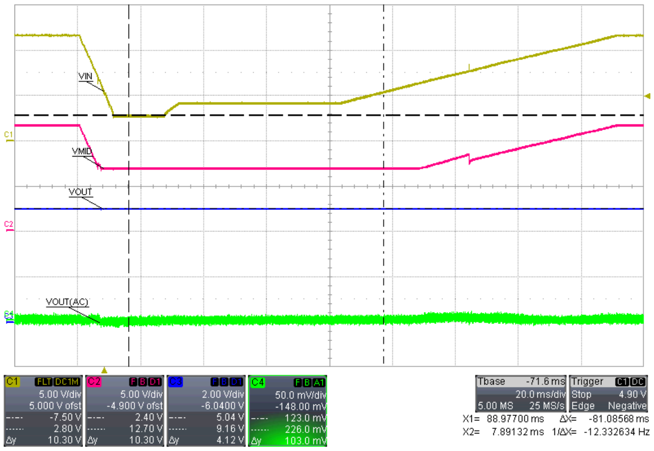
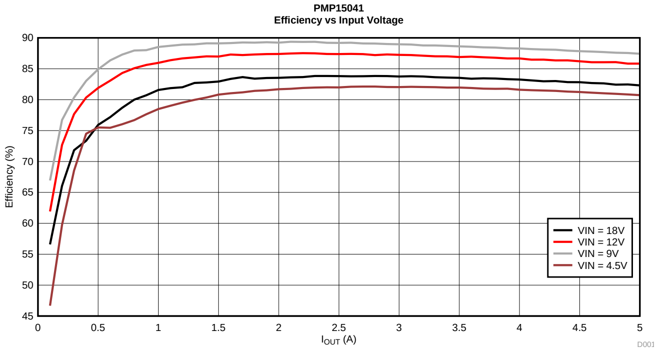
Test Report: TIDT001
25-W, Automotive, Start-Stop Reference Design Operating at 2.2 MHz

Description

Automotive 12-V batteries typically operate in the range of 9 V to 16 V. However, this voltage can vary widely due to transient conditions such as cold crank and load dump. This reference design creates a well regulated 25-W (5-V, 5-A) output, regardless of large input voltage transients, by using the LM5150-Q1 and LM5141-Q1 controllers. The LM5150-Q1 is implemented as a pre-boost, only switching when the input voltage is below 6.8 V. When the pre-boost stage is in bypass mode and not switching, the boost inductor is used as a differential mode EMI filter. The LM5141-Q1 operates as a buck controller to regulate the 5-V output. A switching frequency of 2.2 MHz is selected to help minimize the component size and avoid electromagnetic interference in the medium-wave frequency band (0.53 MHz to 1.8 MHz) and short-wave frequency band (5.9 MHz to 6.2 MHz). This test report discusses a number of design considerations and presents test results and waveforms from a demonstration board to a specific design requirement.





1 System Parameters

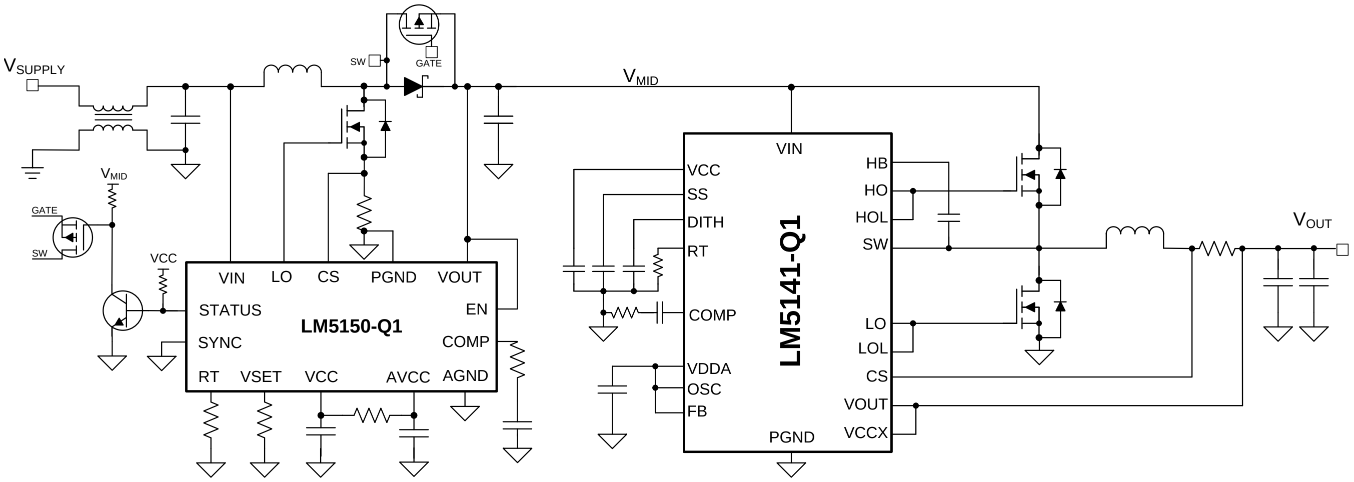


Figure 1. System Block Diagram

1.1 Voltage and Current Requirements

Table 1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
V_{IN} (DC range)	4.5 V to 18 V (5-V start-up)
V_{IN} (transient range)	2.8 V to 40 V
V_{OUT}	5 V, 5 A (peak), 3 A (continuous)
Nominal switching frequency	LM5150: 2.2 MHz, LM5141: 2.2 MHz

1.2 Required Test Equipment

- Power supply
- Electronic load
- Oscilloscope

1.3 Design Considerations

1.3.1 Switching Frequency

Selecting a switching frequency of 2.2 MHz for the both the LM5150-Q1 and the LM5141-Q1 provides a number of benefits when comparing to lower switching frequencies. Component size is reduced, resulting in a smaller solution size and increasing power density. The control loop bandwidth can be increased to higher frequencies, resulting in a faster load transient response. In applications such as automotive radios, the switching frequency is selected to avoid generating noise in the reserved medium-wave frequency band (0.53 MHz to 1.8 MHz) and short-wave frequency band (5.9 MHz to 6.2 MHz). The fundamental frequency (2.2 MHz) and all harmonic frequencies lie outside of the reserved frequency bands, mitigating the effective electrical magnetic interference (EMI) in reserved frequency bands.

1.3.2 Bypass P-Channel MOSFET

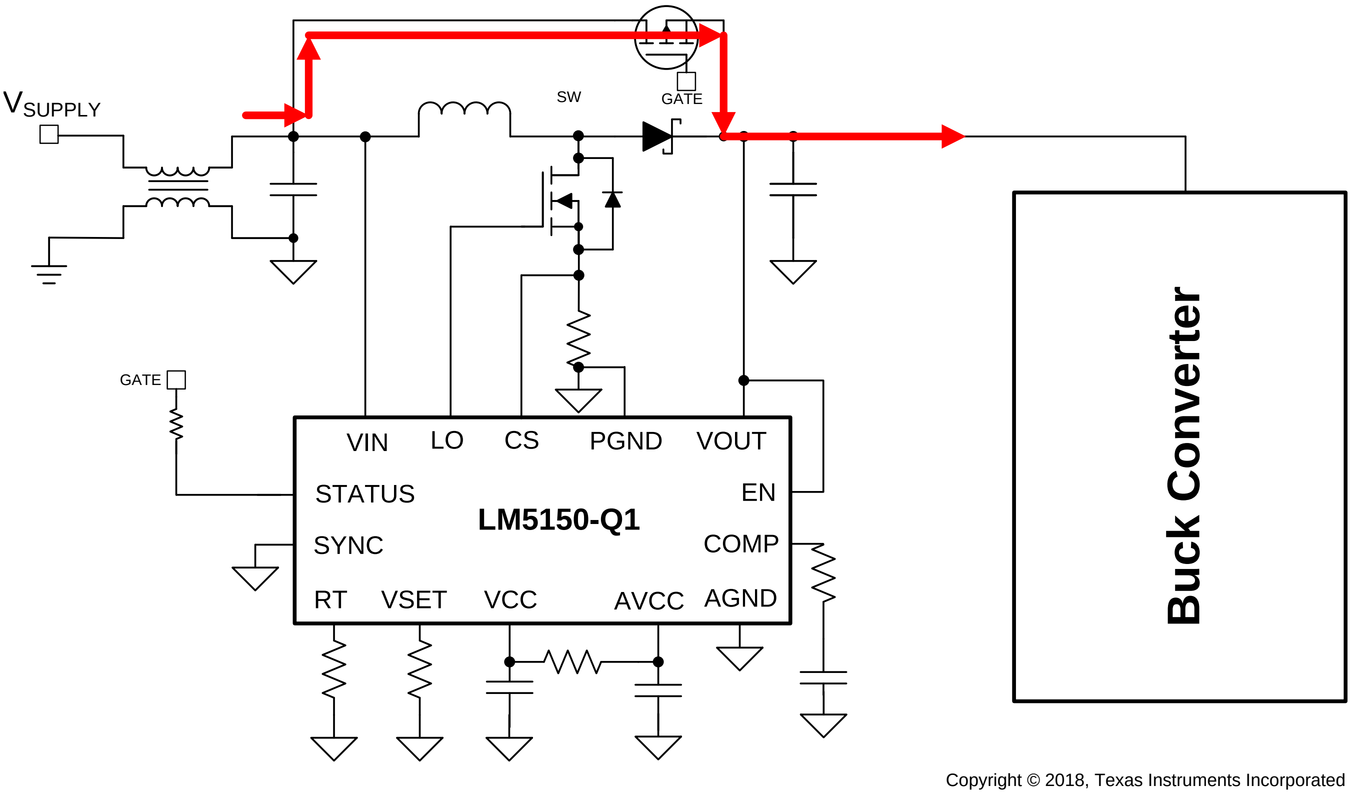


Figure 2. Boost Bypass Switch

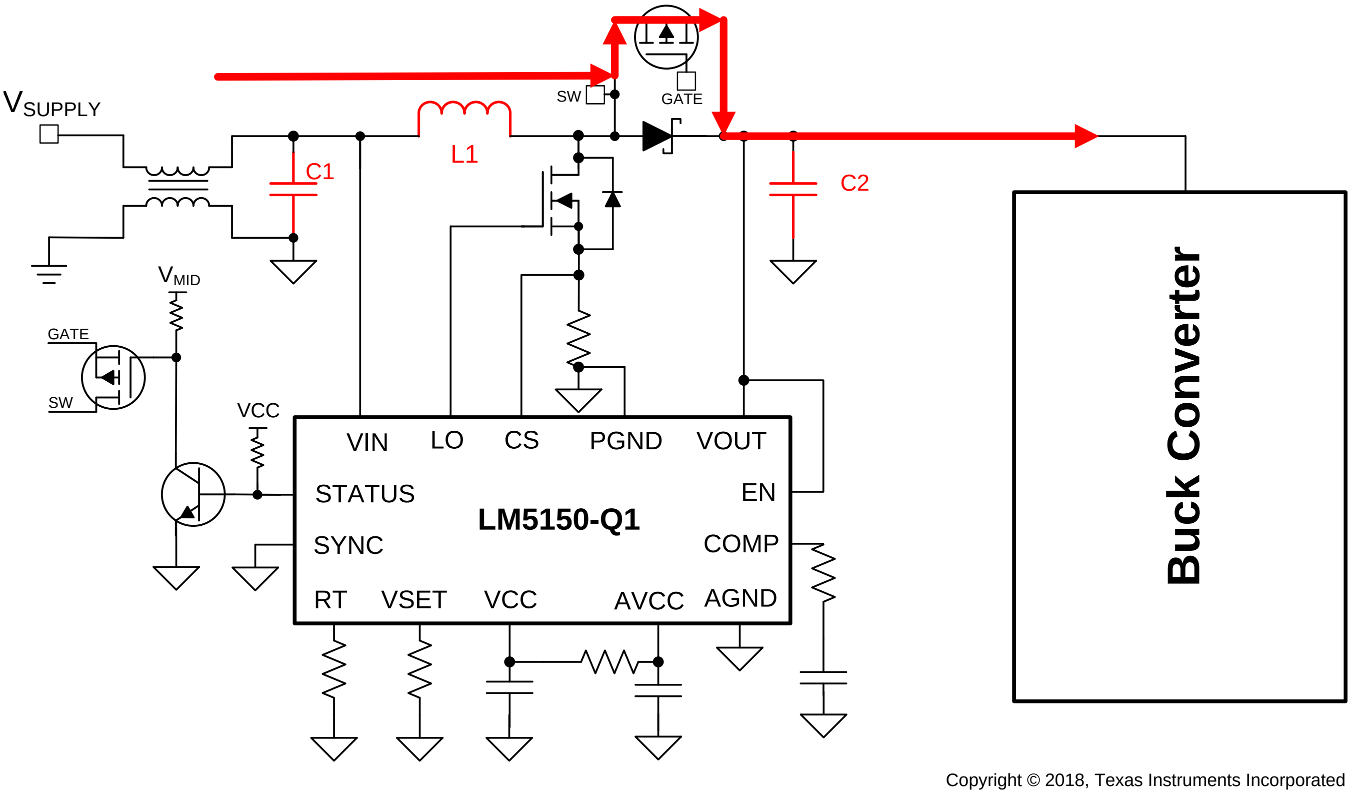


Figure 3. Diode Bypass Switch

The STATUS pin of the LM5150-Q1 is used to implement a bypass MOSFET. The bypass MOSFET is only enabled when the LM5150-Q1 is not operating. For details on the STATUS pin, see *LM5150-Q1 Wide VIN Automotive Low IQ Boost Controller*. Typically, this MOSFET is implemented to short out (bypass) the entirety of boost circuit. Figure 2 shows the typical implementation of the bypass switch. Bypassing the entire boost circuit increases the efficiency by eliminating the diode voltage drop and inductor's series resistance. Figure 3 shows the bypass switch only shorting out the diode. Shorting out the diode helps increase the efficiency but also allows for the boost inductor (L1) to form a differential EMI filter. C1, C2, and L1 in Figure 3 forms the differential EMI filter. Using L1 as a differential mode choke eliminates the need for adding an extra choke for EMI mitigation.

2 Testing and Results

2.1 Performance Graphs

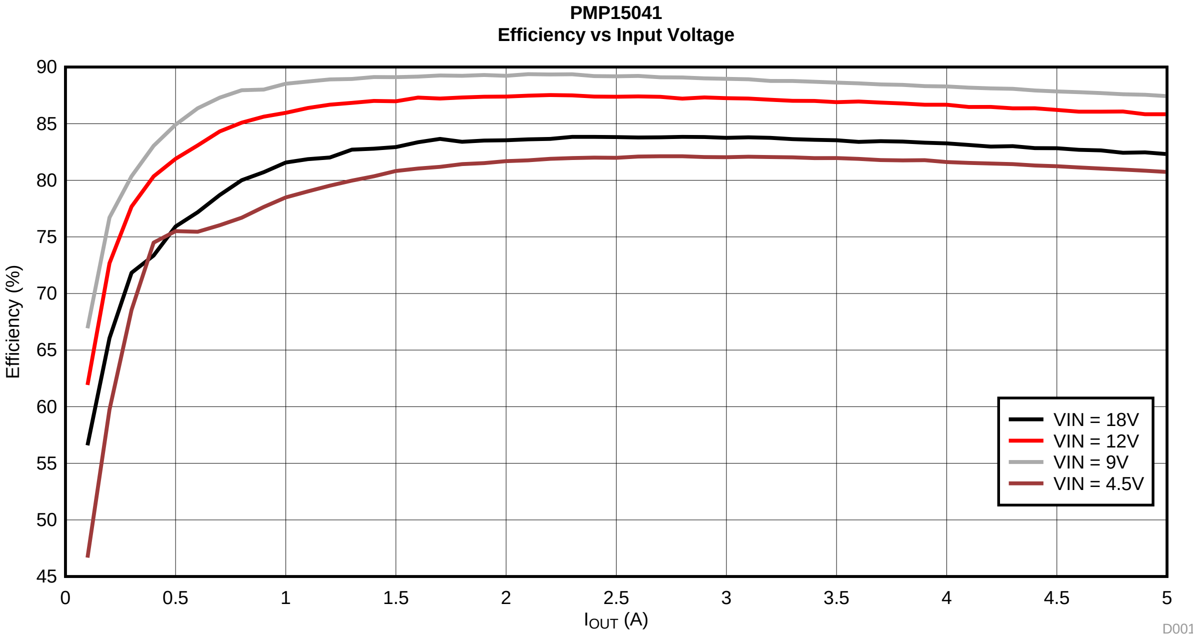


Figure 4. Efficiency vs I_{OUT}

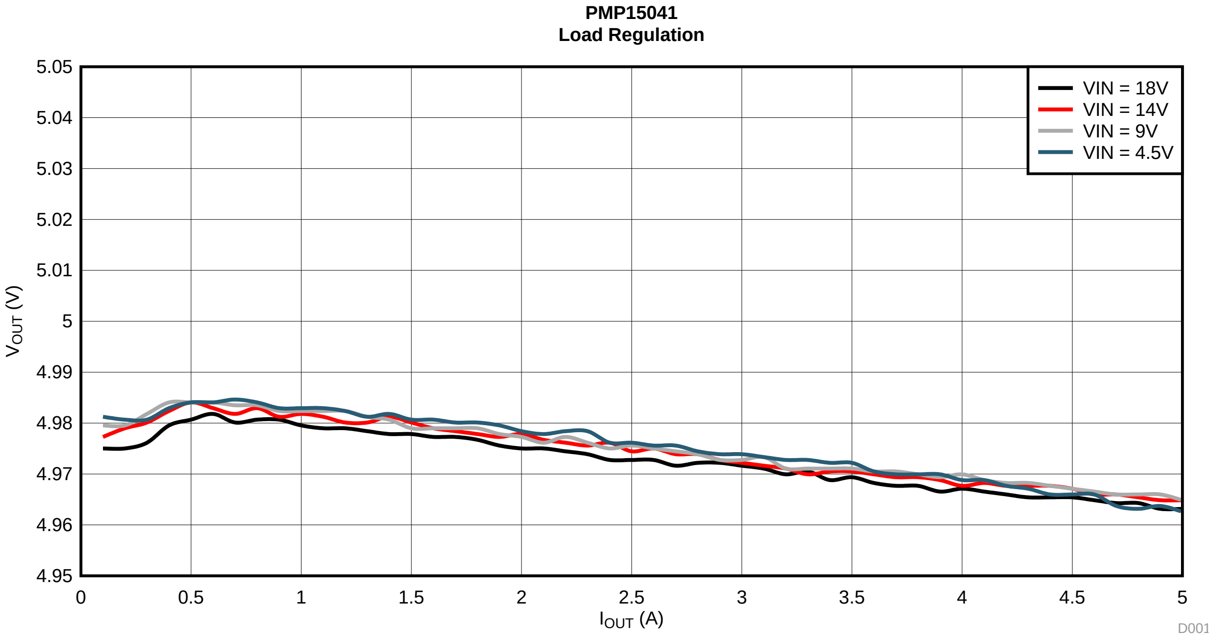


Figure 5. Load Regulation

2.2 Efficiency Data

Table 2. Efficiency Data (V_{IN} = 18 V)

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)
18.007	0.159	4.980	0.421	73.351
18.007	0.348	4.980	1.025	81.572
18.001	0.476	4.978	1.425	82.795
18.012	0.671	4.975	2.029	83.533
18.007	0.801	4.973	2.432	83.839
18.007	1.001	4.972	3.035	83.747
18.007	1.135	4.969	3.438	83.577
18.012	1.339	4.967	4.041	83.262
18.012	1.479	4.965	4.444	82.837
18.001	1.690	4.963	5.045	82.310

Table 3. Efficiency Data (V_{IN} = 14 V)

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)
13.995	0.194	4.982	0.425	77.805
13.990	0.433	4.982	1.028	84.465
13.995	0.595	4.981	1.428	85.408
13.990	0.838	4.978	2.030	86.240
13.995	1.002	4.976	2.433	86.370
13.984	1.252	4.972	3.035	86.219
13.995	1.422	4.971	3.437	85.848
14.001	1.679	4.968	4.041	85.388
13.990	1.853	4.968	4.444	85.148
13.990	2.117	4.965	5.046	84.587

Table 4. Efficiency Data (V_{IN} = 9 V)

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)
9.002	0.283	4.984	0.424	83.046
9.002	0.642	4.982	1.026	88.532
9.002	0.887	4.981	1.429	89.119
9.002	1.258	4.977	2.030	89.234
9.002	1.508	4.975	2.434	89.207
9.002	1.886	4.973	3.036	88.961
9.002	2.141	4.971	3.439	88.705
9.002	2.527	4.970	4.041	88.287
9.002	2.789	4.968	4.444	87.934
9.002	3.183	4.965	5.045	87.426

Table 5. Efficiency Data (V_{IN} = 4.5 V)

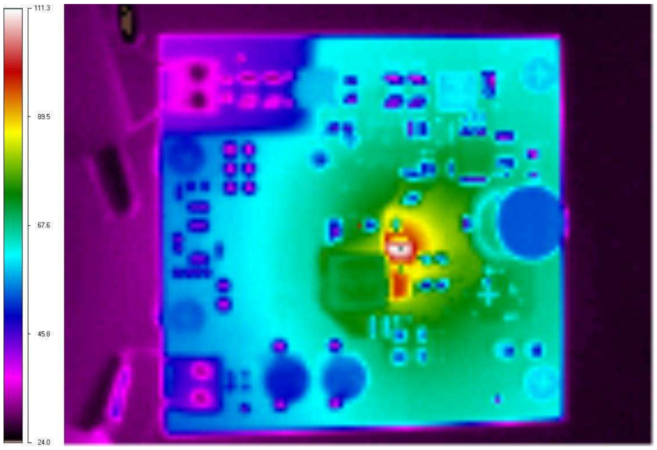
V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)
4.509	0.628	4.983	0.423	74.494
4.509	1.447	4.983	1.028	78.487
4.510	1.963	4.982	1.428	80.351
4.509	2.745	4.978	2.031	81.690

Table 5. Efficiency Data (V_{IN} = 4.5 V) (continued)

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)
4.508	3.276	4.976	2.434	82.001
4.509	4.081	4.974	3.035	82.039
4.509	4.627	4.972	3.439	81.959
4.508	5.457	4.969	4.041	81.612
4.508	6.021	4.966	4.444	81.306
4.508	6.881	4.963	5.046	80.728

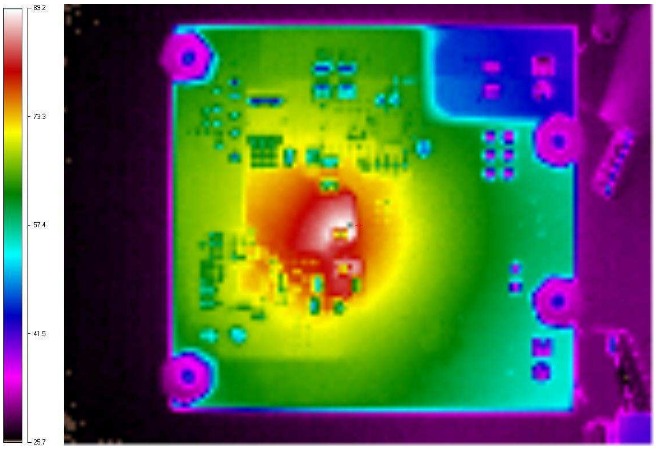
2.3 Thermal Images

Figure 6 and Figure 7 show the temperature of the evaluation board with V_{IN} at 12 V and a continuous load of 5 A. The maximum continuos load is 3 A, which results in lower temperatures. The hottest location is the high-side MOSFET of the LM5141. The temperature of this component can be reduced by increasing the copper thickness or the copper area around the high-side MOSFET.



Max temperature = 111.3ºC

Figure 6. Front Side: V_{IN} = 12 V, I_{OUT} = 5 A



Max temperature = 89.2ºC

Figure 7. Rear Side: V_{IN} = 12 V, I_{OUT} = 5 A

2.4 Dimensions

The evaluation board dimensions are 2.2 in × 2.1 in.

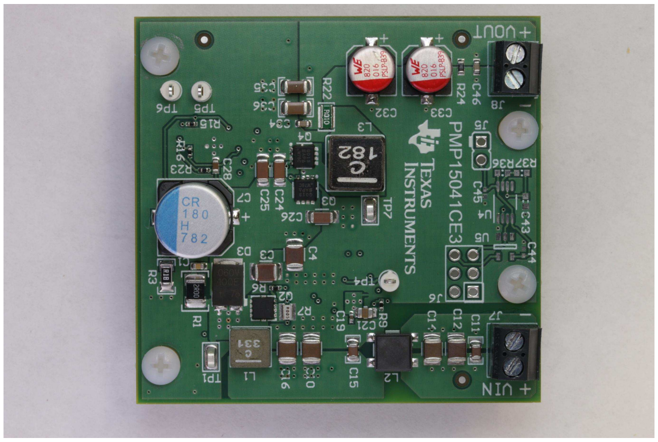


Figure 8. Front of Evaluation Board

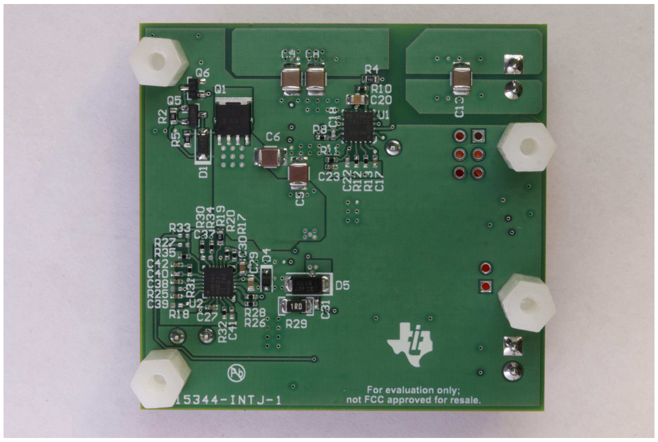


Figure 9. Rear of Evaluation Board

3 Waveforms

3.1 Input Voltage Transients

Figure 10 through Figure 11 show the response to a cold crank input voltage transient. The minimum voltage on the input terminals is 2.8 V.

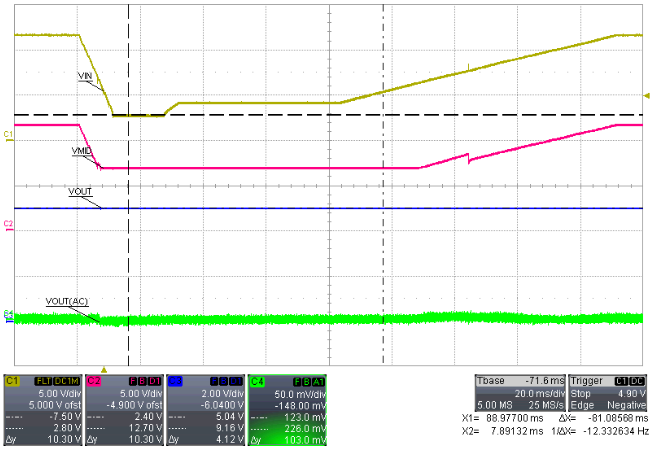


Figure 10. Input Voltage Transient Response

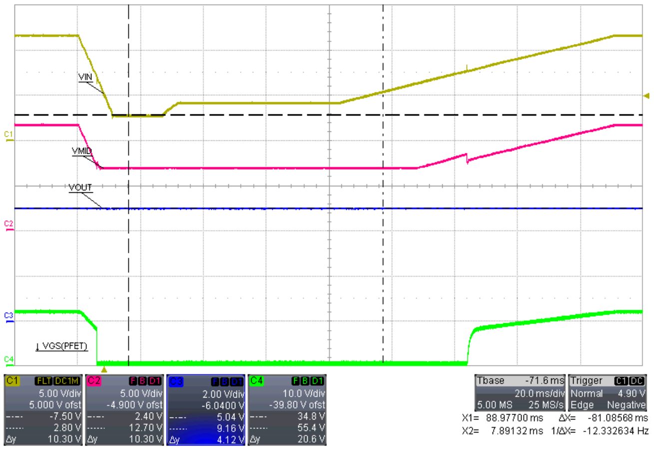
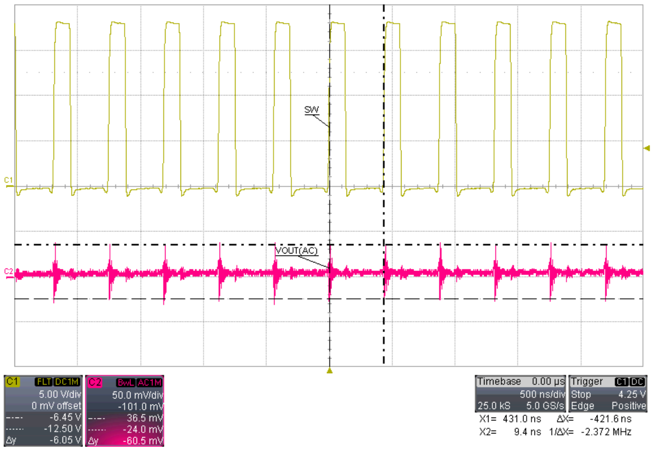


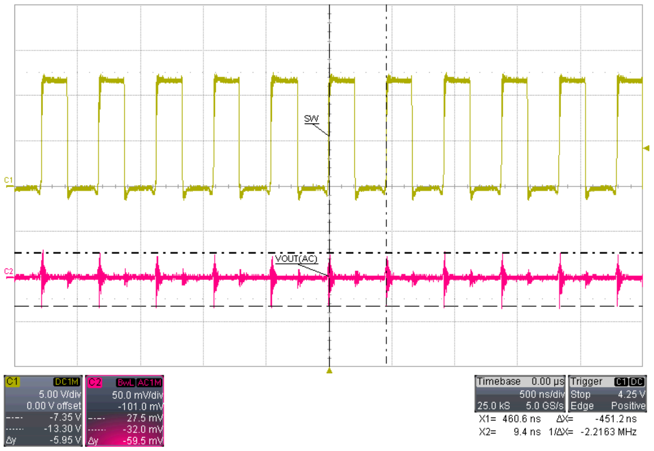
Figure 11. Input Voltage Transient Response (Bypass MOSFET)

3.2 Output Voltage Ripple



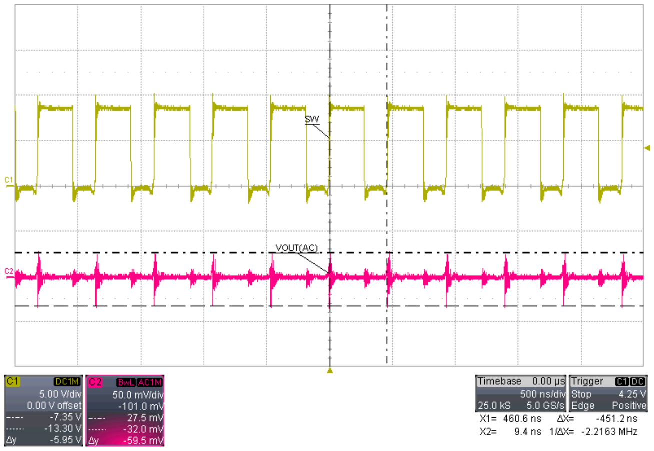
CH1 = TP7 (LM5141 SW pin), CH2 = VOUT (AC)

Figure 12. V_{SUPPLY} = 18 V, I_{OUT} = 5 A



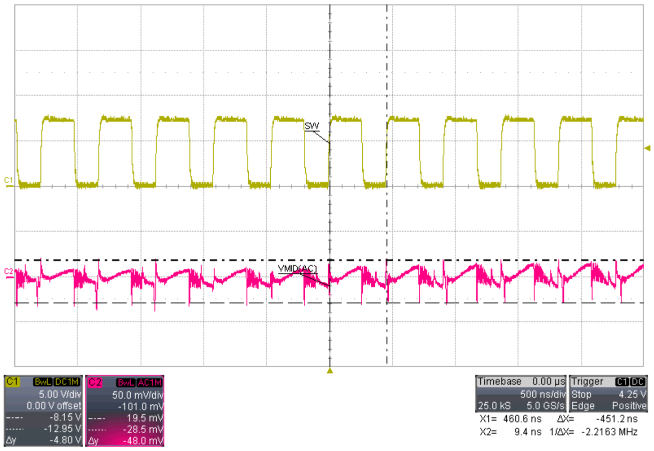
CH1 = TP7 (LM5141 SW pin), CH2 = VOUT (AC)

Figure 13. V_{SUPPLY} = 12 V, I_{OUT} = 5 A



CH1 = TP7 (LM5141 SW pin), CH2 = VOUT (AC)

Figure 14. V_{SUPPLY} = 9 V, I_{OUT} = 5 A



CH1 = TP1 (LM5150 SW pin), CH2 = VOUT (AC)

Figure 15. V_{SUPPLY} = 4.5 V, I_{OUT} = 5 A

3.3 Short Circuit Recovery

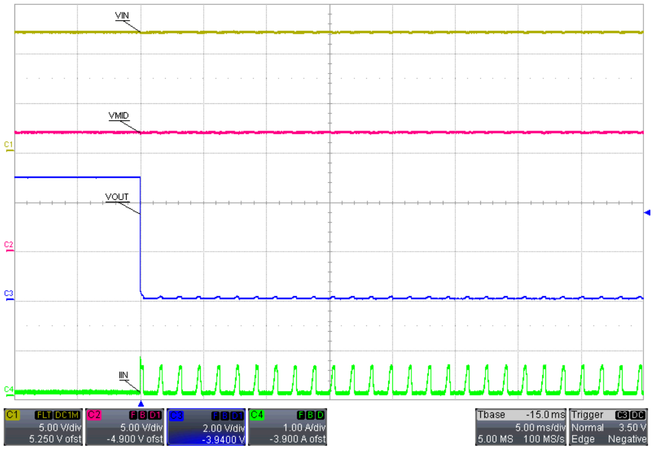


Figure 16. V_{IN} = 12 V, Short Circuit

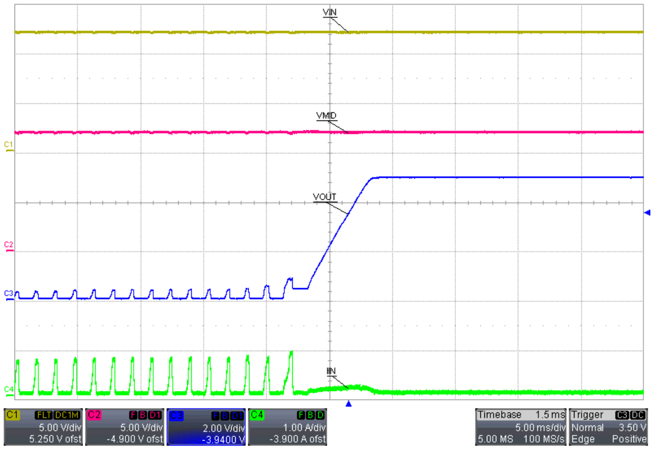


Figure 17. V_{IN} = 12 V, Short Circuit Recovery

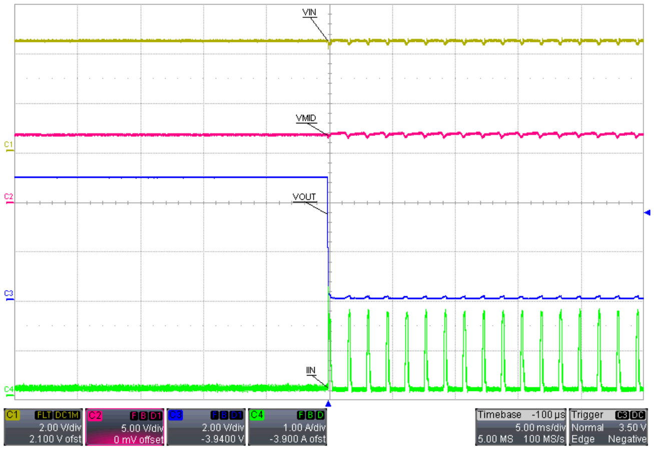


Figure 18. V_{IN} = 4.5 V, Short Circuit

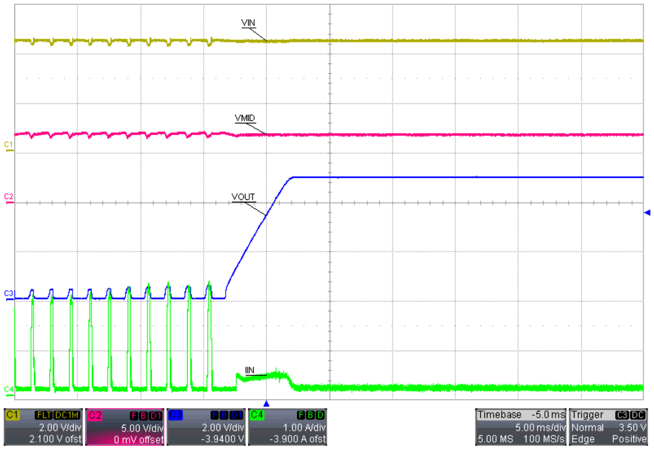


Figure 19. V_{IN} = 4.5 V, Short Circuit Recovery

3.4 Load Transients

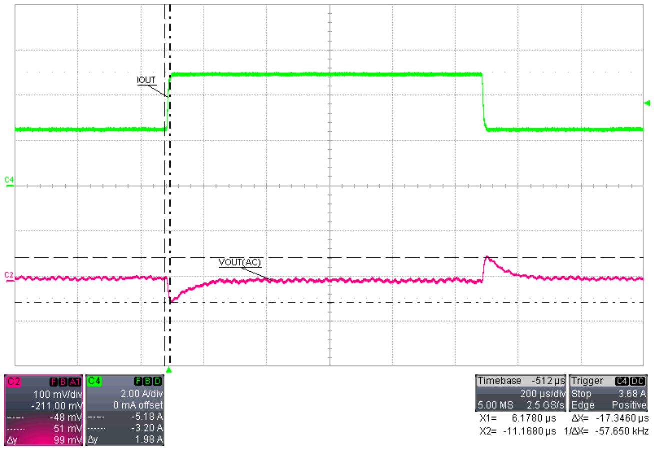


Figure 20. V_{IN} = 18 V, I_{OUT} = 2.5 A to 5 A

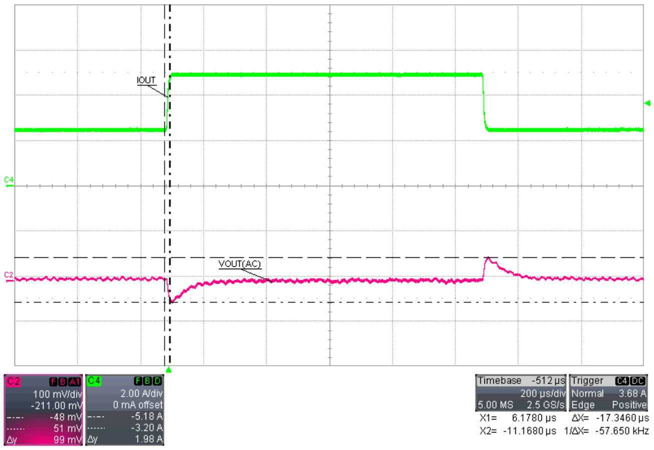


Figure 21. V_{IN} = 12 V, I_{OUT} = 2.5 A to 5 A

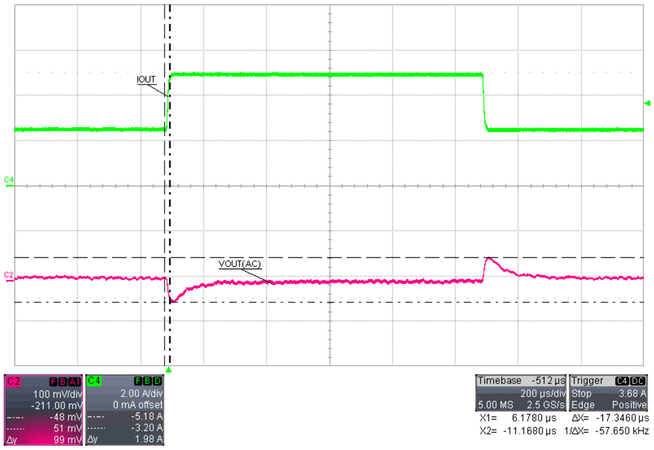


Figure 22. V_{IN} = 9 V, I_{OUT} = 2.5 A to 5 A

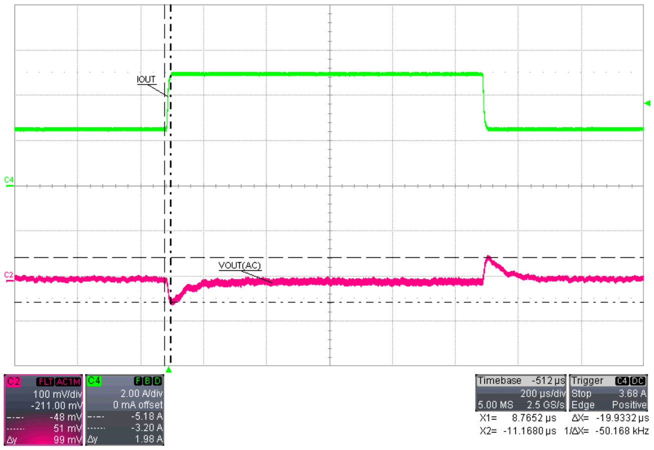


Figure 23. V_{IN} = 4.5 V, I_{OUT} = 2.5 A to 5 A

3.5 Start-up Sequence

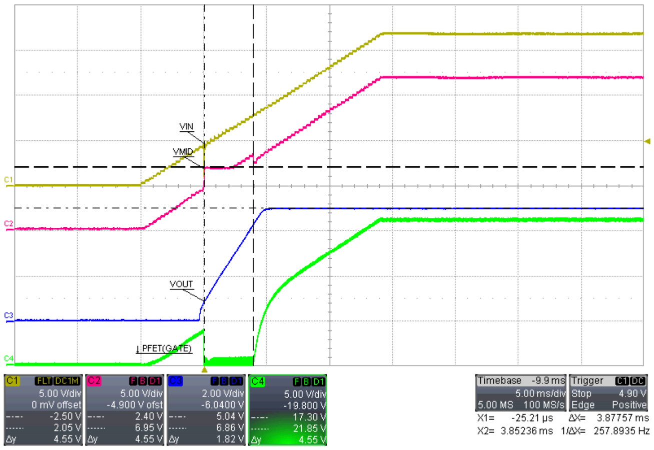


Figure 24. V_{IN} = 18 V, I_{OUT} = 5 A

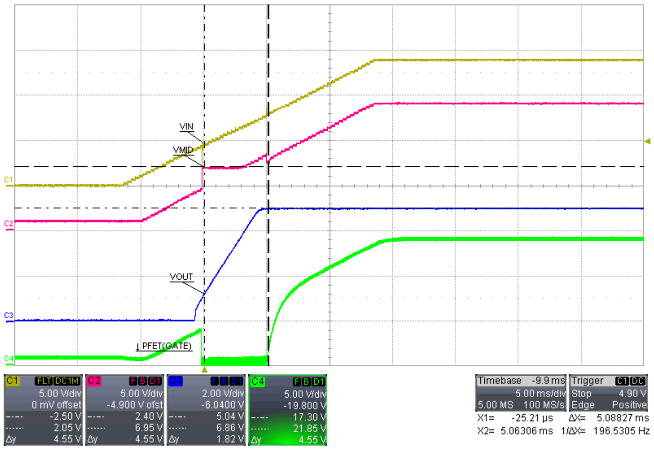


Figure 25. V_{IN} = 14 V, I_{OUT} = 5 A

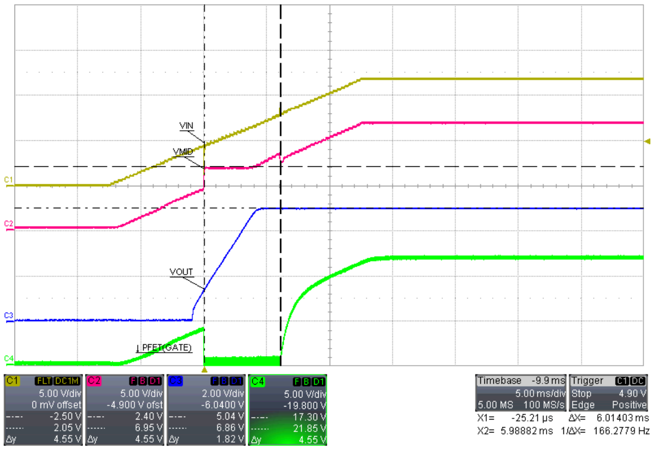


Figure 26. V_{IN} = 12 V, I_{OUT} = 5 A

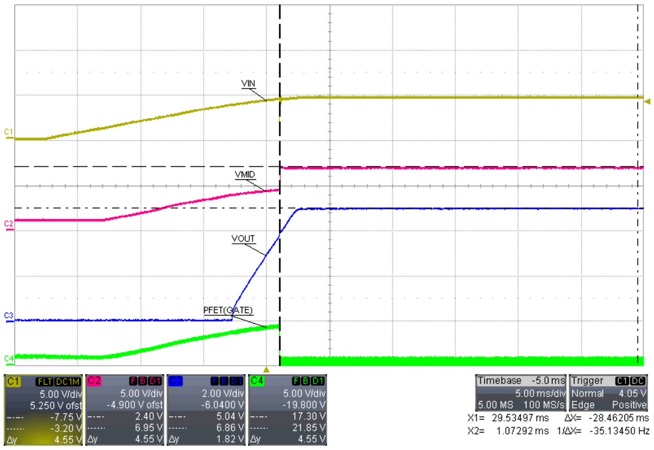


Figure 27. V_{IN} = 5 V, I_{OUT} = 5 A

3.6 Bode Plot

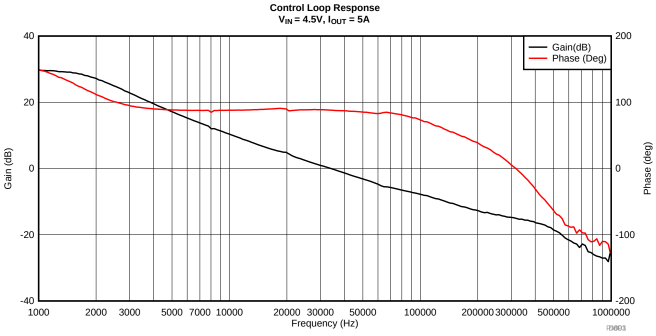


Figure 28. Buck Stage Bode Plot, V_{IN} = 4.5 V

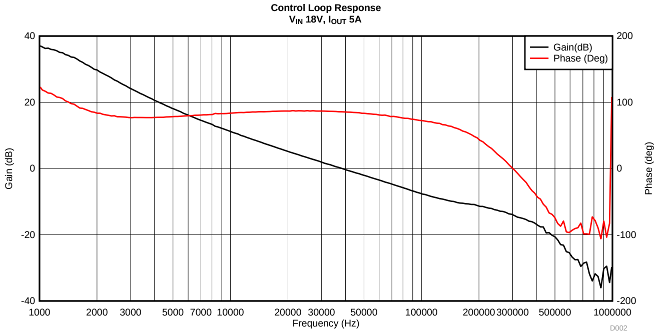
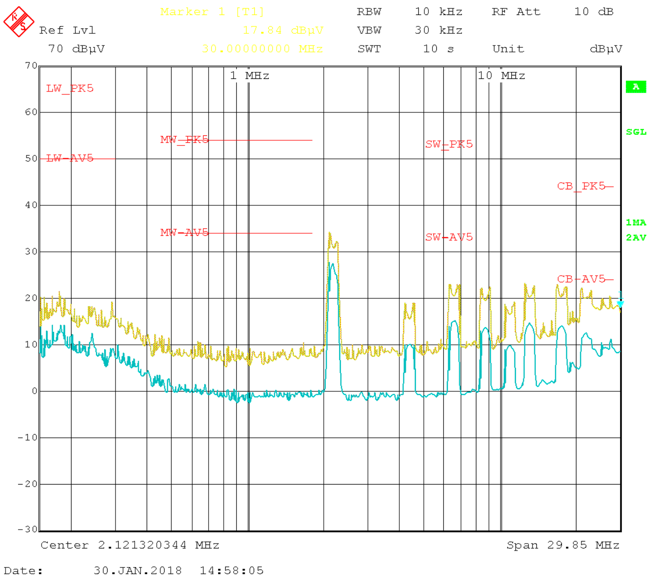


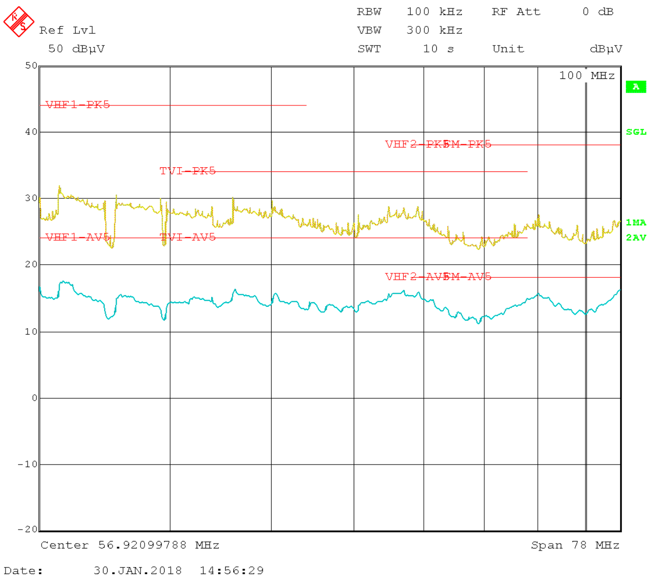
Figure 29. Buck Stage Bode Plot, V_{IN} = 18 V

3.7 EMI Performance



VIN = 13.5 V, IOUT = 5 A

Figure 30. Conducted EMI Low-Frequency Measurements



VIN = 13.5 V, IOUT = 5 A

Figure 31. Conducted EMI High-Frequency Measurements

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (https:www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2021, Texas Instruments Incorporated