TI Designs
15-W System-Level Power Reference Design for Automotive Body Control Module

TEXAS INSTRUMENTS

Design Overview

The TIDA-00745 is a 14-W, system-optimized (CISPR25 class 4) SMPS design specified for automotive body control modules.

Design Resources

TIDA-00745	Design Folder
LM53601-Q1	Product Folder
LM53602-Q1	Product Folder
LM26420-Q1	Product Folder
TPS40210-Q1	Product Folder
TPS7B4250-Q1	Product Folder
TPS7B4253-Q1	Product Folder

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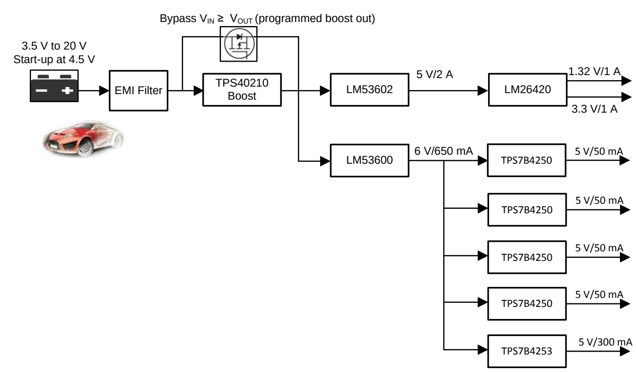
Design Features

- 15-W Pre-Boost Solution
- 5 V at 2 A, 6 V at 0.65 A, 3.3 V at 1 A, and 1.32 V at 1-A Outputs From 2.1-MHz Switching Converter
- Input: 3.5 V to 32 V With Start-up at 4.7 V
- 86.5% System Efficiency at Full Load at 12 V_{IN}
- Switching Frequency: 2.1 MHz for Buck and 450 KHz for Boost
- Lossless Bypass Operation: Avoids Loss in Boost Diode
- Wide V_{IN} Integrated Front-End DC-DC Converters:LM53603Q1 and LM53601
- Passes CISPR 25 Class 4 FM Radio Band
- All ICs AEC-Q100 Qualified Versions
- 3.5 V to 30 V (20 V Overvoltage Protection) Wide V_{IN} Range: Supports Cold Cranking Conditions

Featured Applications

- SMPS for Automotive Body Control Module



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1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION
V_{IN} minimum	3.5 V (start-up at 4.7 V)
V_{IN} maximum	36 V
V_{IN} nominal	12 V (automotive design)
V_{OUT} 1 (pre-boost)	7.5 V at 2 A (supply to buck converters and LDOs)
I_{OUT} 1	2 A
Switching frequency (pre-boost)	450 KHz
V_{OUT} 2	5 V (supply to LM26420 for 3.3 V and 1.32 V)
I_{OUT} 2	2 A
V_{OUT} 3	3.3 V
I_{OUT} 3	1 A
V_{OUT} 4	1.32 V
I_{OUT}4	1 A
V_{OUT} 5	6 V (supply to 5-V LDOs downstream)
I_{OUT} 5	0.65 A
Switching frequency	2.1 MHz for all switching buck regulators
EMI	Testing performed per CISPR25 standards

2 System Description

The TIDA-00745 is a 14-W, system-optimized (CISPR25 class 4) switched-mode power supply (SMPS) design for automotive body control modules. The TIDA-00745 uses buck converters that switch at 2.1 MHz. The design is divided into four major blocks:

1. EMI filter: The electromagnetic interference (EMI) filter is a common mode and differential filter for conducted EMI suppression.
2. Pre-boost (TPS40210): The TPS40210 pre-boost controller is an efficient, low-cost, non-synchronous pre-boost design for 15-W applications. The output is maintained at 7.5 V and when the V_{IN} surpasses the V_{OUT} (programmed boost out) the output follows the input and the losses in the boost diode are avoided by the bypass operation through a conducting p-channel field-effect transistor (FET).
3. Buck converters (LM53603, LM53601, and LM26420): Each buck converter in this design switches at 2.1 MHz to avoid the AM frequency and provide a small size solution. The LM53603 and LM53601 devices have been placed at the front end and both are synchronous, wide-input automotive buck converters with a high level of integration.
4. Downstream LDOs: The design uses low-dropout regulators (LDOs) that have been placed downstream at the output of the buck converter and have a trackable output voltage.

3 Block Diagram

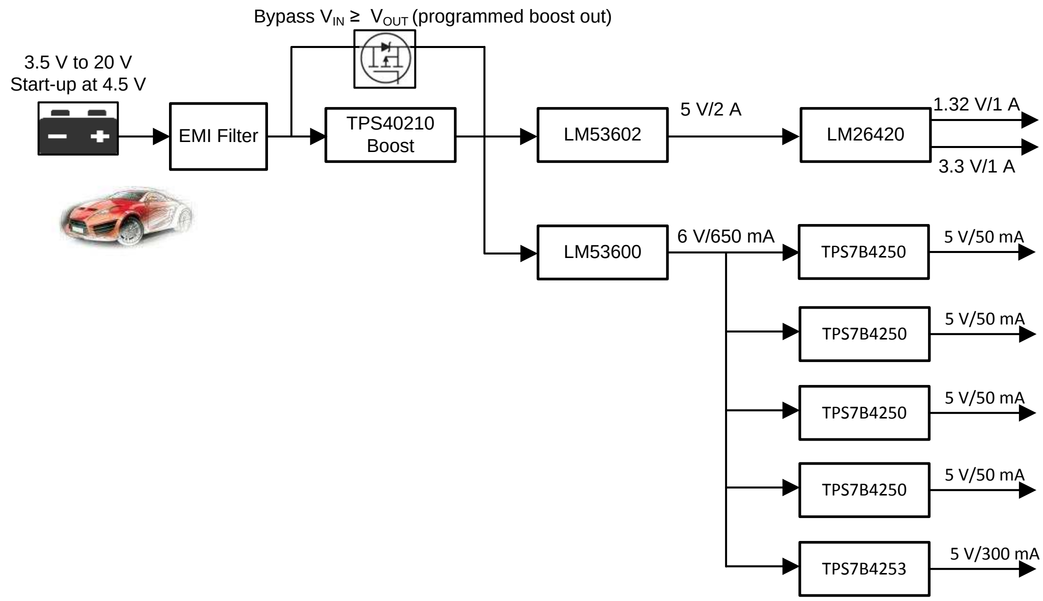

Figure 1. TIDA-00745 Block Diagram

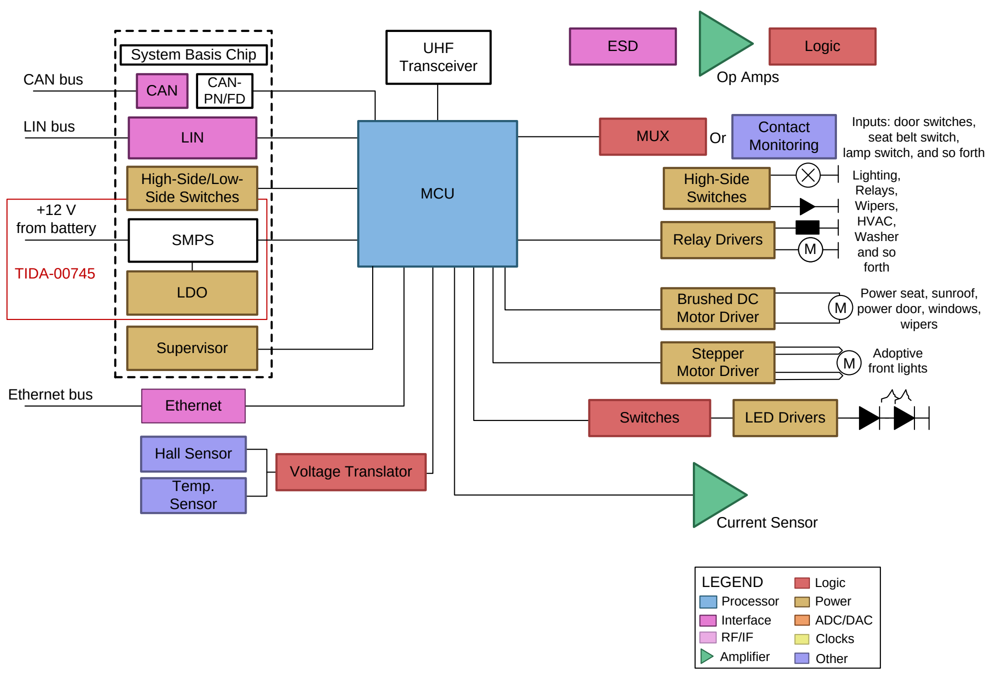

Figure 2. Example of Automotive Body Control Module Highlighting TIDA-00745

3.1 Highlighted Products

The TIDA-00745 design uses the following products from TI:

- LM53601-Q1
  - Synchronous buck converter
  - Qualified for automotive applications (AEC-Q100 qualified)
  - Wide operating input voltage: 3.55 V to 36 V (with transient to 42 V)
  - Spread spectrum option available—helps with EMI compliance
  - 2.1-MHz fixed switching frequency—avoids AM band
  - Low quiescent current: 23 µA
  - Shutdown current: 1.8 µA
  - Adjustable, 3.3-V, or 5-V output
  - Maximum current load: 650 mA for LM53600-Q1, 1000 mA for LM53601-Q1
  - 10-lead, 3-mm × 3-mm SON package with wettable flanks
- LM53602-Q1
  - Synchronous buck converter
  - Qualified for automotive applications (AEC-Q100 qualified)
  - 3- or 2-A maximum load current specifically designed for automotive applications
  - Input voltage range from 3.5 V to 36 V (transients to 42-V option)
  - 2.1-MHz fixed switching frequency
  - 1.7-µA shutdown current (typical)
  - 24-µA input supply current at no load (typical)
  - Thermally enhanced 16-lead package: 5 mm × 4.4 mm × 1 mm
- LM26420-Q1
  - Dual synchronous buck converter
  - LM26420-Q0: AEC-Q100 grade 0 (Q0) qualified (T_J = –40°C to 150°C) LM26420-Q1: AEC-Q100 grade 1 (Q1) qualified (T_J = –40°C to 125°C)
  - Input voltage range of 3 V to 5.5 V
  - Output voltage range of 0.8 V to 4.5 V
  - 2-A output current per regulator
  - High switching frequency: 2.2 MHz
  - Current mode, PWM operation
  - Compliant with CISPR25 Class 5 conducted emissions
- TPS40210-Q1
  - For boost, flyback, SEPIC, light-emitting diode (LED) drive applications (non synchronous)
  - Wide input operating voltage: 4.5 V to 52 V
  - Adjustable oscillator frequency
  - Internal slope compensation
  - Programmable closed-loop soft-start
  - Overcurrent protection
  - Low current disable function
- TPS7B4250-Q1
  - Low-dropout voltage-tracking LDO
  - Qualified for automotive applications (AEC-Q100 qualified)
  - –20- to 45-V wide, maximum input voltage
  - Output current, 50 mA
  - 40-µA low quiescent current at light load
  - Over 150-mV low dropout voltage when I_{OUT} = 10 mA
  - Output short-circuit proof to ground and supply

4 System Design Theory

The switched-mode power supply (SMPS) is designed to support a low V_{IN} during start and stop conditions or cold crank conditions, which is why the design requires a pre-boost solution. During normal operation, when the V_{IN} is high enough (7.5 V), avoiding any loss across the boost rectifier diode is desirable. Avoid this loss by enabling a bypass operation using a PFET.

As the schematic in Figure 3 shows, the PFET SQJ461 only turns on when the V_{IN} > 7.5 V and achieves a true bypass operation.

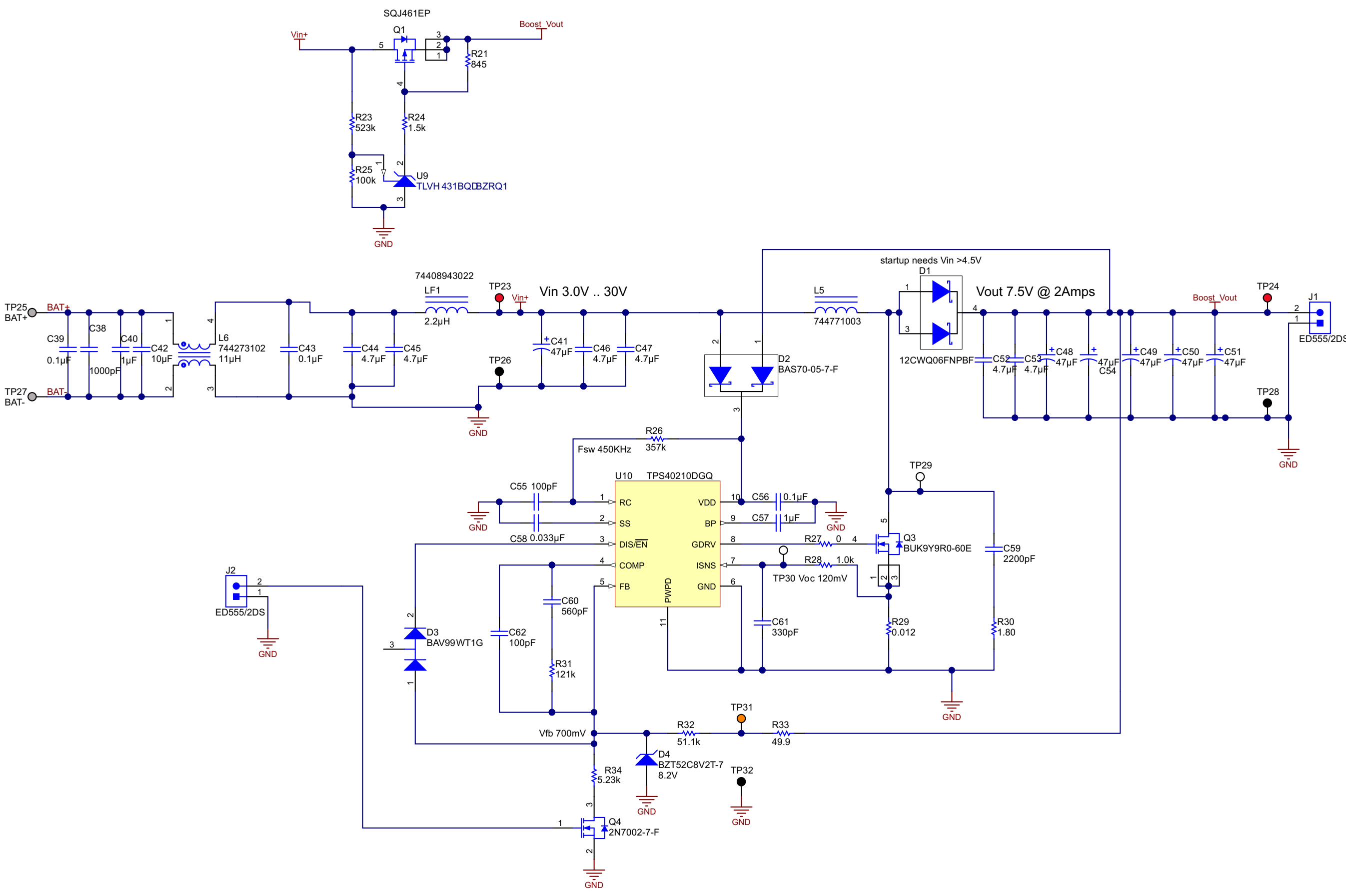

Figure 3. TIDA-00745 Schematic

The normal operating frequency for all the synchronous buck converters that the design uses (LM53601,LM53602, and LM26420) is 2.1 MHz, which allows the use of small passive components. At 2.1 MHz, the frequency is above the AM band, which allows a significant saving in input filtering. These parts have low, unloaded current consumption and do not require an external back-up LDO. The low shutdown current and high maximum operating voltage of the LM53601-Q1 and LM53602-Q1 devices also eliminate the requirement of an external load switch.

Refer to the datasheets of the devices used for design calculations and layout examples:

- LM53601-Q1 datasheet (http://www.ti.com/product/lm53601-Q1)
- LM53602-Q1 datasheet (http://www.ti.com/product/lm53602-q1)
- LM26420-Q1 datasheet (http://www.ti.com/product/LM26420-q1)
- TPS40120-Q1 datasheet (http://www.ti.com/product/tps40210-q1)
- TPS7B4250-Q1 datasheet (http://www.ti.com/product/TPS7B4250-q1)

5 Test Results

5.1 Thermal Data

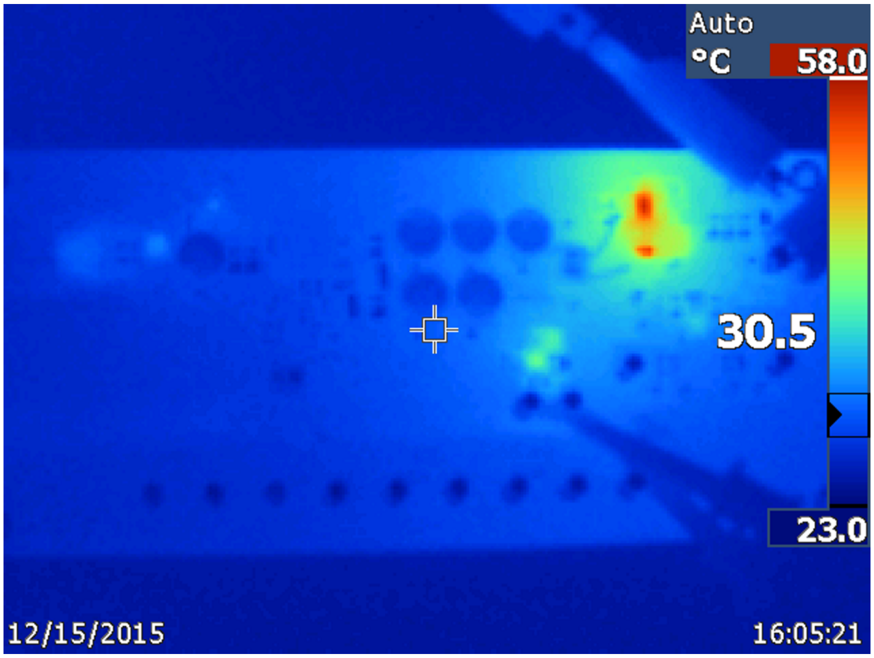

Figure 4. Setup: IR Thermal Image at Steady State With 12 V_{IN} and 5 V at 2 A and 6 V at 0.65 A (Boost Bypassed)

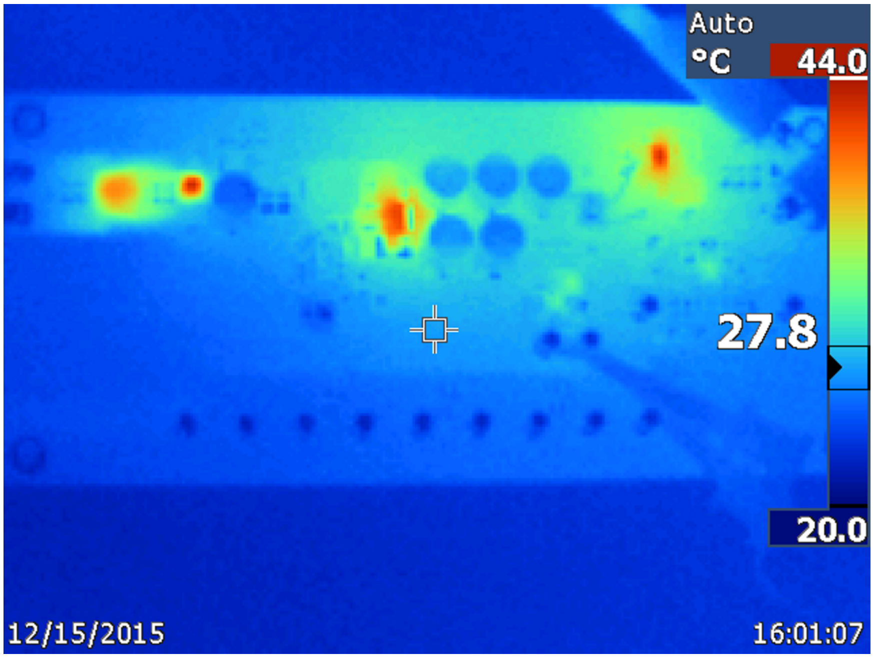

Figure 5. Setup: IR Thermal Image Taken at Steady State With 5.6 V_{IN} and 5 V at 2 A and 6 V at 0.65 A (Boost Operational)

5.2 Efficiency Data

5.2.1 Boost Efficiency—TPS40210 Only

Table 2. Efficiency Data—Boost Efficiency Only

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)
14.5	1.82	14.32	1.82	98.759%
12	1.82	11.82	1.82	98.500%
10.8	1.82	10.6	1.82	98.148%
6.98	2.1412	7.5	1.82	91.331%
5.95	2.5678	7.5	1.82	89.342%
5.01	3.1652	7.5	1.82	86.078%
4.5	3.635	7.5	1.82	83.448%
3.94	4.29	7.5	1.82	80.757%

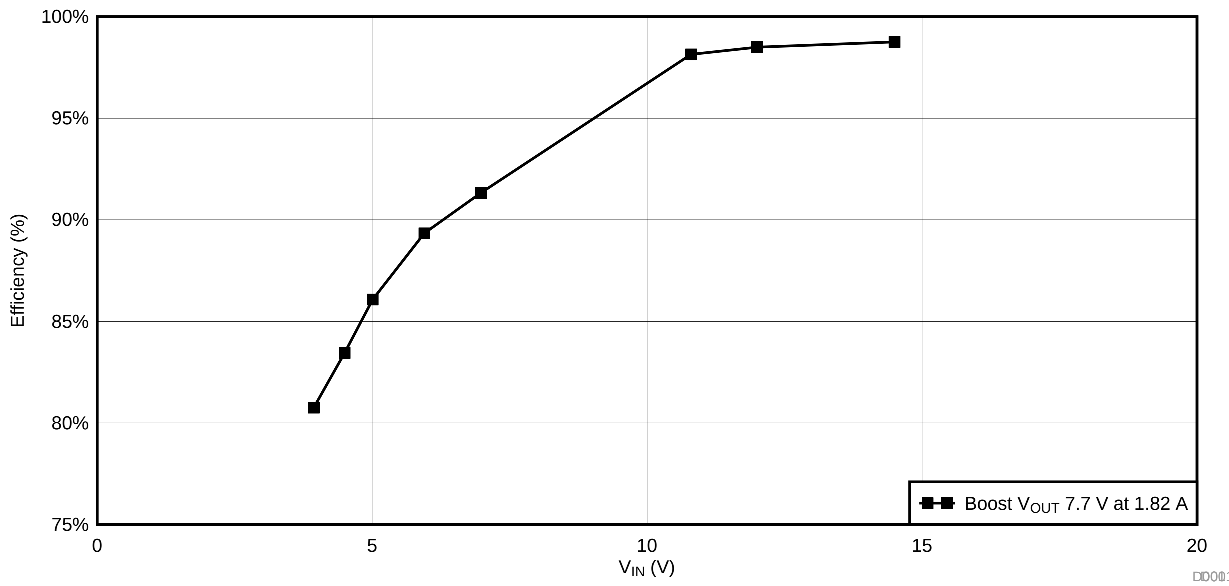

Figure 6. Boost Efficiency vs Input Voltage at Full Load (Boost and Smart Diode Only)

5.2.2 System Efficiency (Pre-Boost and Two Bucks)

Table 3. Efficiency Data—Complete Efficiency Data of System

V_{IN} (V)	I_{IN} (A)	V_{OUT1} (V)	I_{OUT1} (A)	V_{OUT2} (V)	I_{OUT2} (A)	EFFICIENCY (%)
18.09	0.9397	6	0.65	5.005	2	81.828%
16.07	1.0362	6	0.65	5.005	2	83.535%
14.4	1.1444	6	0.65	5.005	2	84.409%
12	1.3438	6	0.65	5.005	2	86.260%
10.72	1.4994	6	0.65	5.005	2	86.540%
9.41	1.7122	6	0.65	5.005	2	86.334%
7.57	2.2373	6	0.65	5.005	2	82.131%
6.13	2.8509	6	0.65	5.005	2	79.595%
5.09	3.563	6	0.65	5.005	2	76.700%
4.45	4.248	6	0.65	5.005	2	73.584%

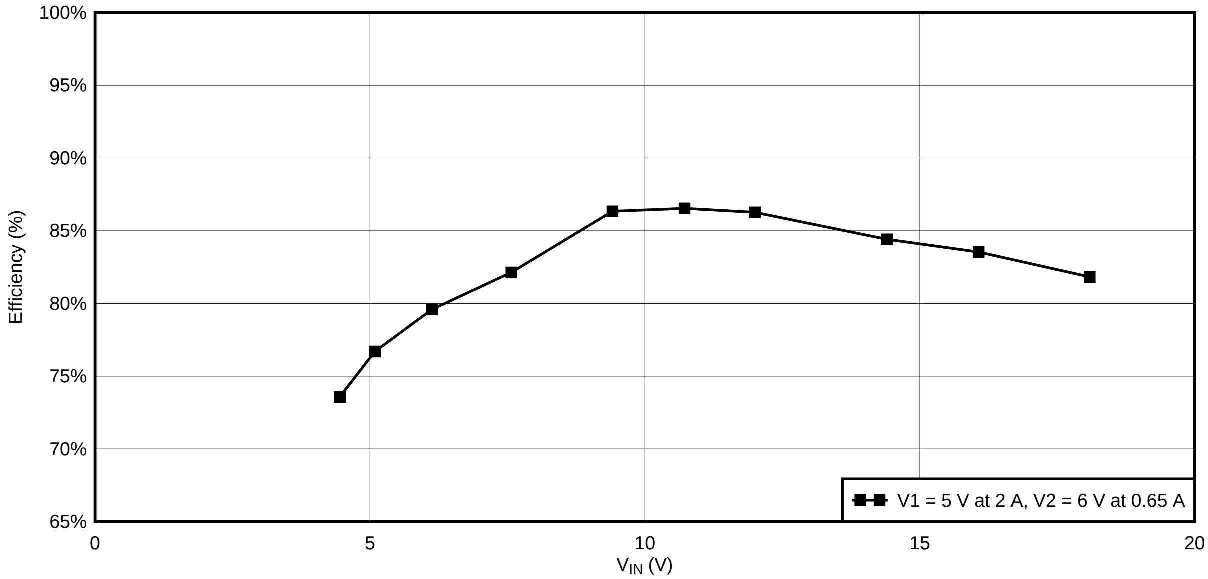

Figure 7. Efficiency vs Input Voltage at Full Load—Pre-Boost (7.5 V) and Dual Buck (5 V and 6 V)

Table 4. Efficiency Data at Fixed Input Voltage and Varying Output Current

V_{IN} (V)	I_{IN} (A)	V_{OUT1} (V)	I_{OUT1} (A)	V_{OUT2} (V)	I_{OUT2} (A)	EFFICIENCY (%)
12	0.076	6	0.05	5.005	0.05	60.334%
12	0.2535	6	0.15	5.005	0.25	70.718%
12	0.4632	6	0.25	5.005	0.6	81.013%
12	0.6792	6	0.35	5.005	0.95	84.103%
12	0.8977	6	0.45	5.005	1.3	85.464%
12	1.1192	6	0.55	5.005	1.65	86.060%
12	1.3438	6	0.65	5.005	2	86.260%

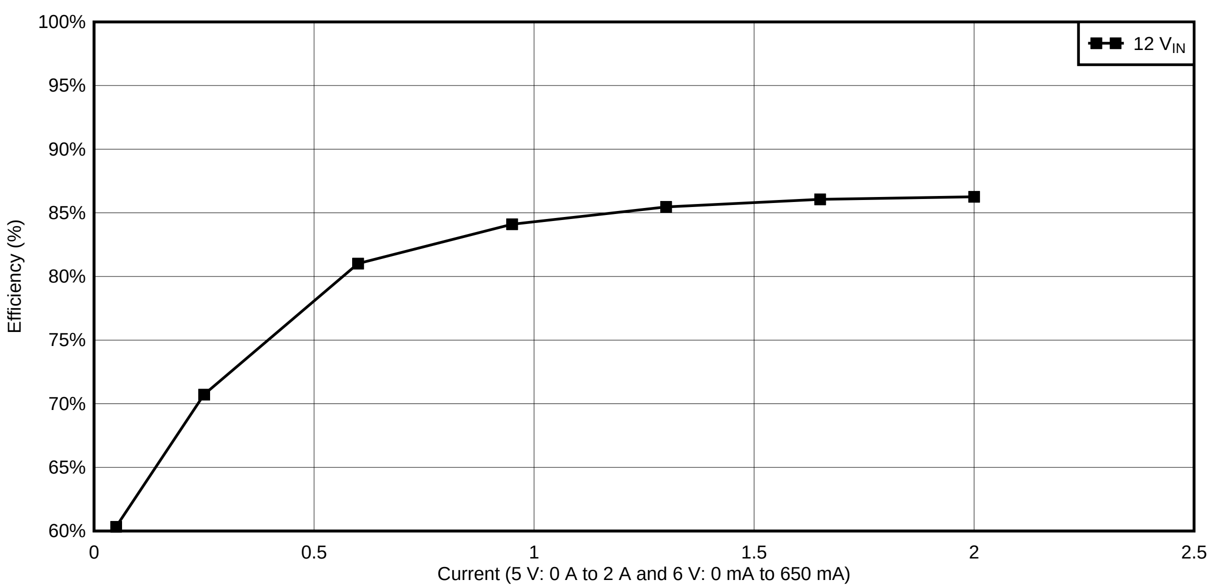

Figure 8. Efficiency vs Load Current—Pre-Boost (7.5 V) and Dual Buck (5 V and 6 V)

6 Waveforms

6.1 Output Ripple Performance

6.1.1 Pre-Boost

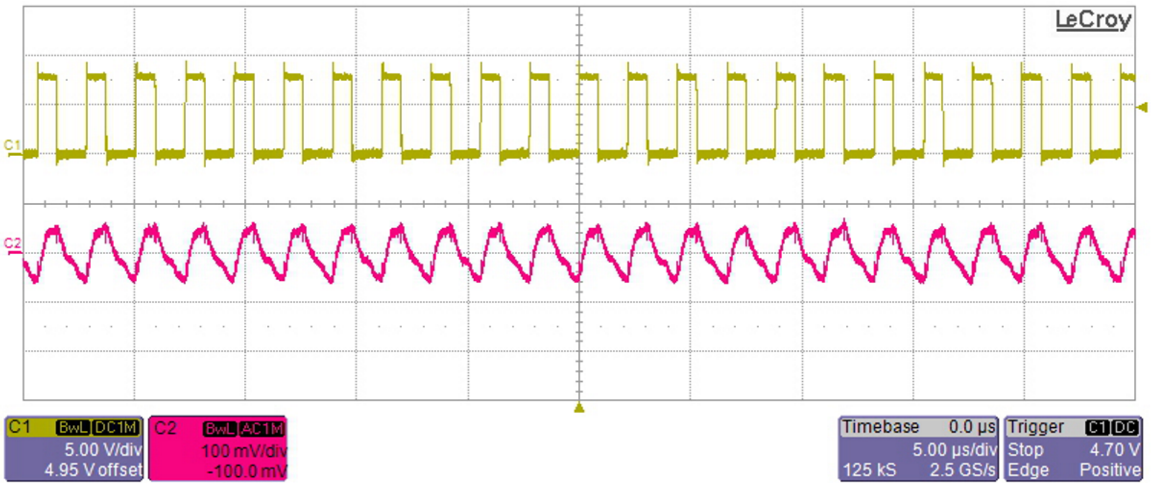

Figure 9. Ch1: Switch Node 7.5-V Boost
Ch2: Pre-Boost 7.5-V Ripple at 3.5-V_{IN} and 2-A Load

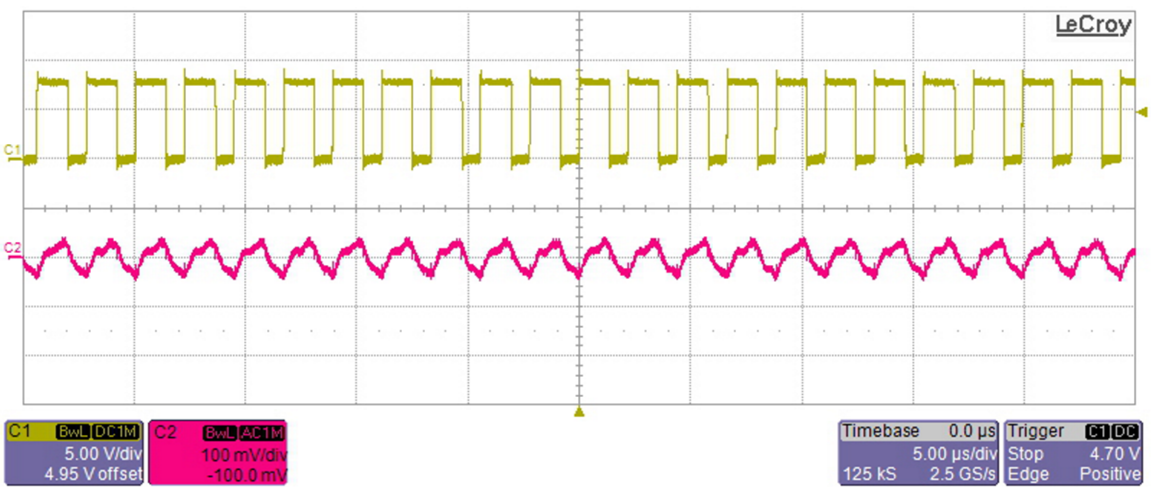

Figure 10. Ch1: Switch Node 7.5-V Boost
Ch2: Pre-Boost 7.5-V Ripple at 5-V_{IN} and 2-A Load

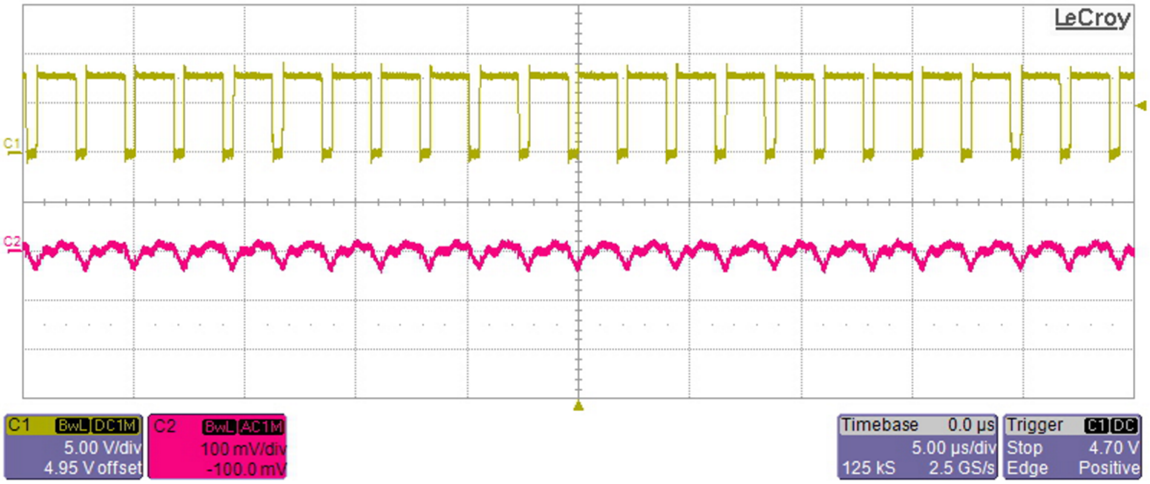

Figure 11. Ch1: Switch Node 7.5-V Boost
Ch2: Pre-Boost 7.5-V Ripple at 6.3-V_{IN} and 2-A Load

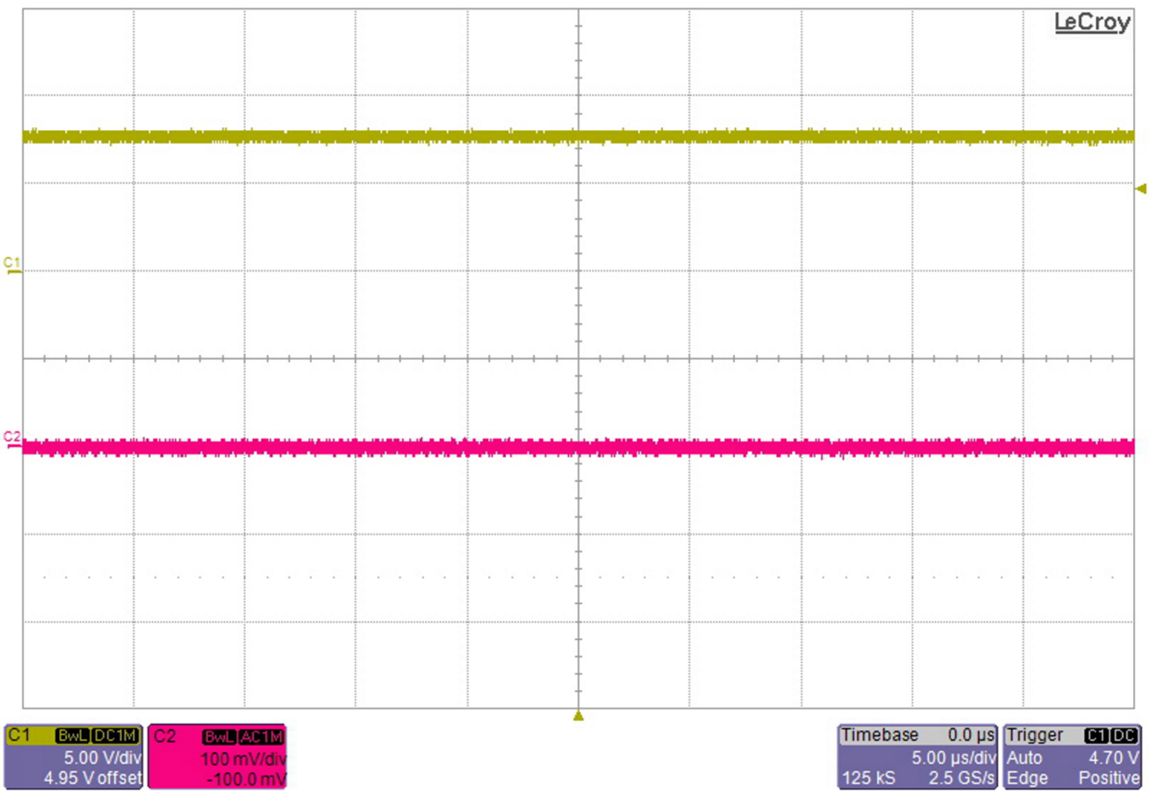

Figure 12. Ch1: Switch Node 7.5-V Boost
Ch2: Pre-Boost 7.5-V Ripple at 8-V_{IN} (No Ripple—Boost Bypassed at 8 V) and 2-A Load

6.1.2 Dual Bucks

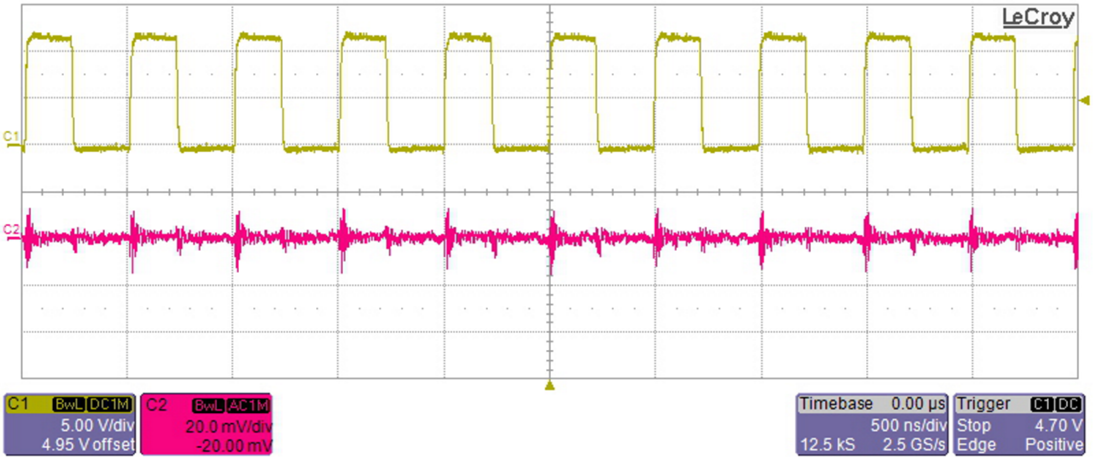

Figure 13. Ch1: 5-V Ripple at 12-V_{IN} and 2-A Load Ch2: Switch Node 5-V Buck

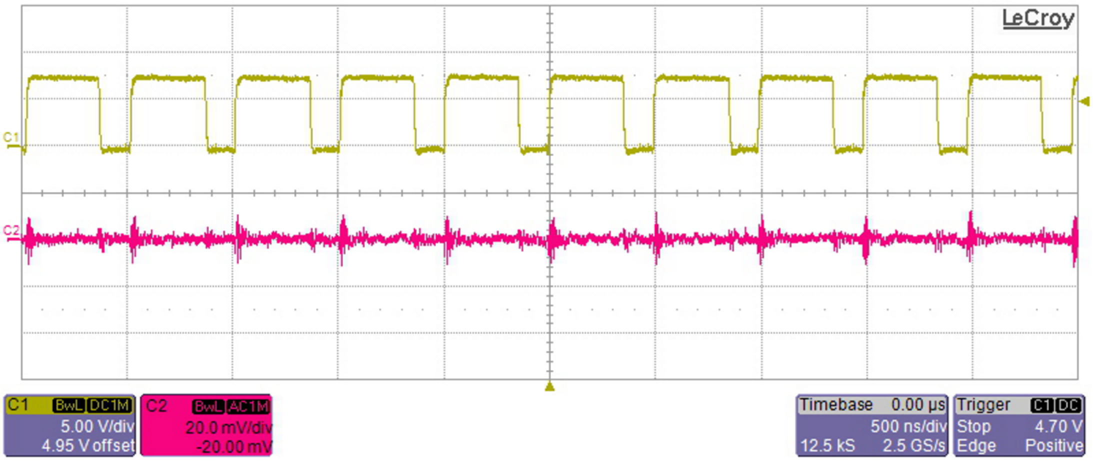

Figure 14. Ch1: 5-V Ripple at 4.5-V_{IN} and 2-A Load Ch2: Switch Node 5-V Buck

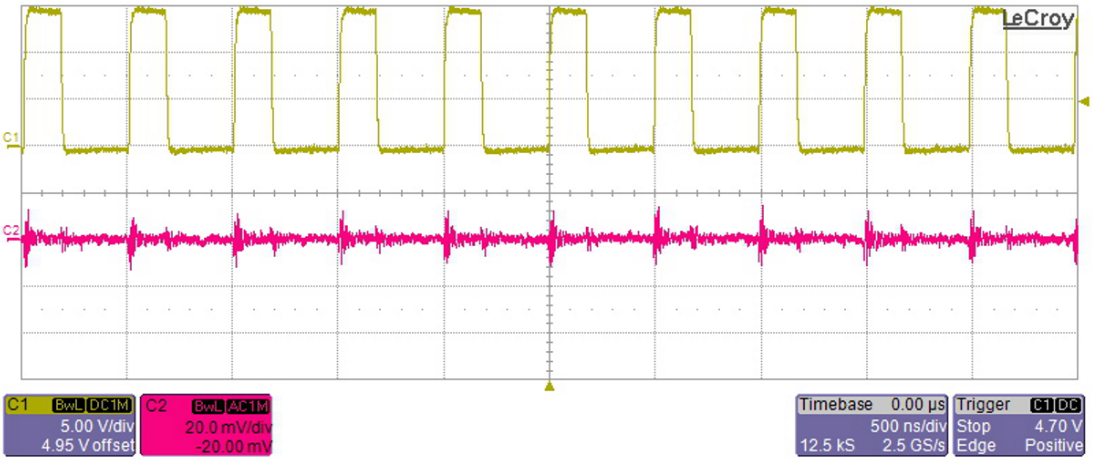

Figure 15. Ch1: 5-V Ripple at 15-V_{IN} and 2-A Load Ch2: Switch Node 5-V Buck

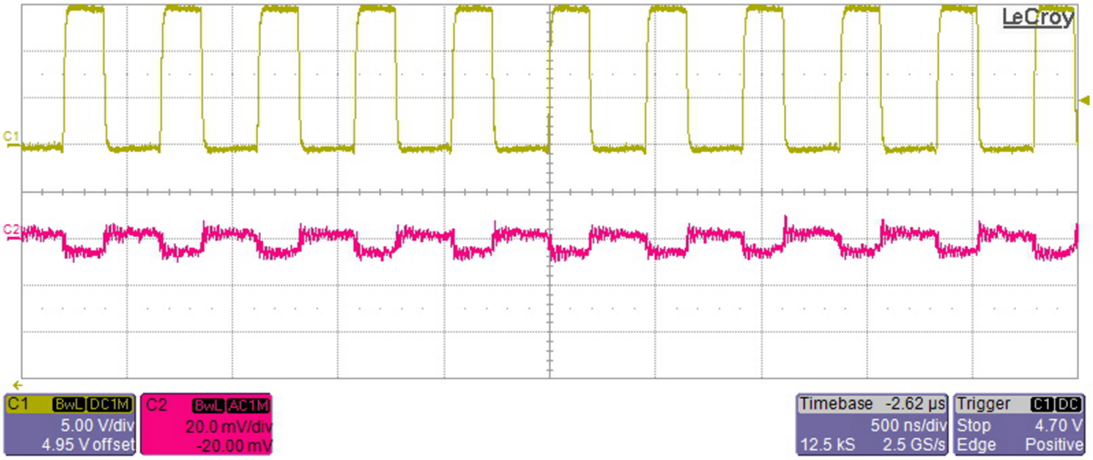

Figure 16. Ch1: 6.5-V Ripple at 15-V_{IN} and 0.65-A Load Ch2: Switch Node 6.5-V Buck

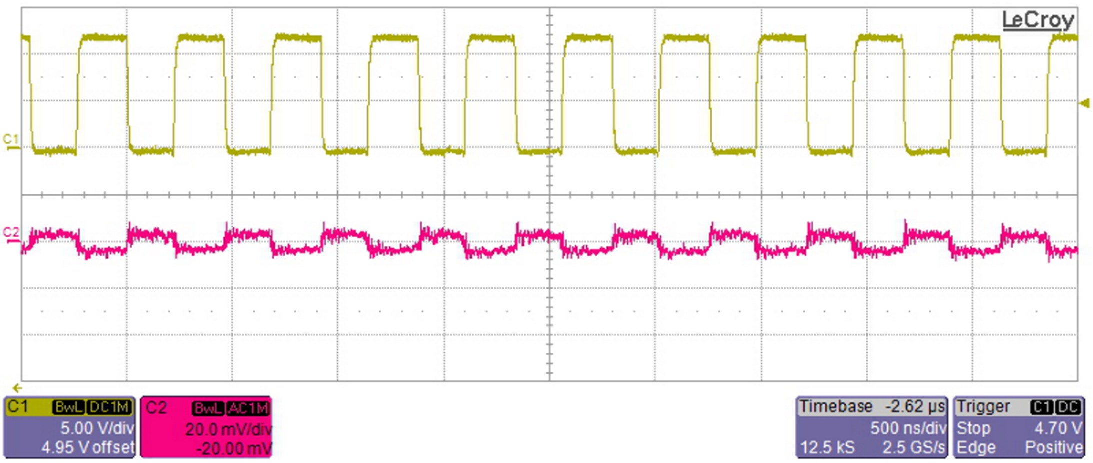

Figure 17. Ch1: 6.5-V Ripple at 12-V_{IN} and 0.65-A Load Ch2: Switch Node 6.5-V Buck

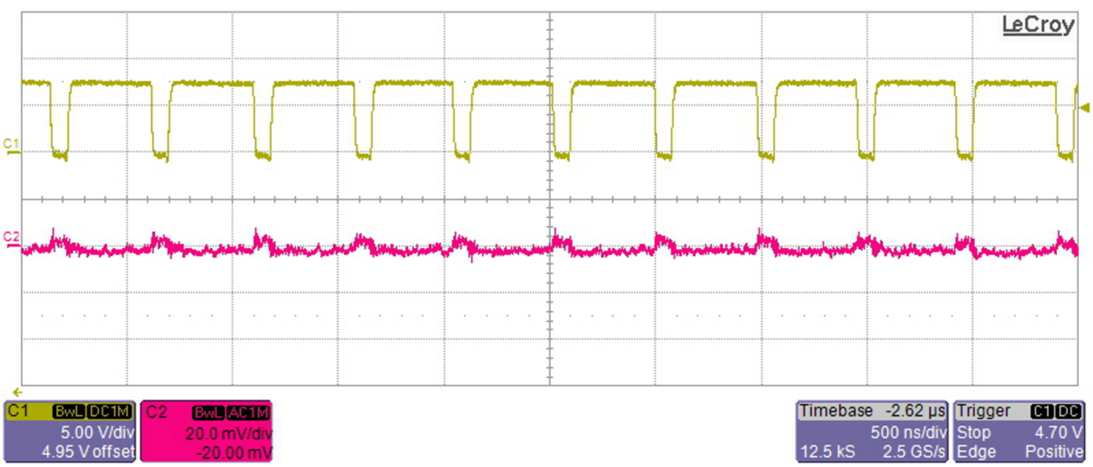

Figure 18. Ch1: 6.5-V Ripple at 4-V_{IN} and 0.65-A Load Ch2: Switch Node 6.5-V Buck

6.2 System Start-up Waveforms

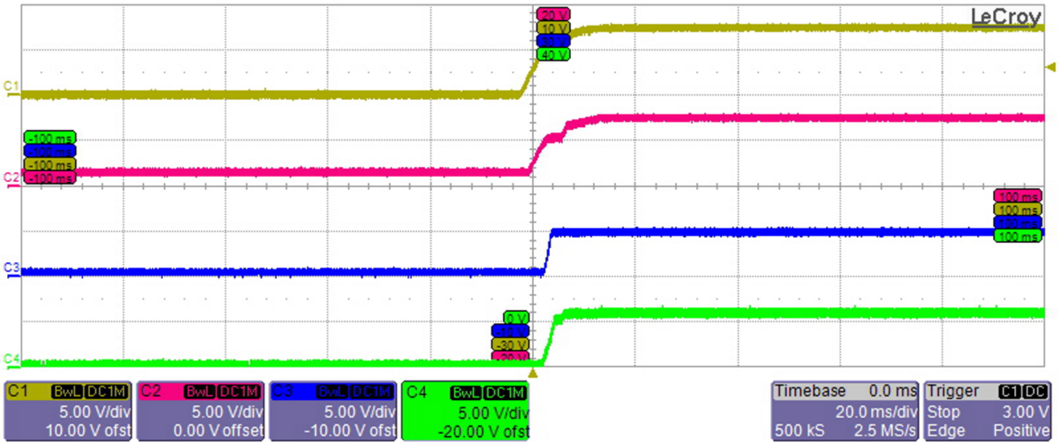

Figure 19. Start-up—No Load at 7.5-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

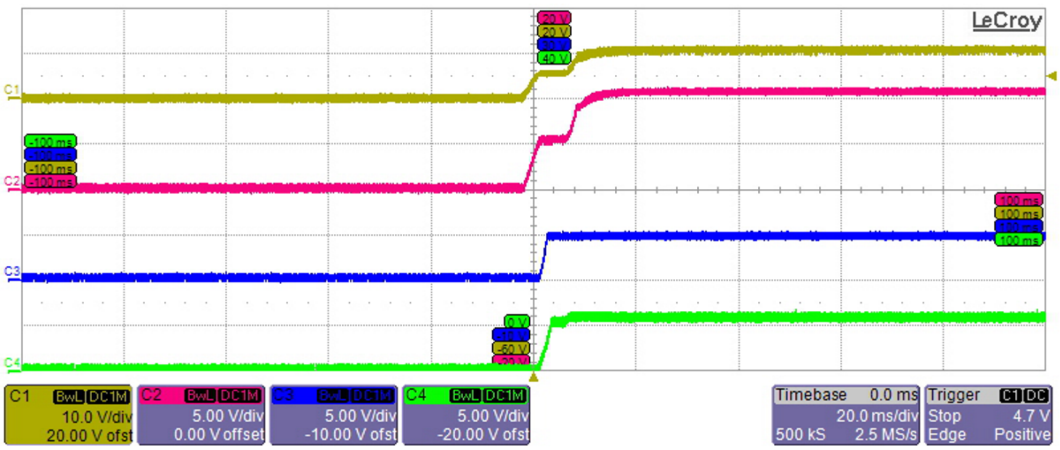

Figure 20. Start-up—No Load at 10.8-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

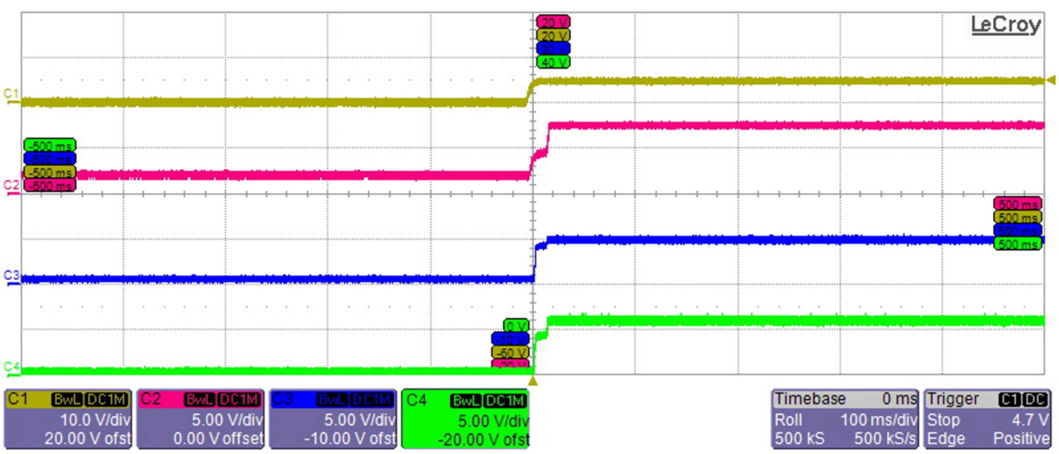

Figure 21. Start-up—No Load at 4.5-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

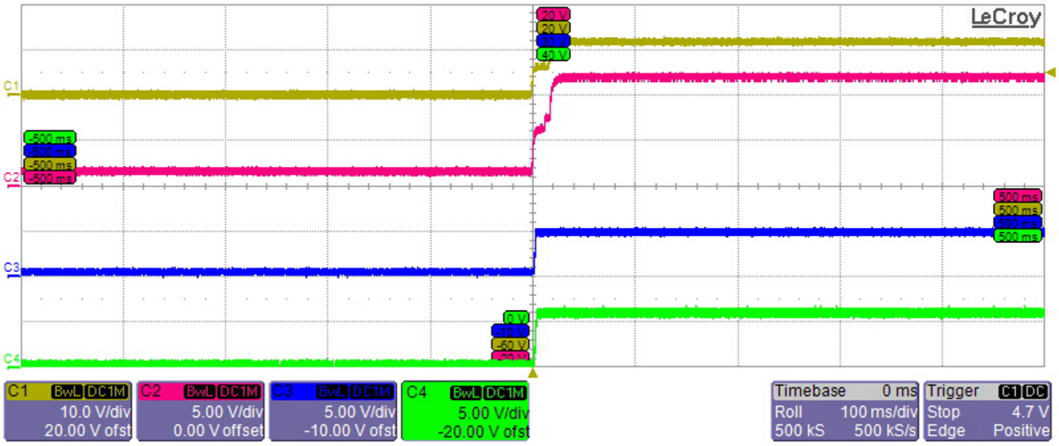

Figure 22. Start-up—No Load at 12-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

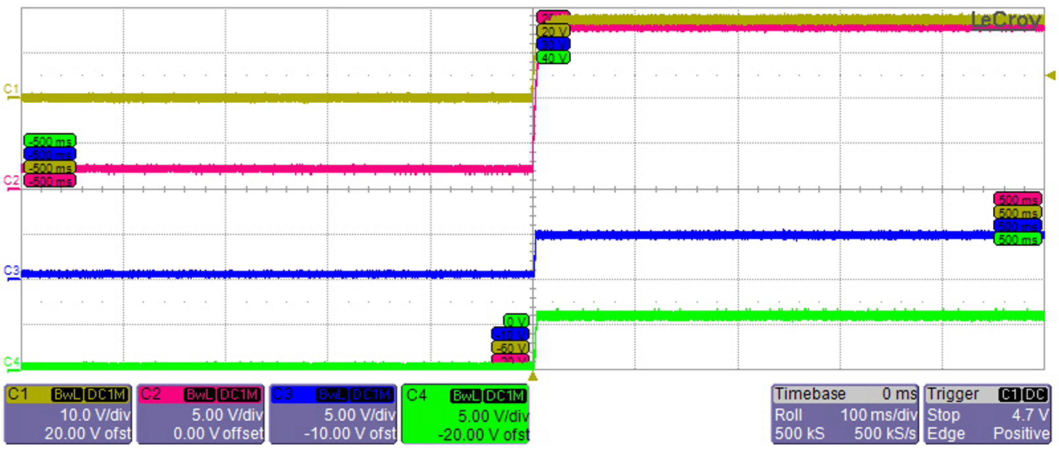

Figure 23. Start-up—No Load at 18-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

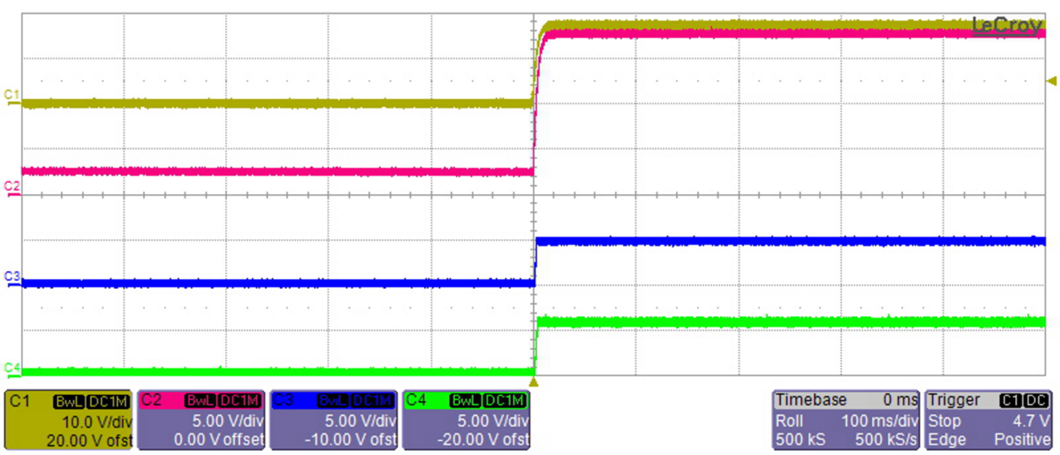

Figure 24. Start-up—Full Load at 18-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

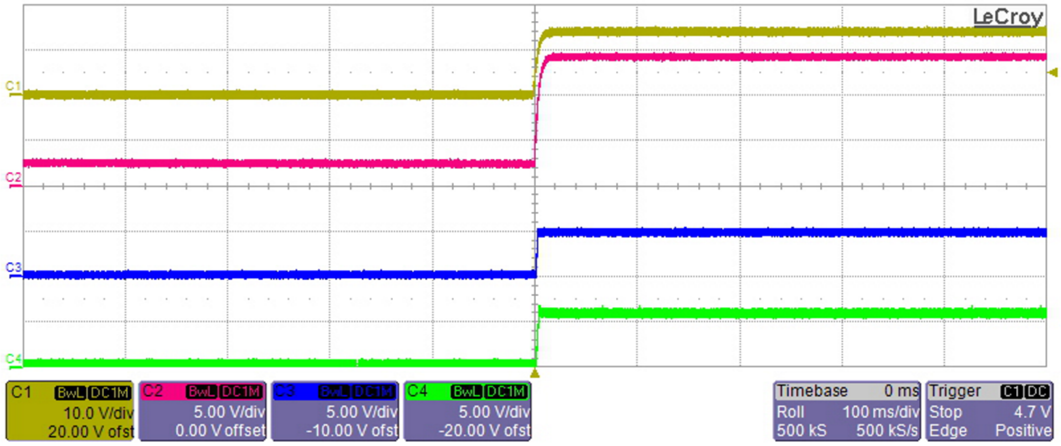

Figure 25. Start-up—Full Load at 14.4-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

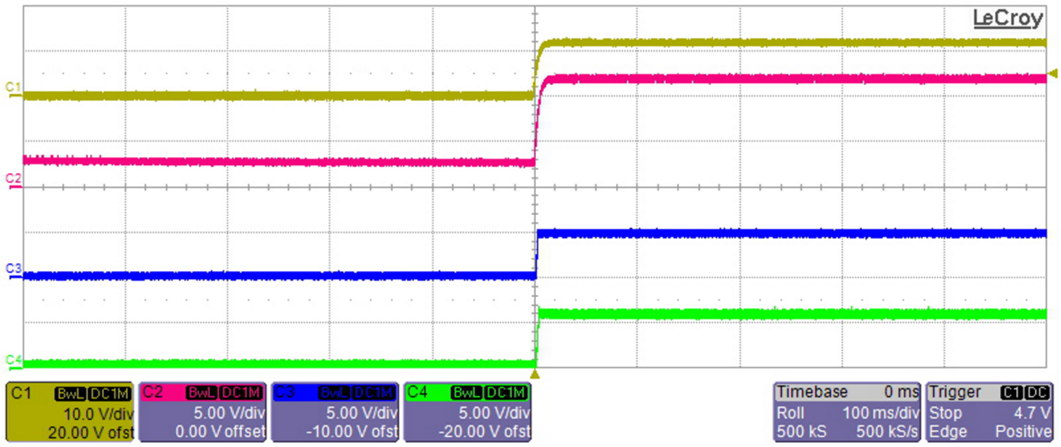

Figure 26. Start-up—Full Load at 12-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

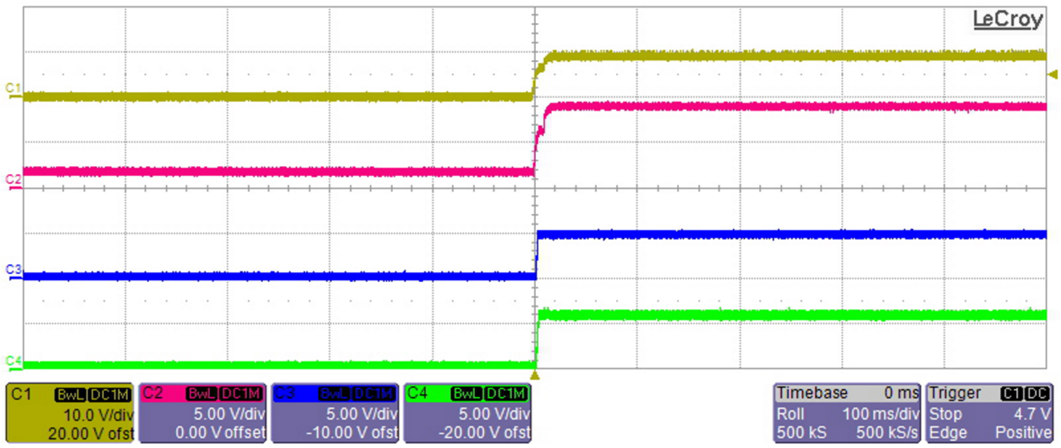

Figure 27. Start-up—Full Load at 9-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

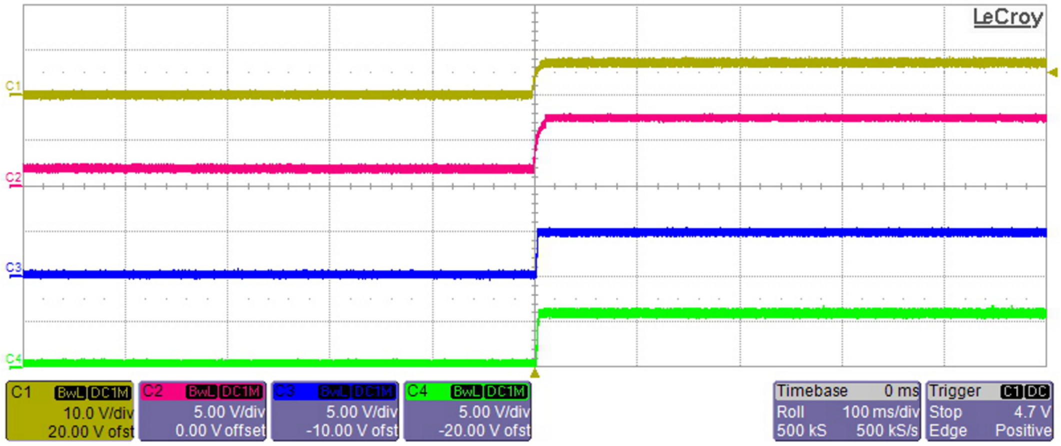

Figure 28. Start-up—Full Load at 7-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

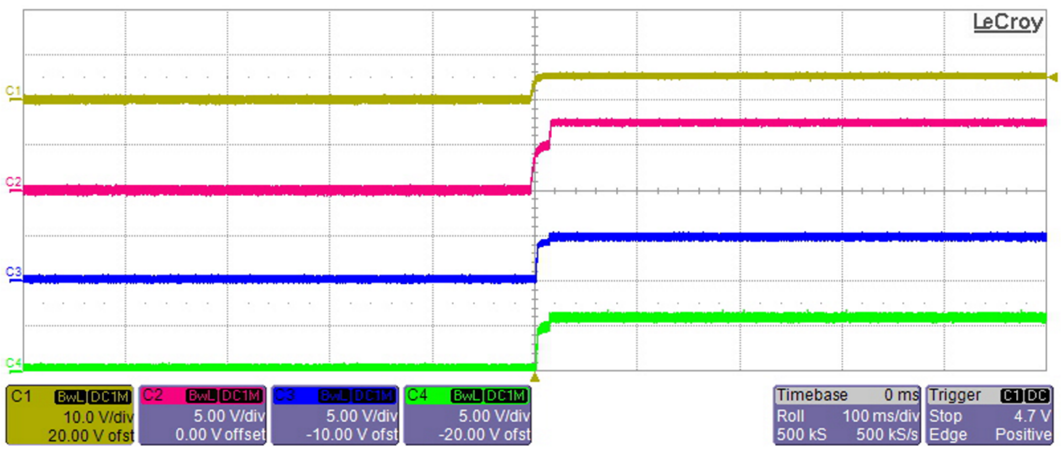

Figure 29. Start-up—Full Load at 5-V_{IN}
Ch1: V_{IN}, Ch2: Boost V_{OUT}, Ch3: 5-V $Buck_{OUT}$, Ch4: 6.5-V $Buck_{OUT}$

6.3 System Transient Performance

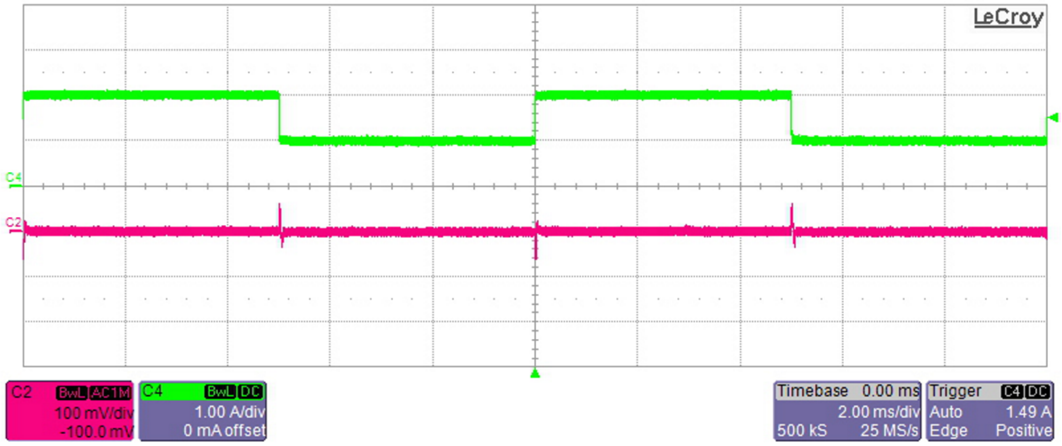

Figure 30. Transient Performance of 5-V Buck at 12-V_{IN} and 1- to 2-A Current Transient Ch2: 5-V AC Coupled, Ch4: 5-V Load

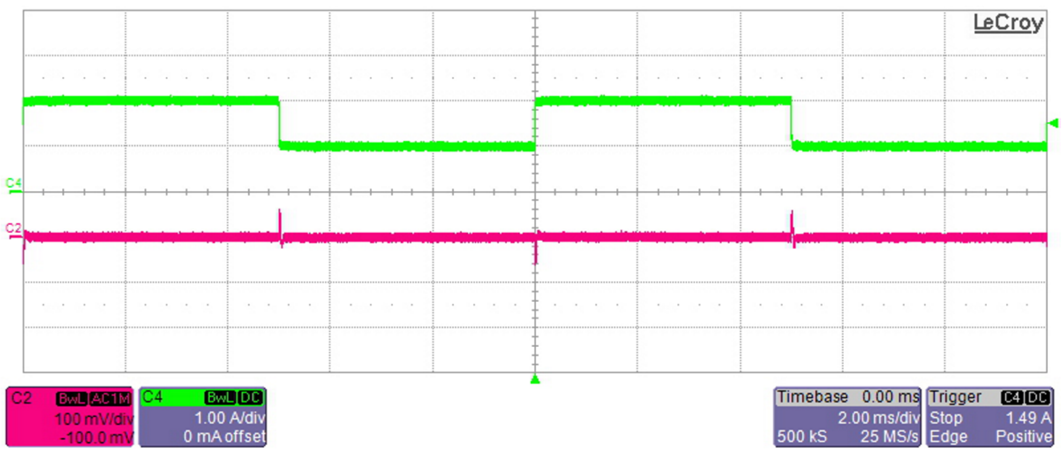

Figure 31. Transient Performance of 5-V Buck at 4.5-V_{IN} and 1- to 2-A Current Transient Ch2: 5-V AC Coupled, Ch4: 5-V Load

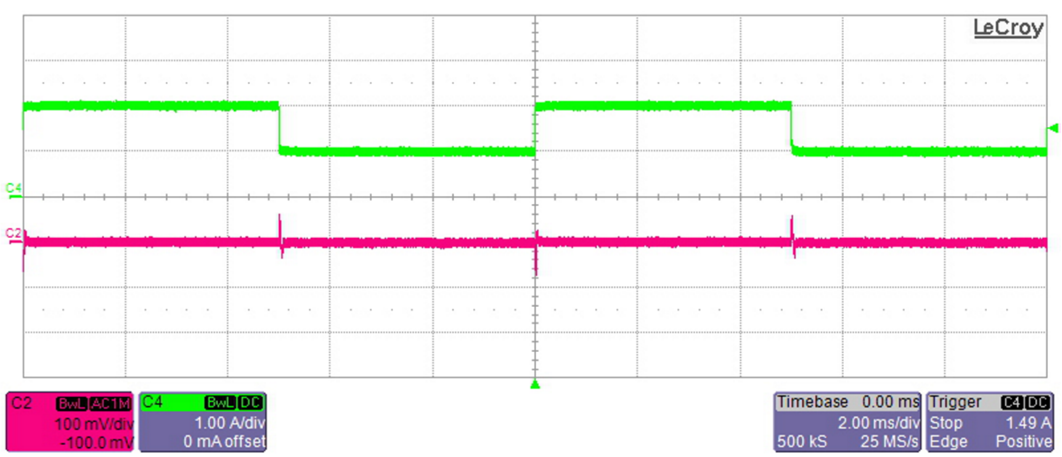

Figure 32. Transient Performance of 5-V Buck at 14.4-V_{IN} and 1- to 2-A Current Transient Ch2: 5-V AC Coupled, Ch4: 5-V Load

7 Conducted Emissions

The conducted emissions have been tested following the CISPR 25 standards. The examined frequency band spans from 150 kHz to 108 MHz and covers the AM, FM, VHF, and TV bands as specified in the CISPR 25.

Figure 33 and Figure 34 show the test results. Figure 33 shows the test result using a peak detector and average detector measurement, respectively, up to 30 MHz. Figure 34 shows the test result using an average detector and peak detector measurement from 30 MHz to 108 MHz. The red limit lines are the Class 5 limits (up to 30 MHz) and Class 4 limits (30 MHz to 108 MHz) for conducted disturbances specified in the CISPR 25. The yellow traces (peak detector measurement) and blue traces (average detector measurement) are the test results. The user can observe that the power supply operates quietly and the noise is below the Class 4 limit.

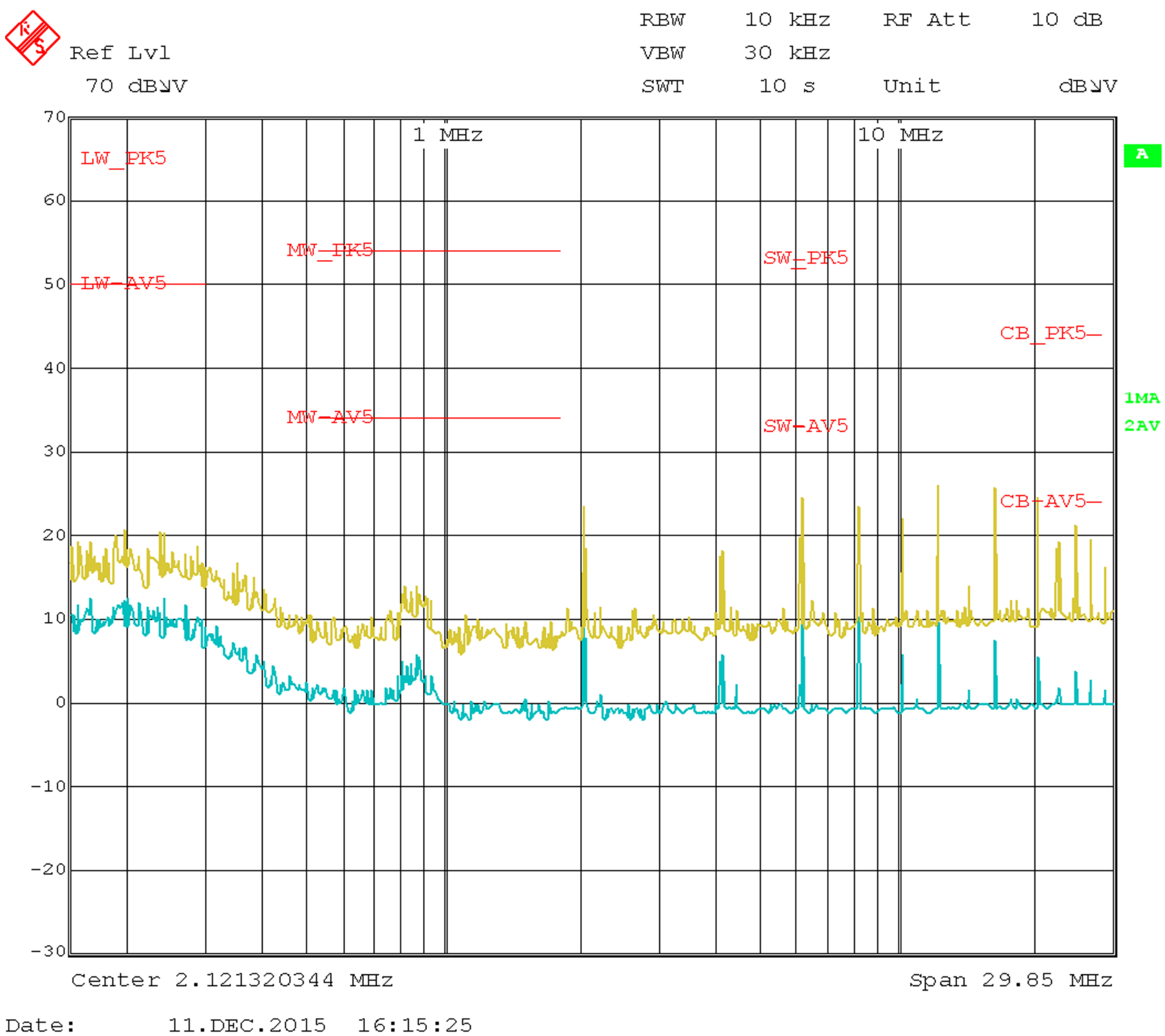

Figure 33. Test Result—up to 30-MHz Conducted Emission: Peak and Average Detection (Both Front-End Buck Switching With Full Load)

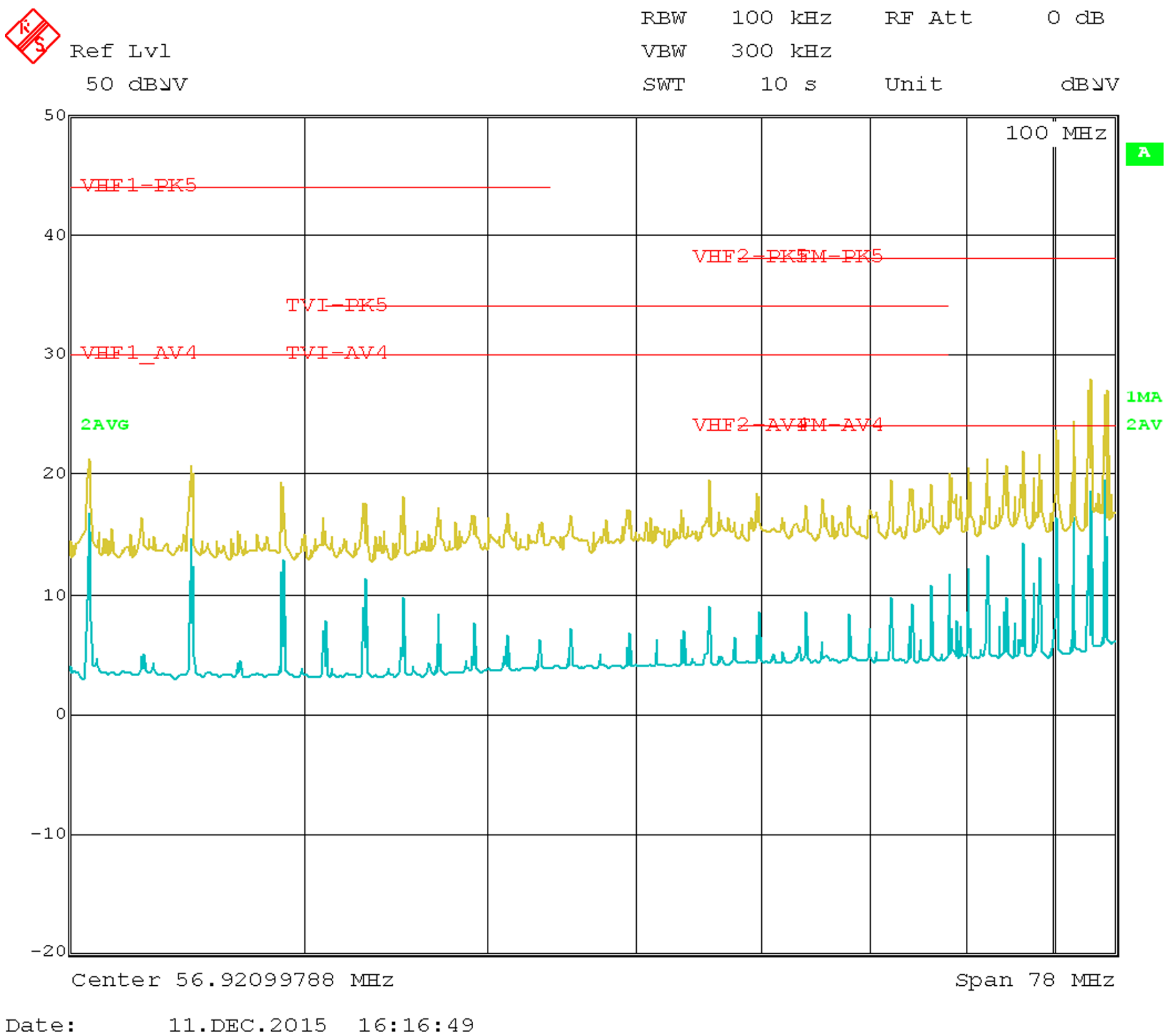

Figure 34. Test Result—30 MHz to 108 MHz Conducted Emission: Peak and Average Detection

8 Design Files

8.1 Schematics

To download the schematics, see the design files at TIDA-00745.

8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00745.

8.3 Layout Prints

To download the layer plots, see the design files at TIDA-00745.

8.4 Altium Project

To download the Altium project files, see the design files at TIDA-00745.

8.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00745.

8.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00745.

9 Software Files

To download the software files, see the design files at TIDA-00745.

10 References

1. Texas Instruments, *LM53600/01-Q1, 0.65A/1A, 36V Synchronous, 2.1MHz, Automotive Step Down DC-DC Converter*, LM53600-Q1 and LM53601-Q1 Datasheet (SNAS660)
2. Texas Instruments, *LM53603-Q1 (3 A), LM53602-Q1 (2 A) 3.5 V to 36 V Wide-V_{IN} Synchronous 2.1 MHz Step-Down Converters for Automotive Applications*, LM53602-Q1 and LM53603-Q1 Datasheet (SNVSA42)
3. Texas Instruments, *LM26420/LM26420-Q0/Q1 Dual 2-A Automotive-Qualified, High-Efficiency Synchronous DC-DC Converter*; LM26420, LM26420-Q0, and LM26420-Q1 Datasheet (SNVS579)
4. Texas Instruments, *TPS4021x-Q1 4.5-V to 52-V Input, Current-Mode Boost Controllers*, TPS40210-Q1 and TPS40211-Q1 Datasheet (SLVS861)
5. Texas Instruments, *TPS7B4250-Q1 Low-Dropout Voltage-Tracking LDO*, TPS7B4250-Q1 Datasheet (SLVSCA0)

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