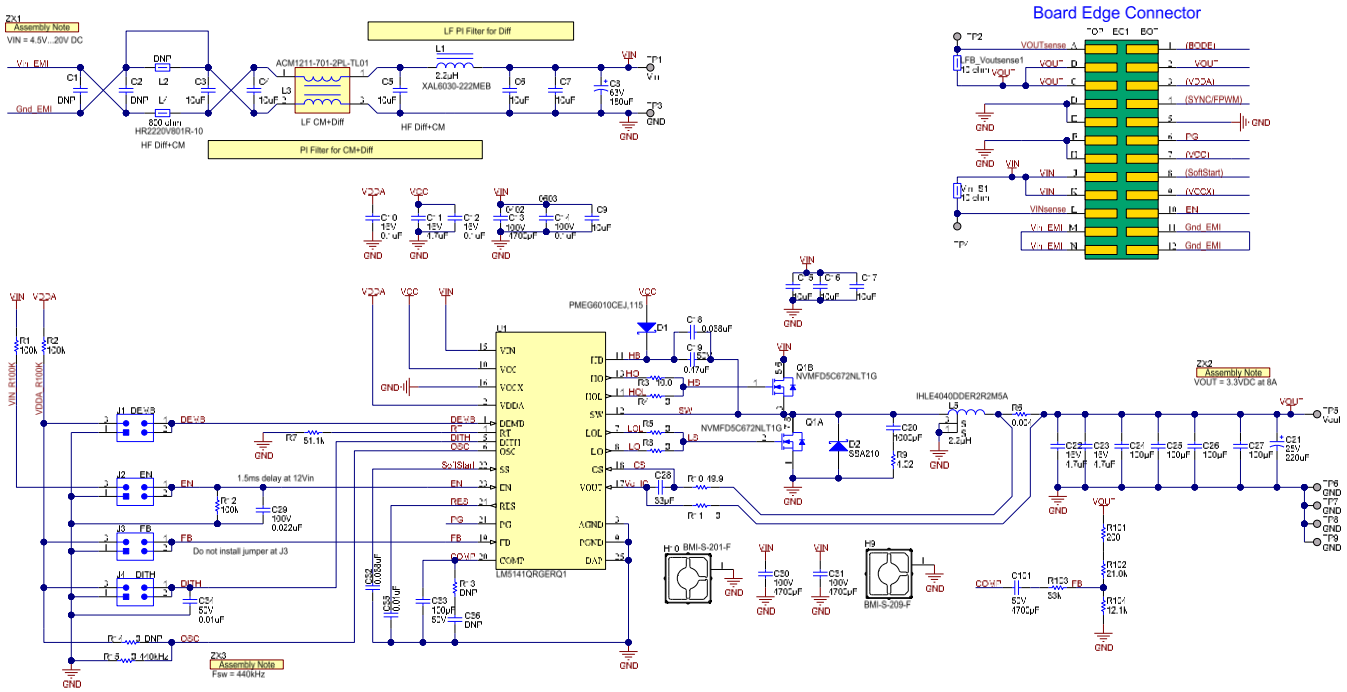
Test Report: PMP21795

Automotive EMI and Thermally Optimized Synchronous Buck Converter Reference Design

Description

This reference design is an EMI and thermally optimized synchronous buck converter for automotive applications. The circuit is powered from the nominal 12-V battery to provide an output voltage of 3.3 V at 8 A. The design uses a synchronous buck controller operating at a switching frequency of 440 kHz. Forced pulse width modulation (FPWM) or diode emulation mode (DEMB) is jumper selectable. Frequency dithering is used to improve the EMI performance.



1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
Input Voltage	4.5 V – 20 V
Output Voltage	3.3 V
Output Current	8 A

1.2 Required Equipment

- DC power supply
- Electronic load
- Oscilloscope

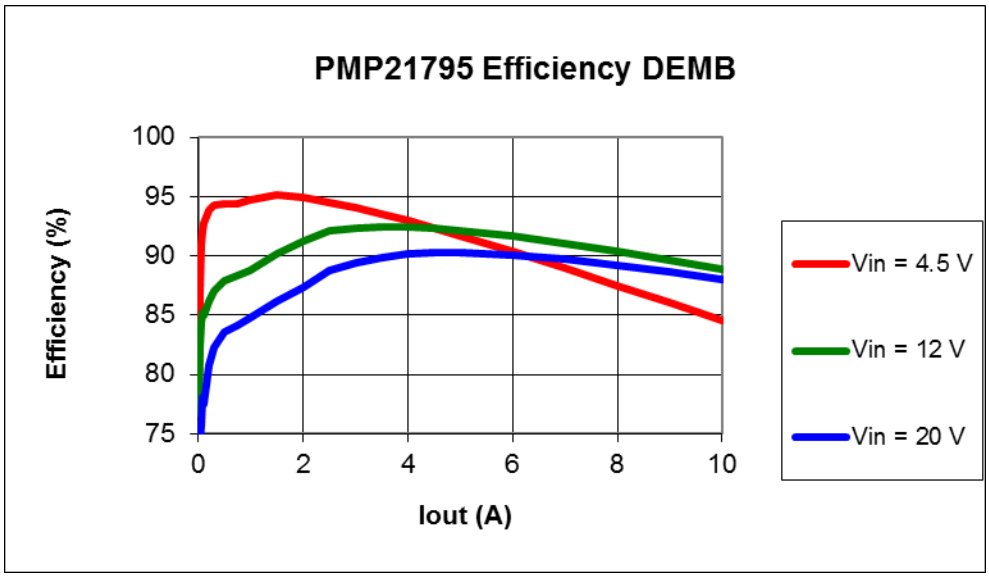
1.3 Considerations

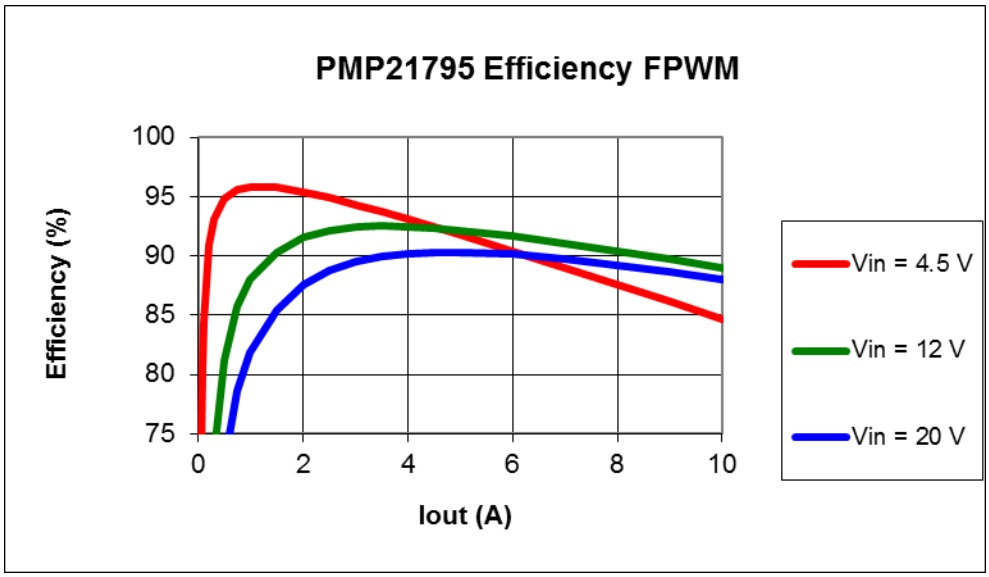
All tests were performed at room temperature on an open bench.

2 Testing and Results

2.1 Efficiency Graphs

Figures show the converter efficiency with 4.5-V, 12-V, and 20-V inputs.





2.2 Efficiency Data

Table 2, Table 3, Table 4, Table 5, Table 6, and Table 7 shows the efficiency data with 4.5-V, 12-V, and 20-V inputs.

Table 2. Efficiency Data 4.5-V Input, DEMB

V_{IN}	I_{IN}	V_{OUT}	I_{OUT}	P_{IN}	P_{OUT}	Losses	Efficiency
4.5138	0.0017	3.2898	0.0000	0.008	0.000	0.008	0.00
4.5140	0.0097	3.2895	0.0104	0.044	0.034	0.010	78.13
4.5137	0.0212	3.2894	0.0253	0.096	0.083	0.012	86.97
4.5138	0.0403	3.2894	0.0503	0.182	0.165	0.016	90.96
4.5138	0.0595	3.2893	0.0752	0.269	0.247	0.021	92.10
4.5138	0.0787	3.2892	0.1002	0.355	0.330	0.026	92.78
4.5139	0.1552	3.2889	0.2000	0.701	0.658	0.043	93.89
4.5138	0.2315	3.2885	0.2996	1.045	0.985	0.060	94.29
4.5137	0.3855	3.2877	0.4993	1.740	1.642	0.098	94.34
4.5139	0.5775	3.2871	0.7486	2.607	2.461	0.146	94.40
4.5136	0.7670	3.2865	0.9981	3.462	3.280	0.182	94.75
4.5136	1.1452	3.2855	1.4968	5.169	4.918	0.251	95.14
4.5136	1.5406	3.2846	2.0097	6.954	6.601	0.353	94.93
4.5135	1.9303	3.2835	2.5081	8.712	8.235	0.477	94.53
4.5134	2.3257	3.2826	3.0068	10.497	9.870	0.627	94.03
4.5132	2.7266	3.2815	3.5055	12.306	11.503	0.802	93.48
4.5134	3.1294	3.2806	4.0052	14.124	13.139	0.985	93.03
4.5134	3.5433	3.2796	4.5044	15.992	14.773	1.220	92.37
4.5132	3.9630	3.2786	5.0032	17.886	16.403	1.482	91.71
4.5129	4.8227	3.2767	6.0004	21.764	19.661	2.103	90.34
4.5128	5.7108	3.2747	6.9991	25.772	22.920	2.852	88.93
4.5126	6.6282	3.2727	7.9977	29.910	26.174	3.736	87.51
4.5123	7.5775	3.2708	8.9949	34.192	29.421	4.771	86.05
4.5119	8.5646	3.2689	9.9942	38.643	32.670	5.973	84.54

Table 3. Efficiency Data 12-V Input, DEMB

V_{IN}	I_{IN}	V_{OUT}	I_{OUT}	P_{IN}	P_{OUT}	Losses	Efficiency
12.0416	0.0006	3.2918	0.0001	0.007	0.000	0.007	4.56
12.0417	0.0037	3.2891	0.0104	0.045	0.034	0.010	76.78
12.0417	0.0084	3.2891	0.0253	0.101	0.083	0.018	82.27
12.0420	0.0163	3.2891	0.0503	0.196	0.165	0.031	84.29
12.0420	0.0241	3.2891	0.0752	0.290	0.247	0.043	85.23
12.0419	0.0322	3.2895	0.1002	0.388	0.330	0.058	85.01
12.0419	0.0634	3.2891	0.2000	0.763	0.658	0.106	86.16
12.0420	0.0940	3.2889	0.2997	1.132	0.986	0.146	87.08
12.0419	0.1552	3.2883	0.4993	1.869	1.642	0.227	87.85
12.0417	0.2314	3.2877	0.7487	2.786	2.461	0.325	88.34
12.0416	0.3070	3.2870	0.9981	3.697	3.281	0.416	88.75
12.0417	0.4531	3.2855	1.4969	5.456	4.918	0.538	90.14
12.0417	0.6003	3.2842	2.0088	7.229	6.597	0.631	91.27
12.0417	0.7424	3.2830	2.5074	8.940	8.232	0.708	92.08
12.0415	0.8869	3.2820	3.0062	10.680	9.866	0.813	92.39

12.0417	1.0327	3.2810	3.5051	12.435	11.500	0.935	92.48
12.0417	1.1800	3.2799	4.0049	14.209	13.136	1.074	92.44
12.0416	1.3283	3.2788	4.5040	15.995	14.768	1.227	92.33
12.0415	1.4779	3.2778	5.0026	17.796	16.397	1.399	92.14
12.0417	1.7810	3.2757	6.0002	21.446	19.655	1.791	91.65
12.0415	2.0898	3.2737	6.9990	25.164	22.913	2.252	91.05
12.0413	2.4040	3.2716	7.9972	28.947	26.164	2.783	90.38
12.0413	2.7235	3.2695	8.9944	32.795	29.407	3.388	89.67
12.0413	3.0500	3.2674	9.9936	36.726	32.653	4.073	88.91

Table 4. Efficiency Data 20-V Input, DEMB

V_{IN}	I_{IN}	V_{OUT}	I_{OUT}	P_{IN}	P_{OUT}	Losses	Efficiency
20.0652	0.0006	3.2940	0.0001	0.012	0.000	0.012	2.74
20.0653	0.0027	3.2892	0.0105	0.054	0.035	0.020	63.75
20.0652	0.0056	3.2892	0.0254	0.112	0.084	0.029	74.35
20.0651	0.0109	3.2888	0.0503	0.219	0.165	0.053	75.64
20.0655	0.0158	3.2891	0.0752	0.317	0.247	0.070	78.02
20.0650	0.0212	3.2895	0.1002	0.425	0.330	0.096	77.49
20.0653	0.0406	3.2893	0.2000	0.815	0.658	0.157	80.75
20.0656	0.0597	3.2890	0.2996	1.198	0.985	0.213	82.26
20.0652	0.0979	3.2885	0.4993	1.964	1.642	0.322	83.59
20.0651	0.1458	3.2879	0.7487	2.925	2.462	0.464	84.14
20.0651	0.1928	3.2871	0.9982	3.869	3.281	0.587	84.82
20.0651	0.2845	3.2859	1.4969	5.709	4.919	0.790	86.16
20.0653	0.3763	3.2845	2.0086	7.551	6.597	0.953	87.37
20.0653	0.4623	3.2835	2.5070	9.276	8.232	1.045	88.74
20.0653	0.5497	3.2824	3.0058	11.030	9.866	1.164	89.45
20.0653	0.6376	3.2814	3.5048	12.794	11.501	1.293	89.89
20.0652	0.7263	3.2804	4.0045	14.573	13.136	1.437	90.14
20.0651	0.8155	3.2793	4.5036	16.363	14.769	1.594	90.26
20.0651	0.9054	3.2782	5.0024	18.167	16.399	1.768	90.27
20.0651	1.0872	3.2761	5.9996	21.815	19.655	2.159	90.10
20.0652	1.2728	3.2741	6.9990	25.539	22.915	2.624	89.73
20.0651	1.4614	3.2720	7.9971	29.323	26.166	3.157	89.23
20.0652	1.6535	3.2699	8.9945	33.178	29.411	3.767	88.65
20.0651	1.8492	3.2678	9.9935	37.104	32.657	4.448	88.01

Table 5. Efficiency Data 4.5-V Input, FPWM

V_{IN}	I_{IN}	V_{OUT}	I_{OUT}	P_{IN}	P_{OUT}	Losses	Efficiency
4.5138	0.0127	3.2878	0.0000	0.057	0.000	0.057	0.00
4.5139	0.0204	3.2878	0.0103	0.092	0.034	0.058	36.78
4.5137	0.0314	3.2877	0.0253	0.142	0.083	0.059	58.69
4.5137	0.0497	3.2877	0.0502	0.224	0.165	0.059	73.57
4.5135	0.0681	3.2877	0.0752	0.307	0.247	0.060	80.43
4.5137	0.0865	3.2876	0.1002	0.390	0.329	0.061	84.37
4.5138	0.1602	3.2874	0.2000	0.723	0.657	0.066	90.93

4.5138	0.2343	3.2873	0.2996	1.058	0.985	0.073	93.12
4.5136	0.3835	3.2868	0.4992	1.731	1.641	0.090	94.79
4.5137	0.5704	3.2864	0.7486	2.575	2.460	0.114	95.56
4.5136	0.7582	3.2858	0.9980	3.422	3.279	0.143	95.82
4.5137	1.1375	3.2848	1.4967	5.134	4.916	0.218	95.76
4.5138	1.5328	3.2838	2.0096	6.919	6.599	0.320	95.38
4.5135	1.9224	3.2828	2.5078	8.677	8.233	0.444	94.88
4.5135	2.3178	3.2818	3.0066	10.461	9.867	0.594	94.32
4.5133	2.7195	3.2809	3.5056	12.274	11.501	0.772	93.71
4.5134	3.1276	3.2799	4.0053	14.116	13.137	0.979	93.06
4.5133	3.5411	3.2790	4.5044	15.982	14.770	1.212	92.42
4.5131	3.9605	3.2780	5.0030	17.874	16.400	1.474	91.75
4.5129	4.8184	3.2761	6.0004	21.745	19.658	2.087	90.40
4.5128	5.7049	3.2741	6.9993	25.745	22.916	2.829	89.01
4.5124	6.6202	3.2721	7.9974	29.873	26.169	3.704	87.60
4.5120	7.5676	3.2702	8.9946	34.145	29.415	4.730	86.15
4.5119	8.5508	3.2682	9.9937	38.581	32.662	5.919	84.66

Table 6. Efficiency Data 12-V Input, FPWM

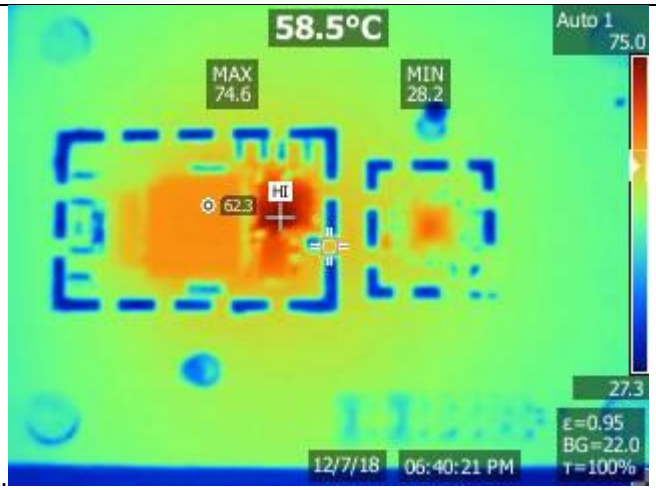
V_{IN}	I_{IN}	V_{OUT}	I_{OUT}	P_{IN}	P_{OUT}	Losses	Efficiency
12.0420	0.0282	3.2875	0.0001	0.340	0.000	0.339	0.10
12.0419	0.0309	3.2875	0.0104	0.372	0.034	0.338	9.19
12.0415	0.0349	3.2875	0.0249	0.420	0.082	0.338	19.48
12.0417	0.0419	3.2875	0.0502	0.505	0.165	0.340	32.71
12.0415	0.0489	3.2875	0.0752	0.589	0.247	0.342	41.98
12.0420	0.0558	3.2874	0.1002	0.672	0.329	0.343	49.02
12.0419	0.0837	3.2872	0.2000	1.008	0.657	0.350	65.23
12.0415	0.1115	3.2871	0.2996	1.343	0.985	0.358	73.35
12.0417	0.1677	3.2868	0.4992	2.019	1.641	0.379	81.25
12.0419	0.2383	3.2863	0.7486	2.870	2.460	0.409	85.73
12.0413	0.3096	3.2857	0.9981	3.728	3.279	0.449	87.97
12.0417	0.4522	3.2846	1.4968	5.445	4.916	0.529	90.29
12.0416	0.5982	3.2835	2.0083	7.203	6.594	0.609	91.55
12.0417	0.7415	3.2825	2.5066	8.929	8.228	0.701	92.15
12.0417	0.8860	3.2815	3.0053	10.669	9.862	0.807	92.43
12.0415	1.0316	3.2804	3.5047	12.422	11.497	0.925	92.55
12.0413	1.1792	3.2794	4.0043	14.199	13.132	1.067	92.48
12.0415	1.3276	3.2783	4.5035	15.986	14.764	1.222	92.35
12.0416	1.4771	3.2773	5.0024	17.787	16.394	1.392	92.17
12.0412	1.7799	3.2752	5.9997	21.432	19.650	1.782	91.69
12.0413	2.0886	3.2732	6.9988	25.150	22.908	2.241	91.09
12.0411	2.4024	3.2711	7.9968	28.927	26.159	2.769	90.43
12.0413	2.7219	3.2691	8.9942	32.775	29.403	3.372	89.71
12.0411	3.0481	3.2670	9.9934	36.702	32.648	4.054	88.95

Table 7. Efficiency Data 20-V Input, FPWM

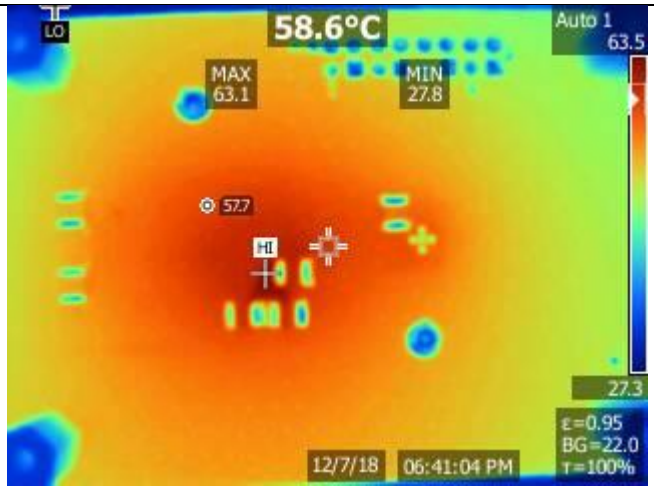
V_{IN}	I_{IN}	V_{OUT}	I_{OUT}	P_{IN}	P_{OUT}	Losses	Efficiency
20.0652	0.0279	3.2882	0.0002	0.560	0.001	0.559	0.12
20.0655	0.0296	3.2882	0.0104	0.594	0.034	0.560	5.76
20.0651	0.0320	3.2882	0.0253	0.642	0.083	0.559	12.96
20.0653	0.0362	3.2881	0.0503	0.726	0.165	0.561	22.77
20.0655	0.0404	3.2881	0.0752	0.811	0.247	0.563	30.50
20.0653	0.0446	3.2881	0.1002	0.895	0.329	0.565	36.82
20.0653	0.0616	3.2879	0.2000	1.236	0.658	0.578	53.20
20.0651	0.0786	3.2876	0.2996	1.577	0.985	0.592	62.45
20.0650	0.1129	3.2873	0.4993	2.265	1.641	0.624	72.45
20.0653	0.1561	3.2869	0.7487	3.132	2.461	0.671	78.57
20.0651	0.1996	3.2864	0.9981	4.005	3.280	0.725	81.90
20.0652	0.2871	3.2854	1.4969	5.761	4.918	0.843	85.37
20.0651	0.3753	3.2841	2.0078	7.530	6.594	0.937	87.56
20.0652	0.4619	3.2831	2.5062	9.268	8.228	1.040	88.78
20.0653	0.5491	3.2821	3.0051	11.018	9.863	1.155	89.52
20.0648	0.6370	3.2811	3.5039	12.781	11.496	1.285	89.95
20.0651	0.7256	3.2800	4.0037	14.559	13.132	1.427	90.20
20.0650	0.8150	3.2789	4.5030	16.353	14.765	1.588	90.29
20.0647	0.9049	3.2779	5.0017	18.157	16.395	1.762	90.30
20.0647	1.0868	3.2758	5.9993	21.806	19.652	2.154	90.12
20.0648	1.2722	3.2737	6.9982	25.526	22.910	2.616	89.75
20.0647	1.4608	3.2716	7.9963	29.311	26.161	3.150	89.25
20.0646	1.6527	3.2695	8.9938	33.161	29.405	3.756	88.67
20.0644	1.8485	3.2674	9.9929	37.089	32.651	4.438	88.03

2.3 Thermal Images

Figures show thermal performance at 12-V input and 8-A load with no airflow. The images were taken with the board at thermal equilibrium.



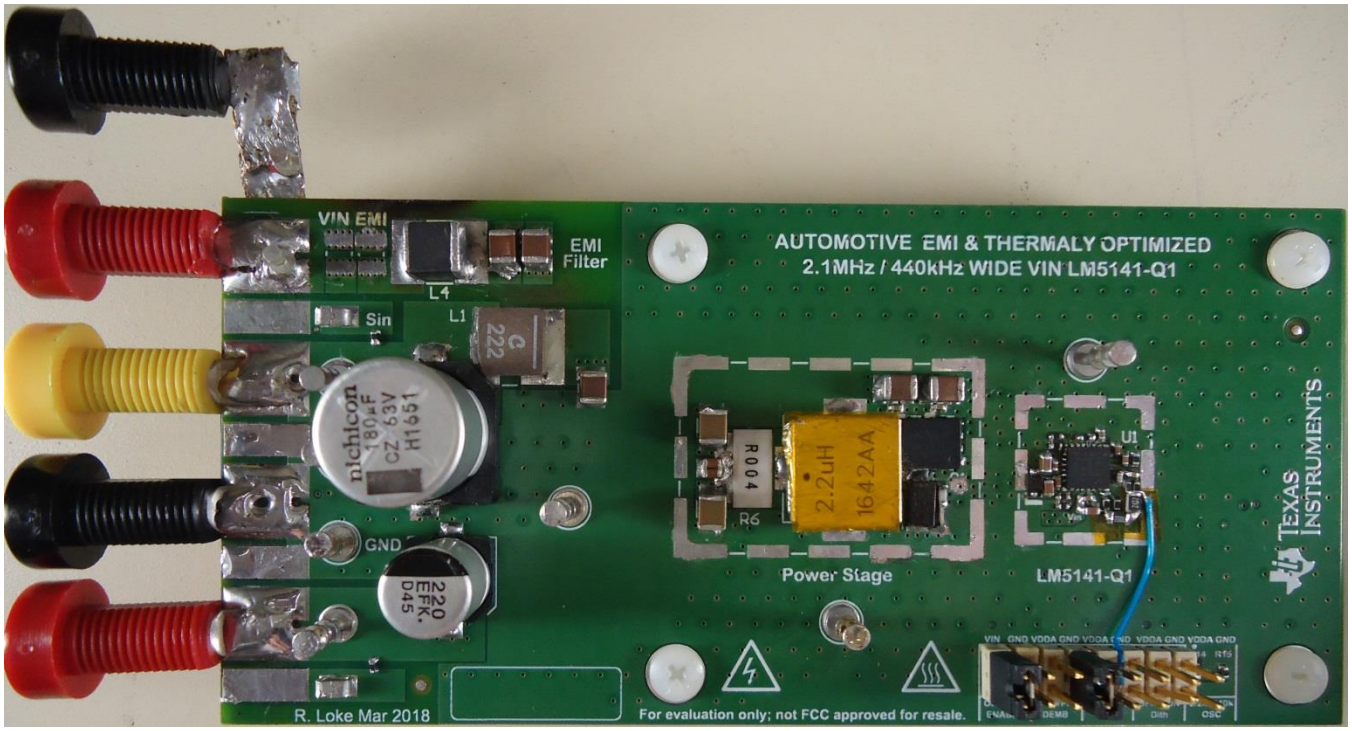
Thermal Image, Top View, 12-V Input, 8-A Load



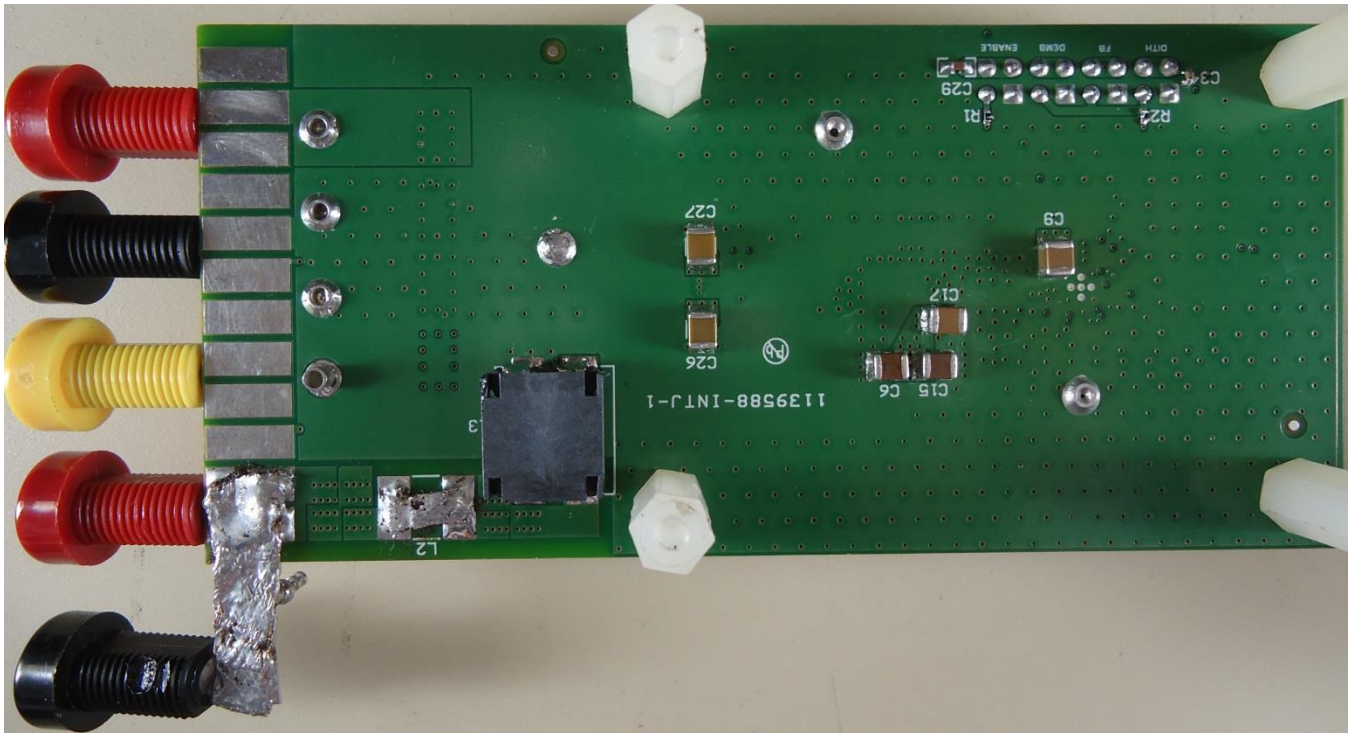
Thermal Image, Bottom View, 12-V Input, 8-A Load

2.4 Dimensions

PMP21795 Rev A assembly was built on PMP21566 Rev B printed circuit board. This is a 4-layer PCB with 1 oz. copper. Board dimensions are 4.340 in. x 2.010 in.



Top of PMP21795 Board

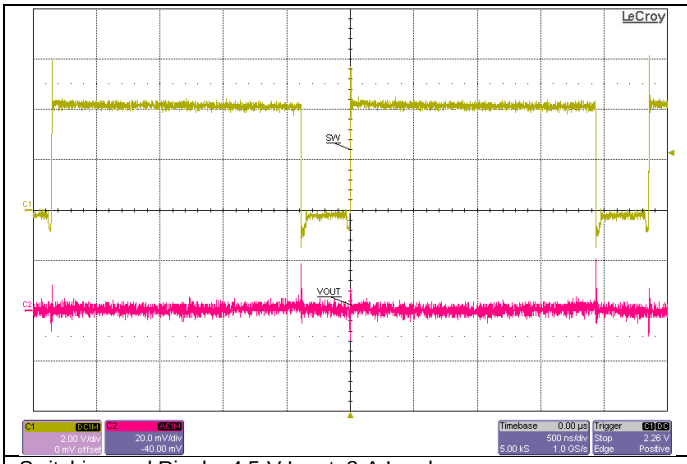


Bottom of PMP21795 Board

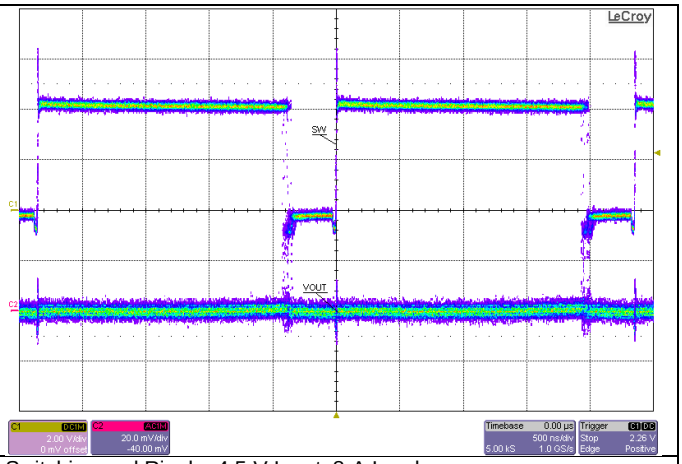
3 Waveforms

3.1 Switching and Output Voltage Ripple

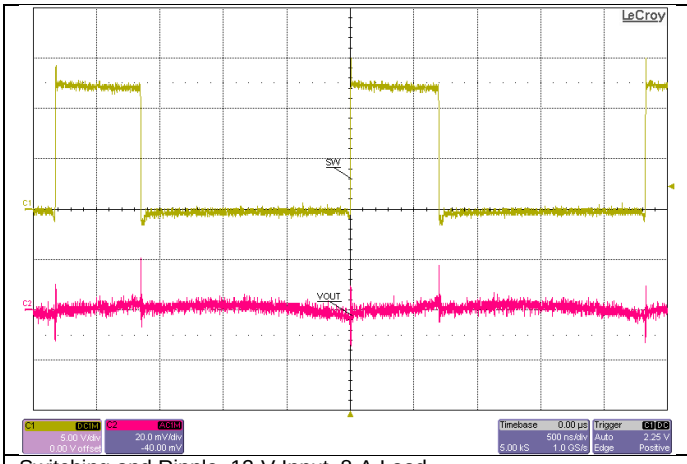
Figures show the switch node voltage and output voltage ripple of the converter.



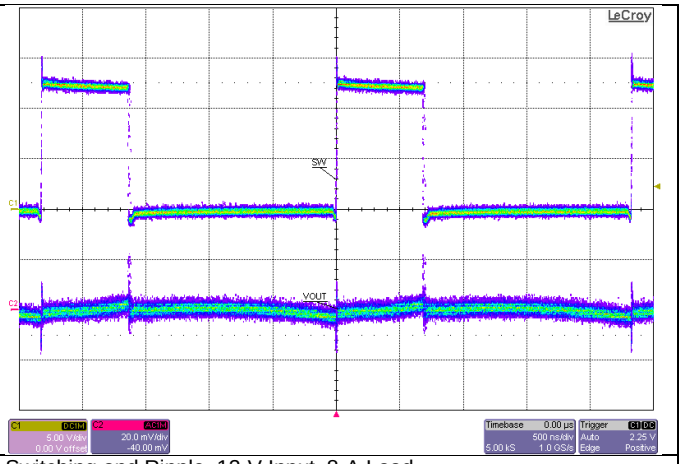
Switching and Ripple, 4.5-V Input, 8-A Load



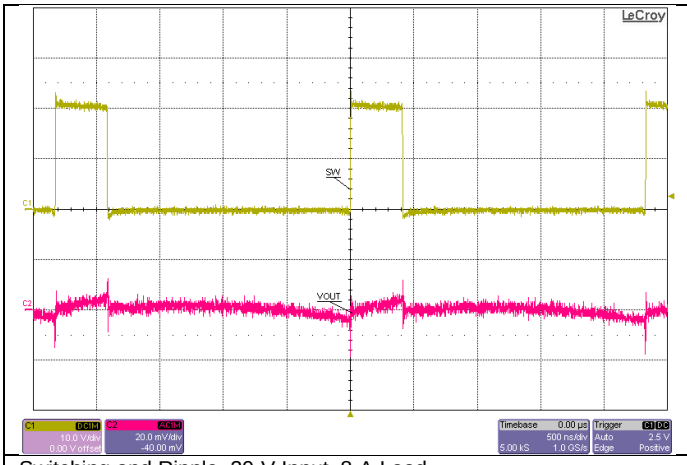
Switching and Ripple, 4.5-V Input, 8-A Load



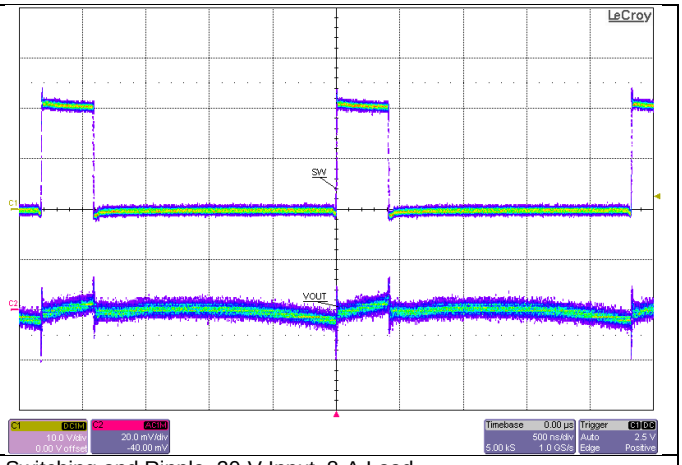
Switching and Ripple, 12-V Input, 8-A Load



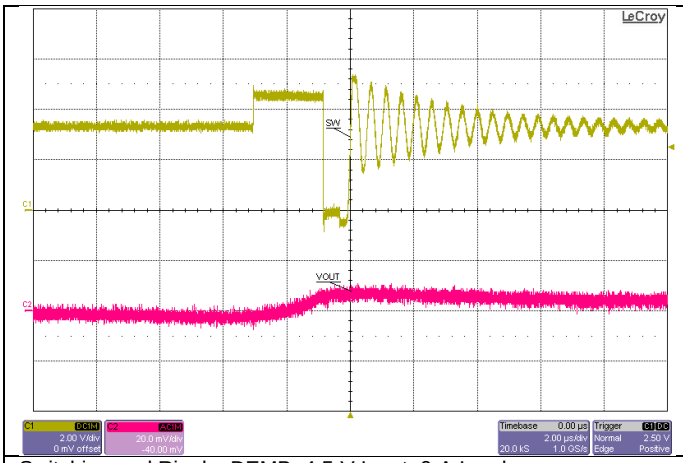
Switching and Ripple, 12-V Input, 8-A Load



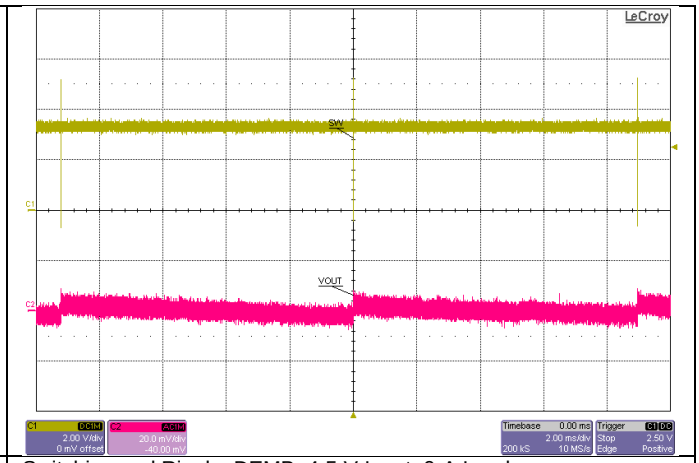
Switching and Ripple, 20-V Input, 8-A Load



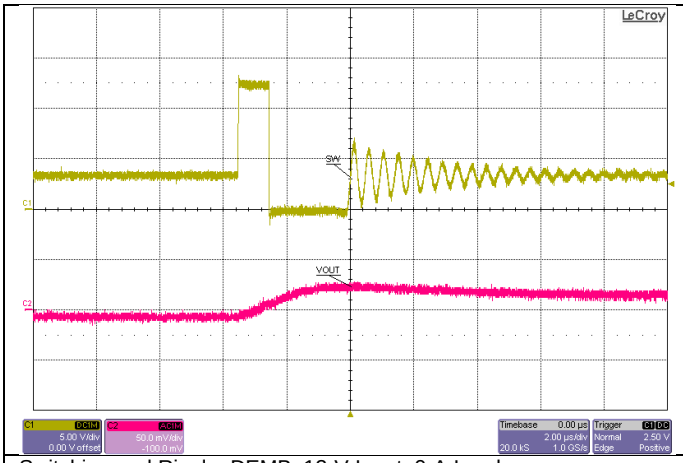
Switching and Ripple, 20-V Input, 8-A Load



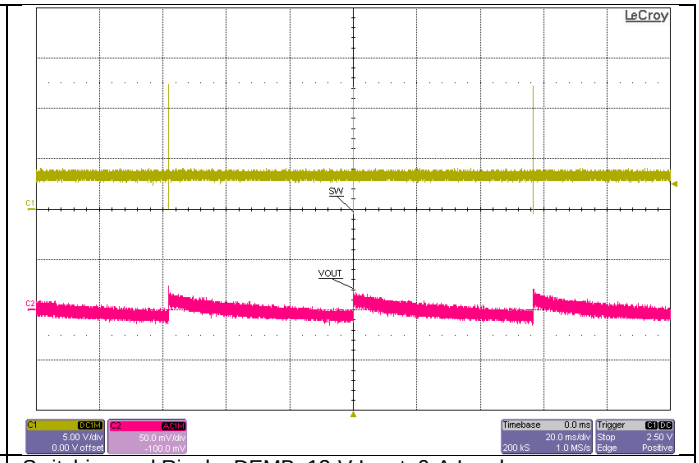
Switching and Ripple, DEMB, 4.5-V Input, 0-A Load



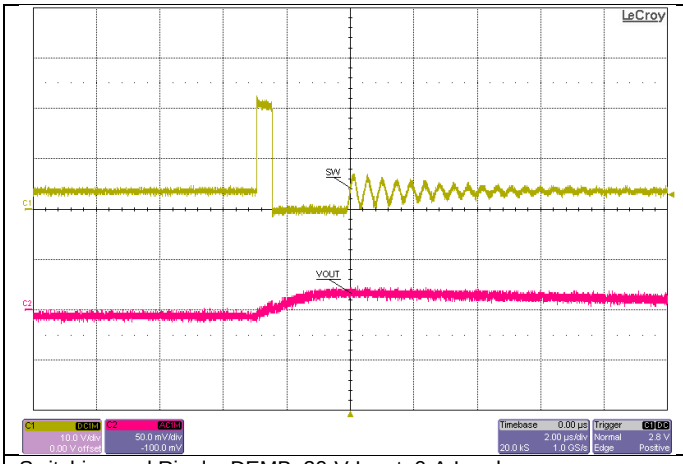
Switching and Ripple, DEMB, 4.5-V Input, 0-A Load



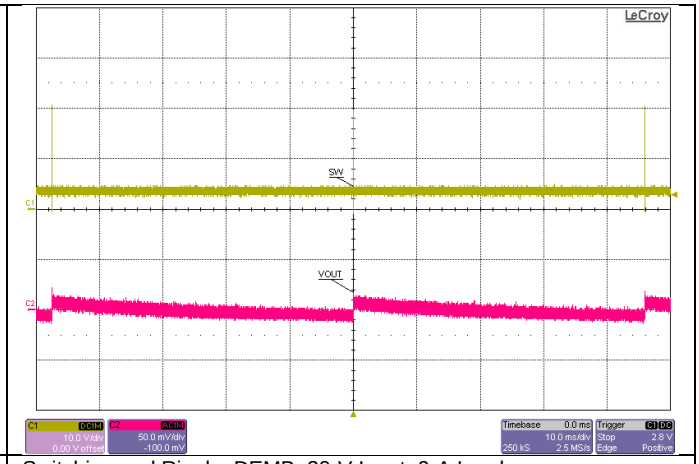
Switching and Ripple, DEMB, 12-V Input, 0-A Load



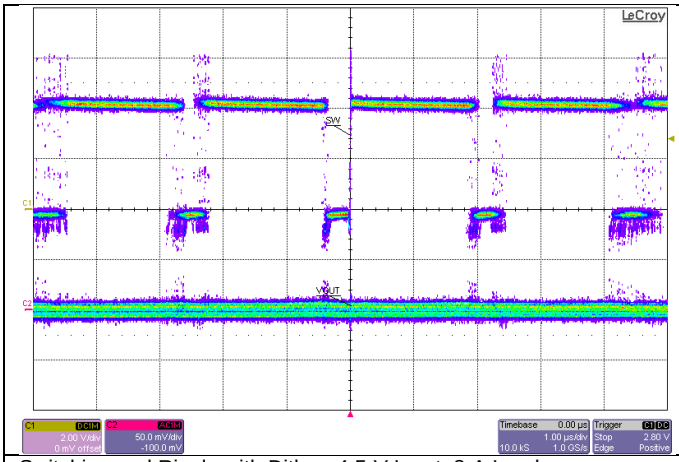
Switching and Ripple, DEMB, 12-V Input, 0-A Load



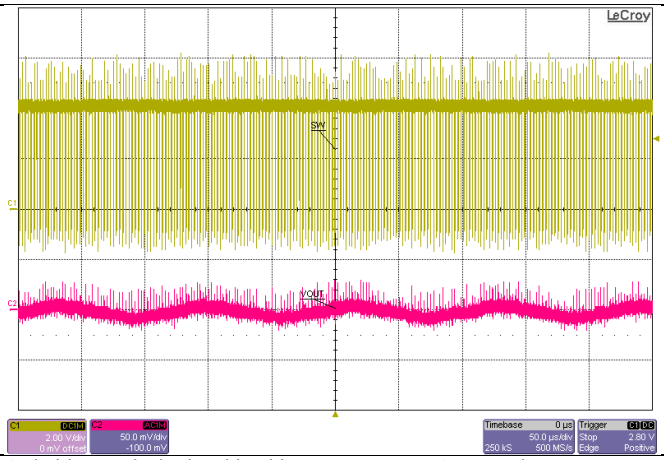
Switching and Ripple, DEMB, 20-V Input, 0-A Load



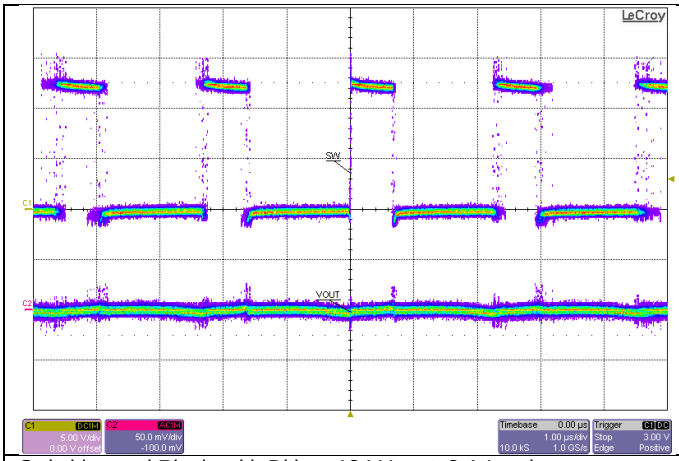
Switching and Ripple, DEMB, 20-V Input, 0-A Load



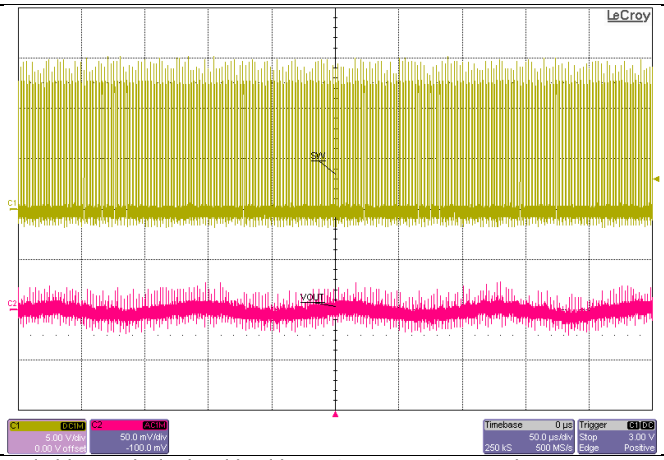
Switching and Ripple with Dither, 4.5-V Input, 8-A Load



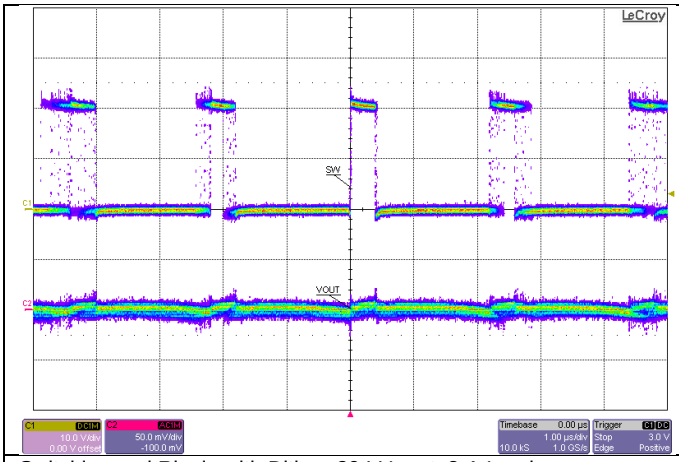
Switching and Ripple with Dither, 4.5-V Input, 8-A Load



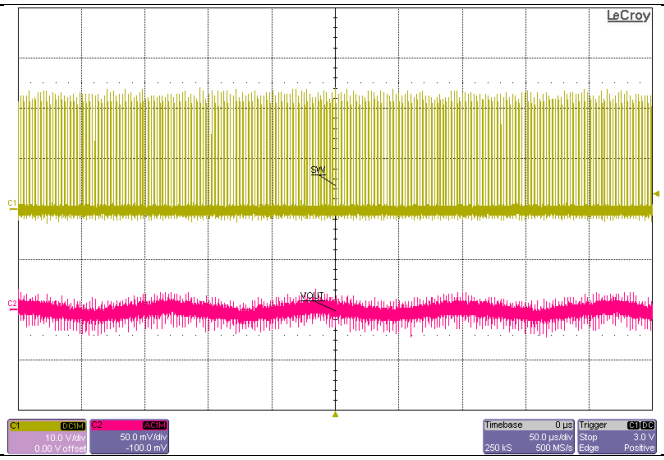
Switching and Ripple with Dither, 12-V Input, 8-A Load



Switching and Ripple with Dither, 12-V Input, 8-A Load



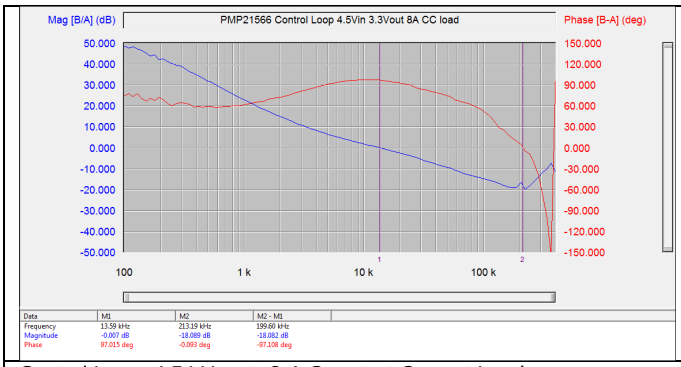
Switching and Ripple with Dither, 20-V Input, 8-A Load



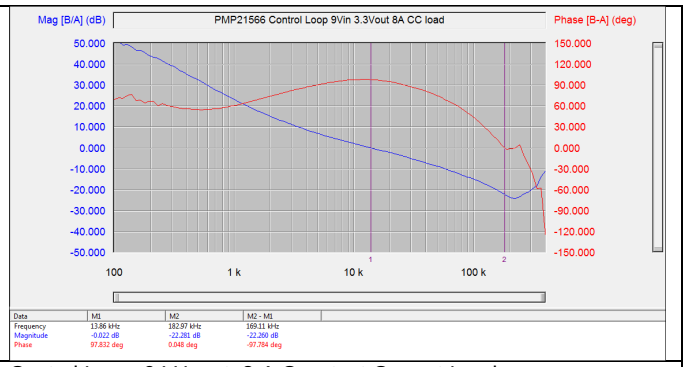
Switching and Ripple with Dither, 20-V Input, 8-A Load

3.2 Bode Plots

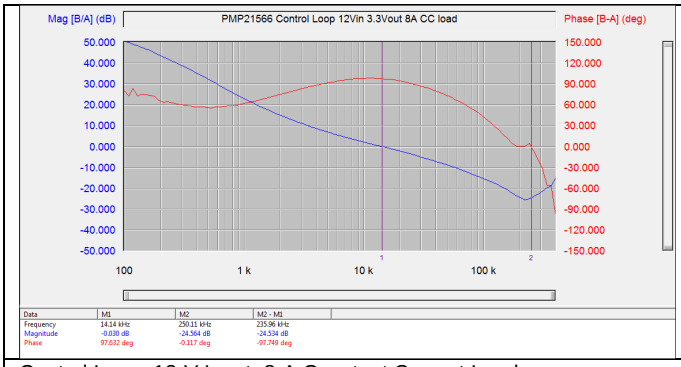
Figures show Bode plots of the control loop at 8-A constant current load.



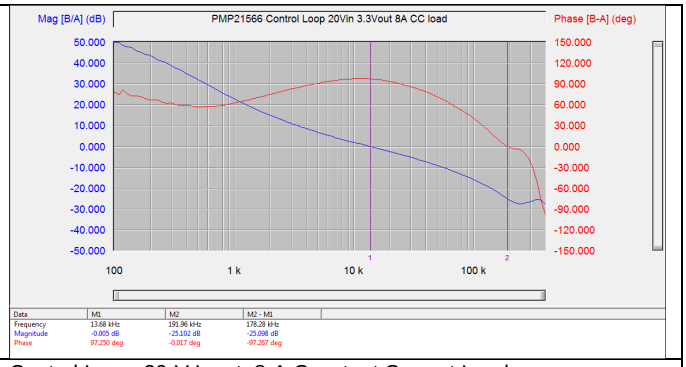
Control Loop, 4.5-V Input, 8-A Constant Current Load



Control Loop, 9-V Input, 8-A Constant Current Load



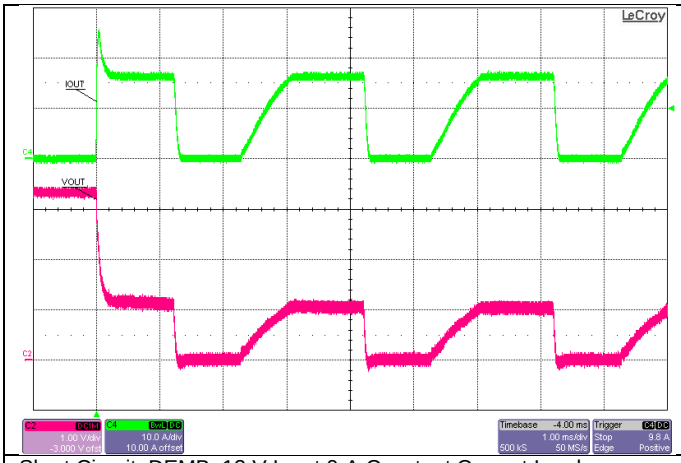
Control Loop, 12-V Input, 8-A Constant Current Load



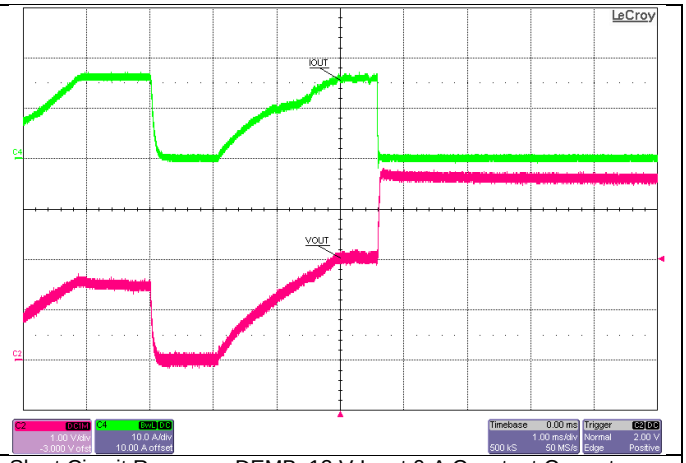
Control Loop, 20-V Input, 8-A Constant Current Load

3.3 Short Circuit Recovery

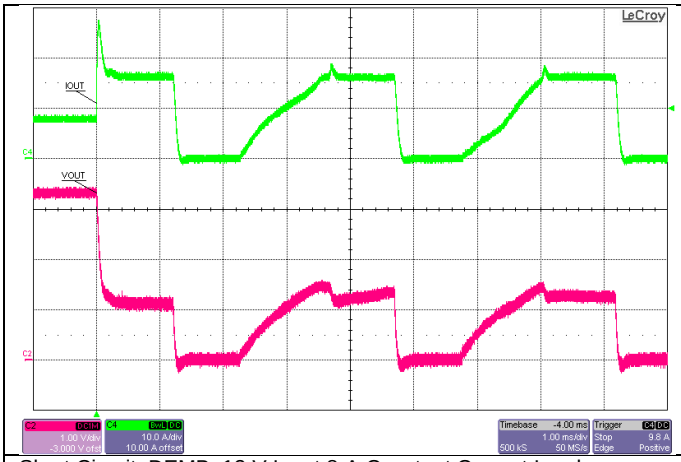
Figures show short circuit cycling and recovery of the converter at 12-V input.



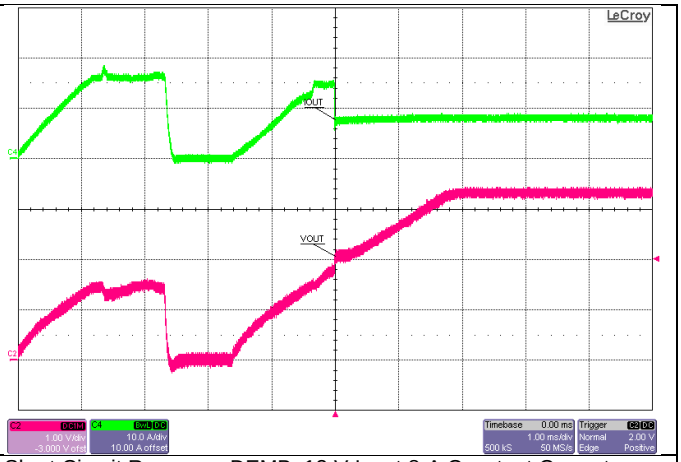
Short Circuit, DEMB, 12-V Input 0-A Constant Current Load



Short Circuit Recovery, DEMB, 12-V Input 0-A Constant Current Load



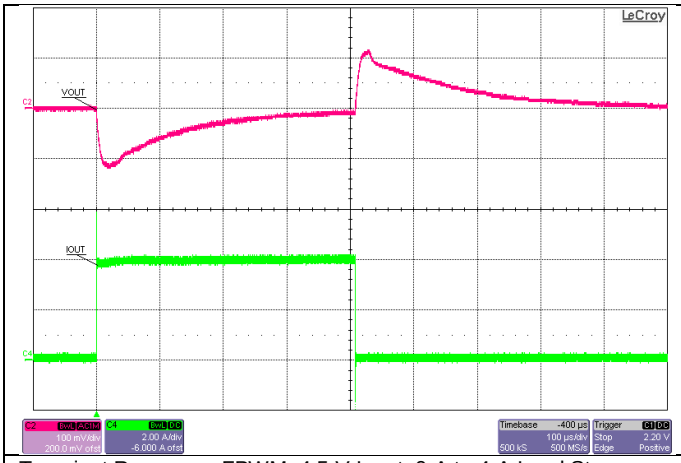
Short Circuit, DEMB, 12-V Input 8-A Constant Current Load



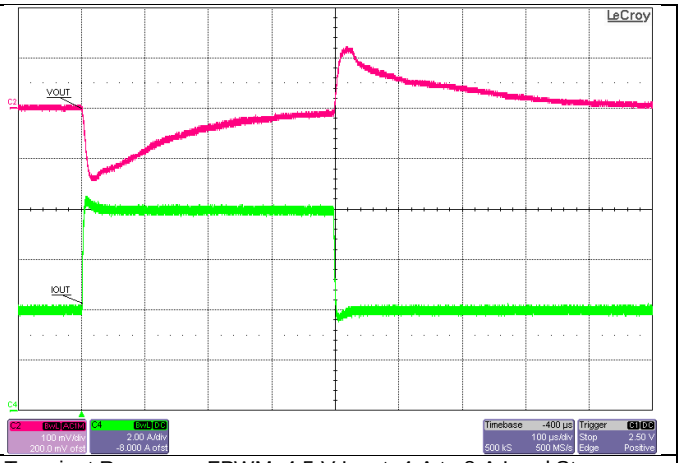
Short Circuit Recovery, DEMB, 12-V Input 8-A Constant Current Load

3.4 Load Transients

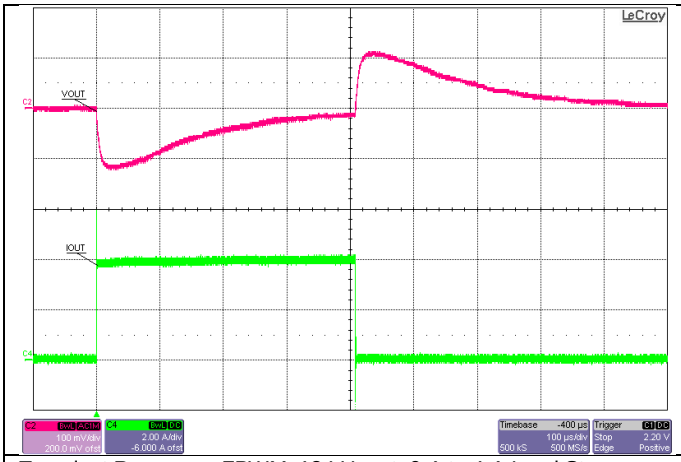
Figures show the load transient response of the converter for a 50% load step.



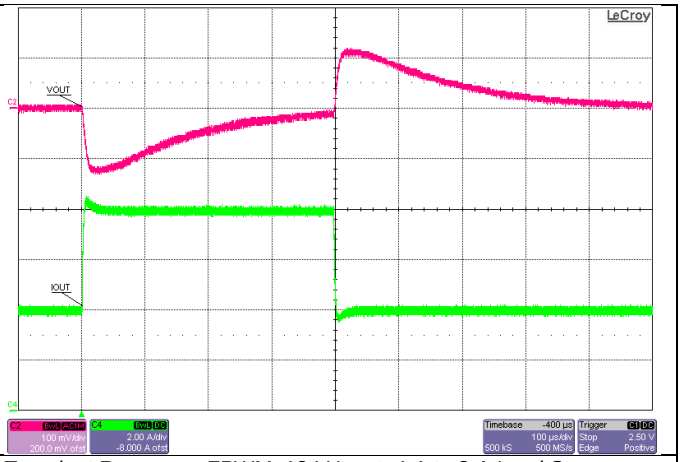
Transient Response, FPWM, 4.5-V Input, 0-A to 4-A Load Step



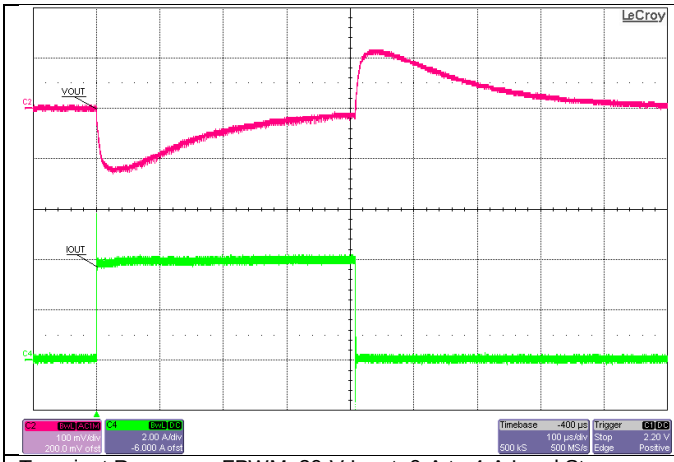
Transient Response, FPWM, 4.5-V Input, 4-A to 8-A Load Step



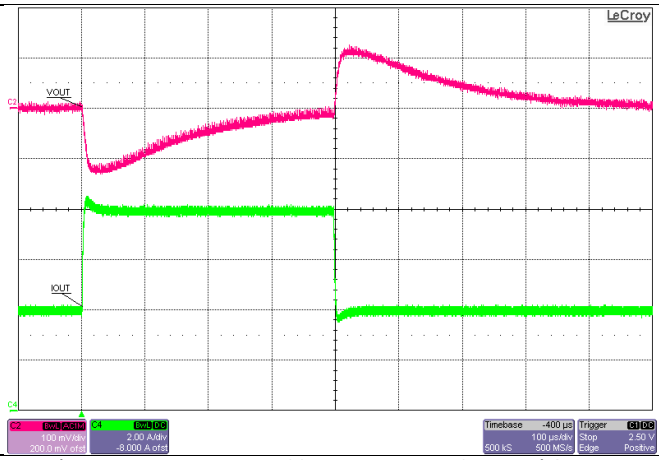
Transient Response, FPWM, 12-V Input, 0-A to 4-A Load Step



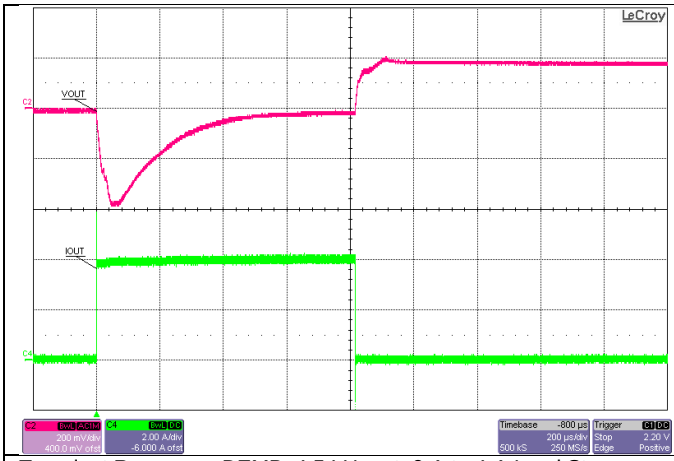
Transient Response, FPWM, 12-V Input, 4-A to 8-A Load Step



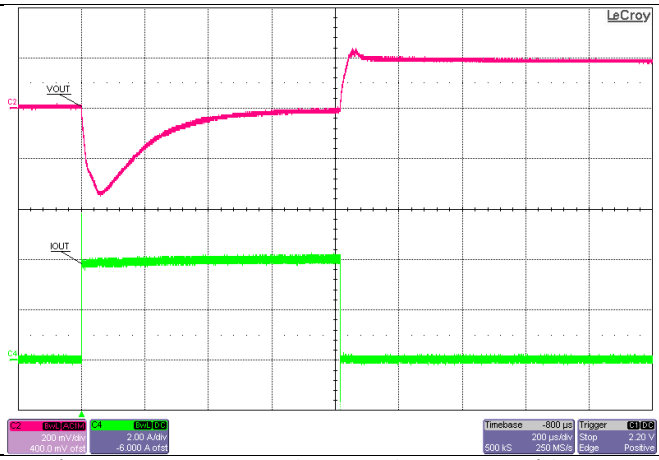
Transient Response, FPWM, 20-V Input, 0-A to 4-A Load Step



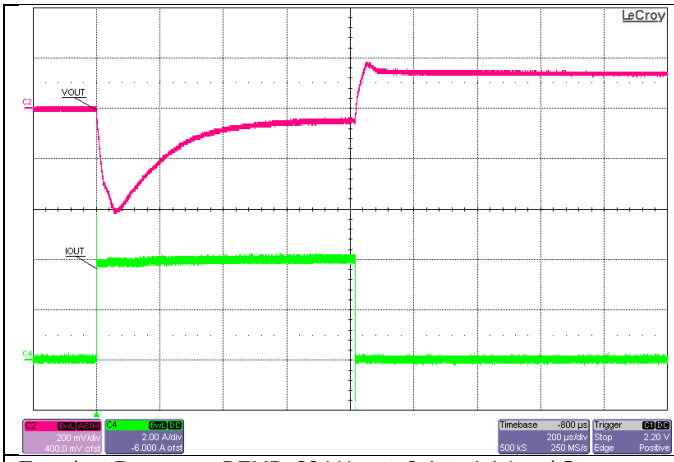
Transient Response, FPWM, 20-V Input, 4-A to 8-A Load Step



Transient Response, DEMB, 4.5-V Input, 0-A to 4-A Load Step



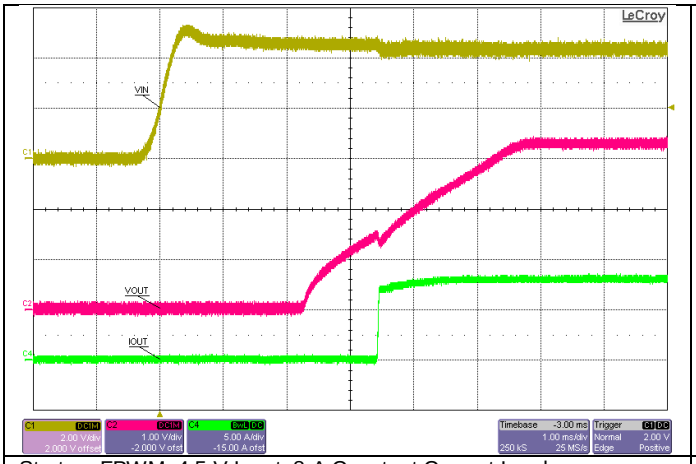
Transient Response, DEMB, 12-V Input, 0-A to 4-A Load Step



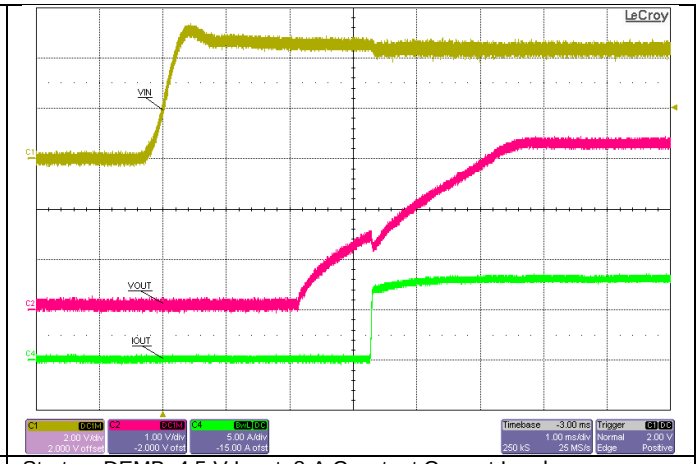
Transient Response, DEMB, 20-V Input, 0-A to 4-A Load Step

3.5 Start-up

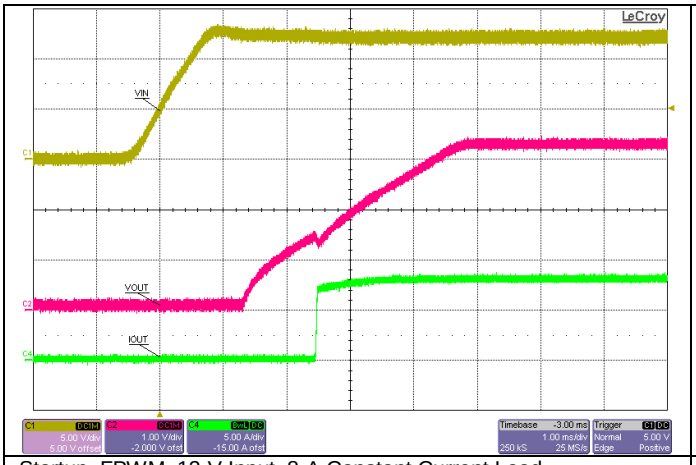
Figures show the startup performance using an 8-A constant current load.



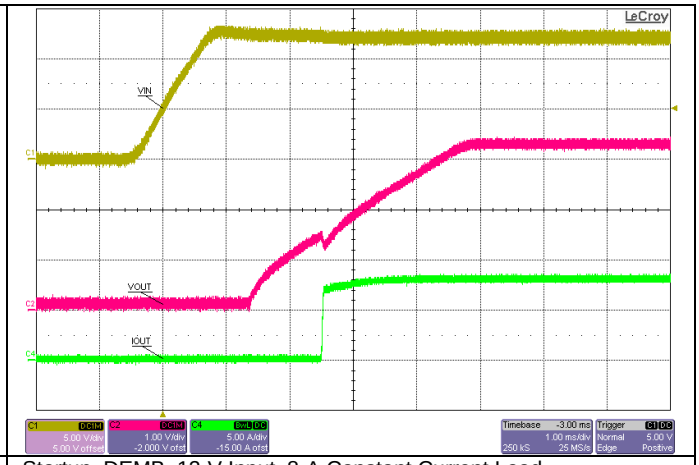
Startup, FPWM, 4.5-V Input, 8-A Constant Current Load



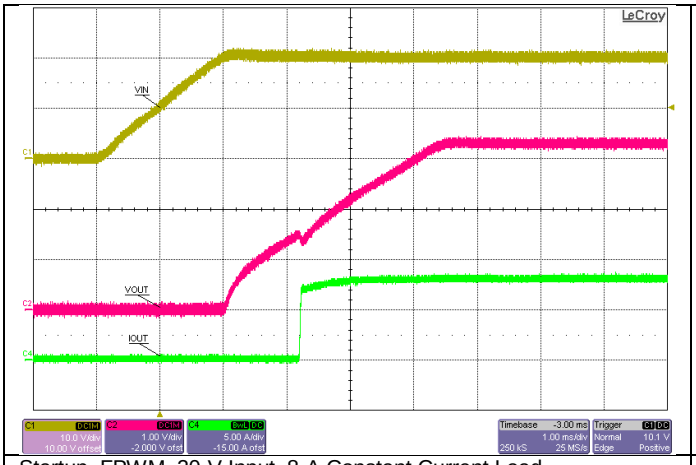
Startup, DEMB, 4.5-V Input, 8-A Constant Current Load



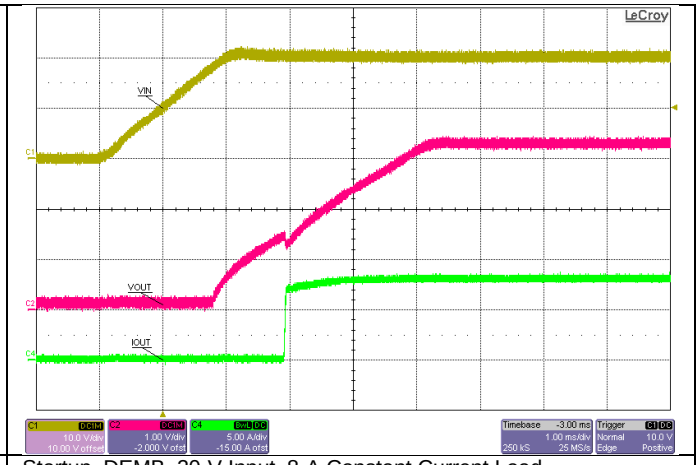
Startup, FPWM, 12-V Input, 8-A Constant Current Load



Startup, DEMB, 12-V Input, 8-A Constant Current Load



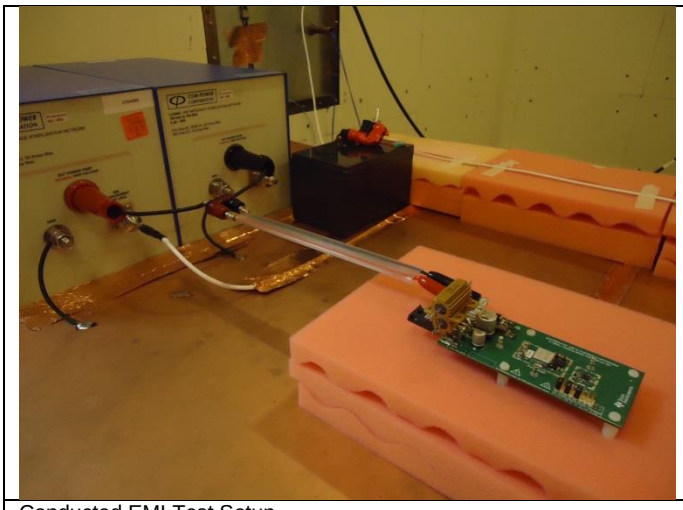
Startup, FPWM, 20-V Input, 8-A Constant Current Load



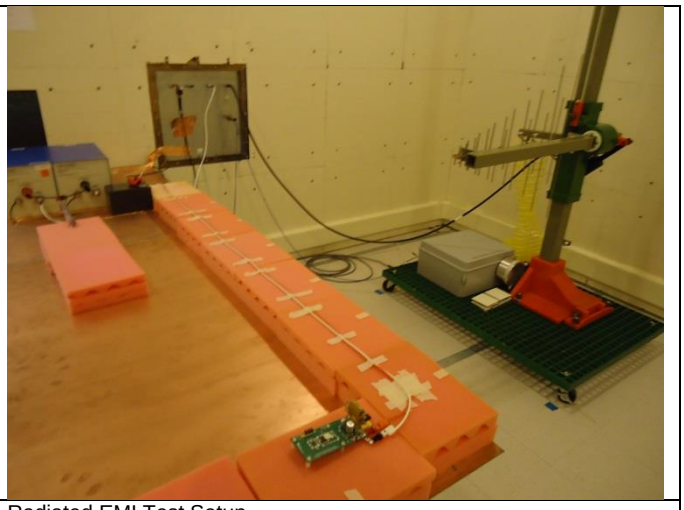
Startup, DEMB, 20-V Input, 8-A Constant Current Load

3.6 EMI

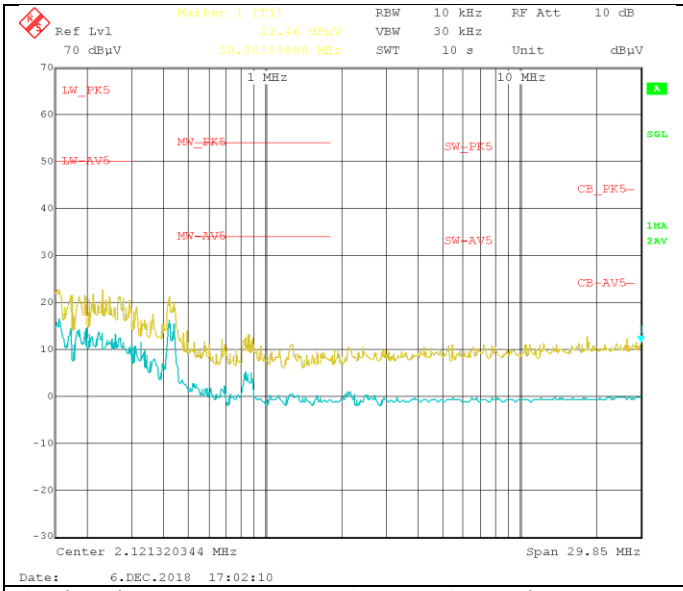
Figures show the EMI test setup and performance for conducted and radiated emissions. CISPR 25 Class 5 limit lines are used.



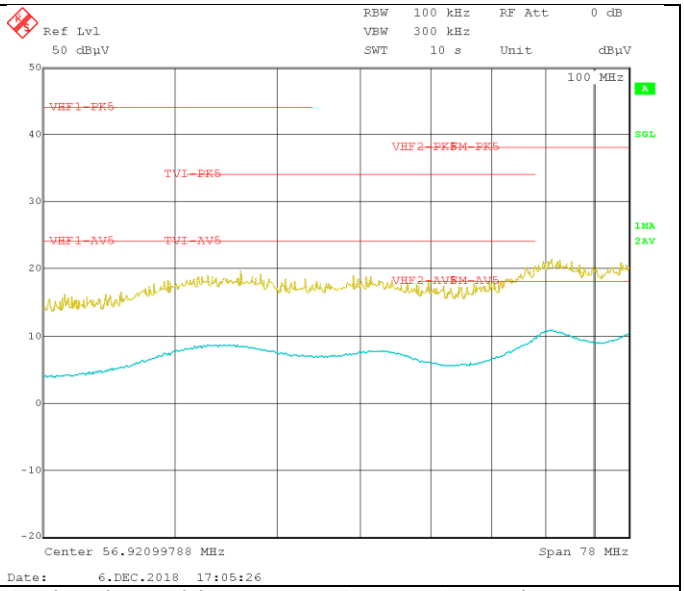
Conducted EMI Test Setup



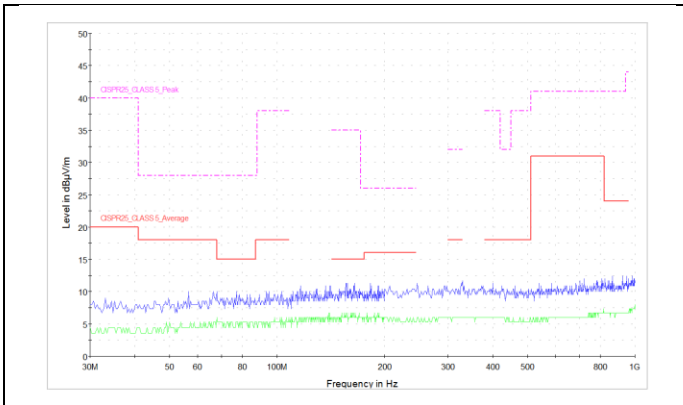
Radiated EMI Test Setup



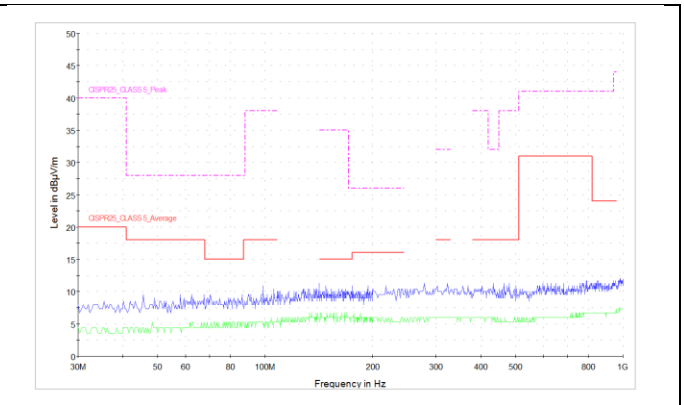
Conducted EMI, Low Frequency, 12-V Input, 8-A Load



Conducted EMI, High Frequency, 12-V Input, 8-A Load



Radiated EMI, Horizontal, 12-V Input, 8-A Load



Radiated EMI, Vertical, 12-V Input, 8-A Load

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