

Automotive, 24V to 60V Input, Two-Port USB Power Delivery 60W Maximum Each Reference Design



Description

This reference design offers power for automotive advanced driver assistance systems (ADAS), infotainment, and cluster applications. Operation is over the 24V to 60VDC input range with focus on 48VDC power. Two USB Power Delivery (PD) outputs are provided to allow charging of both a personal computer and smart phone at the same time. The design exhibits a conversion efficiency of 96% for the maximum 60W, 20V, 3A output off 48V_{in}. The test report includes thermal images, operational data spanning the full input range, and includes output transitions between the four most common output voltages (5V, 9V, 15V, and 20V).

Resources

[PMP23501](#)

Design Folder

[TPS26744E-Q1](#)

Product Folder

[LM72880-Q1](#)

Product Folder

[TMP61-Q1](#)

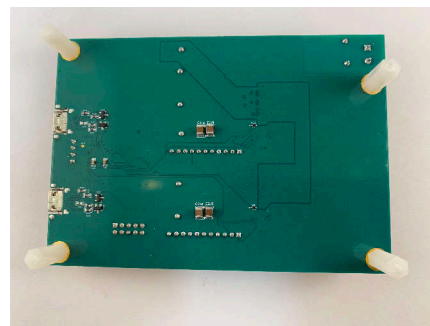
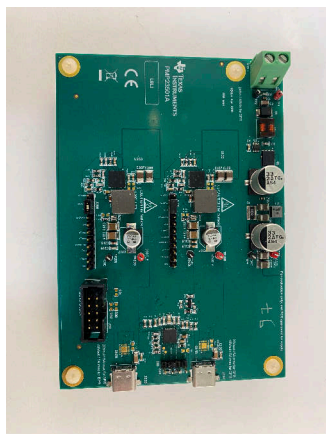
Product Folder

Features

- TPS26744E-Q1 provides USB-PD control for two ports
- Fully integrated LM72880-Q1 power converter for each port
- USB PD: 60W maximum per port and 20V_{out} maximum
- Allows charging of both personal computer and phone from the car at the same time
- Thermal foldback and cable drop compensation can be programmed if needed

Applications

- [Automotive USB charging](#)
- [Automotive media hub](#)



1 Test Prerequisites

This section provides the testing guide used in the detailed testing of the 48V_{in} two-port USB-PD Universal Serial Bus Power Delivery, each port with 20V maximum and 3A maximum.

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input power 24V to 60V steady-state	Use J1 onboard (On-Shore Technology ED120/2DS terminal block). Source needs to be able to deliver 96W, or 4A at 24V _{in} and 2A at 48V _{in} .
Port-A and Port-B outputs: loads up to 3A each off 20V _{out} maximum	Use J130 for Port-A and J230 for Port-B, each 24-pin USB-C® female connector.
J10 connector for programming the USB-PD controller and debug	Pin 1 ground; pin 2 I2C to host for clock; pin 3 I2C to host data; pin 4 for debug
J100 for Port-A DC/DC and J200 for Port-B DC/DC	Jumper pin 2 to pin 3 on each for forced continuous conduction mode operation of each converter, unless PD controller is being used to drive PA_SYNC and PB_SYNC to synchronize the DC/DCs from the PD controller.

1.2 Required Equipment

- V_{IN} power supply 24V to 60V, at least 100W at the input voltage of board under test, or 4A for the full load off a 24V 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
- Thermal camera such as FLIR E75
- USB-PD tester such as Charger LAB Power-Z KM003C
- Keysight 34970 data acquisition, switch unit along with calibrated 5A or 10A current shunts for efficiency measurements
- The TPS26744E-Q1 needs to be programmed through pins 1-2-3 of J10. Personal Computer to TPS267xx interface board also needed. See below for more details.

1.3 Dimensions

The dimensions of the board are 4.95in × 3.45in.

1.4 Programming the TPS26744E-Q1

Use either the TPS26742EQ1EVM or the TPS26744EQ1EVM (both orderable from ti.com) with a USB connection to a personal computer and three jumpers to the J10 connector on the PMP23501 board as shown in Figure 1-1. Both the PMP23501 and the above mentioned EVMs have male pins to make these three jumper connections easier. During programming, the PMP23501 needs 24V (or up to 60V) applied to the main input J1. The 3.3V from the PC USB connection powers the interface circuitry of the above mentioned EVMs.

To order either of the above mentioned EVMs and to program the PD controller on the PMP23501, click [here](#).

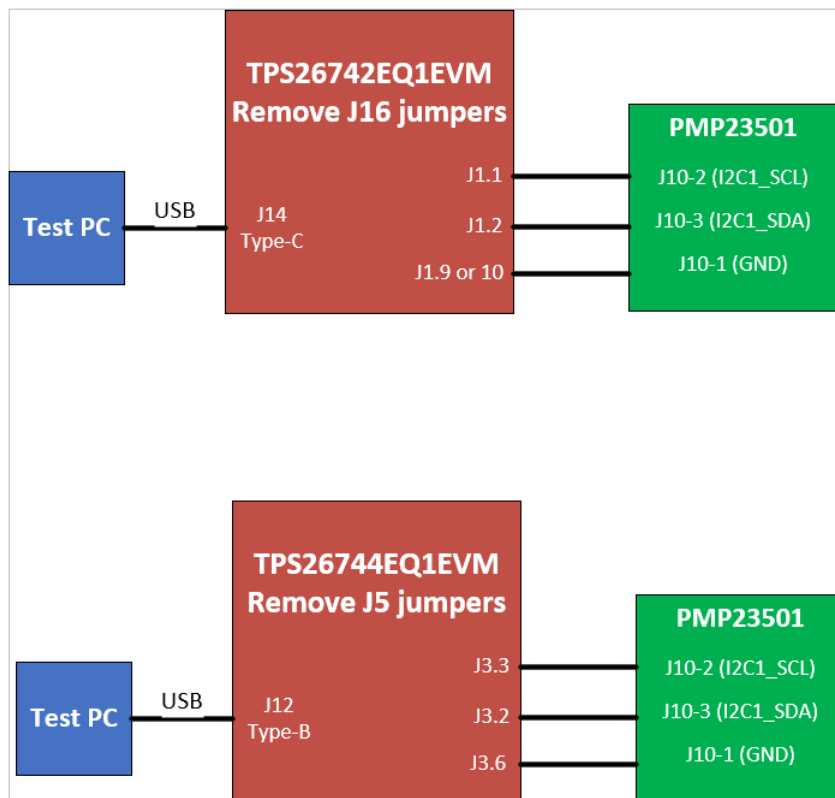


Figure 1-1. Connections for Programming the USB-PD Controller

1.5 Test Setup

Shown is Port-A delivering 5V at 2.8A, and Port-B delivering 20V at 2.4A.

Input J1 (top left of board) connected to 48V source.

Port-A J130 is connected to USB-PD rated to 5A 24-pin male to male 1-meter cable. Other end of cable is connected to Power-Z KM003C being used as a load monitor. The other end of KM003C is connected to 1.7 Ω load with CCx pins pulled down with 5.1k resistors to get 5V at 3A max.

Port-B J230 is connected to Power-Z KM003C being used as a *clicker* to get 20V_{out} 3A max. Other end of KM003C is connected to USB-PD rated to 5A 24-pin male to male 1-meter cable. Other end of cable is connected to a *breakout board* allowing the USB-PD power to be connected to an electronic load (not shown) through standard banana cables.

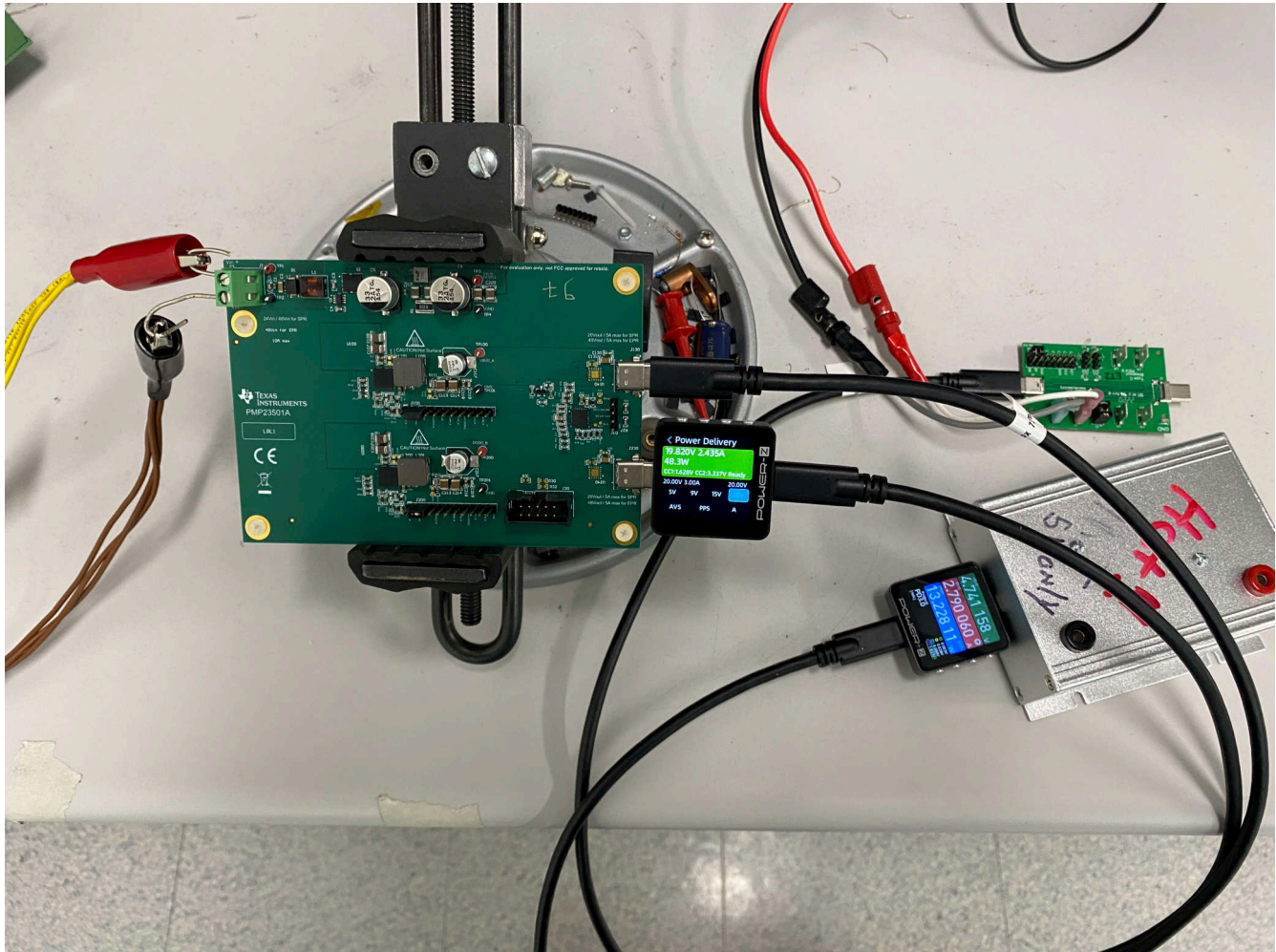


Figure 1-2. Test Setup

2 Testing and Results

2.1 Efficiency and Loss Graphs

Figure 2-1 does not include losses in input EMI filter; PFM (Pulse Frequency Modulation or diode emulation) mode selected.

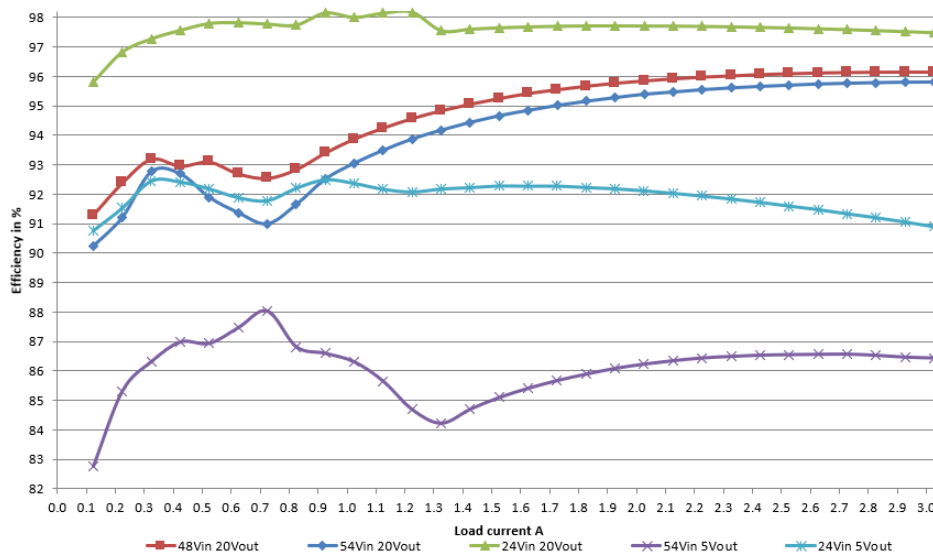


Figure 2-1. Efficiency Graph Showing DC/DC Conversion Performance

Figure 2-2 does not include losses in input EMI filter; PFM mode.

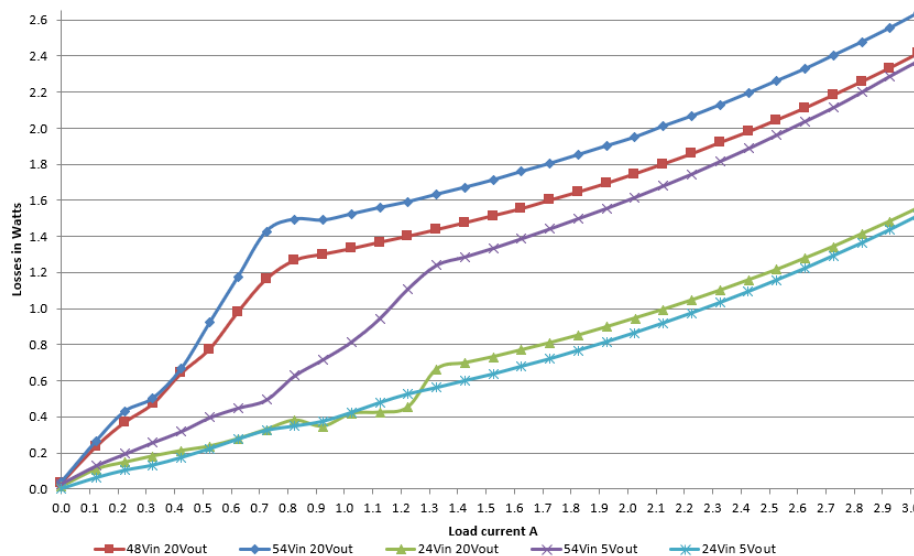


Figure 2-2. Loss Graph Showing DC/DC Conversion Performance

2.2 Efficiency and Loss Data

Efficiency and loss data is shown in [Table 2-1](#) for 48V_{in} and 20V_{out} off Port B PFM mode.

Table 2-1. Efficiency and Loss Data: 48V_{in} 20V_{out}

V _{in}	I _{in}	Power In	Control and Port A	Corr. Power In	V _{out}	I _{out}	Power Out	Eff	Loss
V	A	W	W	W	V	A	W	%	W
47.995	0.002	0.108	0.076	0.032	19.969	0.000	0.000	0.000	0.032
47.992	0.058	2.776	0.076	2.700	19.965	0.123	2.465	91.305	0.235
47.989	0.102	4.912	0.076	4.836	19.963	0.224	4.468	92.393	0.368
47.987	0.146	7.012	0.076	6.936	19.956	0.324	6.464	93.199	0.472
47.984	0.191	9.175	0.076	9.099	19.950	0.424	8.458	92.961	0.640
47.981	0.236	11.304	0.076	11.228	19.945	0.524	10.454	93.102	0.774
47.978	0.281	13.505	0.076	13.429	19.941	0.624	12.449	92.702	0.980
47.976	0.327	15.675	0.076	15.599	19.937	0.724	14.437	92.552	1.162
47.973	0.370	17.772	0.076	17.696	19.933	0.824	16.430	92.847	1.266
47.970	0.413	19.799	0.076	19.723	19.933	0.924	18.423	93.409	1.300
47.968	0.455	21.830	0.076	21.754	19.932	1.025	20.424	93.883	1.331
47.965	0.497	23.861	0.076	23.785	19.932	1.125	22.419	94.256	1.366
47.963	0.540	25.890	0.076	25.814	19.932	1.225	24.415	94.578	1.400
47.960	0.582	27.921	0.076	27.845	19.932	1.325	26.409	94.844	1.436
47.957	0.625	29.954	0.076	29.878	19.931	1.425	28.404	95.066	1.474
47.955	0.667	31.988	0.076	31.912	19.931	1.525	30.398	95.257	1.513
47.952	0.710	34.023	0.076	33.947	19.931	1.625	32.395	95.428	1.552
47.950	0.752	36.066	0.076	35.990	19.931	1.726	34.391	95.556	1.599
47.947	0.795	38.104	0.076	38.028	19.931	1.826	36.384	95.676	1.644
47.944	0.837	40.148	0.076	40.072	19.930	1.926	38.379	95.776	1.692
47.942	0.880	42.197	0.076	42.121	19.930	2.026	40.376	95.857	1.745
47.939	0.923	44.247	0.076	44.171	19.930	2.126	42.372	95.926	1.800
47.936	0.966	46.302	0.076	46.226	19.930	2.226	44.370	95.985	1.856
47.934	1.009	48.354	0.076	48.278	19.930	2.326	46.360	96.027	1.918
47.931	1.052	50.413	0.076	50.337	19.930	2.426	48.359	96.070	1.978
47.928	1.095	52.470	0.076	52.394	19.930	2.526	50.351	96.100	2.044
47.926	1.138	54.532	0.076	54.456	19.929	2.627	52.346	96.126	2.110
47.923	1.181	56.597	0.076	56.521	19.929	2.727	54.340	96.141	2.181
47.920	1.224	58.668	0.076	58.592	19.929	2.827	56.337	96.150	2.256
47.918	1.268	60.736	0.076	60.660	19.928	2.927	58.328	96.155	2.332
47.915	1.311	62.813	0.076	62.737	19.928	3.027	60.325	96.154	2.413

Efficiency and loss data is shown in [Table 2-2](#) for 54V_{in} and 20V_{out} off Port B PFM mode.

Table 2-2. Efficiency and Loss Data: 54V_{in} 20V_{out}

V _{in}	I _{in}	Power In	Control and Port A	Corr. Power In	V _{out}	I _{out}	Power Out	Eff	Loss
V	A	W	W	W	V	A	W	%	W
53.995	0.002	0.121	0.083	0.038	19.970	0.000	0.000	0.000	0.038
53.992	0.052	2.808	0.083	2.725	19.965	0.123	2.459	90.245	0.266
53.989	0.092	4.978	0.083	4.895	19.960	0.224	4.466	91.224	0.430
53.987	0.131	7.048	0.083	6.965	19.957	0.324	6.462	92.772	0.503
53.984	0.171	9.207	0.083	9.124	19.949	0.424	8.457	92.693	0.667
53.982	0.212	11.455	0.083	11.372	19.944	0.524	10.451	91.899	0.921
53.979	0.254	13.709	0.083	13.626	19.940	0.624	12.451	91.375	1.175
53.977	0.295	15.950	0.083	15.867	19.934	0.724	14.439	91.002	1.428
53.974	0.334	18.009	0.083	17.926	19.928	0.825	16.431	91.660	1.495
53.972	0.370	19.994	0.083	19.911	19.929	0.924	18.421	92.519	1.489
53.970	0.408	22.028	0.083	21.945	19.929	1.025	20.421	93.057	1.524
53.968	0.446	24.062	0.083	23.979	19.929	1.125	22.419	93.498	1.559
53.965	0.483	26.088	0.083	26.005	19.929	1.225	24.413	93.881	1.591
53.963	0.521	28.124	0.083	28.041	19.929	1.325	26.409	94.179	1.632
53.961	0.559	30.153	0.083	30.070	19.929	1.425	28.399	94.443	1.671
53.958	0.597	32.188	0.083	32.105	19.928	1.525	30.393	94.668	1.712
53.956	0.634	34.230	0.083	34.147	19.928	1.625	32.388	94.849	1.759
53.954	0.672	36.273	0.083	36.190	19.928	1.726	34.387	95.017	1.803
53.951	0.710	38.310	0.083	38.227	19.928	1.825	36.375	95.156	1.852
53.949	0.748	40.357	0.083	40.274	19.928	1.926	38.373	95.280	1.901
53.947	0.786	42.399	0.083	42.316	19.928	2.026	40.368	95.395	1.949
53.944	0.824	44.457	0.083	44.374	19.927	2.126	42.364	95.470	2.010
53.942	0.862	46.511	0.083	46.428	19.927	2.226	44.362	95.550	2.066
53.940	0.900	48.567	0.083	48.484	19.927	2.326	46.356	95.611	2.128
53.937	0.939	50.631	0.083	50.548	19.927	2.427	48.354	95.661	2.193
53.935	0.977	52.690	0.083	52.607	19.927	2.527	50.346	95.702	2.261
53.932	1.015	54.755	0.083	54.672	19.927	2.627	52.344	95.743	2.327
53.930	1.054	56.820	0.083	56.737	19.927	2.727	54.335	95.767	2.402
53.928	1.092	58.893	0.083	58.810	19.927	2.827	56.334	95.790	2.476
53.925	1.130	60.962	0.083	60.879	19.926	2.927	58.325	95.804	2.554
53.923	1.169	63.040	0.083	62.957	19.926	3.027	60.319	95.809	2.638

Efficiency and loss data is shown in [Table 2-3](#) for 24V_{in} and 20V_{out} off Port B PFM mode.

Table 2-3. Efficiency and Loss Data: 24V_{in} 20V_{out}

V _{in}	I _{in}	Power In	Control and Port A	Corr. Power In	V _{out}	I _{out}	Power Out	Eff	Loss
V	A	W	W	W	V	A	W	%	W
23.998	0.003	0.061	0.050	0.011	19.967	0.000	0.000	0.000	0.011
23.991	0.109	2.622	0.050	2.572	19.962	0.123	2.464	95.811	0.108
23.986	0.194	4.661	0.050	4.611	19.958	0.224	4.464	96.827	0.146
23.981	0.279	6.692	0.050	6.642	19.953	0.324	6.461	97.274	0.181
23.976	0.364	8.726	0.050	8.676	19.954	0.424	8.465	97.566	0.211
23.971	0.448	10.741	0.050	10.691	19.948	0.524	10.456	97.797	0.236
23.966	0.533	12.771	0.050	12.721	19.933	0.624	12.444	97.825	0.277
23.960	0.618	14.814	0.050	14.764	19.932	0.724	14.436	97.777	0.328
23.955	0.704	16.860	0.050	16.810	19.932	0.824	16.430	97.742	0.380
23.950	0.786	18.826	0.050	18.776	19.932	0.925	18.429	98.155	0.346
23.945	0.873	20.895	0.050	20.845	19.932	1.025	20.429	98.002	0.417
23.940	0.956	22.897	0.050	22.847	19.931	1.125	22.423	98.147	0.423
23.935	1.041	24.918	0.050	24.868	19.931	1.225	24.416	98.179	0.453
23.929	1.134	27.127	0.050	27.077	19.931	1.325	26.415	97.553	0.663
23.924	1.219	29.154	0.050	29.104	19.931	1.425	28.407	97.603	0.698
23.919	1.304	31.185	0.050	31.135	19.930	1.525	30.404	97.652	0.731
23.913	1.389	33.214	0.050	33.164	19.930	1.625	32.395	97.680	0.769
23.908	1.475	35.254	0.050	35.204	19.930	1.726	34.395	97.703	0.809
23.903	1.560	37.286	0.050	37.236	19.930	1.826	36.385	97.715	0.851
23.897	1.646	39.328	0.050	39.278	19.930	1.926	38.381	97.717	0.897
23.892	1.732	41.373	0.050	41.323	19.930	2.026	40.378	97.712	0.945
23.887	1.818	43.419	0.050	43.369	19.930	2.126	42.376	97.709	0.994
23.881	1.904	45.468	0.050	45.418	19.929	2.227	44.373	97.698	1.045
23.876	1.990	47.514	0.050	47.464	19.929	2.326	46.364	97.683	1.100
23.870	2.077	49.571	0.050	49.521	19.929	2.427	48.364	97.664	1.157
23.865	2.163	51.622	0.050	51.572	19.929	2.527	50.357	97.645	1.215
23.859	2.250	53.680	0.050	53.630	19.929	2.627	52.352	97.617	1.278
23.854	2.337	55.739	0.050	55.689	19.929	2.727	54.347	97.589	1.342
23.848	2.424	57.803	0.050	57.753	19.929	2.827	56.340	97.554	1.412
23.843	2.511	59.868	0.050	59.818	19.928	2.927	58.335	97.521	1.483
23.837	2.598	61.937	0.050	61.887	19.928	3.027	60.331	97.485	1.557

Efficiency and loss data is shown in [Table 2-4](#) for 54V_{in} and 5V_{out} off Port B PFM mode.

Table 2-4. Efficiency and Loss Data: 54V_{in} 5V_{out}

V _{in}	I _{in}	Power In	Control and Port A	Corr. Power In	V _{out}	I _{out}	Power Out	Eff	Loss
V	A	W	W	W	V	A	W	%	W
53.994	0.002	0.112	0.083	0.029	5.048	0.000	0.000	0.000	0.029
53.994	0.015	0.835	0.083	0.752	5.043	0.123	0.622	82.771	0.130
53.993	0.026	1.407	0.083	1.324	5.045	0.224	1.130	85.322	0.194
53.993	0.037	1.974	0.083	1.891	5.041	0.324	1.632	86.317	0.259
53.992	0.047	2.538	0.083	2.455	5.036	0.424	2.135	86.983	0.320
53.991	0.058	3.116	0.083	3.033	5.031	0.524	2.636	86.935	0.396
53.991	0.068	3.671	0.083	3.588	5.026	0.624	3.138	87.470	0.450
53.990	0.078	4.215	0.083	4.132	5.023	0.724	3.638	88.033	0.495
53.989	0.090	4.849	0.083	4.766	5.019	0.824	4.138	86.820	0.628
53.989	0.101	5.437	0.083	5.354	5.016	0.924	4.637	86.598	0.718
53.988	0.112	6.037	0.083	5.954	5.015	1.025	5.139	86.309	0.815
53.987	0.124	6.671	0.083	6.588	5.016	1.125	5.643	85.654	0.945
53.987	0.136	7.334	0.083	7.251	5.013	1.225	6.141	84.692	1.110
53.986	0.147	7.949	0.083	7.866	5.001	1.325	6.626	84.231	1.240
53.985	0.157	8.496	0.083	8.413	5.001	1.425	7.126	84.705	1.287
53.985	0.168	9.044	0.083	8.961	5.000	1.525	7.626	85.102	1.335
53.984	0.178	9.598	0.083	9.515	5.000	1.625	8.127	85.414	1.388
53.983	0.188	10.152	0.083	10.069	5.000	1.725	8.627	85.676	1.442
53.983	0.198	10.709	0.083	10.626	5.000	1.825	9.127	85.893	1.499
53.982	0.209	11.265	0.083	11.182	4.999	1.926	9.627	86.088	1.556
53.982	0.219	11.826	0.083	11.743	4.999	2.026	10.126	86.233	1.617
53.981	0.230	12.390	0.083	12.307	4.999	2.126	10.627	86.349	1.680
53.980	0.240	12.957	0.083	12.874	4.999	2.226	11.128	86.442	1.745
53.980	0.251	13.525	0.083	13.442	4.999	2.326	11.627	86.493	1.816
53.979	0.261	14.096	0.083	14.013	4.998	2.426	12.127	86.537	1.887
53.978	0.272	14.671	0.083	14.588	4.998	2.526	12.626	86.554	1.961
53.978	0.282	15.245	0.083	15.162	4.998	2.626	13.125	86.565	2.037
53.977	0.293	15.823	0.083	15.740	4.998	2.726	13.626	86.571	2.114
53.976	0.304	16.407	0.083	16.324	4.998	2.827	14.126	86.531	2.199
53.976	0.315	16.996	0.083	16.913	4.997	2.927	14.625	86.470	2.288
53.975	0.326	17.580	0.083	17.497	4.997	3.027	15.125	86.440	2.373

Efficiency and loss data is shown in [Table 2-5](#) for 24V_{in} and 5V_{out} off Port B PFM mode.

Table 2-5. Efficiency and Loss Data: 24V_{in} 5V_{out}

V _{in}	I _{in}	Power In	Control and Port A	Corr. Power In	V _{out}	I _{out}	Power Out	Eff	Loss
V	A	W	W	W	V	A	W	%	W
23.998	0.002	0.053	0.050	0.003	5.049	0.000	0.000	0.000	0.003
23.996	0.031	0.734	0.050	0.684	5.042	0.123	0.621	90.762	0.063
23.995	0.053	1.282	0.050	1.232	5.043	0.224	1.128	91.536	0.104
23.993	0.076	1.814	0.050	1.764	5.038	0.324	1.631	92.457	0.133
23.992	0.098	2.358	0.050	2.308	5.033	0.424	2.133	92.420	0.175
23.991	0.121	2.907	0.050	2.857	5.028	0.524	2.634	92.186	0.223
23.989	0.144	3.462	0.050	3.412	5.023	0.624	3.136	91.887	0.277
23.988	0.167	4.009	0.050	3.959	5.018	0.724	3.634	91.785	0.325
23.987	0.189	4.533	0.050	4.483	5.014	0.824	4.134	92.210	0.349
23.985	0.211	5.060	0.050	5.010	5.013	0.924	4.635	92.498	0.376
23.984	0.234	5.613	0.050	5.563	5.015	1.025	5.138	92.373	0.424
23.983	0.257	6.166	0.050	6.116	5.012	1.125	5.637	92.172	0.479
23.981	0.279	6.702	0.050	6.652	5.001	1.225	6.126	92.082	0.527
23.980	0.302	7.238	0.050	7.188	5.001	1.325	6.627	92.184	0.562
23.978	0.324	7.776	0.050	7.726	5.001	1.425	7.125	92.229	0.600
23.977	0.347	8.313	0.050	8.263	5.000	1.525	7.626	92.288	0.637
23.976	0.369	8.857	0.050	8.807	5.000	1.625	8.127	92.279	0.680
23.974	0.392	9.399	0.050	9.349	5.000	1.725	8.627	92.282	0.721
23.973	0.415	9.944	0.050	9.894	5.000	1.825	9.126	92.234	0.768
23.972	0.438	10.492	0.050	10.442	5.000	1.925	9.626	92.191	0.815
23.970	0.461	11.043	0.050	10.993	5.000	2.026	10.127	92.122	0.866
23.969	0.484	11.596	0.050	11.546	4.999	2.126	10.627	92.037	0.919
23.967	0.507	12.152	0.050	12.102	4.999	2.226	11.127	91.944	0.975
23.966	0.530	12.710	0.050	12.660	4.999	2.326	11.627	91.842	1.033
23.965	0.554	13.270	0.050	13.220	4.998	2.426	12.127	91.729	1.093
23.963	0.577	13.832	0.050	13.782	4.998	2.526	12.624	91.603	1.157
23.962	0.601	14.398	0.050	14.348	4.998	2.626	13.126	91.481	1.222
23.960	0.625	14.967	0.050	14.917	4.998	2.726	13.625	91.338	1.292
23.959	0.649	15.539	0.050	15.489	4.998	2.827	14.126	91.204	1.362
23.957	0.673	16.113	0.050	16.063	4.998	2.927	14.626	91.057	1.437
23.956	0.697	16.690	0.050	16.640	4.997	3.027	15.125	90.896	1.515

2.3 Thermal Images

Thermal images are shown in [Figure 2-3](#) and [Figure 2-4](#).

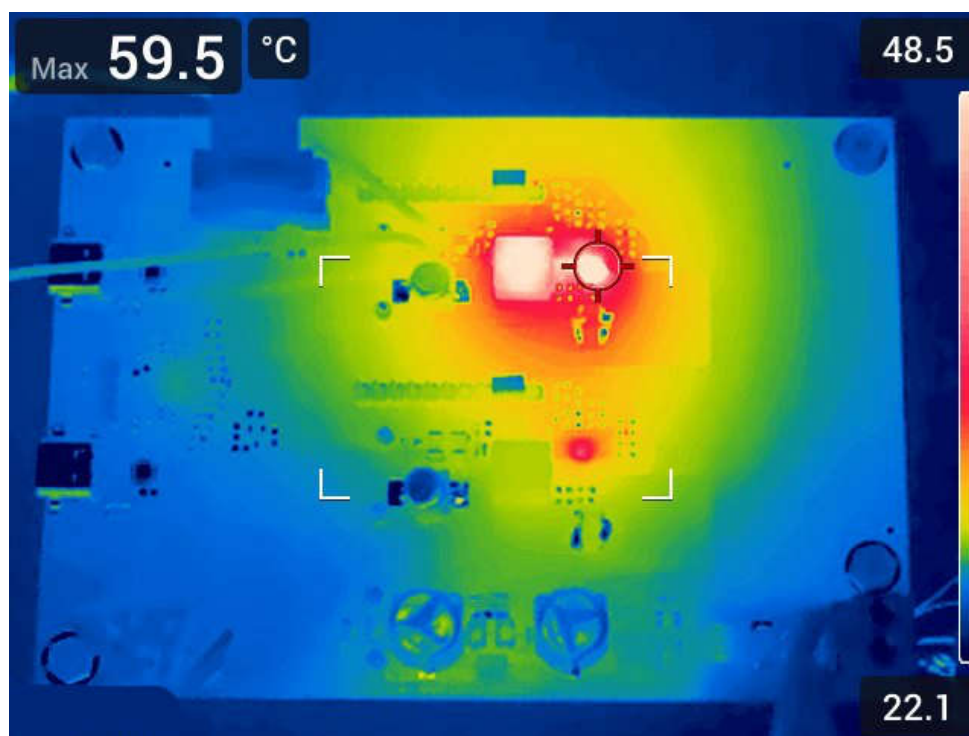


Figure 2-3. Thermal Image for 54V_{in}, 20V_{out} at 3A Off Port B: With Fan After Stabilization

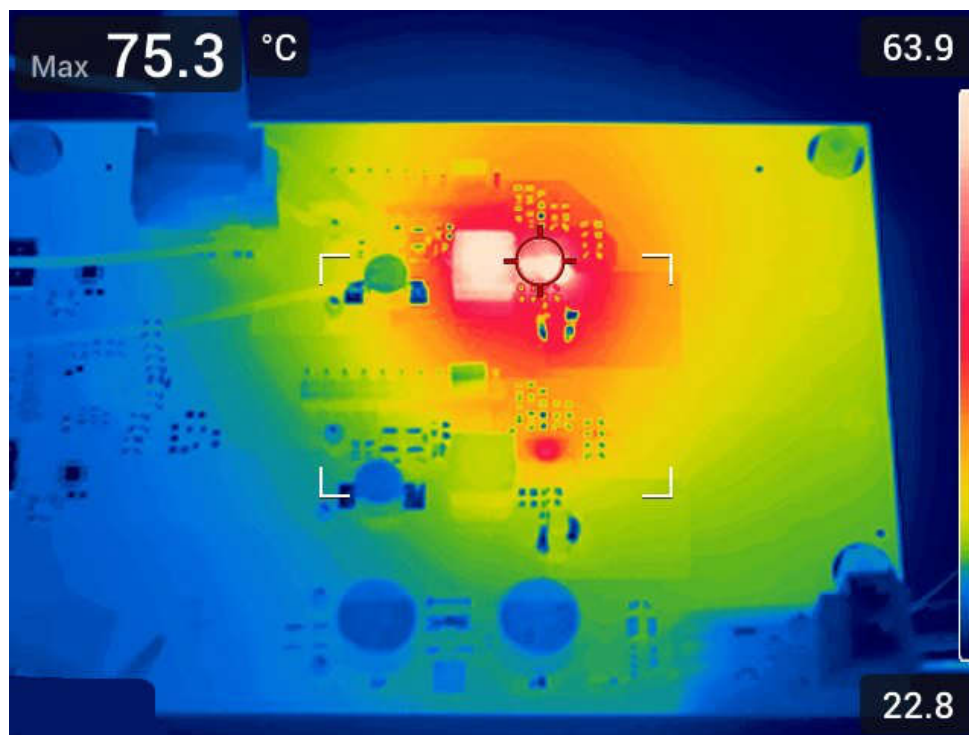


Figure 2-4. Thermal Image for 54V_{in}, 20V_{out} at 3A Off Port B: With No Fan and After Stabilization

3 Waveforms

3.1 Output Transitions

Output transitions between the four main USB-PD SPR voltage levels of 5V, 9V, 15V and 20V are shown in Figure 3-1 through Figure 3-8. For all transitions shown, V_{in} is 48V, scope channel 2 blue is V_{out} , and scope channel 3 purple is I_{out} .

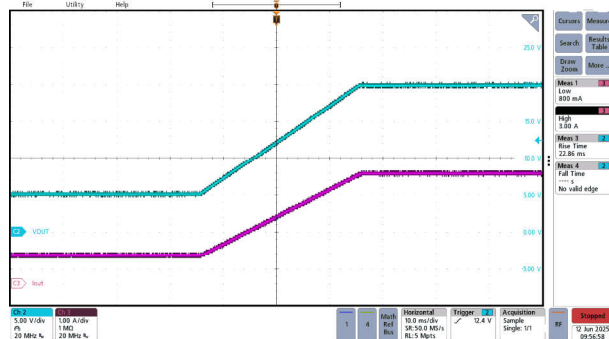


Figure 3-1. Output Transition 5V to 20V With 7Ω Load

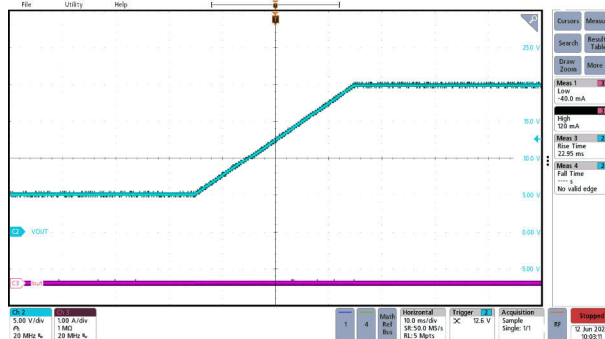


Figure 3-2. Output Transition 5V to 20V With No Load

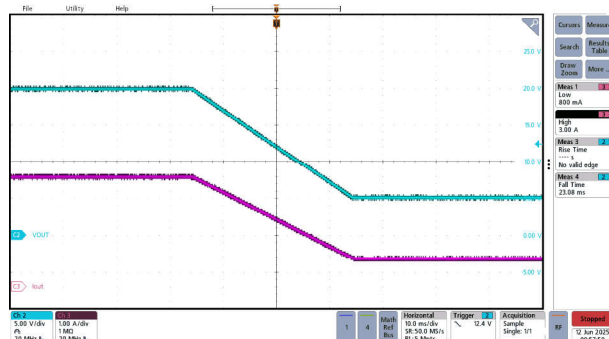


Figure 3-3. Output Transition 20V to 5V With 7Ω Load

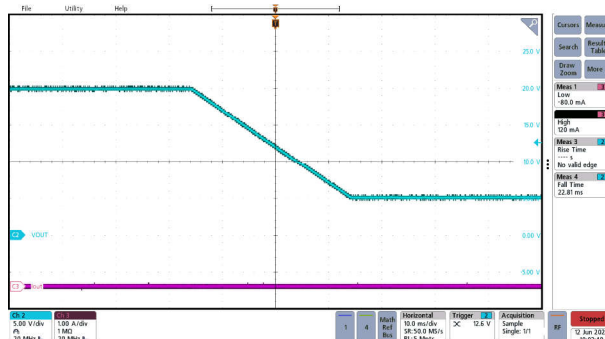


Figure 3-4. Output Transition 20V to 5V With No Load

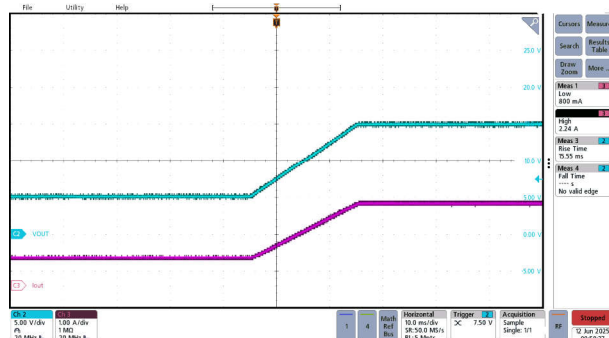


Figure 3-5. Output Transition 5V to 15V With 7Ω Load

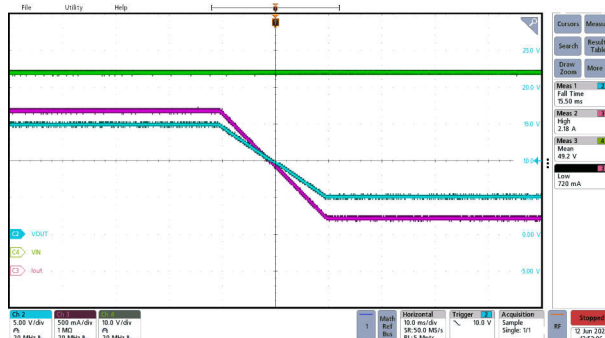


Figure 3-6. Output Transition 15V to 5V With 7Ω Load (V_{in} at 48V Green Also Shown)

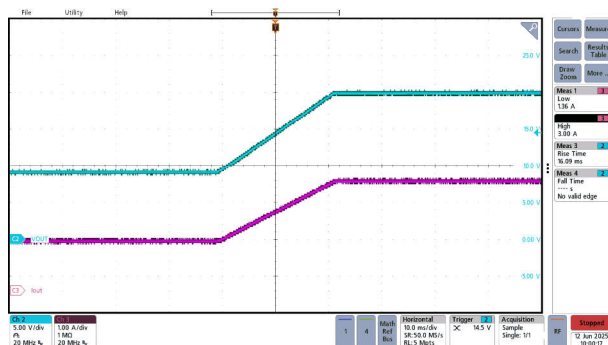


Figure 3-7. Output Transition 9V to 20V With 7Ω Load

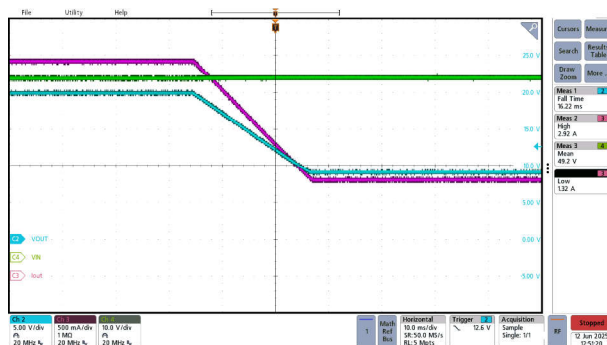


Figure 3-8. Output Transition 20V to 9V With 7Ω Load (V_{in} at 48V Green Also Shown)

3.2 Output Ripple

All ripple scans done with 60V_{in}. Scope channel 2 blue is output AC ripple with 20MHz bandwidth, scope channel 3 purple is load current, scope channel 4 green is V_{in} .

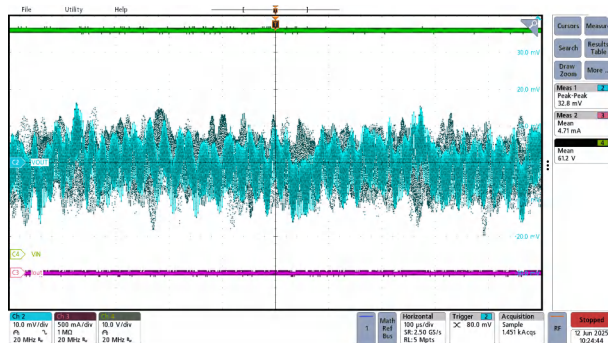


Figure 3-9. Output Ripple 60V_{in} 20V_{out} No Load, Forced Continuous Conduction Mode FCCM, 33mV Peak-To-Peak P-P

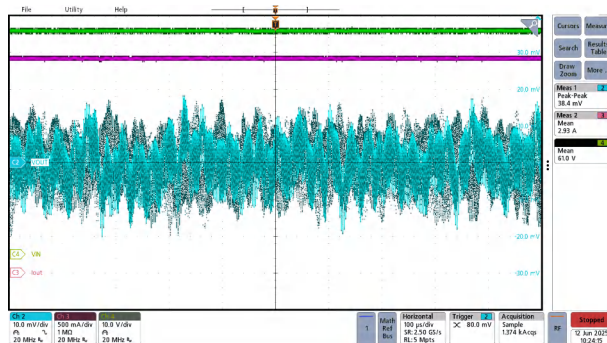


Figure 3-10. Output Ripple 60V_{in} 20V_{out} 3A Load, FCCM, 38mV Peak-To-Peak P-P

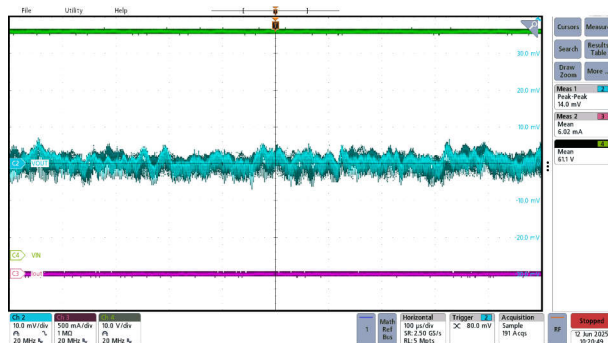


Figure 3-11. Output Ripple 60V_{in} 5V_{out} No Load, FCCM, 14mV Peak-To-Peak P-P

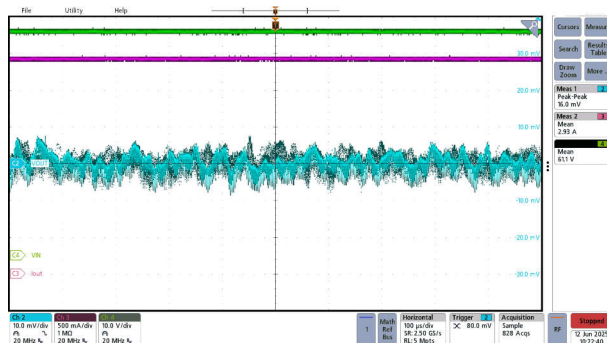


Figure 3-12. Output Ripple 60V_{in} 5V_{out} 3A Load, FCCM, 16mV Peak-To-Peak P-P

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