TI Designs: TIDA-01534
Automotive Off-Battery Dual-Phase Boost Converter Reference Design

TEXAS INSTRUMENTS

Description

This reference design is a high-power, wide-input voltage range circuit (9 V to 20 V nominal, transient down to 6 V and up to 36 V) that uses synchronous boost controllers in a dual-phase configuration for outputting four, switchable 12-V rails. Each of these rails can supply up to 2.5 A with diagnostic features. The reference design also implements a dual synchronous buck controller that generates two high-current, lower-voltage rails (5 V, 3 A and 3.8 V, 6.5 A nominal). The design is suitable for an automotive off-battery infotainment application.

Resources

TIDA-01534	Design Folder
LM74700-Q1	Product Folder
LM25122-Q1	Product Folder
LM5140-Q1	Product Folder
TPS1H100-Q1	Product Folder

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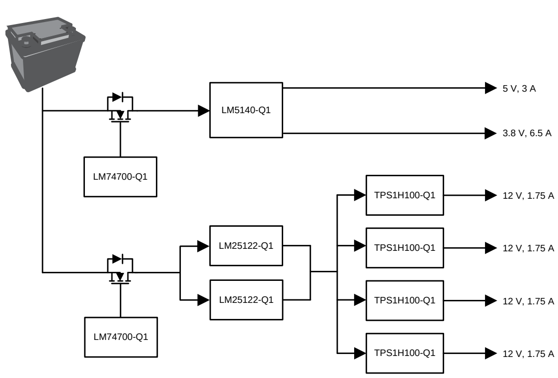
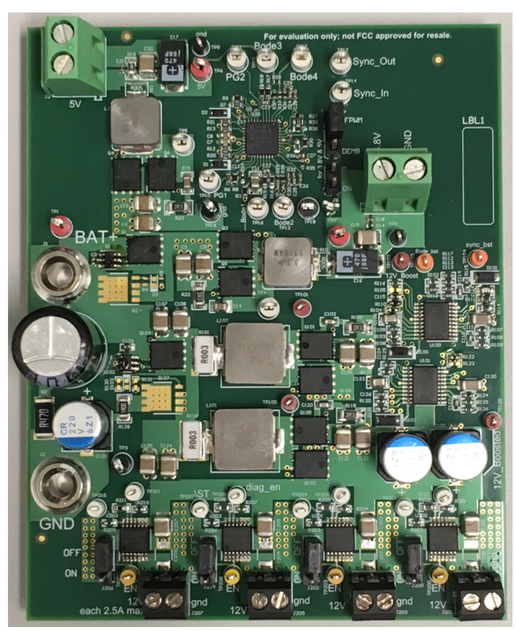
Features

- Wide-Input Voltage Range of 9 V to 20 V, Supports Transient Down to 6 V and up to 36 V
- Dual-Phase High-Current Synchronous Boost Controllers Configuration
  - Four 12-V Switchable Outputs With Diagnostic Capabilities
  - 1.75-A Nominal Current for Each Output
  - Greater than 98% Efficiency Under Typical Operating Conditions
- Dual Synchronous Buck Controller
  - 5 V, 3 A Nominal
  - 3.8 V, 6.5 A Nominal
- Reverse Battery Protection With Zero I_Q Smart Diode Controllers
- Minimized AM Radio Band Interference

Applications

- Automotive Head Unit
- Aftermarket Head Unit





1 System Description

The battery system of a vehicle normally supplies the power to end equipment in typical automotive infotainment applications. This reference design implements a circuit that converts a wide-input voltage to four 12-V outputs using a dual-phase synchronous boost circuit. This design also has a circuit that converts the input voltage to two lower voltages at 3.8 V and 5 V using a dual, synchronous buck circuit. The normal operating input voltage range is from 9 V to 20 V, and the design is able to handle transient voltages down to 6 V and up to 36 V. This design is a good fit for automotive head unit, aftermarket head unit, and voltage conditioning module (VCM) applications.

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Input voltage range	6-V to 36-V DC	Section 2.4.1
Boost output voltage	12.1 V	Section 2.4.2
Boost output current (per channel)	1.75 A	Section 2.4.2
Boost supply switching frequency	398 kHz	Section 2.4.2
Buck output 1 voltage	5 V ± 1%	Section 2.4.3
Buck output 1 current	3 A	Section 2.4.3
Buck output 2 voltage	3.8 V ± 1%	Section 2.4.3
Buck output 2 current	6.5 A	Section 2.4.3
Buck supply switching frequency	440 kHz (default) or 2.2 MHz	Section 2.4.3

2 System Overview

2.1 Block Diagram

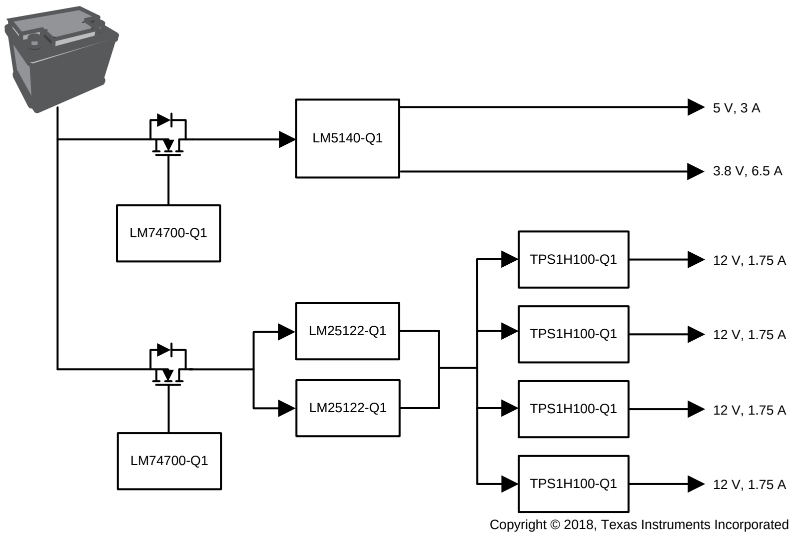


Figure 1. TIDA-01534 Block Diagram

2.2 Design Considerations

Some of the design considerations for off-battery, infotainment-end-equipment applications are:

- Wide-input voltage range
- Reverse battery condition
- Low-loss and high efficiency
- AM radio band electromagnetic interference (EMI)

The devices in this reference design have a wide supply input range that can accommodate the transient conditions in an off-battery application.

Protection from reverse battery conditions, which are typically caused by an incorrect installation or a jump-start connection, is mandatory. Low-loss and high efficient solutions are important, especially in high-current applications. This design utilizes two protection circuits in parallel to further reduce power loss.

Radio band EMI (especially in the AM band) must be minimized in infotainment end equipment. Using power supplies that have switching frequencies outside of the AM band, as well as the capability to operate in out-of-phase mode, helps achieve this objective.

2.3 Highlighted Products

2.3.1 LM74700-Q1

The LM74700-Q1 is a smart diode controller that operates in conjunction with an external N-channel MOSFET to function as an ideal diode rectifier for low-loss reverse polarity protection. The wide supply input range of 3 V to 65 V allows control of many popular DC bus voltages. The device can withstand and protect the loads from negative supply voltages down to –65 V. With a low $R_{DS(ON)}$ external N-channel MOSFET, a very-low forward voltage drop can be achieved while minimizing the amount of power dissipated in the MOSFET.

For low-load currents, the forward voltage is regulated to 20 mV to enable graceful shutdown of the MOSFET. TI recommends external MOSFETs with a 5 V or lower threshold voltage. With the enable pin low, the controller is off and draws approximately 3 μA of current.

The LM74700-Q1 controller provides a charge pump gate drive for an external N-channel MOSFET. The high voltage rating of the LM74700-Q1 helps to simplify the system designs for automotive ISO 7637 protection. Fast response to reverse current blocking makes the device suitable for systems with output voltage holdup requirements during ISO 7637 pulse testing, as well as power fail and brownout conditions. The LM74700-Q1 is also suitable for ORing applications or AC rectification.

Figure 2 shows the LM74700-Q1 functional block diagram.

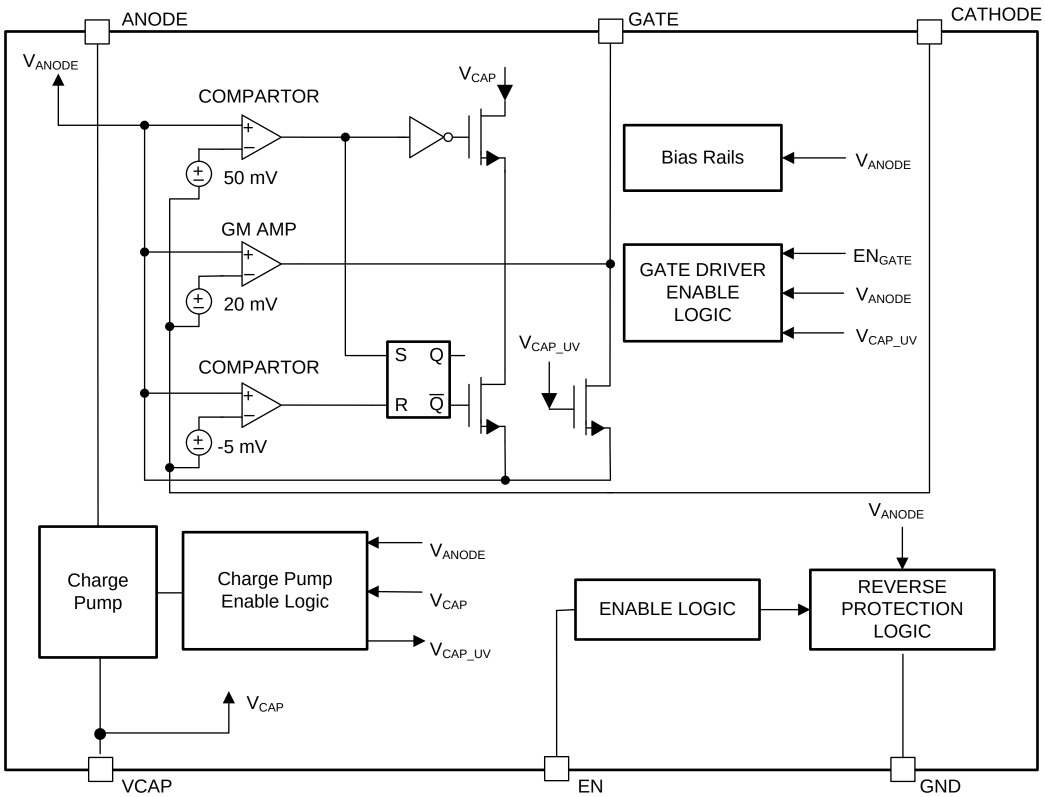


Figure 2. LM74700-Q1 Functional Block Diagram

2.3.2 LM25122-Q1

The LM25122-Q1 is a multiphase-capable synchronous boost controller intended for high-efficiency synchronous boost regulator applications. The control method is based on peak current mode control. Current mode control provides inherent line feedforward, cycle-by-cycle current limiting, and ease-of-loop compensation.

The switching frequency is programmable up to 600 kHz. Higher efficiency is achieved by two robust N-channel MOSFET gate drivers with adaptive deadtime control. A user-selectable diode emulation mode also enables discontinuous mode operation for improved efficiency at light load conditions.

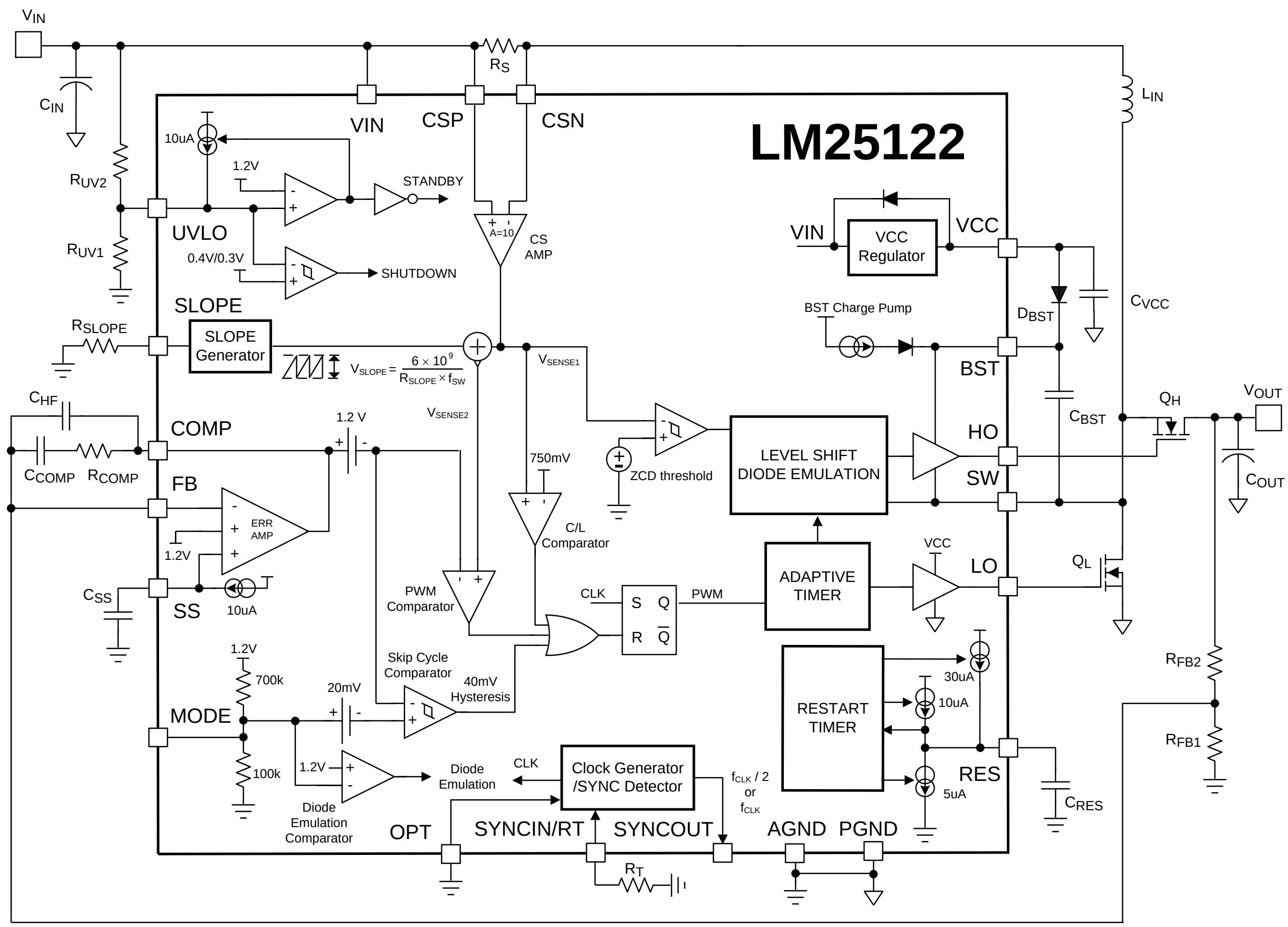


Figure 3. LM25122-Q1 Functional Block Diagram

2.3.3 LM5140-Q1

The LM5140-Q1 is a dual synchronous buck controller intended for high voltage wide VIN step-down converter applications. The control method is based on current mode control. Current mode control provides inherent line feedforward, cycle-by-cycle current limiting, and easier loop compensation.

The LM5140-Q1 features adjustable slew rate control to simplify compliance with the CISPR and automotive EMI requirements. The LM5140-Q1 operates at selectable switching frequencies of 2.2 MHz or 440 kHz, with the two controller channels switching 180° out of phase. In light or no-load conditions, the LM5140-Q1 operates in skip cycle mode for improved low power efficiency. The LM5140-Q1 includes a high voltage bias regulator with automatic switch-over to an external bias supply, to improve efficiency and reduce input current.

Additional features include frequency synchronization, cycle-by-cycle current limit, hiccup mode fault protection for sustained overloads, independent power good outputs, and independent enable inputs.

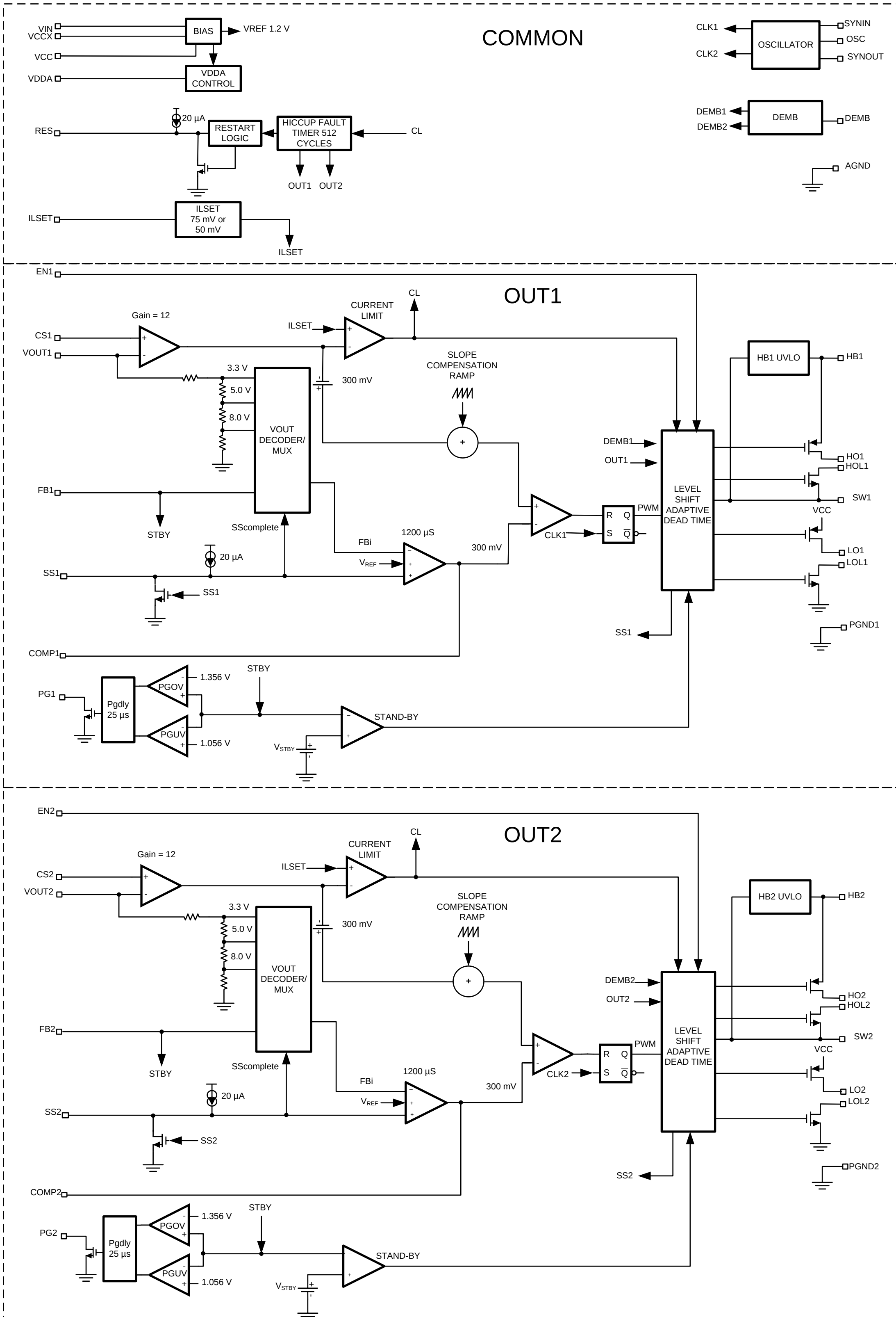


Figure 4. LM5140-Q1 Functional Block Diagram

2.3.4 TPS1H100-Q1

The TPS1H100-Q1 is a high-side power switch that is fully protected and single channel, with integrated NMOS power FET and charge pump. Full diagnostics and high-accuracy current sense features enable intelligent control of the load. Programmable current limit function greatly improves the reliability of the entire system. The device diagnostic reporting has two versions to support both digital status and analog current sense output, both of which can be set as high impedance when diagnostics are disabled, for multiplexing the MCU analog or digital interface among devices.

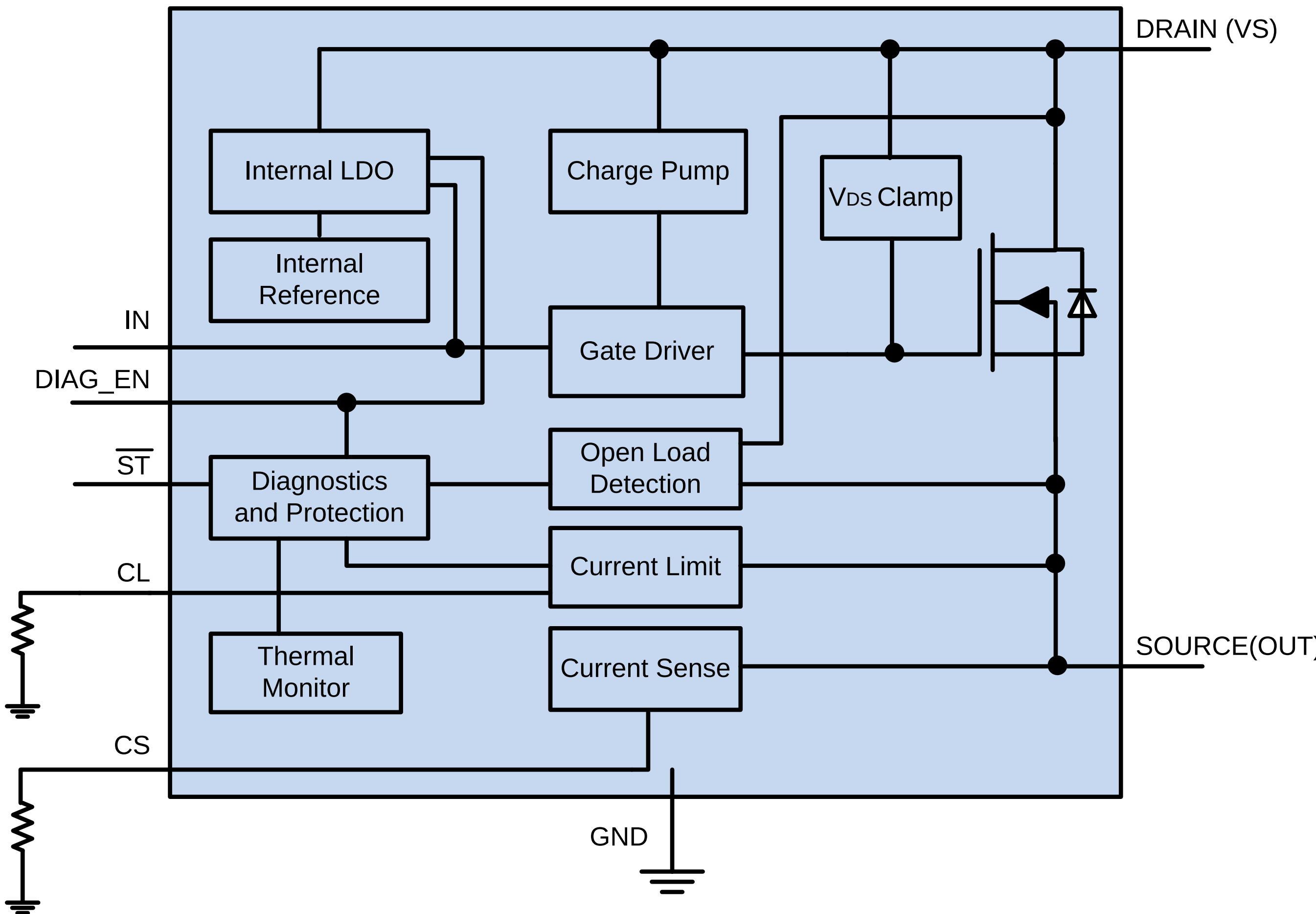


Figure 5. TPS1H100-Q1 Functional Block Diagram

2.4 System Design Theory

2.4.1 Input Protection

The LM74700-Q1 smart diode controller is used to protect the circuit from reverse battery condition. The very low $R_{DS(ON)}$ of the n-channel MOSFET helps reduce power loss, especially during high-current operation. By using two separate input paths, the resistance is reduced to improve overall power loss of the system.

2.4.2 Boost Voltage Supply Controllers (LM25122-Q1)

Two LM25122-Q1s are used to provide high current output for the boost voltage to supply up to 2.5 A for each of the four downstream systems. To help reduce EMI, the two devices are designed to operate in dual phase interleaved operation, with outputs 180° out of phase from each other. U100 is set as the master device with SYNCOUT connecting to SYNCIN of the slave device (U101). Figure 6 shows the connections between a master device and a slave device.

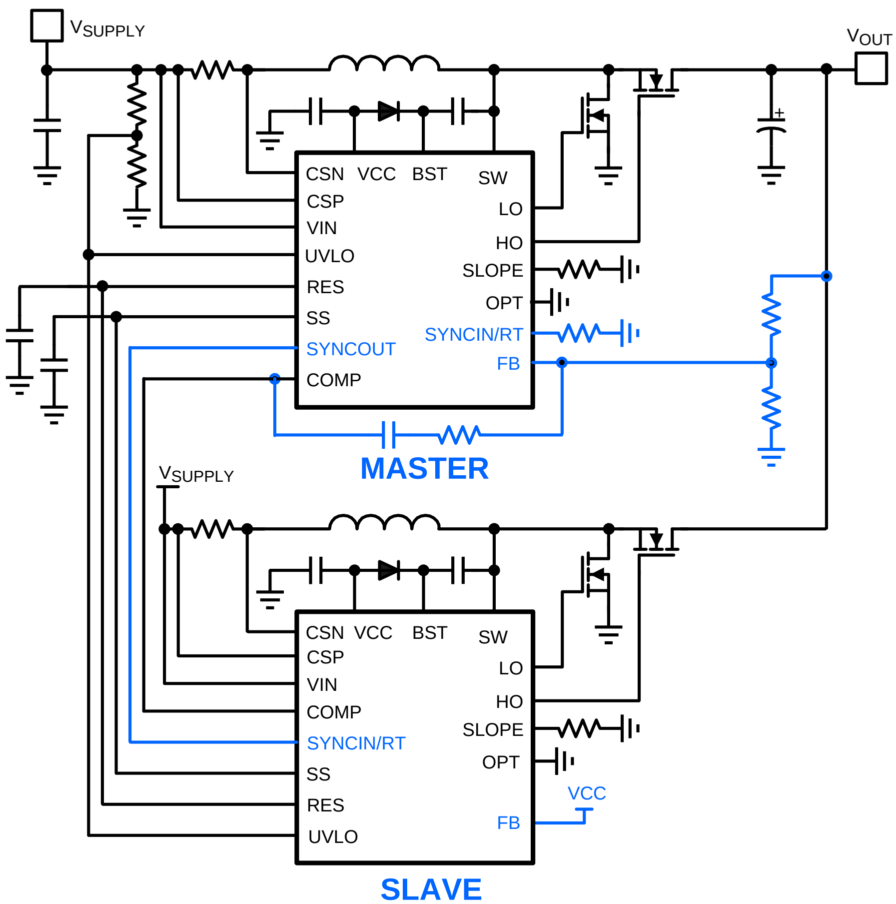


Figure 6. LM25122-Q1 Dual-Phase Interleaved Boost Configuration

To avoid the AM radio band, the SYNCIN/RT pin of U100 is used to set the switching frequency to 398 kHz with resistor R115:

$$f_{SW} = \frac{9 \times 10^9}{R115} = \frac{9 \times 10^9}{22.6\ k} = 398\ kHz \tag{1}$$

The output voltage is set to 12.1 V with feedback resistors R102, R112, and R117 to the master device (U100):

$$V_{OUT}\ (12V\_Boosted) = \frac{51\ \Omega + 90.9\ k\Omega}{10\ k\Omega} + 1 \times 1.2\ V = 12.1\ V \tag{2}$$

Resistor R102 is used to facilitate measurement of loop transfer function of the power supply. For more information, see *AN-1889 How to Measure the Loop Transfer Function of Power Supplies*.

When the input voltage is equal to or greater than the set output voltage (12.1 V), the LM25122-Q1s are in 100% duty cycle operation for the high-side synchronous switch (bypass operation); thus the output voltage is equal to the input voltage.

2.4.3 Buck Voltage Supply Controller (LM5140-Q1)

The LM5140-Q1 generates 5-V and 3.8-V output rails from the battery source. Pin 3 (FB2) is connected to feedback resistors R28, R33, and R37 for 5-V output. Pin 28 (FB1) is connected to feedback resistors R26, R29, and R34 for 3.8-V output. The two outputs switch 180° out of phase to each other to help reduce EMI.

$$V_{OUT}\left(5V0\right) = \frac{51\,\Omega + 31.6\text{ k}\Omega}{10\text{ k}\Omega} + 1 \times 1.2\text{ V} = 5\text{ V} \tag{3}$$

$$V_{OUT}\left(3V8\right) = \frac{165\,\Omega + 21.5\text{ k}\Omega}{10\text{ k}\Omega} + 1 \times 1.2\text{ V} = 3.8\text{ V} \tag{4}$$

To avoid the AM radio band, switching frequency is set to 440 kHz by grounding pin 37 (OSC) through a 0-Ω resistor (R39).

3 Hardware, Testing Requirements, and Test Results

3.1 Required Hardware

The hardware for this design is as follows:

- Agilent 1000-W power supply or other comparable power supply
- Thermal imager for temperature measurements
- Oscilloscope for signal measurements
- Variable loads
- Frequency Response Analyzer (Venable 3120)

3.2 Testing and Results

3.2.1 Test Setup

CAUTION

Hot surface. Contact may cause burns. Avoid touch.

Connect proper variable loads to outputs for desired loading base on specific test

Connect power supply to PCB inputs (J1: V_{IN}, J2: GND)

For boost outputs, install shunt between pins 1 and 2 of corresponding header to enable, or between pins 2 and 3 to disable:

- J200 header for J201 output
- J202 header for J203 output
- J204 header for J205 output
- J206 header for J207 output

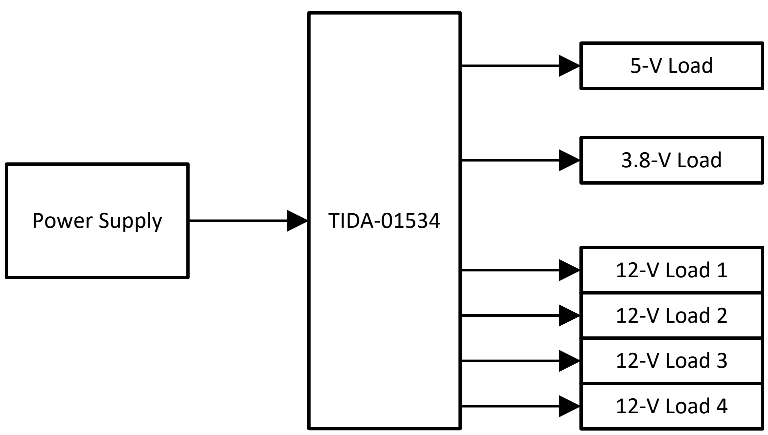


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Figure 7. Test Setup Block Diagram

3.2.2 Test Results

3.2.2.1 Start-up Waveforms

The following three figures show captures of input and outputs during start-up with various input voltages.

- Channel 1, 2 V/div (yellow): V_{IN} source input
- Channel 2, 2 V/div (magenta): 12-V boost output
- Channel 3, 1 V/div (cyan): 3.8-V buck output
- Channel 4, 1 V/div (green): 5-V buck output

Figure 8 shows start-up waveforms with source input voltage (V_{IN}) at 9 V.

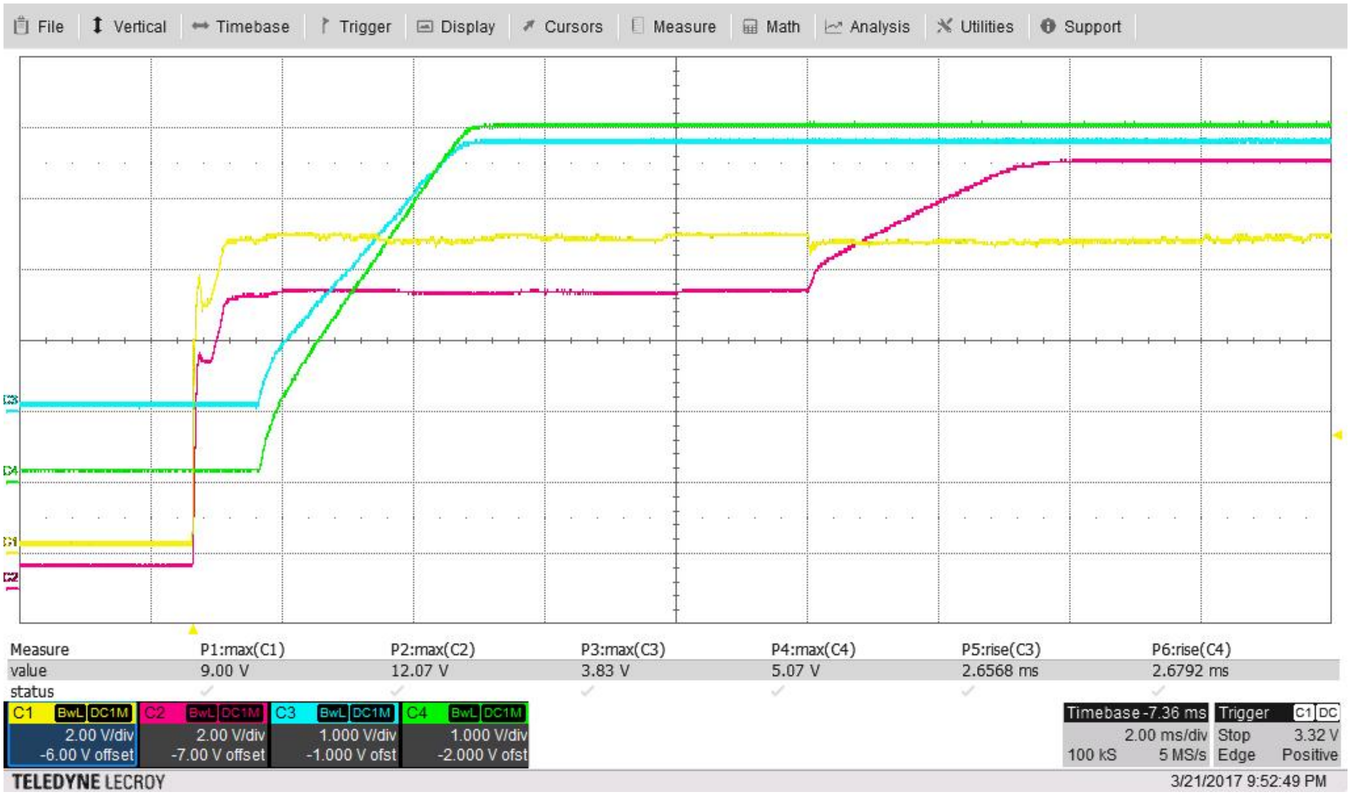

Figure 8. Start-up With Input at 9 V

Figure 9 and Figure 10 show start-up waveforms without soft-start at the boost with source input voltage (V_{IN}) at 6 V and at 9 V, respectively.

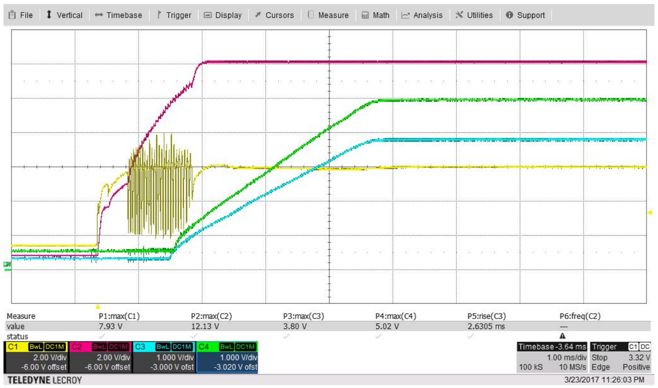

Figure 9. Start-up Without Boost Soft-Start With Input at 6 V

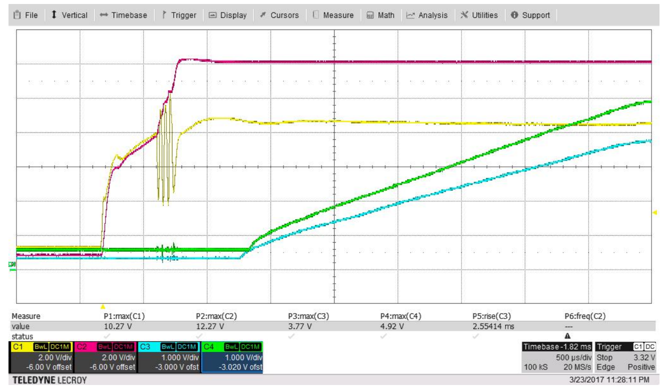

Figure 10. Start-up Without Boost Soft-Start With Input at 9 V

Figure 11 and Figure 12 show the in-rush current during start-up without soft-start at the boost with source input voltage (V_{IN}) at 9 V and at 15 V, respectively.

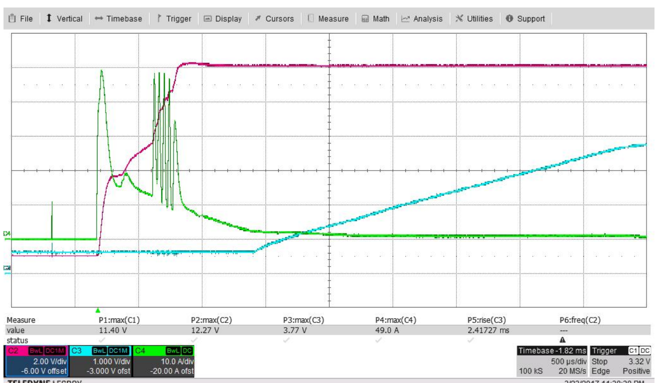

Figure 11. In-rush Current During Start-Up Without Boost Soft-Start With Input at 9 V

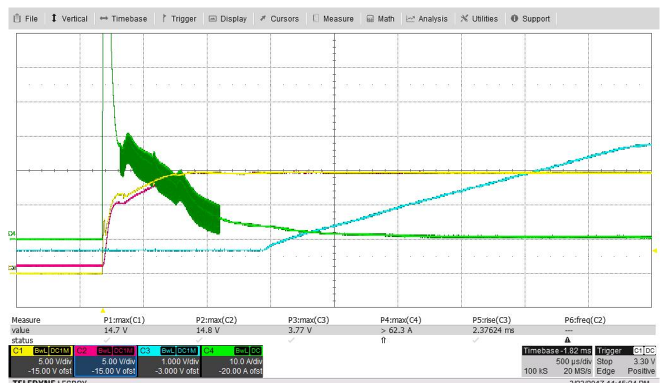

Figure 12. In-rush Current During Start-up Without Boost Soft-Start With Input at 15 V

3.2.2.2 Output Switch Nodes Waveforms

The following figures show the waveforms at the switch nodes at different levels of input voltage.

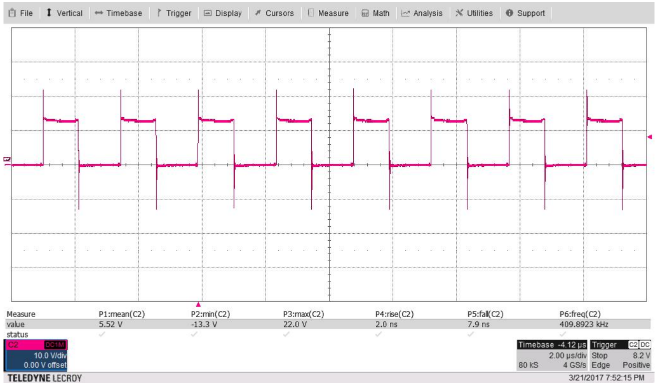

Figure 13. Boost 12-V Output Switch Node 1 (TP101) With Input at 6 V

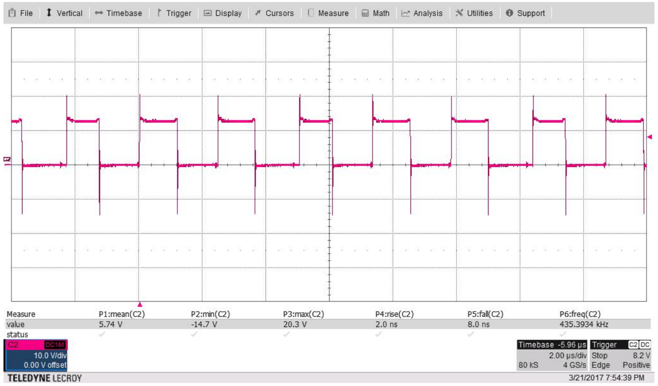

Figure 14. Boost 12-V Output Switch Node 2 (TP105) With Input at 6 V

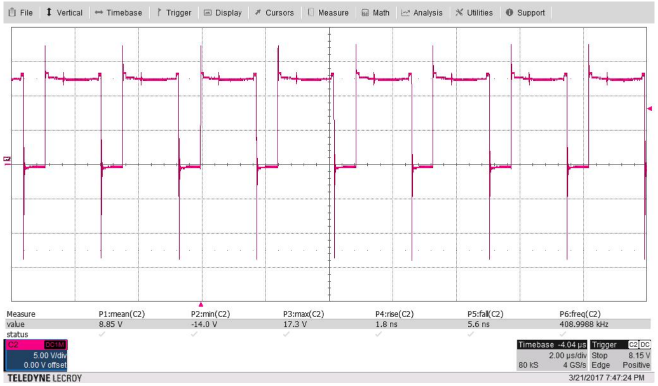

Figure 15. Boost 12-V Output Switch Node 1 (TP101) With Input at 9 V

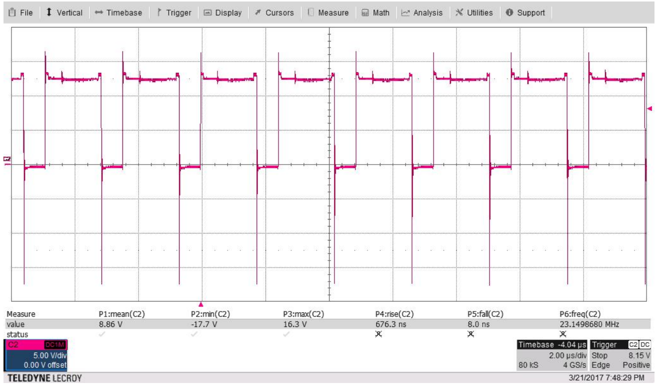

Figure 16. Boost 12-V Output Switch Node 2 (TP105) With Input at 9 V

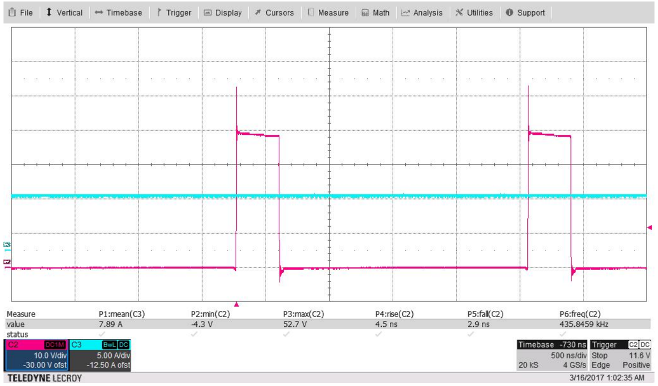

Figure 17. Buck 5-V Output Switch Node (TP5) With Input at 36 V and Output Current at 8 A

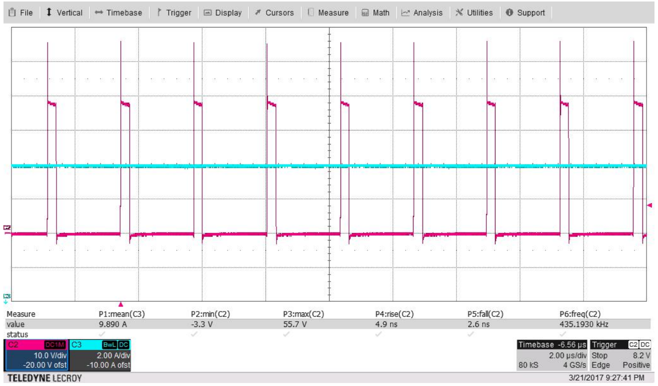

Figure 18. Buck 3.8-V Output Switch Node (TP4) With Input at 36 V and Output Current at 10 A

3.2.2.3 Output Ripple and Dynamic Load-step Waveforms

The following figures show the boost output ripple and response to dynamic current 50% load-step from 5-A half load to 10-A full load at different levels of input voltage.

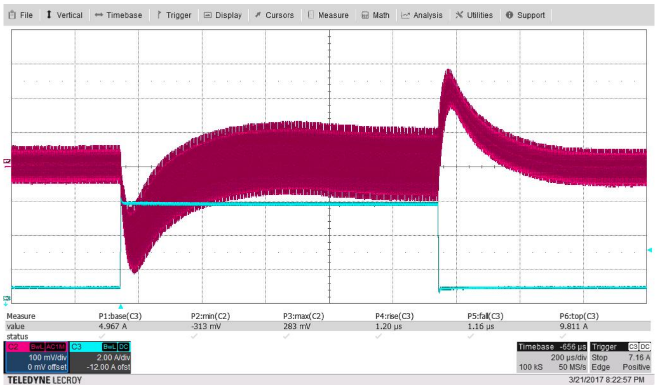

Figure 19. Boost 12-V Output With Load-Step From 5 A to 10 A With Input at 9 V

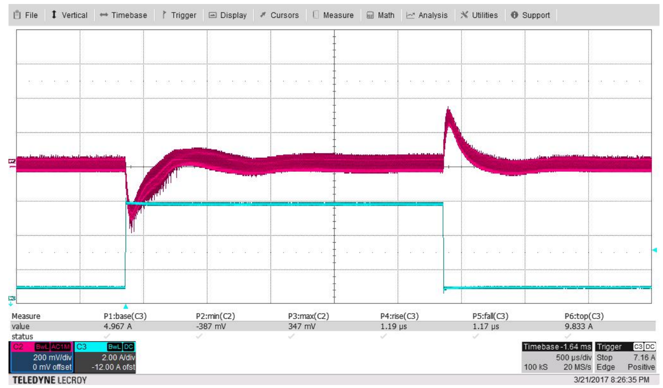

Figure 20. Boost 12-V Output With Load-Step From 5 A to 10 A With Input at 7 V

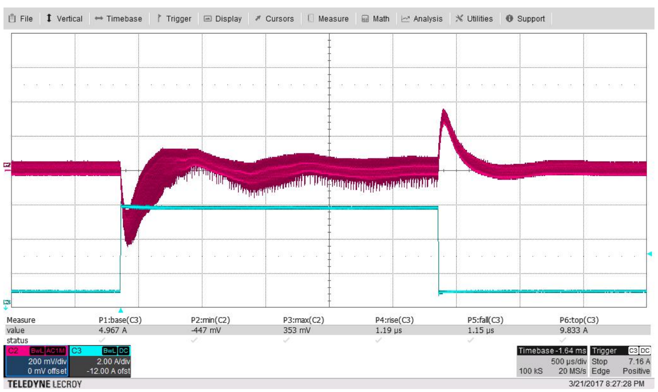

Figure 21. Boost 12-V Output With Load-Step From 5 A to 10 A With Input at 6.5 V

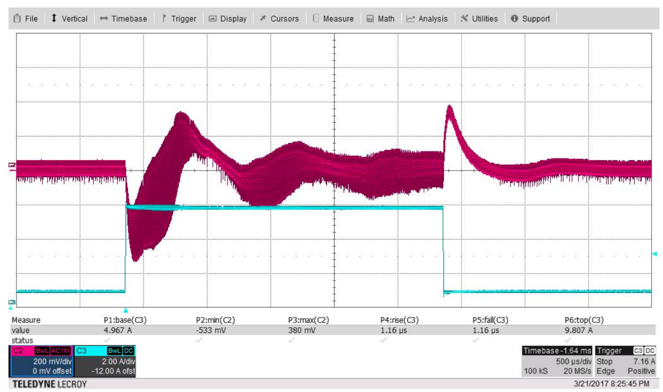

Figure 22. Boost 12-V Output With Load-Step From 5 A to 10 A With Input at 6 V

The following figures show the buck output ripple and response to dynamic current load-step from 3 A to 8 A (for 5-V output), and from 5 A to 10 A (for 3.8-V output), at different levels of input voltage:

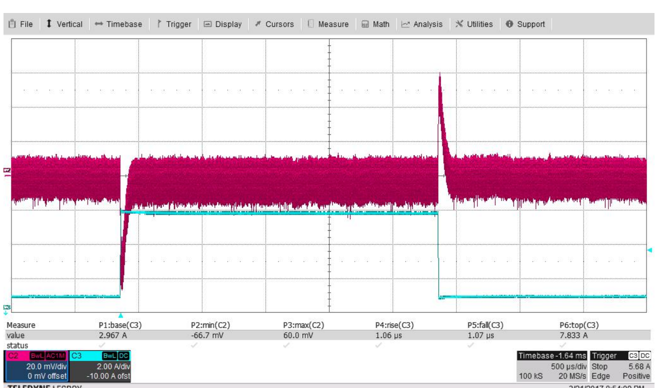

Figure 23. Buck 5-V Output With Load-Step From 3 A to 8 A With Input at 36 V

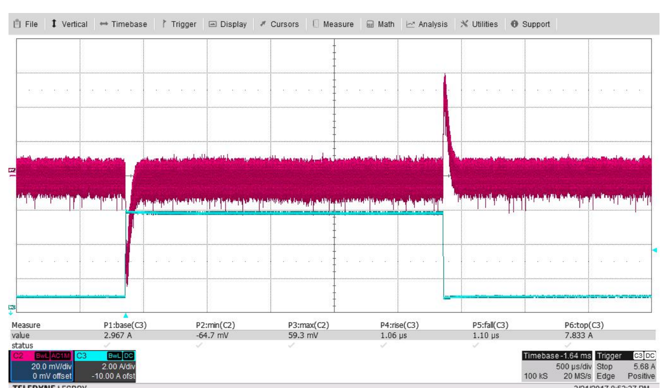

Figure 24. Buck 5-V Output With Load-Step From 3 A to 8 A With Input at 20 V

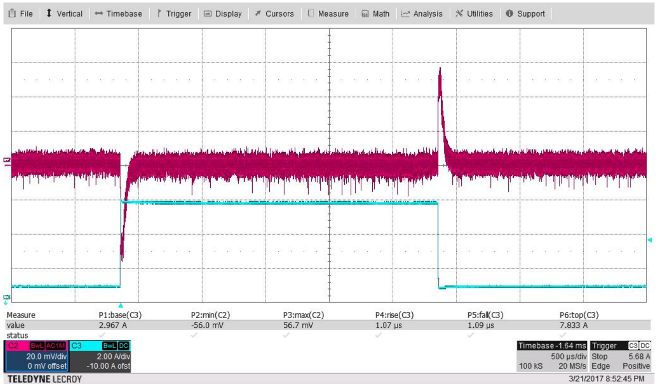

Figure 25. Buck 5-V Output With Load-Step From 3 A to 8 A With Input at 9 V

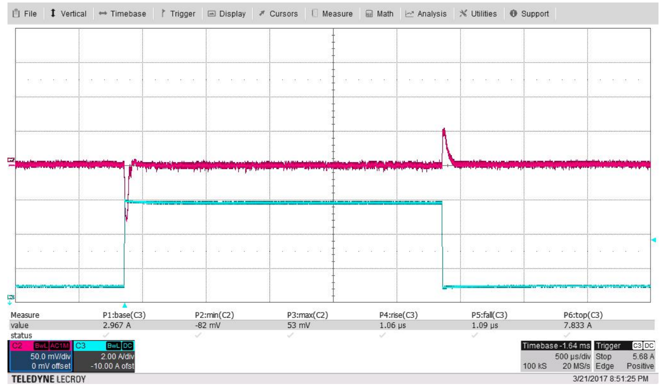

Figure 26. Buck 5-V Output With Load-Step From 3 A to 8 A With Input at 6.5 V

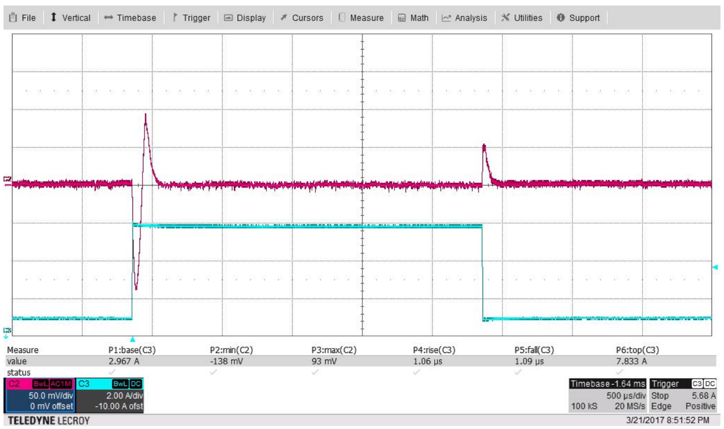

Figure 27. Buck 5-V Output With Load-Step From 3 A to 8 A With Input at 6 V

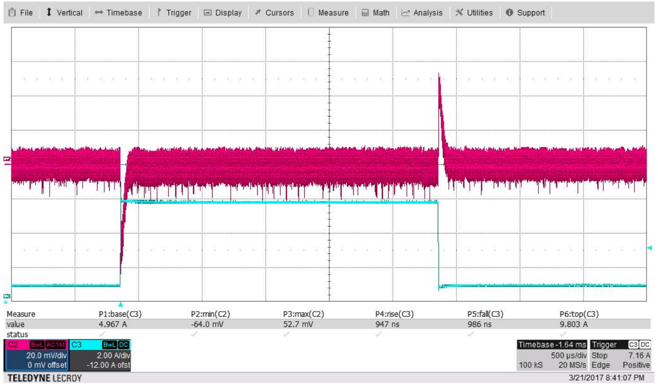

Figure 28. Buck 3.8-V Output With Load-Step From 5 A to 10 A With Input at 36 V

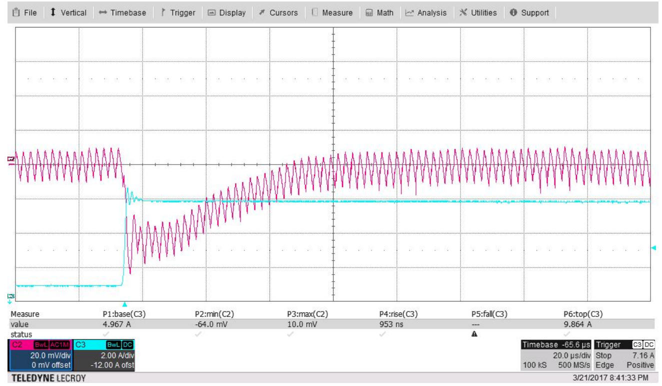

Figure 29. Buck 3.8-V Output With Load-Step From 5 A to 10 A With Input at 36 V (Zoomed)

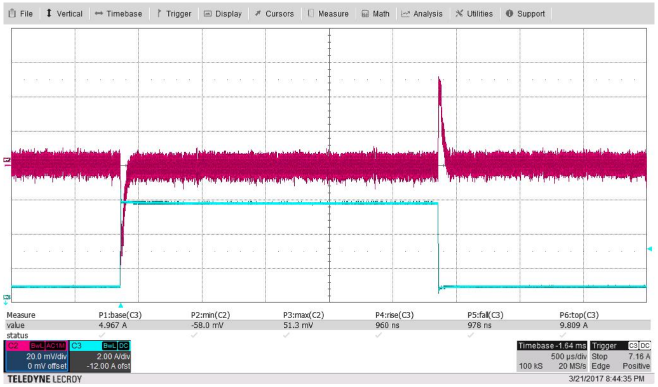

Figure 30. Buck 3.8-V Output With Load-Step From 5 A to 10 A With Input at 9 V

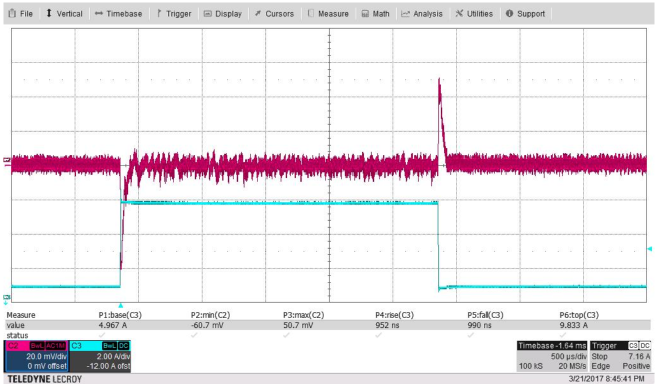

Figure 31. Buck 3.8-V Output With Load-Step From 5 A to 10 A With Input at 6 V

3.2.2.4 Efficiency Measurements

The efficiency of the 12-V outputs are measured at various input voltages, with the disabled buck controller circuit drawing less than 100 µA. At typical operating conditions, the efficiency is more than 95%.

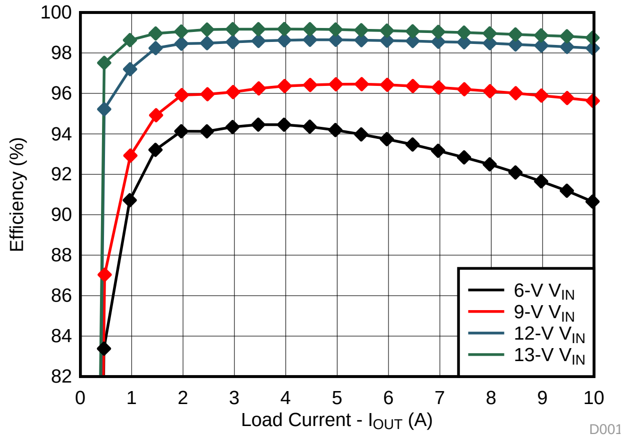

Figure 32. Boost 12-V Output Efficiency

Table 2. Boost 12-V Output Measurements With Input at 6 V

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)	P_{LOSS} (W)
5.999	0.179	12.065	0.000	0.000	1.071
5.999	1.113	12.065	0.461	83.378	1.110
5.999	2.134	12.065	0.963	90.717	1.188
5.999	3.157	12.066	1.463	93.208	1.286
5.999	4.198	12.064	1.965	94.126	1.480
5.999	5.265	12.061	2.465	94.122	1.856
5.999	6.315	12.060	2.964	94.339	2.145
5.999	7.375	12.059	3.465	94.457	2.452
5.999	8.442	12.059	3.967	94.452	2.810
5.999	9.519	12.059	4.468	94.353	3.225
5.999	10.601	12.059	4.967	94.186	3.698
5.999	11.695	12.059	5.468	93.974	4.228
5.999	12.796	12.059	5.968	93.739	4.807
5.999	13.908	12.059	6.468	93.473	5.446
5.999	15.032	12.059	6.967	93.164	6.165
5.999	16.177	12.059	7.471	92.833	6.955
5.999	17.322	12.060	7.970	92.489	7.806
5.999	18.490	12.060	8.471	92.092	8.772
5.999	19.680	12.061	8.972	91.653	9.855
5.999	20.882	12.061	9.472	91.188	11.039
5.999	22.118	12.062	9.973	90.650	12.407

Table 3. Boost 12-V Output Measurements With Input at 9 V

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)	P_{LOSS} (W)
9.000	0.092	12.068	0.000	0.000	0.825
9.000	0.730	12.068	0.474	87.035	0.852
9.000	1.406	12.068	0.975	92.924	0.896
9.000	2.084	12.068	1.475	94.919	0.953
9.000	2.761	12.068	1.975	95.919	1.014
9.000	3.458	12.066	2.475	95.961	1.257
9.000	4.151	12.063	2.975	96.067	1.469
9.000	4.836	12.062	3.473	96.246	1.634
9.000	5.531	12.061	3.977	96.364	1.810
9.000	6.220	12.061	4.475	96.417	2.006
9.000	6.915	12.061	4.977	96.450	2.209
9.000	7.609	12.061	5.477	96.459	2.425
9.000	8.305	12.061	5.976	96.426	2.671
9.000	9.005	12.061	6.475	96.366	2.945
9.000	9.708	12.060	6.976	96.293	3.239
9.000	10.414	12.060	7.476	96.204	3.558
9.000	11.120	12.061	7.976	96.113	3.890
9.000	11.832	12.061	8.477	96.011	4.248
9.000	12.547	12.061	8.978	95.891	4.640
9.000	13.262	12.061	9.477	95.772	5.047
9.000	13.982	12.061	9.978	95.633	5.495

Table 4. Boost 12-V Output Measurements With Input at 12 V

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)	P_{LOSS} (W)
11.999	0.016	12.068	0.000	0.000	0.191
11.999	0.492	12.068	0.465	95.219	0.282
11.999	1.001	12.068	0.968	97.194	0.337
11.999	1.501	12.068	1.467	98.239	0.317
11.999	2.010	12.068	1.968	98.458	0.372
11.999	2.520	12.068	2.468	98.484	0.459
11.999	3.030	12.068	2.969	98.541	0.530
11.999	3.539	12.068	3.469	98.594	0.597
11.999	4.049	12.068	3.971	98.630	0.666
11.999	4.559	12.068	4.472	98.650	0.738
11.999	5.069	12.069	4.972	98.651	0.820
11.999	5.580	12.068	5.473	98.632	0.916
11.999	6.090	12.068	5.971	98.610	1.016
11.999	6.602	12.068	6.471	98.589	1.117
11.999	7.114	12.069	6.971	98.551	1.237
11.999	7.628	12.069	7.473	98.530	1.345
11.999	8.143	12.069	7.973	98.486	1.479
11.999	8.659	12.068	8.473	98.422	1.639
11.999	9.177	12.068	8.976	98.368	1.797
11.999	9.695	12.068	9.475	98.300	1.978
11.999	10.214	12.068	9.976	98.237	2.160

Table 5. Boost 12-V Output Measurements With Input at 13 V

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)	P_{LOSS} (W)
13.004	0.011	12.972	0.000	0.000	0.138
13.004	0.475	12.968	0.465	97.509	0.154
13.004	0.976	12.963	0.966	98.634	0.173
13.004	1.476	12.958	1.466	98.964	0.199
13.004	1.977	12.952	1.966	99.059	0.242
13.004	2.477	12.947	2.467	99.156	0.272
13.004	2.977	12.942	2.967	99.177	0.319
13.004	3.478	12.936	3.467	99.176	0.373
13.004	3.981	12.931	3.971	99.182	0.423
13.004	4.481	12.926	4.471	99.177	0.480
13.004	4.979	12.920	4.969	99.161	0.544
13.004	5.481	12.915	5.470	99.127	0.622
13.004	5.980	12.909	5.970	99.106	0.696
13.004	6.481	12.904	6.470	99.070	0.784
13.004	6.979	12.899	6.969	99.044	0.867
13.004	7.480	12.893	7.470	99.008	0.965
13.004	7.981	12.887	7.970	98.969	1.070
13.004	8.481	12.879	8.471	98.917	1.194
13.004	8.982	12.872	8.972	98.871	1.319
13.004	9.483	12.864	9.474	98.824	1.450
13.004	9.985	12.856	9.974	98.753	1.620

The efficiency of the 5-V output is measured with no load at the 3.8-V output. The estimated 22 mA of input current drawn by the 3.8-V circuit with the input at 13 V (or 23 mA with the input at 20 V), and 11 mA by the boost circuit, are subtracted in the calculations. At typical operating conditions, the efficiency is more than 90%.

Similarly, the efficiency of the 3.8-V output is measured with no load at the 5-V output. The estimated 26 mA of input current drawn by the 5-V circuit with the input at 13 V (or 27 mA with the input at 20 V), and 11 mA by the boost circuit, are subtracted in the calculations. At typical operating conditions, the efficiency is more than 90%.

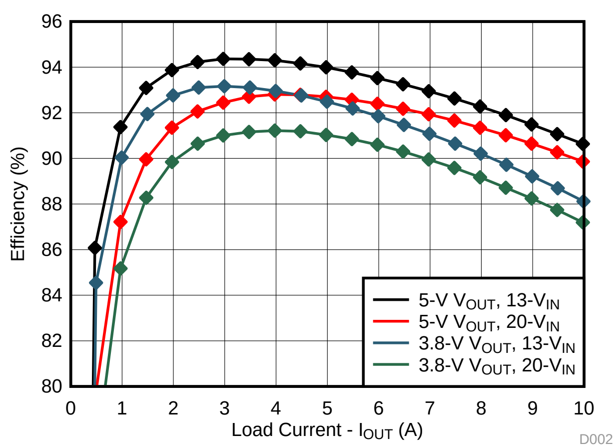

Figure 33. Buck 5-V and 3.8-V Output Efficiency

Table 6. Buck 5-V Output Measurements With Input at 13 V

V_{IN} (V)	I_{IN} (A)		V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)	P_{LOSS} (W)
	MEASURED	CORRECTED				
13.004	0.059	0.026	5.035	0.000	0.000	0.341
13.004	0.244	0.211	5.035	0.469	86.074	0.382
13.004	0.444	0.411	5.035	0.969	91.376	0.460
13.004	0.644	0.611	5.034	1.470	93.091	0.549
13.004	0.846	0.813	5.034	1.972	93.875	0.648
13.004	1.049	1.016	5.034	2.472	94.225	0.763
13.004	1.252	1.219	5.034	2.972	94.363	0.894
13.004	1.457	1.424	5.034	3.472	94.350	1.047
13.004	1.665	1.632	5.034	3.975	94.304	1.209
13.004	1.872	1.839	5.034	4.474	94.163	1.396
13.004	2.082	2.049	5.034	4.975	93.993	1.600
13.004	2.293	2.260	5.034	5.476	93.774	1.830
13.004	2.506	2.473	5.034	5.974	93.522	2.083
13.004	2.720	2.687	5.033	6.474	93.251	2.358
13.004	2.937	2.904	5.033	6.975	92.948	2.664
13.004	3.157	3.124	5.033	7.476	92.628	2.995
13.004	3.378	3.345	5.033	7.975	92.276	3.360
13.004	3.603	3.570	5.033	8.477	91.897	3.762
13.004	3.831	3.798	5.033	8.978	91.490	4.203
13.004	4.061	4.028	5.033	9.477	91.065	4.680
13.004	4.294	4.261	5.033	9.978	90.634	5.189

Table 7. Buck 5-V Output Measurements With Input at 20 V

V_{IN} (V)	I_{IN} (A)		V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)	P_{LOSS} (W)
	MEASURED	CORRECTED				
20.499	0.061	0.027	5.035	0.000	0.000	0.557
20.494	0.179	0.145	5.035	0.469	79.431	0.611
20.489	0.307	0.273	5.035	0.970	87.216	0.716
20.301	0.439	0.405	5.035	1.470	89.959	0.826
19.993	0.577	0.543	5.035	1.971	91.349	0.940
19.993	0.710	0.676	5.035	2.471	92.061	1.073
19.993	0.843	0.809	5.034	2.971	92.446	1.222
19.993	0.977	0.943	5.034	3.472	92.706	1.375
19.993	1.112	1.078	5.034	3.974	92.804	1.551
19.993	1.248	1.214	5.034	4.474	92.789	1.750
19.993	1.385	1.351	5.034	4.974	92.701	1.972
19.993	1.523	1.489	5.034	5.476	92.574	2.211
19.993	1.662	1.628	5.034	5.975	92.394	2.476
19.992	1.803	1.769	5.034	6.475	92.177	2.766
19.992	1.944	1.910	5.034	6.973	91.935	3.079
19.992	2.087	2.053	5.034	7.475	91.660	3.424
19.992	2.232	2.198	5.033	7.975	91.343	3.804
19.992	2.379	2.345	5.033	8.476	91.015	4.212
19.992	2.528	2.494	5.033	8.978	90.649	4.662
19.992	2.677	2.643	5.033	9.477	90.270	5.142
19.992	2.830	2.796	5.033	9.978	89.858	5.668

Table 8. Buck 3.8-V Output Measurements With Input at 13 V

V_{IN} (V)	I_{IN} (A)		V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)	P_{LOSS} (W)
	MEASURED	CORRECTED				
13.333	0.059	0.022	3.821	0.000	0.000	0.294
13.327	0.204	0.167	3.820	0.493	84.545	0.344
13.321	0.353	0.316	3.820	0.993	90.039	0.420
13.314	0.503	0.466	3.820	1.493	91.946	0.500
13.308	0.654	0.617	3.820	1.994	92.763	0.594
13.301	0.806	0.769	3.820	2.493	93.107	0.705
13.295	0.960	0.923	3.820	2.992	93.165	0.838
13.288	1.115	1.078	3.820	3.491	93.107	0.987
13.282	1.272	1.235	3.820	3.994	92.957	1.156
13.275	1.430	1.393	3.819	4.493	92.758	1.340
13.268	1.591	1.554	3.819	4.992	92.486	1.549
13.261	1.753	1.716	3.819	5.493	92.191	1.777
13.254	1.916	1.879	3.819	5.991	91.852	2.030
13.247	2.083	2.046	3.819	6.491	91.468	2.312
13.240	2.250	2.213	3.819	6.989	91.079	2.614
13.233	2.421	2.384	3.819	7.489	90.648	2.950
13.226	2.593	2.556	3.818	7.987	90.208	3.311
13.218	2.770	2.733	3.818	8.488	89.721	3.713
13.211	2.949	2.912	3.818	8.990	89.215	4.149
13.203	3.131	3.094	3.818	9.489	88.692	4.619
13.195	3.317	3.280	3.818	9.989	88.116	5.143

Table 9. Buck 3.8-V Output Measurements With Input at 20 V

V_{IN} (V)	I_{IN} (A)		V_{OUT} (V)	I_{OUT} (A)	EFFICIENCY (%)	P_{LOSS} (W)
	MEASURED	CORRECTED				
20.499	0.061	0.023	3.821	0.000	0.000	0.475
20.495	0.152	0.114	3.821	0.469	76.528	0.550
20.491	0.250	0.212	3.820	0.970	85.172	0.645
20.487	0.349	0.311	3.820	1.471	88.275	0.746
20.483	0.447	0.409	3.820	1.973	89.843	0.852
20.478	0.547	0.509	3.820	2.473	90.645	0.975
20.474	0.647	0.609	3.820	2.972	91.006	1.122
20.470	0.749	0.711	3.820	3.473	91.161	1.286
20.465	0.851	0.813	3.820	3.975	91.220	1.461
20.461	0.954	0.916	3.819	4.475	91.189	1.651
20.456	1.058	1.020	3.819	4.975	91.030	1.872
20.452	1.164	1.126	3.819	5.477	90.848	2.107
20.447	1.270	1.232	3.819	5.975	90.597	2.368
20.443	1.378	1.340	3.819	6.476	90.300	2.656
20.438	1.487	1.449	3.819	6.974	89.955	2.974
20.433	1.597	1.559	3.819	7.475	89.583	3.319
20.428	1.710	1.672	3.818	7.975	89.171	3.698
20.423	1.824	1.786	3.818	8.476	88.714	4.117
20.418	1.941	1.903	3.818	8.979	88.244	4.567
20.413	2.058	2.020	3.818	9.477	87.741	5.056
20.408	2.179	2.141	3.818	9.977	87.193	5.595

3.2.2.5 Bode Plots

The following figures show the bode plots of the design.

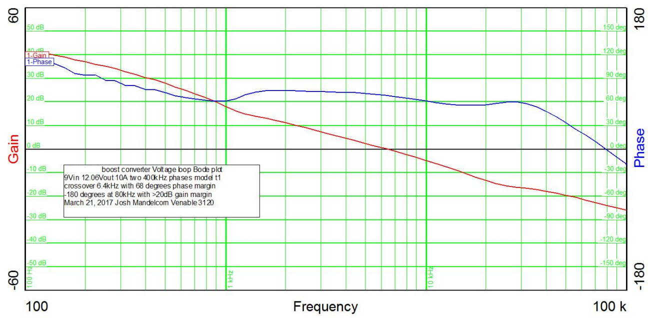

Figure 34. Boost 12-V Output Bode Plot With Input at 9 V and Output Current at 10 A

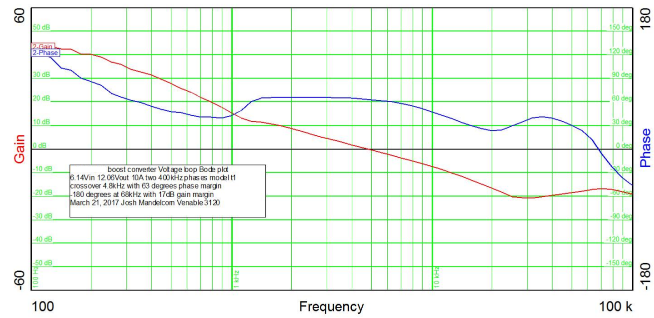

Figure 35. Boost 12-V Output Bode Plot With Input at 6 V and Output Current at 10 A

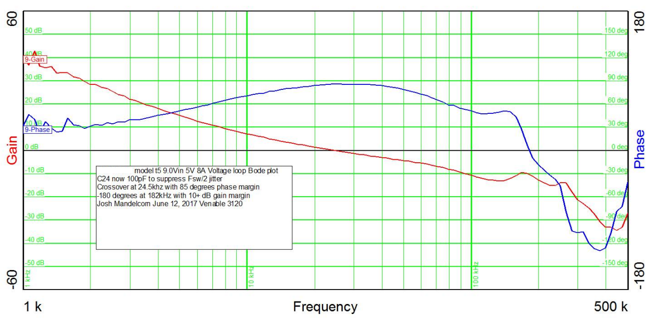

Figure 36. Buck 5-V Output Bode Plot With Input at 9 V and Output Current at 8 A

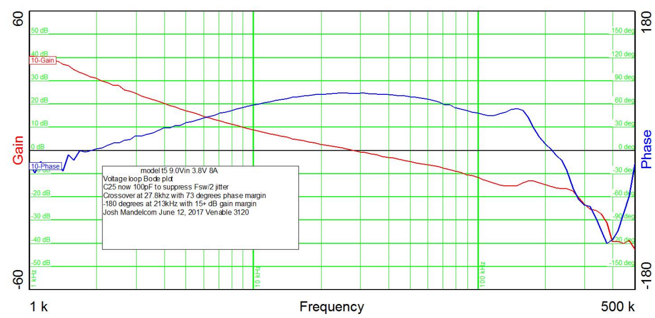

Figure 37. Buck 3.8-V Output Bode Plot With Input at 9 V and Output Current at 8 A

3.2.2.6 Thermal Measurements

The temperature of the dual LM25122-Q1 boost controllers is measured at steady state input voltage of 9 V, at the ambient temperature of 25°C. One measurement is done with a combined load of 7 A in free air, and the other is done with a combined load of 10 A with airflow of 2 m/s. The temperature of the hottest LM25122-Q1 is 72°C and 61.3°C, respectively, as shown in Figure 38 and Figure 39.

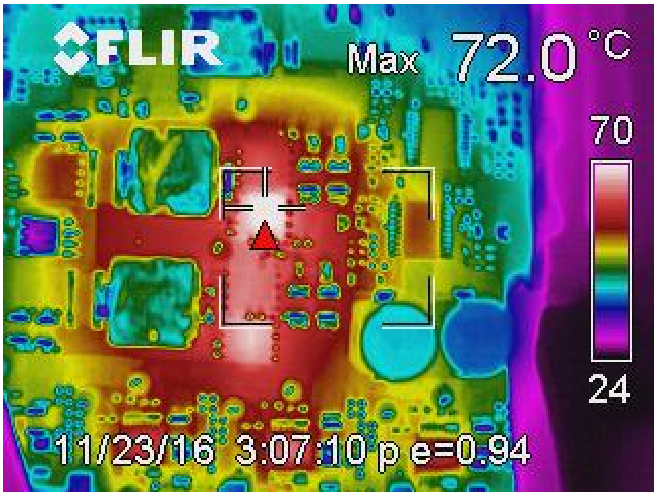

Figure 38. Thermal Measurement of LM25122-Q1 With Output at 7 A

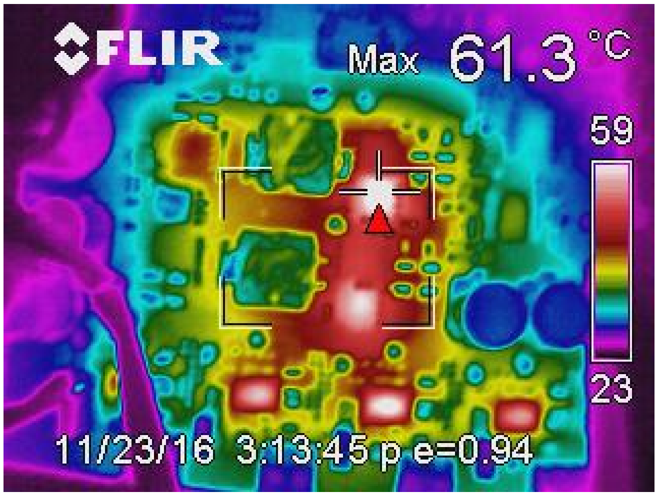

Figure 39. Thermal Measurement of LM25122-Q1 With Output at 10 A

The temperature of the LM5140-Q1 buck controller is measured at steady state input voltage of 20 V, at the ambient temperature of 25°C. The 5-V output is connected to a 5-A load, and the 3.8-V output is connected to a 6.5-A load. Both measurements are taken in free air. The temperature of the LM5140-Q1 is 56.4°C and 66.5°C, respectively, as shown in Figure 40 and Figure 41.

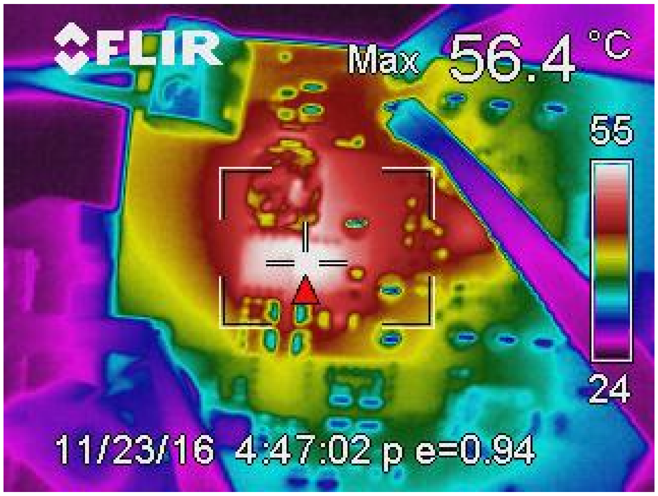

Figure 40. Thermal Measurement of LM5140-Q1 With 5-V Output at 5 A

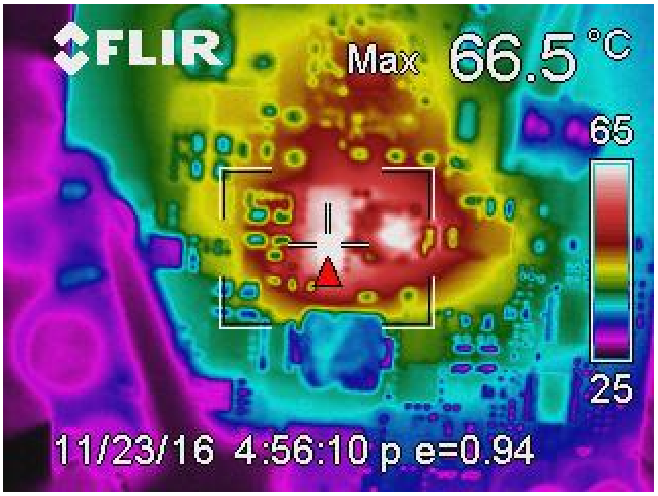

Figure 41. Thermal Measurement of LM5140-Q1 With 3.8-V Output at 6.5 A

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01534.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01534.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01534.

4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01534.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01534.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01534.

5 Related Documentation

1. Texas Instruments, *AN-1889 How to Measure the Loop Transfer Function of Power Supplies*

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