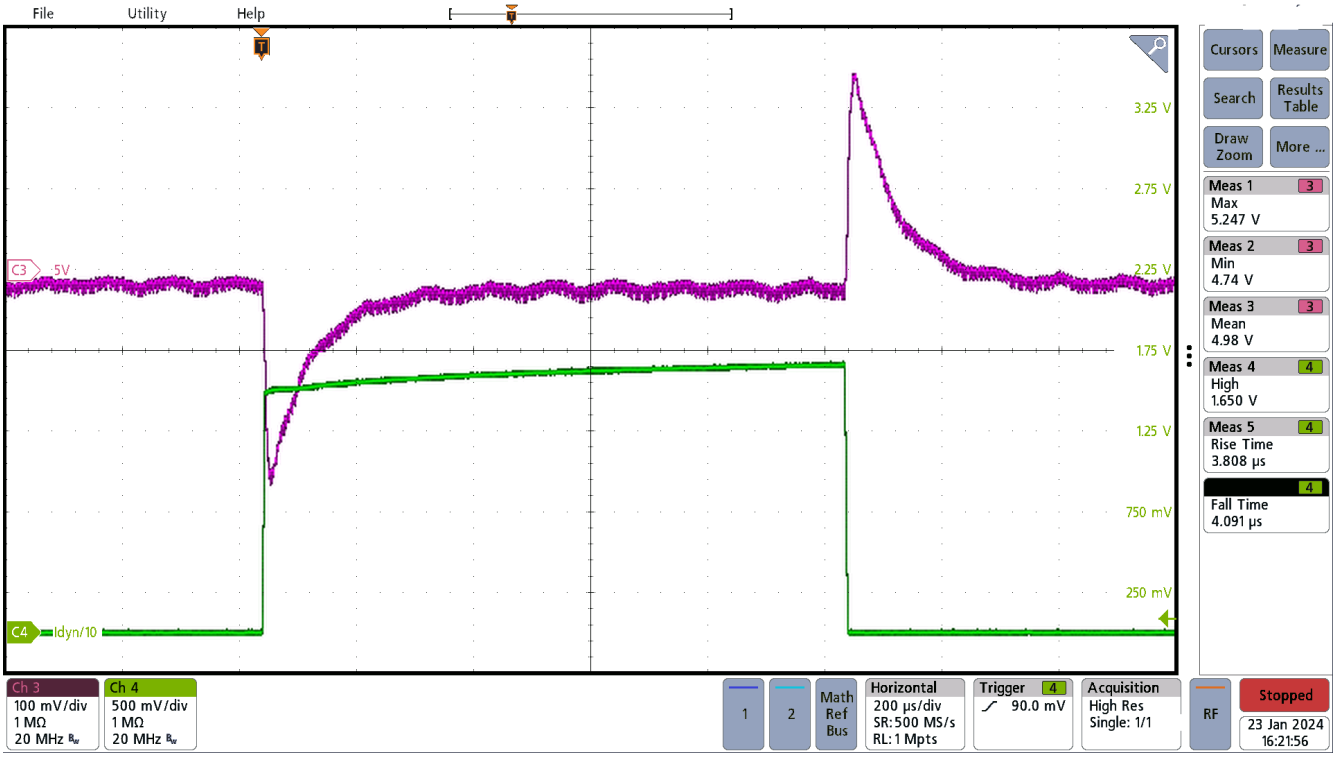


Figure 3-4. Load Dynamics: 5V 15A Step and Dump

3.3 Start-Up Sequence

Start-up behavior is shown in Figure 3-5.

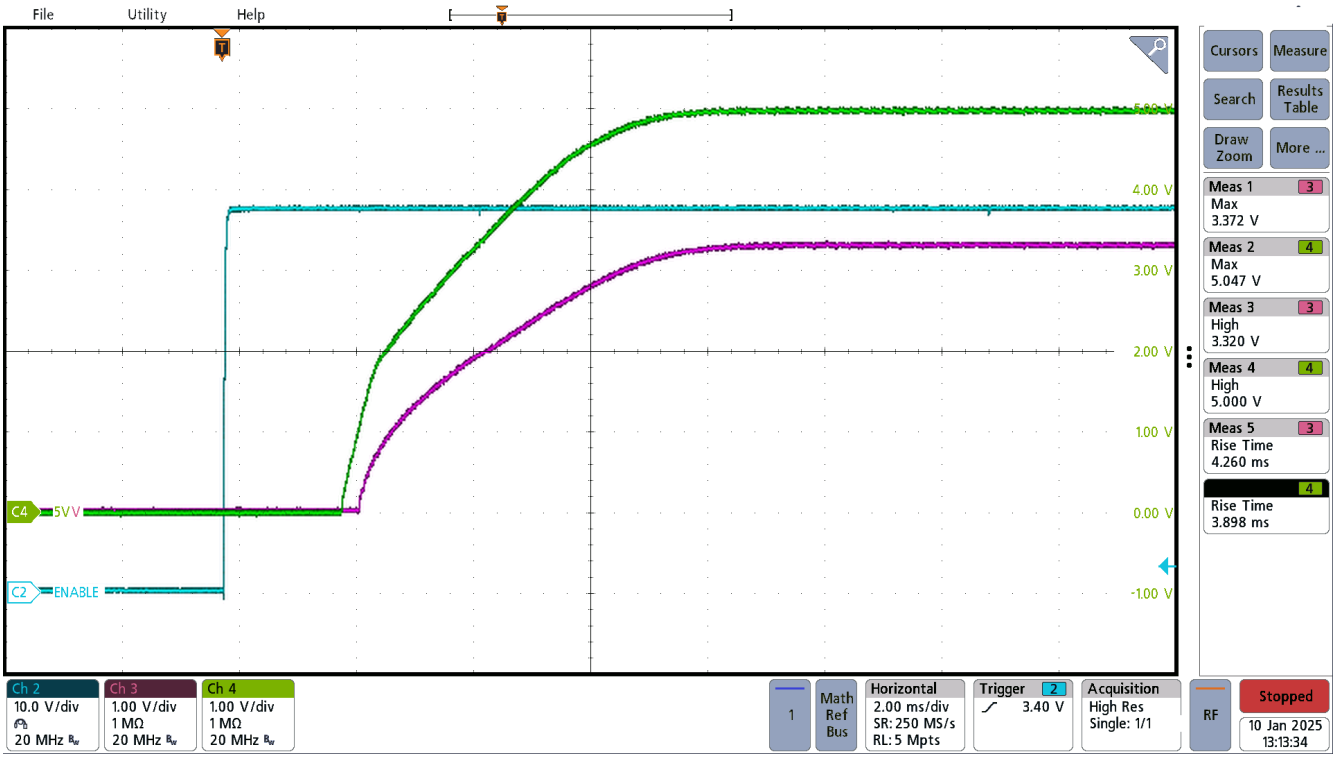


Figure 3-5. Start-Up From Enable Going High, 48V_{in} Diode Emulation Mode, 100mA Load on Each Output (Css1 and Css2 Each 220nF)

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