TI Designs: PMP20249

CISPR 25 Class 4 Rated Design for Dual Automotive USB Charger Reference Design

Description

PMP20249 is an EMI-optimized design for an automotive USB charger system with dual 12.5-W outputs.

Resources

PMP20249	Design Folder
LMS3655-Q1	Product Folder
LMS3635-Q1	Product Folder
TPS2549-Q1	Product Folder

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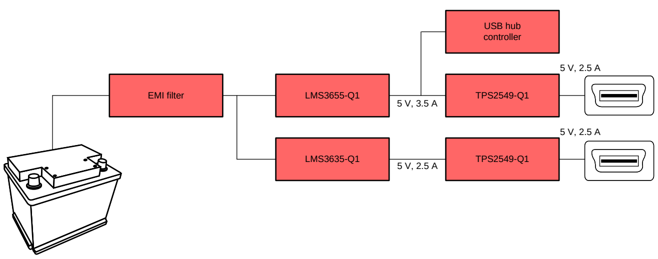
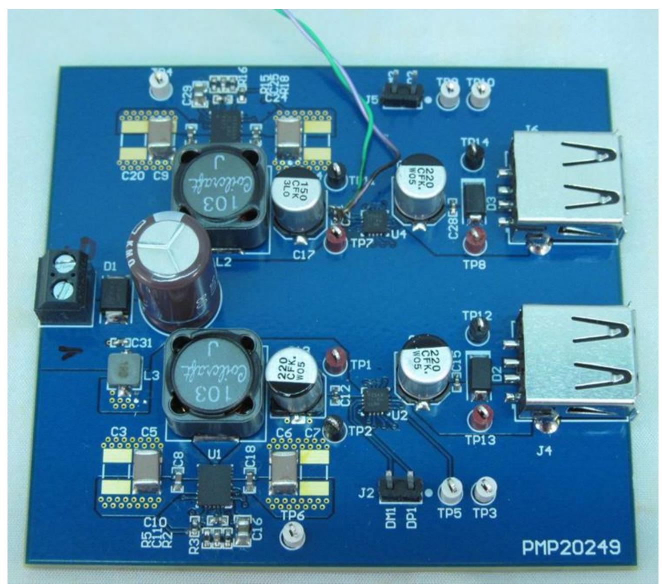
Features

- Wide-Vin Front-End Power Supply for USB Charger System
- Off-Battery Operation With Positive and Negative Overvoltage Protection
- Passed CISPR 25 Class 4 Conducted EMI Test
- Switching Frequency: Outside AM Band (400 kHz) for all Converters
- All AEC-Q100-Qualified Devices
- Supports 6-V to 18-V Wide-Vin Range

Applications

- Automotive USB Charger System
- Automotive Infotainment System





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1 System Description

PMP20249 is an EMI-optimized design for dual-automotive USB charger system using the LMS3635 and LMS3655 regulators (400-kHz fully-integrated, synchronous buck for automotive applications) and the TPS2549 USB switch (TPS2549-Q1 automotive USB charging port controller with integrated power switch and cable compensation). The design accepts an input voltage range of 6 Vin to 18 Vin and regulates two outputs of 5 V at 2.5 A for dual-USB ports. This highly efficient design features an inexpensive solution and small-size customized for an automotive USB charger application. A four-layer PCB was used for this design.

The design is divided into four major blocks:

- Front-end protection: Front-end protection against positive and negative pulses (ISO7630 pulse 1, 2a, 3a/b) through TVS.
- EMI filter: Differential filter for conducted EMI suppression.
- Low-EMI front-end DC-DC converters: LMS3655-Q1 and LMS3635-Q1 are switching, synchronous 5.5-A and 3.5-A buck regulators, and in this design the devices are used as front-end DC-DC converters. These 400-kHz parts are automotive optimized and have low EMI. The device comes in an automotive-qualified HotRod™ QFN package with wettable flanks, which reduces parasitic inductance and resistance while increasing efficiency, minimizing switch node ringing, and dramatically lowering EMI. The spread spectrum feature is a factory option which further reduces EMI. This feature eliminates peak emissions at specific frequencies by spreading emissions across a wider range of frequencies.
- Downstream USB charging-port controller and power switch: TPS2549-Q1 maintains 5 V at the USB port during heavy charging currents.

1.1 *Key System Specifications*

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Vin minimum	6 V	Section 1
Vin maximum	18 V	Section 1
Vin nominal	12 V (automotive design)	Section 1
Vout 1	5 V	Section 1
Iout 1	2.5 A	Section 1
Vout 2	5 V	Section 1
Iout 2	2.5 A	Section 1
Approximate switching frequency	400 kHz	Section 1
ISO pulse test	Transient voltage suppressor (TVS) diode used for protection	Section 1
EMI	Passed CISPR25 class 4 limits	Section 3.2.2.6

2 System Overview

2.1 Block Diagram

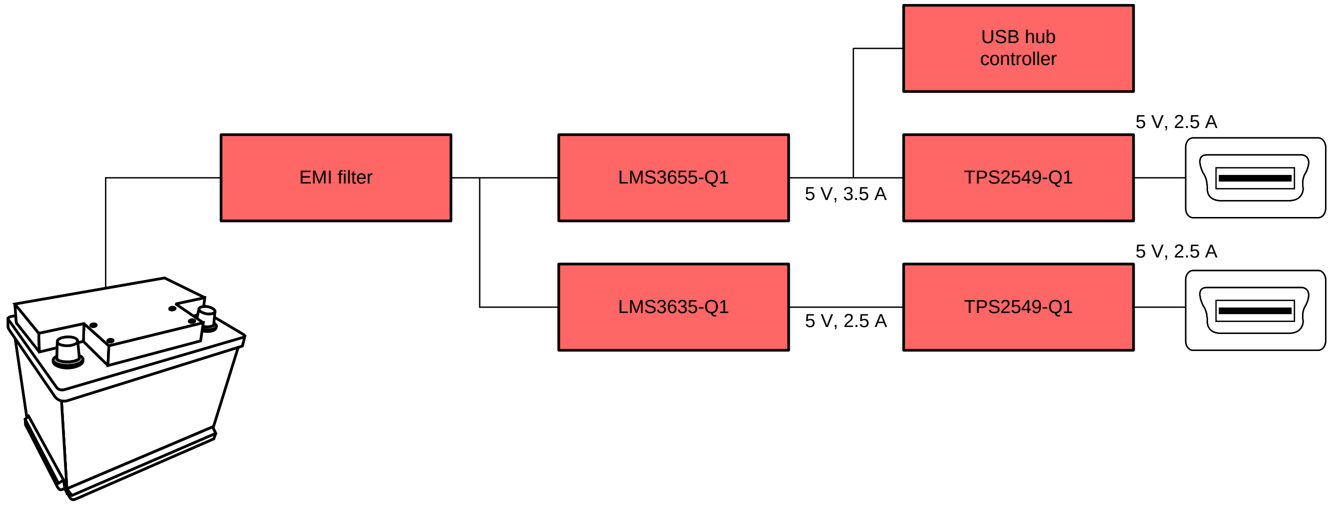

Figure 1. PMP20249 Block Diagram

2.2 Design Considerations

The dual-USB charger has multiple protections at the front end of the design. TVSs are used to clamp or filter bidirectional, high-voltage electrical fast transients and maintain operation during positive pulses. These pulses include clamped load dump (up to 38 V) and other transients outlined in ISO 7637-2:2004. An EMI filter is included in the front end, and the design is compliant with the stringent CISPR 25 class 4 automotive EMI standard.

The operating frequency for all the synchronous buck converters (LMS3635 and LMS3655) is 400 kHz. These devices have a low-unloaded current consumption, which eliminates the need for an external back-up LDO. The low-shutdown current and high-maximum operating voltage of the LMS36X5 also allows the elimination of an external load switch. If the target application is non-automotive, then the designer can consider using the commercial version LMS3655 for this system design.

The power switch (TPS2549) has a current-sense output that is able to control the upstream supply. Consequently, the output is regulated at a constant 5-V output even with heavy charging currents. For design calculations and layout examples, refer to the datasheet of the devices used.

- *LMS3635/55-Q1, 3.5-A /5.5-A, 36-V Synchronous, 400-kHz, Step-Down Converter*[2]
- *LMS3655 5.5-A, 36-V Synchronous, 400-kHz DC-DC Step-Down Converter*[3]

2.3 Highlighted Products

2.3.1 LMS36X5-Q1

- Synchronous buck converter
- Qualified for automotive applications (AEC-Q100 qualified)
- Wide-operating input voltage: 3.5 V to 36 V (with transient to 42 V)
- Spread spectrum option available, which helps in EMI compliance
- 400-kHz fixed switching frequency, which avoids AM band
- Low-quiescent current: 15 µA
- –40°C to 150°C junction temperature range
- Adjustable, 3.3-V, or 5-V output
- Maximum current load: 3.5 A for LMS3635-Q1, 5.5 A for LMS3655-Q1
- 4 mm × 5 mm, 0.5-mm pitch VQFN package with wettable flanks

2.3.2 TPS2549-Q1

- USB port controller and power switch with cable compensation
- Qualified for automotive applications (AEC-Q100 qualified)
- Input voltage range of 4.5 V to 5.5 V
- 3.2-A continuous output current
- Compliant with CISPR25 class 5 conducted emissions

3 Hardware, Testing Requirements, and Test Results

3.1 Required Hardware

3.1.1 Hardware

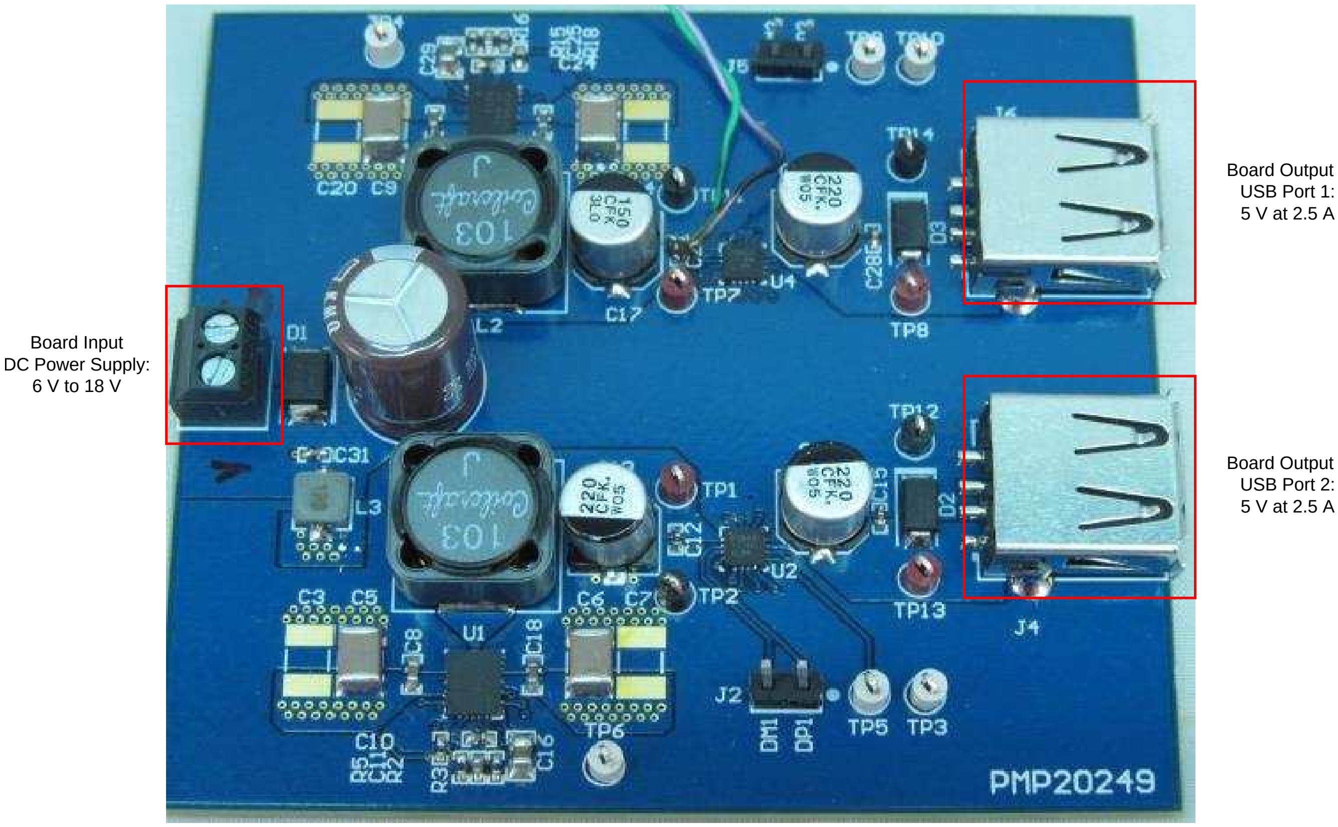

Figure 2. PMP20249 Board Setup

1. Connect a DC power supply to the board input as identified in Figure 2.
2. In order to imitate the typical load of a USB output, connect an electronic or resistive load to the dual output test points, as shown in Section 3.1.1.1. Each 5-V output is rated to a maximum current of 2.5 A.
3. Begin evaluating the performance of PMP20249 through the appropriate test points and headers, as described in Section 3.1.1.1.

3.1.1.1 Evaluation Headers and Test Points

Table 2. Evaluation Headers and Test Points

COMPONENT DESIGNATOR	PIN NUMBER	SIGNAL
DATA HOST CONTROLLER HEADER CONNECTIONS		
J2	1	Hub DP1
	2	Hub DM1
J5	1	Hub DP2
	2	Hub DM2
BOARD TEST POINTS		
TP1	1	LMS3635A-Q1 output (U1)
TP2	1	GND
TP3	1	TPS2549 fault pin (U2)
TP4	1	LMS3635A-Q1 SYNC pin (U3)
TP5	1	TPS2549 status pin (U2)
TP6	1	LMS3635A-Q1 SYNC pin (U1)
TP7	1	LMS3635A-Q1 output (U3)
TP8	1	TPS2549 output (U4)
TP9	1	TPS2549 status pin (U4)
TP10	1	TPS2549 fault pin (U4)
TP11	1	GND
TP12	1	GND
TP13	1	TPS2549 output (U2)
TP14	1	GND

3.2 Testing and Results

3.2.1 Test Setup

3.2.1.1 Thermal Data

IR thermal image was taken at steady state with 12 Vin and all outputs at full load (no airflow).

3.2.2 Test Results

3.2.2.1 Thermal Data

Figure 3 shows the IR thermal image of the thermal data testing.

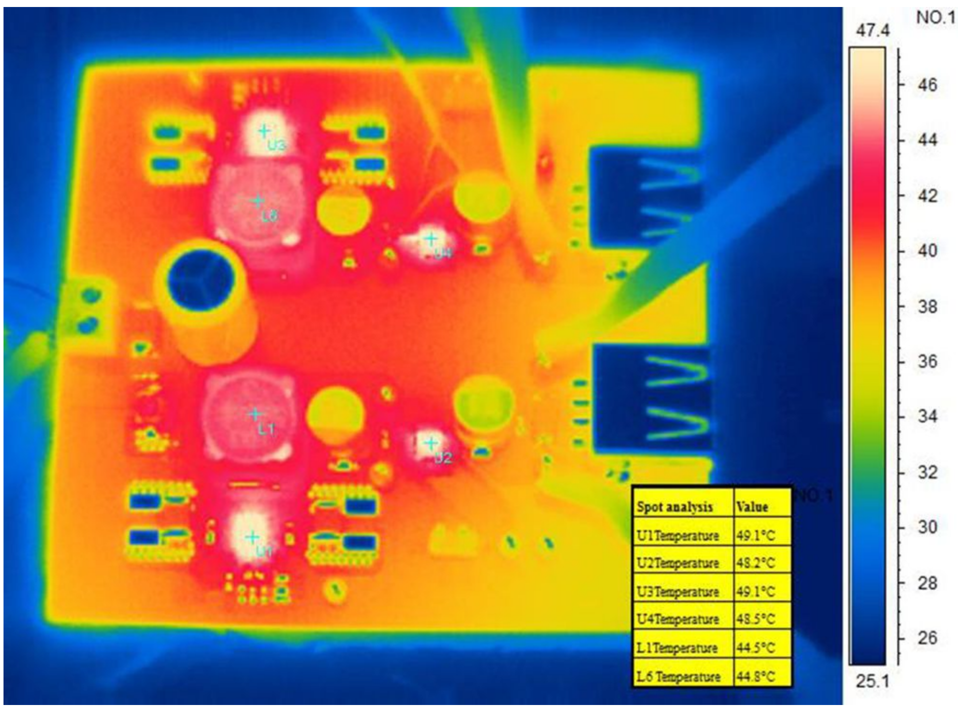

Figure 3. IR Thermal Image

3.2.2.2 Efficiency Data

Figure 4 shows the graph of the converter efficiency and power loss verse load current with a 12-V input. The black trace is the LMS3655 efficiency loaded up to 3.5 A before the USB switch. The red trace is for the LMS3655 efficiency loaded up to 2.5 A after the USB switch. These plots were taken with each output individually loaded. The corresponding power-loss measurements are in green and blue traces.

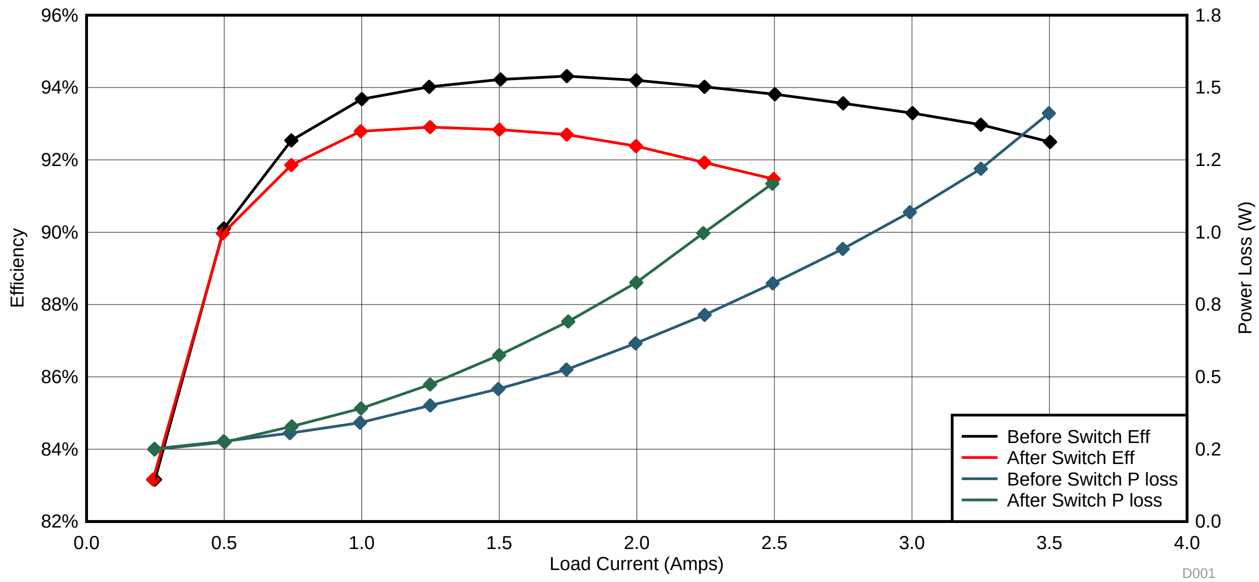

Figure 4. Efficiency and Power Loss Versus Load Current

Table 3. System's Efficiency Data When Output is at Full Load (3.5 A) - Before Switch

Iout (A)	Vout (V)	Vin (V)	Iin (A)	Pin (W)	Pout (W)	LOSSES (W)	EFFICIENCY (%)
0.000	5.030	12.20	0.020	0.2240	0.00	0.24	0.00
0.250	5.028	12.18	0.124	1.5103	1.26	0.25	83.2
0.500	5.026	12.17	0.229	2.7869	2.51	0.27	90.2
0.750	5.024	12.15	0.335	4.0703	3.77	0.30	92.6
1.000	5.022	12.13	0.442	5.3615	5.02	0.34	93.7
1.250	5.019	12.11	0.551	6.6726	6.27	0.40	94.0
1.500	5.017	12.10	0.660	7.9860	7.53	0.46	94.2
1.750	5.014	12.08	0.770	9.3016	8.77	0.53	94.3
2.000	5.011	12.06	0.882	10.6369	10.02	0.61	94.2
2.250	5.007	12.04	0.995	11.9798	11.27	0.71	94.0
2.500	5.003	12.02	1.109	13.3302	12.51	0.82	93.8
2.750	4.999	12.00	1.224	14.6880	13.75	0.94	93.6
3.000	4.994	11.98	1.340	16.0532	14.98	1.07	93.3
3.250	4.988	11.96	1.458	17.4377	16.21	1.23	93.0
3.500	4.982	11.95	1.577	18.8452	17.44	1.41	92.5

Table 4. System's Efficiency Data When Output is at Full Load (2.5 A) - After Switch

Iout (A)	Vout (V)	Vin (V)	Iin (A)	Pin (W)	Pout (W)	LOSSES (W)	EFFICIENCY (%)
0.000	5.026	12.20	0.020	0.224	0.00	0.24	0.00
0.250	5.033	12.18	0.124	1.510	1.26	0.25	83.3
0.500	5.042	12.17	0.230	2.799	2.52	0.28	90.1
0.750	5.049	12.15	0.339	4.119	3.79	0.33	91.9
1.000	5.057	12.13	0.449	5.446	5.06	0.39	92.9
1.250	5.064	12.11	0.562	6.806	6.33	0.48	93.0
1.500	5.071	12.10	0.677	8.185	7.61	0.58	92.9
1.750	5.078	12.08	0.793	9.580	8.89	0.69	92.8
2.000	5.084	12.06	0.912	10.999	10.17	0.83	92.4
2.250	5.089	12.04	1.034	12.449	11.45	1.00	92.0
2.500	5.094	12.02	1.157	13.907	12.74	1.17	91.6

3.2.2.3 Start Up

Figure 5 shows the start-up waveform with a 12-V input and 5-V output loaded to 0 A. The pink waveform is the output after the switch, the yellow waveform is the output before the switch, and the blue waveform is the input voltage.

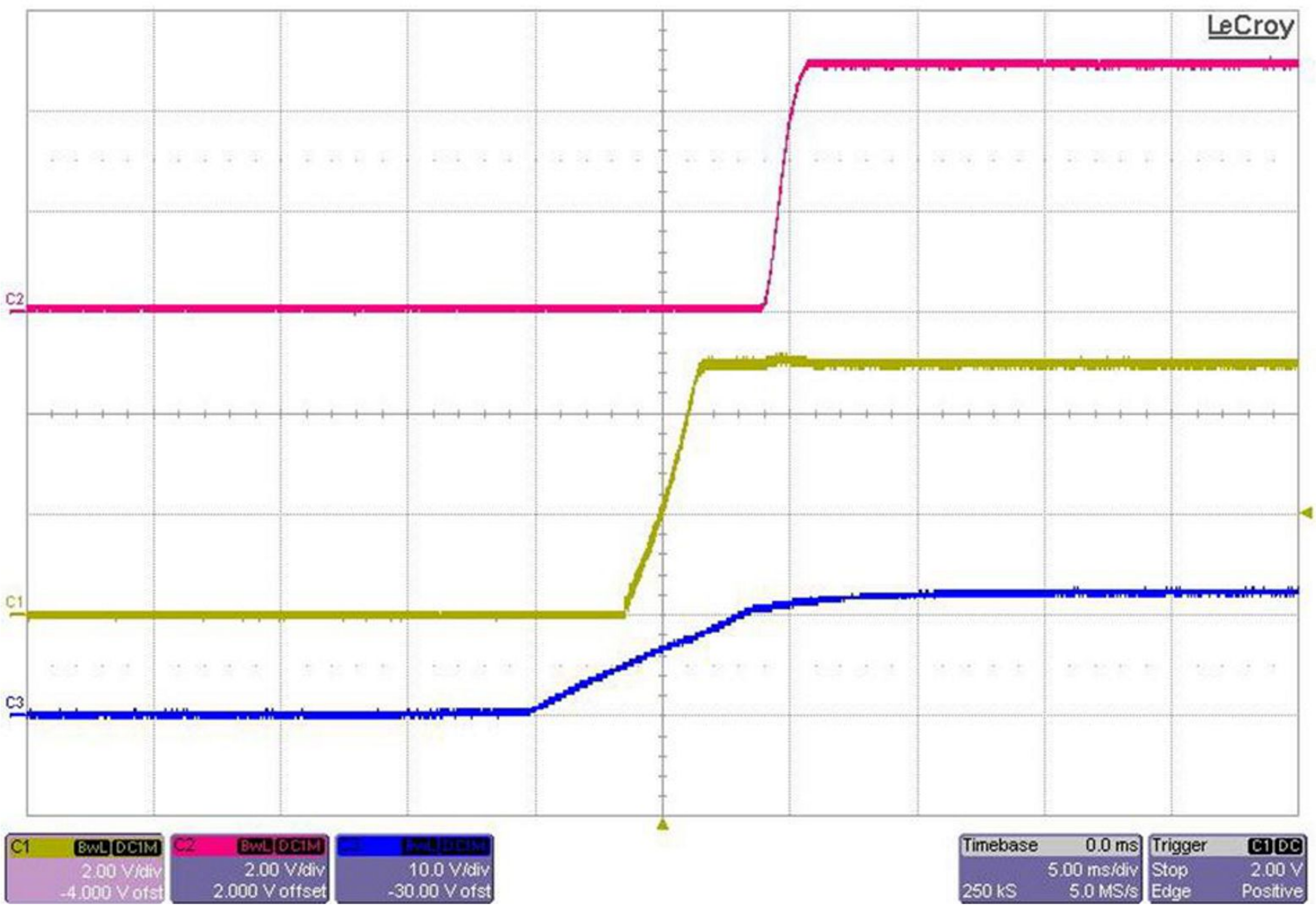

Figure 5. Start-Up Waveform: Vin = 12 V, Vout = 5 V, Iload = 0 A

3.2.2.4 Load Transient

The load transient waveforms monitor the output voltage and the load current. The output voltage trace is channel one (yellow), and this channel is AC coupled. The shift in the voltage level is due to the cable compensation network. Channel four (green) monitors the load current. The following figures show the load transient response with 12.2 Vin.

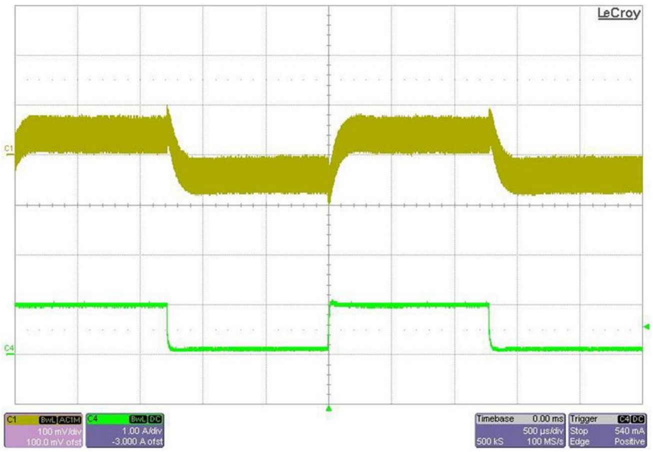

Figure 6. Load Transient of 1 A to 8 mA

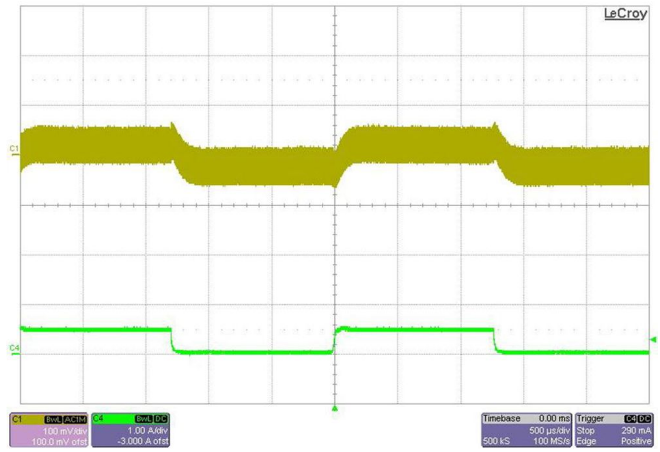

Figure 7. Load Transient of .5 A to 0 A

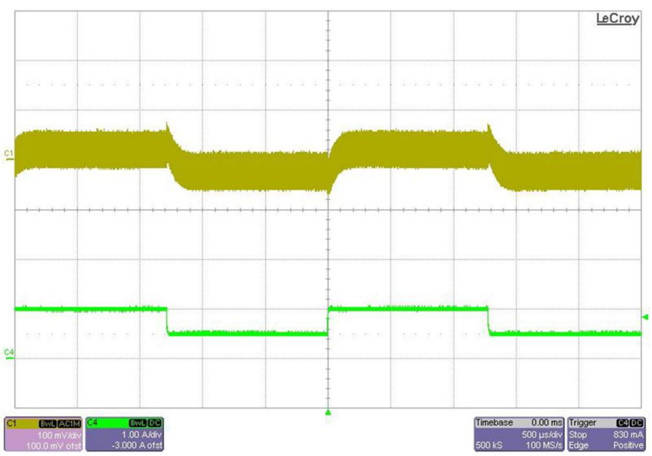

Figure 8. Load Transient of 1 A to .5 A

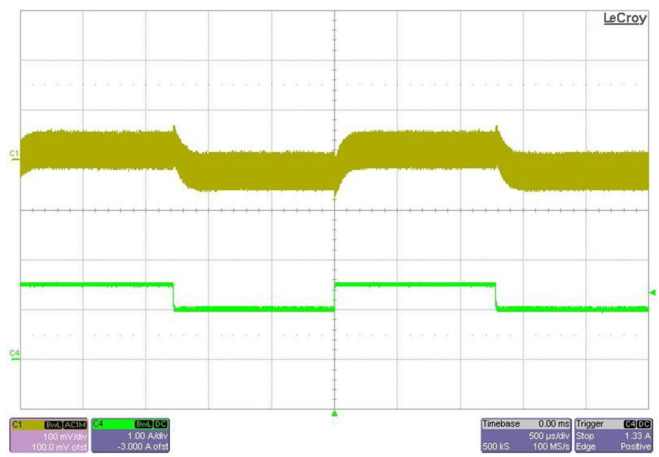

Figure 9. Load Transient of 1.5 A to 1 A

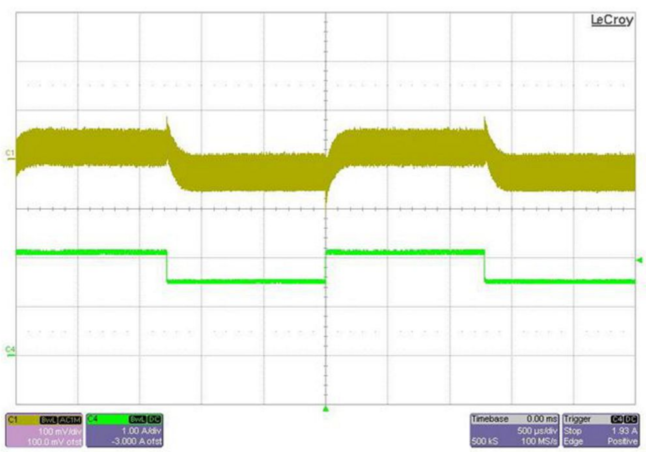

Figure 10. Load Transient of 2.1 A to 1.5 A

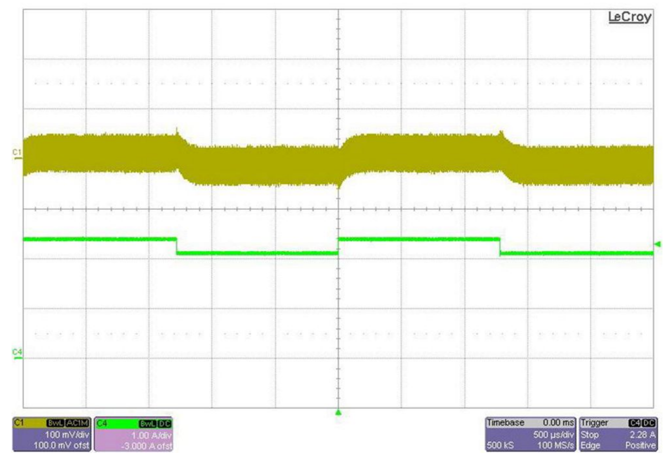

Figure 11. Load Transient of 2.4 A to 2.1 A

3.2.2.5 Switch Node Voltage

Figure 12 shows the switch-node voltage. The input voltage is 12.2 V, and the 5-V output is loaded to 2.5 A.

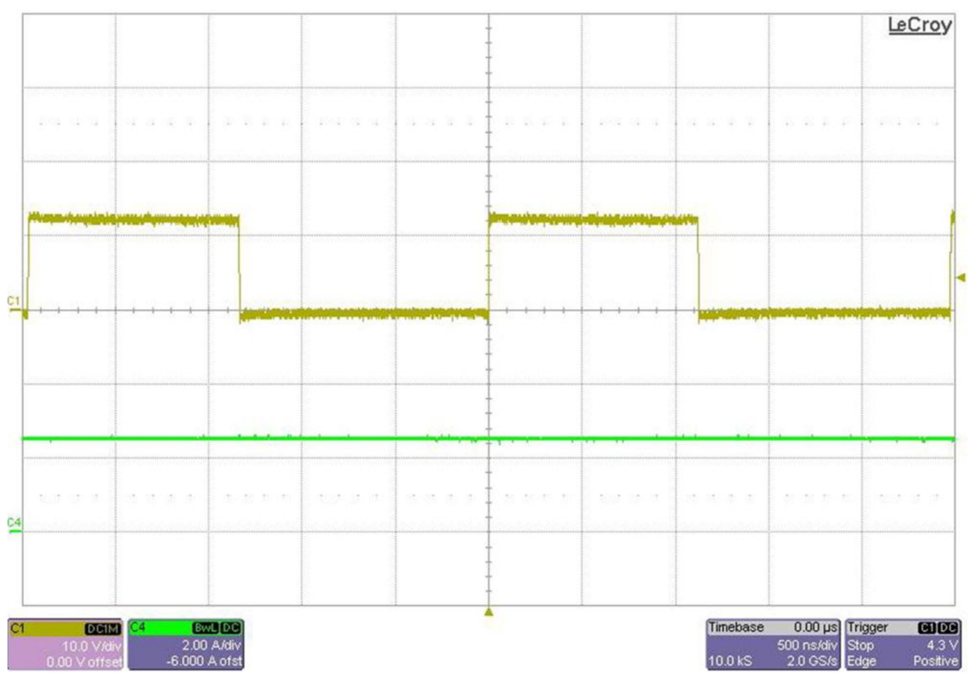

Figure 12. Switch Node Waveform (Channel One (Yellow) Trace: Switch Node; Channel Four (Green) Trace: Vout)

Figure 13 and Figure 14 provide zoomed-in views of the switch node's rising and falling edges.

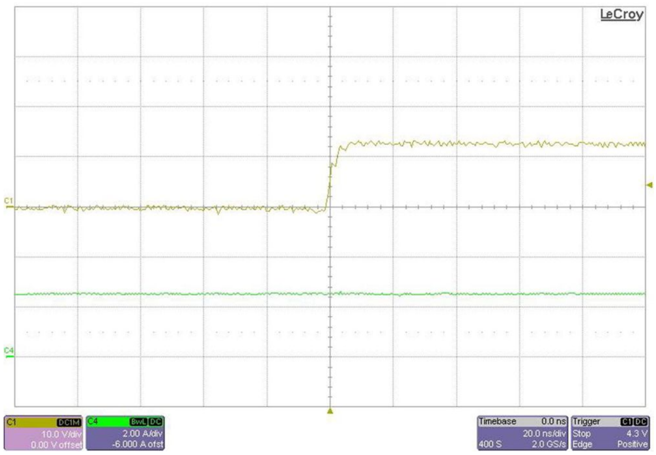

Figure 13. Rising Edge Switch Node Waveform (Channel One (Yellow) Trace: Switch Node; Channel Four (Green) Trace: Vout)

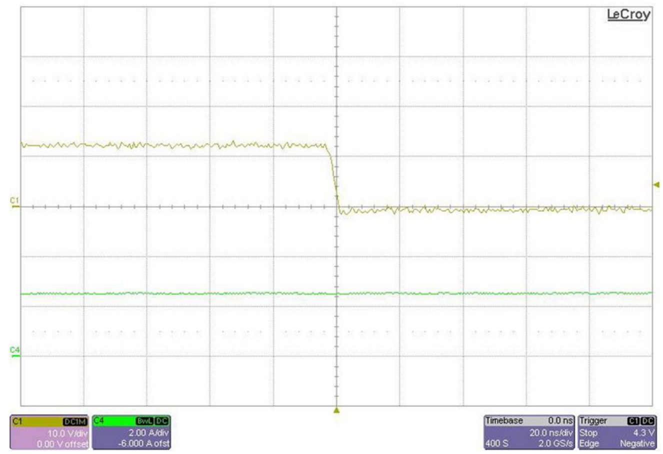

Figure 14. Falling Edge Switch Node Waveform (Channel One (Yellow) Trace: Switch Node; Channel Four (Green) Trace: Vout)

3.2.2.6 Conducted Emissions

The conducted emissions are tested to the CISPR 25 class 4 standards. The CISPR 25 class 4 compliance was achieved without a common-mode choke or shielding. The frequency band examined spans from 150 kHz to 108 MHz covering the AM, FM radio bands, VHF band, and TV band specified in the CISPR 25.

The test results are shown below in Figure 15 and Figure 16. Figure 15 shows the peak detector measurement from 150 kHz to 30 MHz, and Figure 16 shows the peak detector measurement for the stringent FM band. It can be seen that the power supply operates quietly and the noise is much below the stringent class 4 limits.

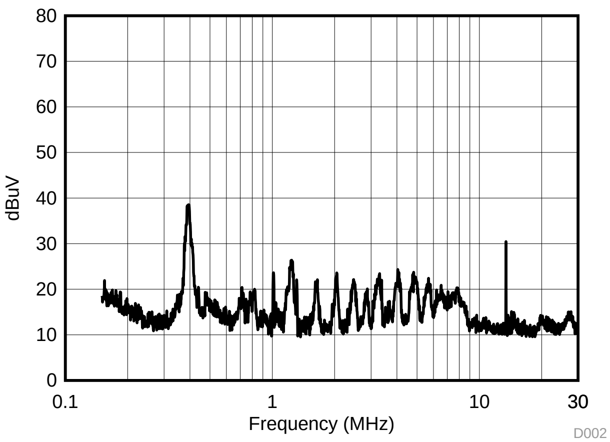

Figure 15. Up to 30-MHz Conducted Emission - Peak Detection

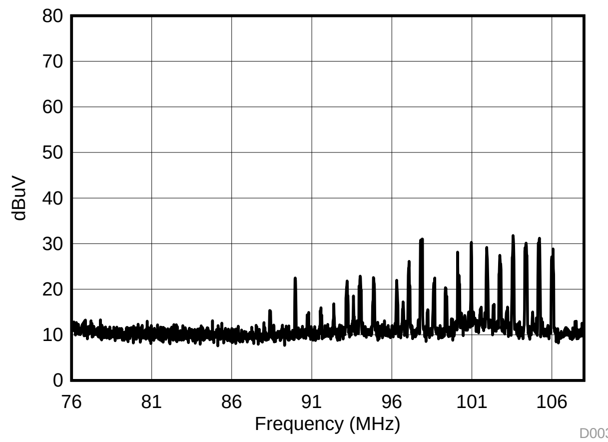

Figure 16. 30-MHz to 108-MHz Conducted Emission - Peak Detection

4 Design Files

4.1 Schematics

To download the schematics, see the design files at PMP20249.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at PMP20249.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at PMP20249.

4.4 Altium Project

To download the Altium project files, see the design files at PMP20249.

4.5 Gerber Files

To download the Gerber files, see the design files at PMP20249.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at PMP20249.

5 Related Documentation

1. Texas Instruments, *PMP20249 - CISPR 25 Class 4 Rated Design for Dual Automotive USB Charger Reference Design*, TI Design (TIDUCU2)
2. Texas Instruments, *LMS3635/55-Q1, 3.5-A /5.5-A, 36-V Synchronous, 400-kHz, Step-Down Converter*, LMS3655-Q1, LMS3635-Q1 Datasheet (SNAS714)
3. Texas Instruments, *LMS3655 5.5-A, 36-V Synchronous, 400-kHz DC-DC Step-Down Converter*, TPS2549-Q1 Datasheet (SNAS744)

5.1 Trademarks

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