Test Report: PMP31073

1.44-kW, Six-Phase Interleaved Boost Converter Reference Design

Description

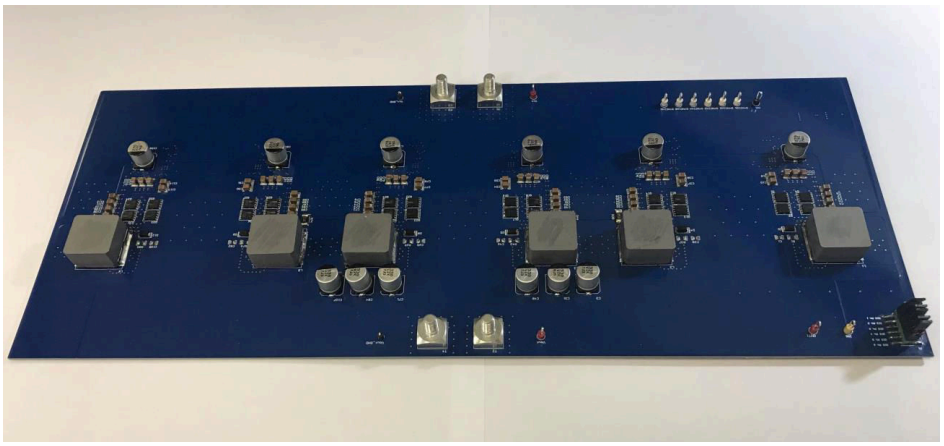
This reference design showcases an interleaved boost converter controlled by the LM5122-Q1 device, operating from a 9.0-V to 16.0-V input voltage range, generating an output voltage of 24.0 V with a maximum load current of 60.0 A (10.0 A per phase).

Features

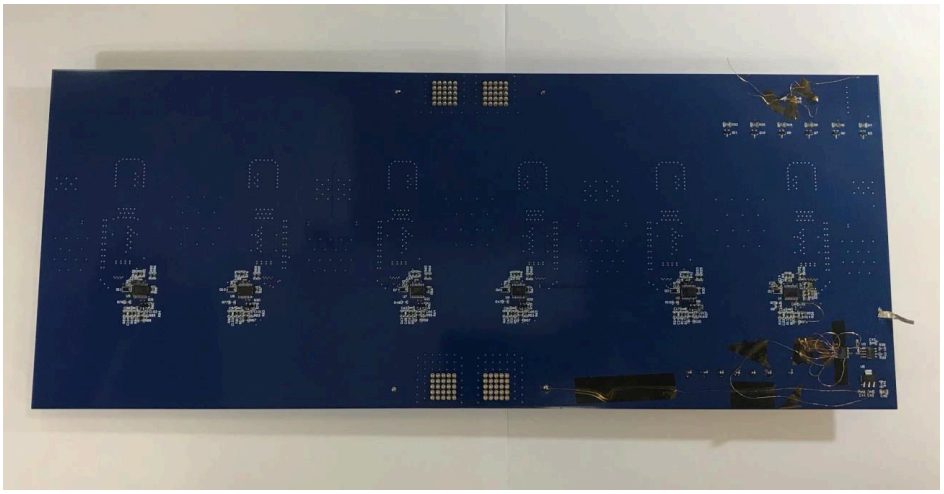
- Input voltage range: 9.0 V to 16.0 V
- Output voltage range: 24.0 V
- Output current: 60.0 A
- Modular design which enables easy modification for higher and lower output power by removing or adding phases

Applications

- Aftermarket audio amplifier



Top View



Bottom View

1 Test Prerequisites

The DC source must provide at least 170 A.

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
V_{IN}	9.0 V to 16.0 V
V_{OUT}	24.0 V
I_{OUT}	60.0 A
Effective switching frequency	1.2 MHz (200 kHz per phase)

1.2 Considerations

Connect the lab power supply to the PCB with very short cables (less than 30 cm) to avoid resonances between the output of the lab power supply and the input circuit on the PCB, which can influence the look and results of the frequency analysis.

1.3 Dimensions

PCB: 43.0 cm × 16.2 cm

2 Testing and Results

2.1 Efficiency Graphs

Efficiency and losses are shown in the following figure.

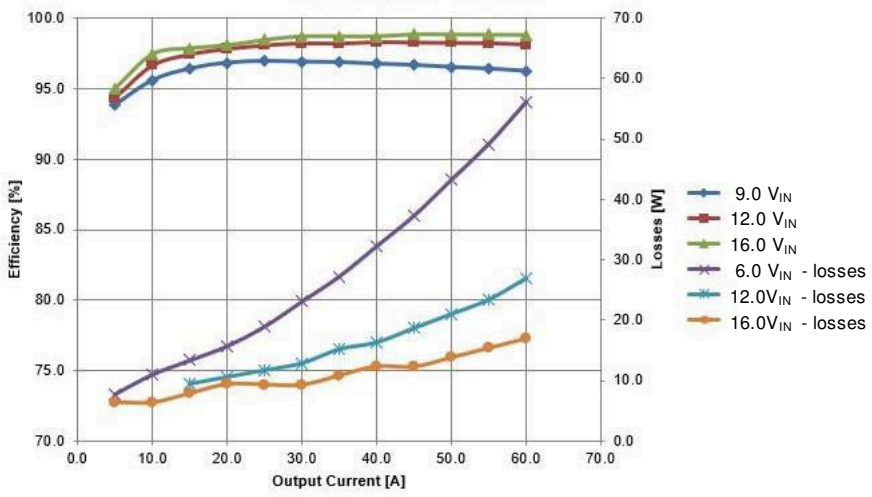


Figure 2-1. Efficiency and Losses Graphs at 9.0 V_{IN}, 12.0 V_{IN} and 16.0 V_{IN}

2.2 Efficiency Data

Table 2-1, Table 2-2, and Table 2-3 detail the efficiency data.

Table 2-1. Efficiency Data at 9.0 V_{IN}

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
9.001	166.300	24.015	59.998	1496.866	1440.852	56.014	96.3
9.001	152.200	24.016	54.998	1369.952	1320.832	49.120	96.4
9.001	138.200	24.016	49.998	1243.938	1200.752	43.186	96.5
9.001	124.200	24.016	44.998	1117.924	1080.672	37.252	96.7
9.001	110.300	24.016	39.998	992.810	960.592	32.218	96.8
9.001	96.400	24.015	34.998	867.696	840.477	27.219	96.9
9.001	82.600	24.015	29.998	743.483	720.402	23.081	96.9
9.001	68.800	24.015	24.998	619.269	600.327	18.942	96.9
9.001	55.100	24.014	19.998	495.955	480.232	15.723	96.8
9.001	41.500	24.014	14.998	373.542	360.162	13.380	96.4
9.001	27.900	24.014	9.998	251.128	240.092	11.036	95.6
9.001	14.200	24.014	4.998	127.814	120.022	7.792	93.9

Table 2-2. Efficiency Data at 12.0 V_{IN}

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
12.000	122.300	24.011	59.998	1467.600	1440.612	26.988	98.2
12.000	112.000	24.011	54.998	1344.000	1320.557	23.443	98.3
12.000	101.800	24.012	49.998	1221.600	1200.552	21.048	98.3
12.000	91.600	24.012	44.998	1099.200	1080.492	18.708	98.3
12.000	81.400	24.013	39.998	976.800	960.472	16.328	98.3
12.000	71.300	24.013	34.998	855.600	840.407	15.193	98.2
12.000	61.100	24.013	29.998	733.200	720.342	12.858	98.2
12.000	51.000	24.014	24.998	612.000	600.302	11.698	98.1
12.000	40.900	24.014	19.998	490.800	480.232	10.568	97.8
12.000	30.800	24.014	14.998	369.600	360.162	9.438	97.4
12.000	20.700	24.014	9.998	248.400	240.092	8.308	96.7
12.000	10.600	24.015	4.998	127.200	120.027	7.173	94.4

Table 2-3. Efficiency Data at 16.0 V_{IN}

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT}(W)	P_{LOSS}(W)	Efficiency (%)
16.000	91.100	24.010	59.998	1457.600	1440.552	17.048	98.8
16.000	83.500	24.011	54.998	1336.000	1320.557	15.443	98.8
16.000	75.900	24.012	49.998	1214.400	1200.552	13.848	98.9
16.000	68.300	24.012	44.998	1092.800	1080.492	12.308	98.9
16.000	60.800	24.012	39.998	972.800	960.432	12.368	98.7
16.000	53.200	24.012	34.998	851.200	840.372	10.828	98.7
16.000	45.600	24.013	29.998	729.600	720.342	9.258	98.7
16.000	38.100	24.013	24.998	609.600	600.277	9.323	98.5
16.000	30.600	24.013	19.998	489.600	480.212	9.388	98.1

Table 2-3. Efficiency Data at 16.0 V_{IN} (continued)

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT}(W)	P_{LOSS}(W)	Efficiency (%)
16.000	23.000	24.014	14.998	368.000	360.162	7.838	97.9
16.000	15.400	24.014	9.998	246.400	240.092	6.308	97.4
16.000	7.900	24.015	4.998	126.400	120.027	6.373	95.0

2.3 Thermal Image

Figure 2-2 shows the thermal image of the top side of the PCB, taken at room temperature, 12.0 V_{IN} and 60.0-A load current.

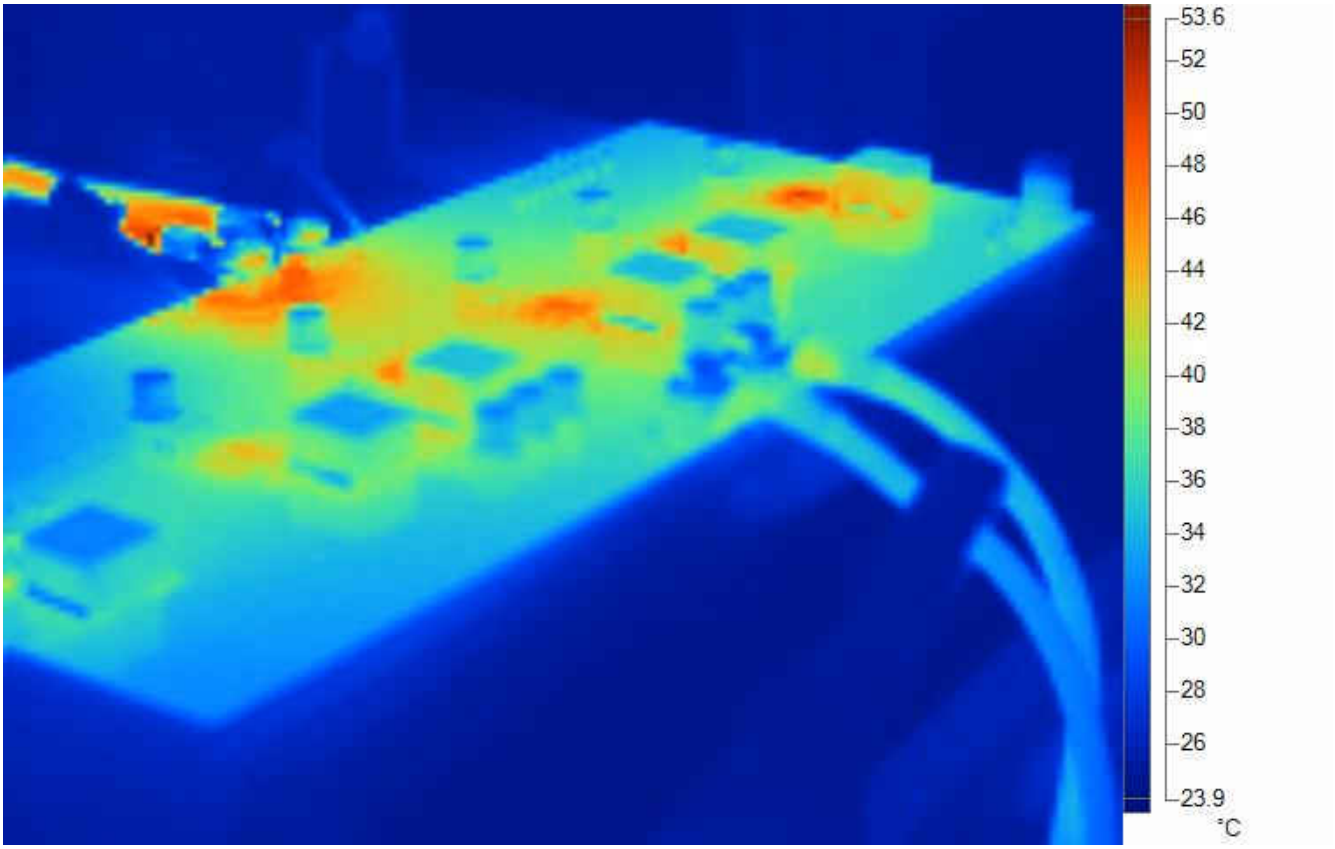
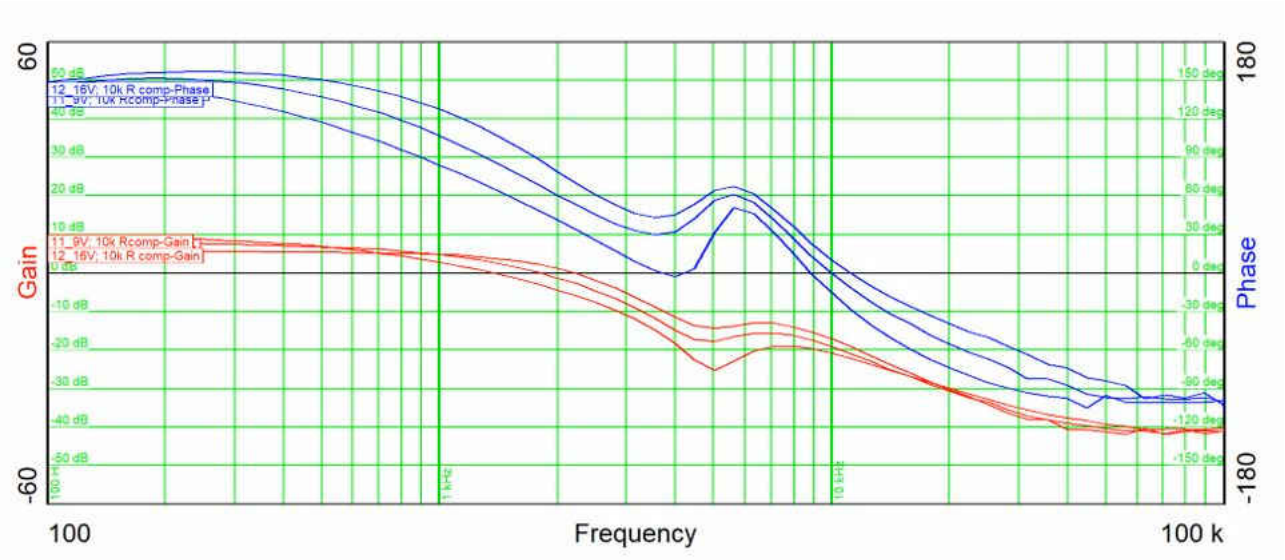


Figure 2-2. Thermal Image

2.4 Bode Plot

Figure 2-3 shows the Bode plot.



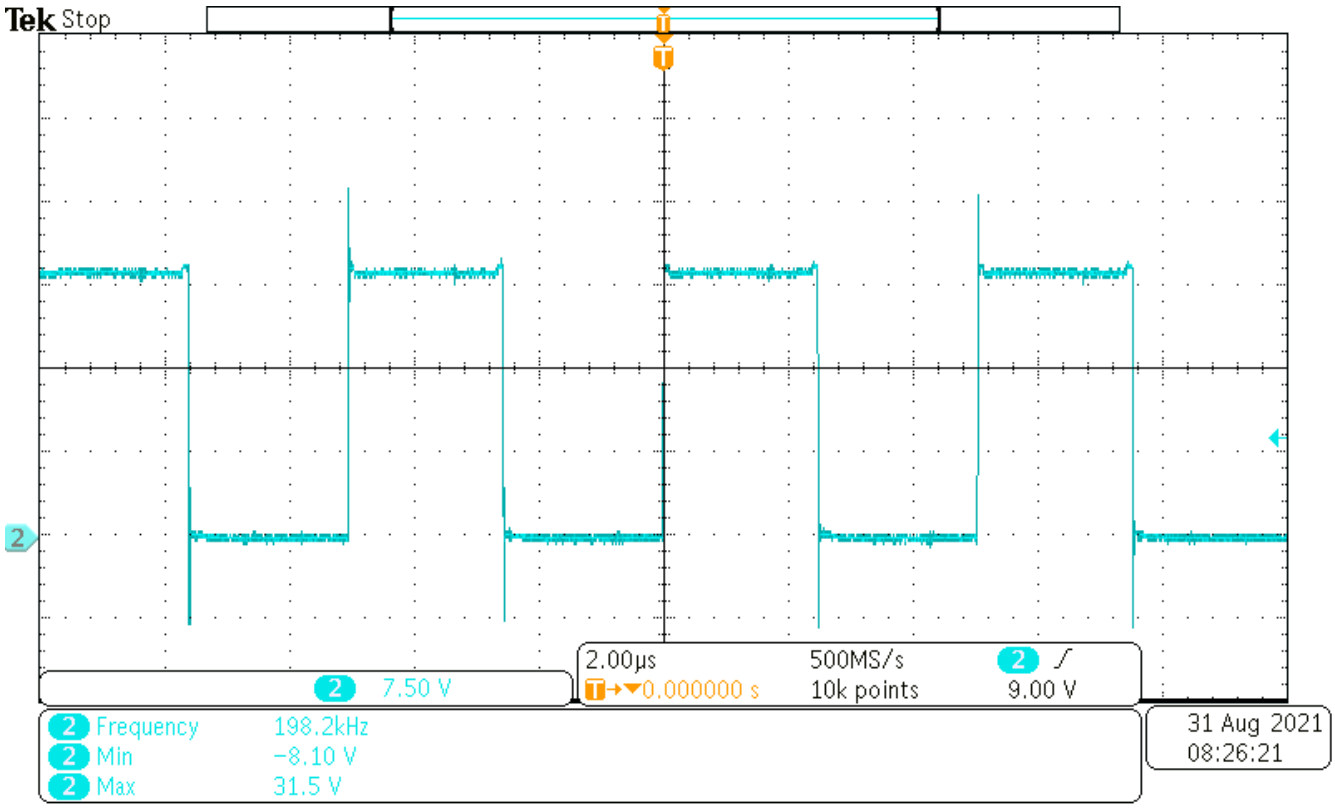
9.0 V_{IN}, 60.0-A load current: fco 1.36 kHz, 66.1-deg phase margin, –15.81-dB gain margin
12.0 V_{IN}, 60.0-A load current: fco 1.802 kHz, 67.88-deg phase margin, –19.1-dB gain margin
16.0 V_{IN}, 60.0-A load current: fco 2.19 kHz, 71.37-deg phase margin, –19.1-dB gain margin

Figure 2-3. Bode Plot

3 Waveforms

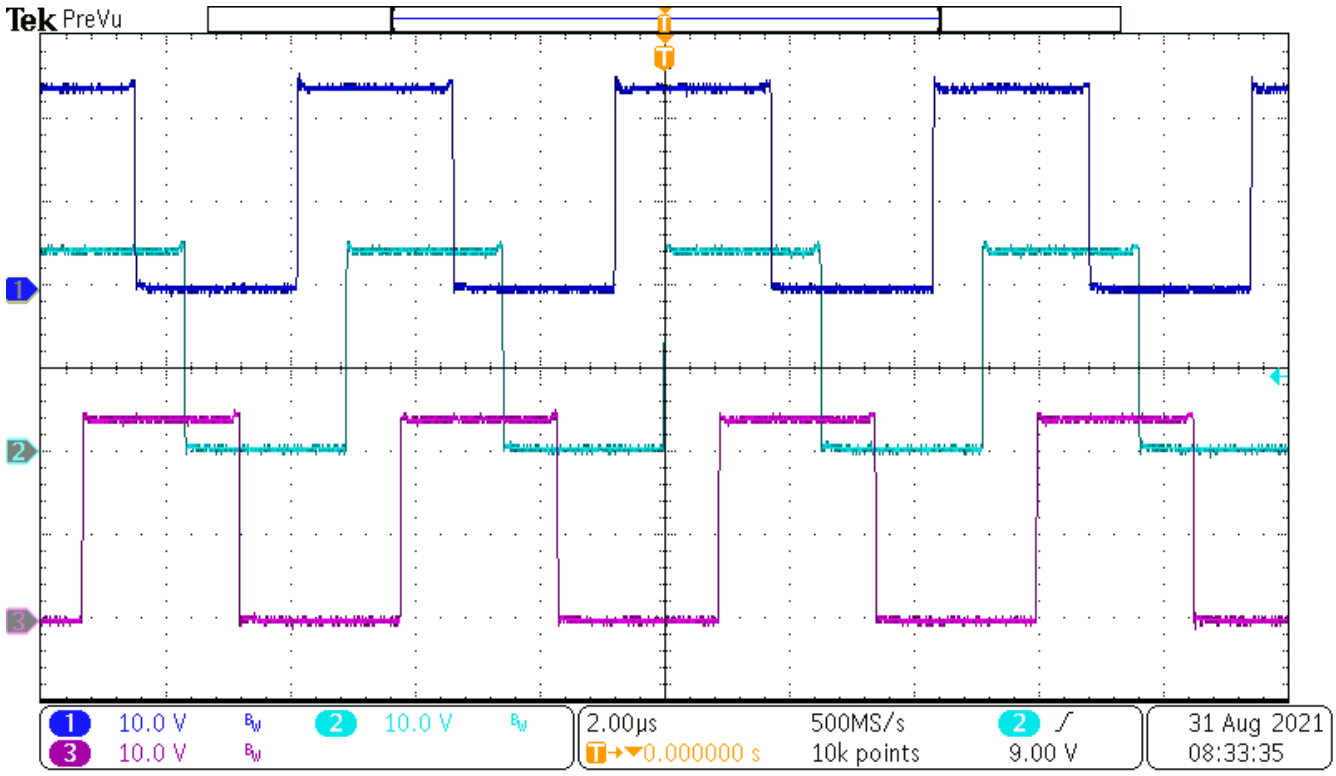
3.1 Switching

Switching behavior is shown in Figure 3-1 and Figure 3-2.



Ch2: Switching node at 12.0 V_{IN} and 60.0-A load current [scale: 7.50 V/div, 2.0 µs/div], phase 4

Figure 3-1. Switching Single Phase

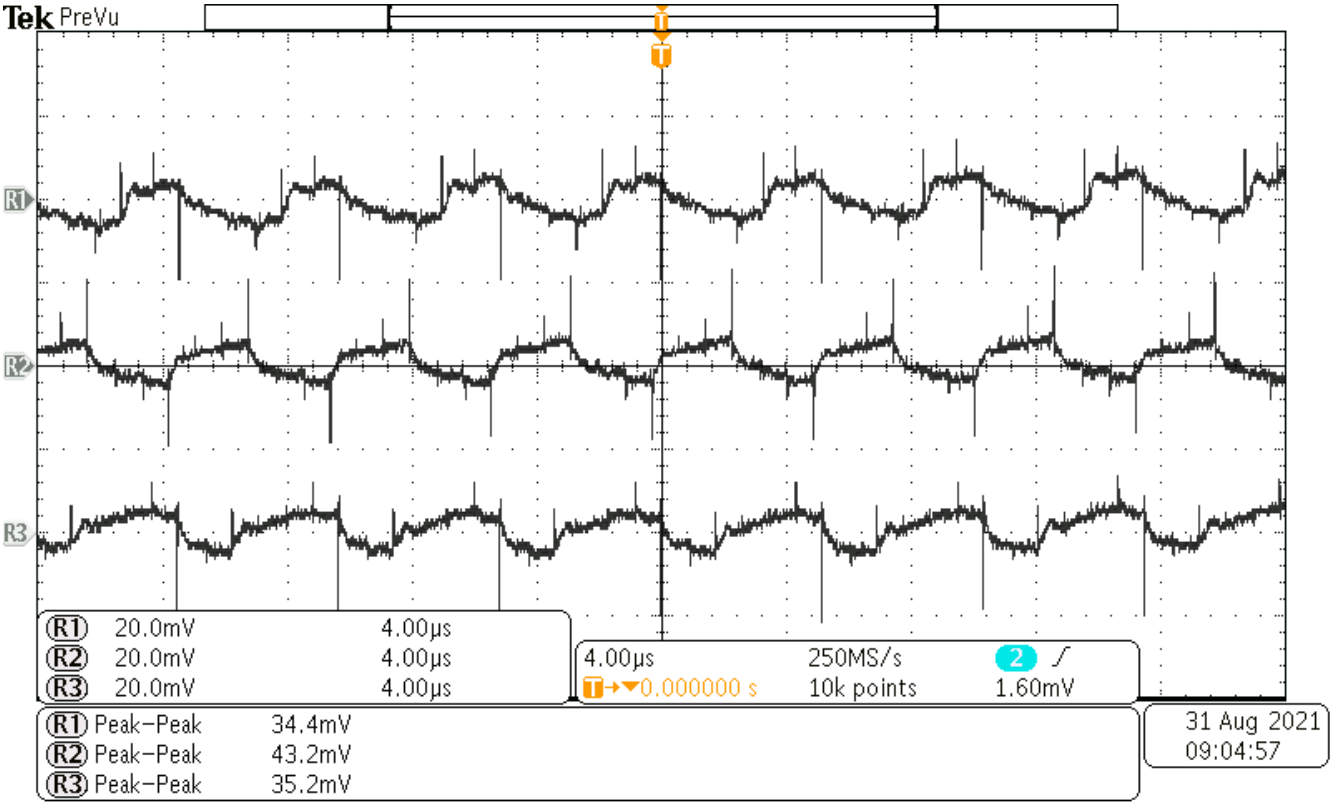


Ch1: Switching node at 12.0 V_{IN} and 60.0-A load current [scale: 10.0 V/div, 2.0 µs/div], phase 1
Ch2: Switching node at 12.0 V_{IN} and 60.0-A load current [scale: 10.0 V/div, 2.0 µs/div], phase 2
Ch3: Switching node at 12.0 V_{IN} and 60.0-A load current [scale: 10.0 V/div, 2.0 µs/div], phase 3

Figure 3-2. Switching Multiple Phases

3.2 Input Voltage Ripple

Figure 3-3 shows the input voltage ripple at 9.0 V, 12.0 V, and 16.0 V for a load current of 60.0 A.

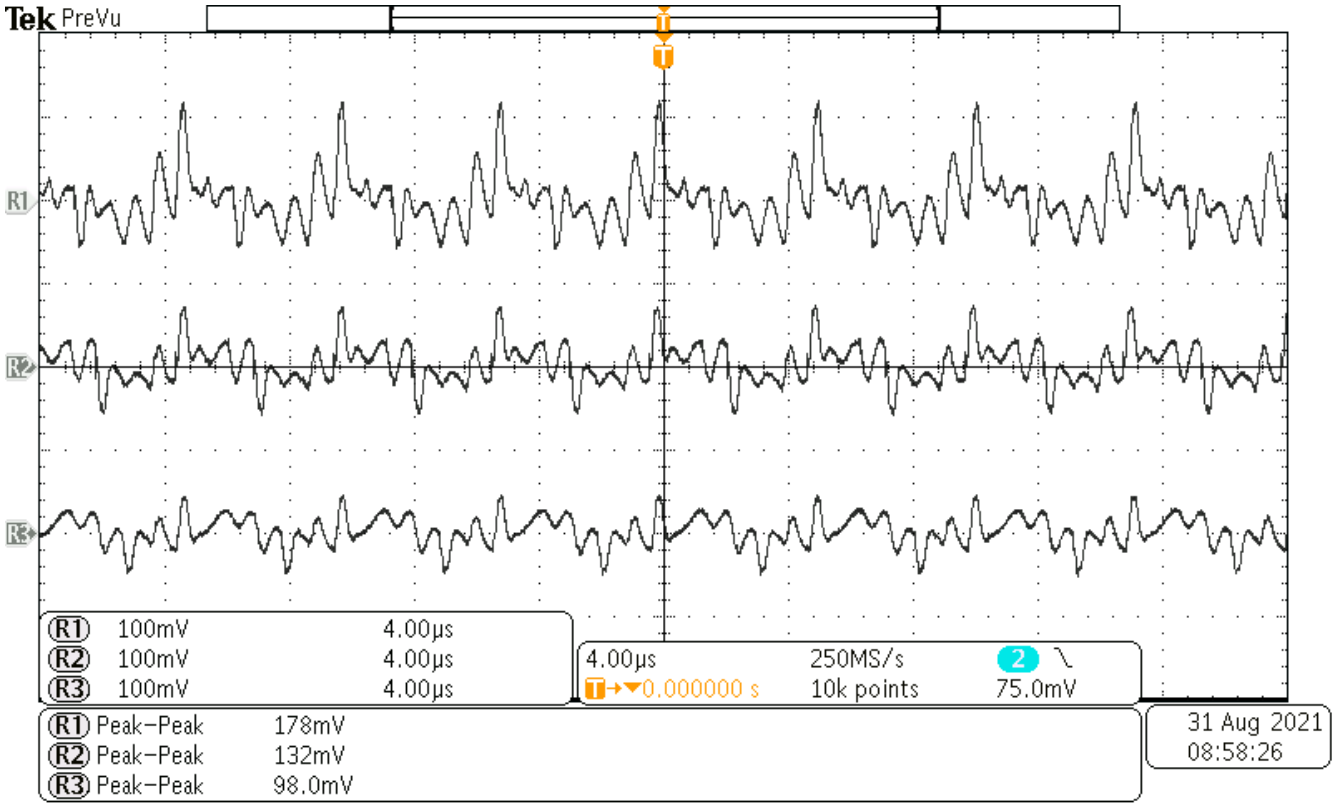


R1: 9.0 V_{IN}, 60.0-A load, 34.4-mV peak-peak-ripple [scale: 20 mV/div, 4.0 µs/div]
R2: 12.0 V_{IN}, 60.0-A load, 43.2-mV peak-peak-ripple [scale: 20 mV/div, 4.0 µs/div]
R3: 16.0 V_{IN}, 60.0-A load, 35.2-mV peak-peak-ripple [scale: 20 mV/div, 4.0 µs/div]

Figure 3-3. Input Voltage Ripple

3.3 Output Voltage Ripple

Figure 3-4 shows the output voltage ripple at 9.0 V, 12.0 V, and 16.0 V for a load current of 60.0 A.

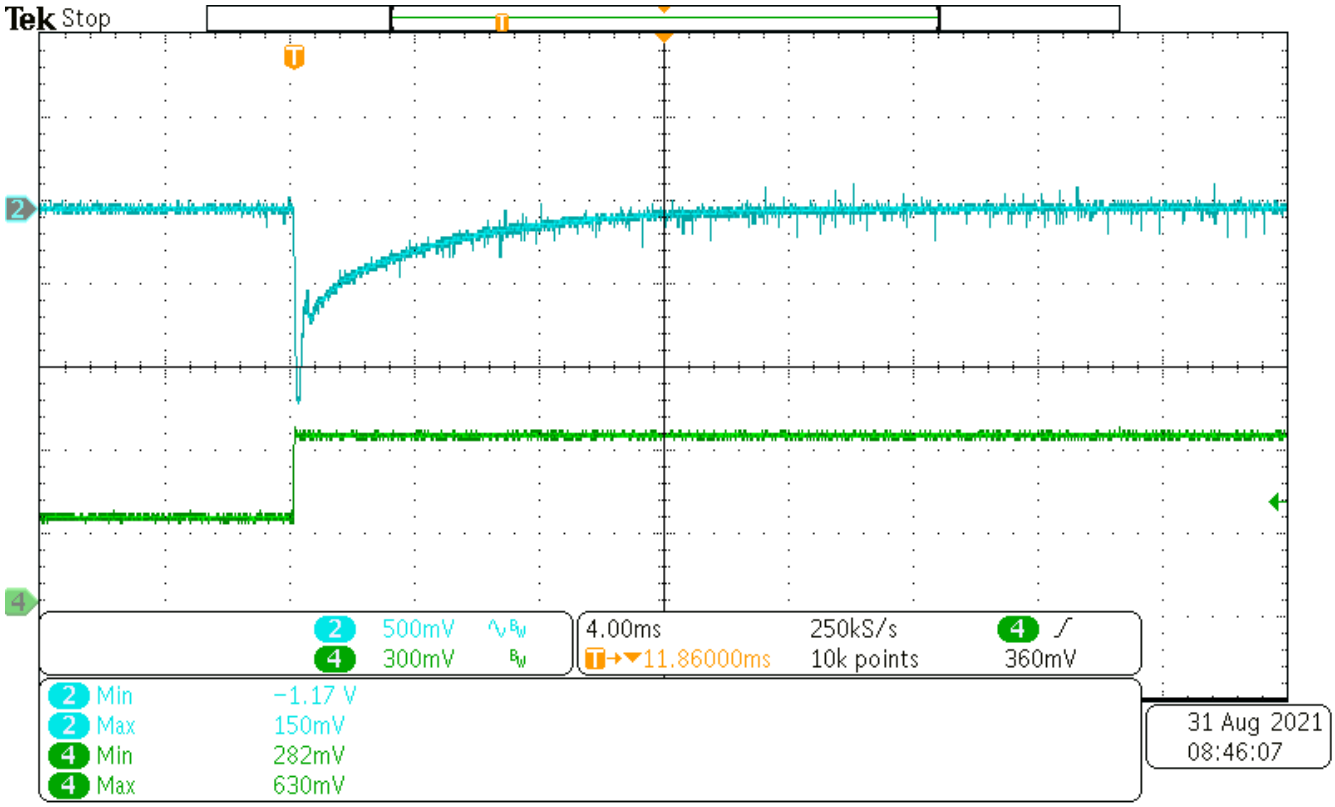


R1: 9.0 V_{IN}, 60.0-A load, 178.0-mV peak-peak-ripple [scale: 100 mV/div, 4.0 µs/div]
R2: 12.0 V_{IN}, 60.0-A load, 132.0-mV peak-peak-ripple [scale: 100 mV/div, 4.0 µs/div]
R3: 16.0 V_{IN}, 60.0-A load, 98.0-mV peak-peak-ripple [scale: 100 mV/div, 4.0 µs/div]

Figure 3-4. Output Voltage Ripple

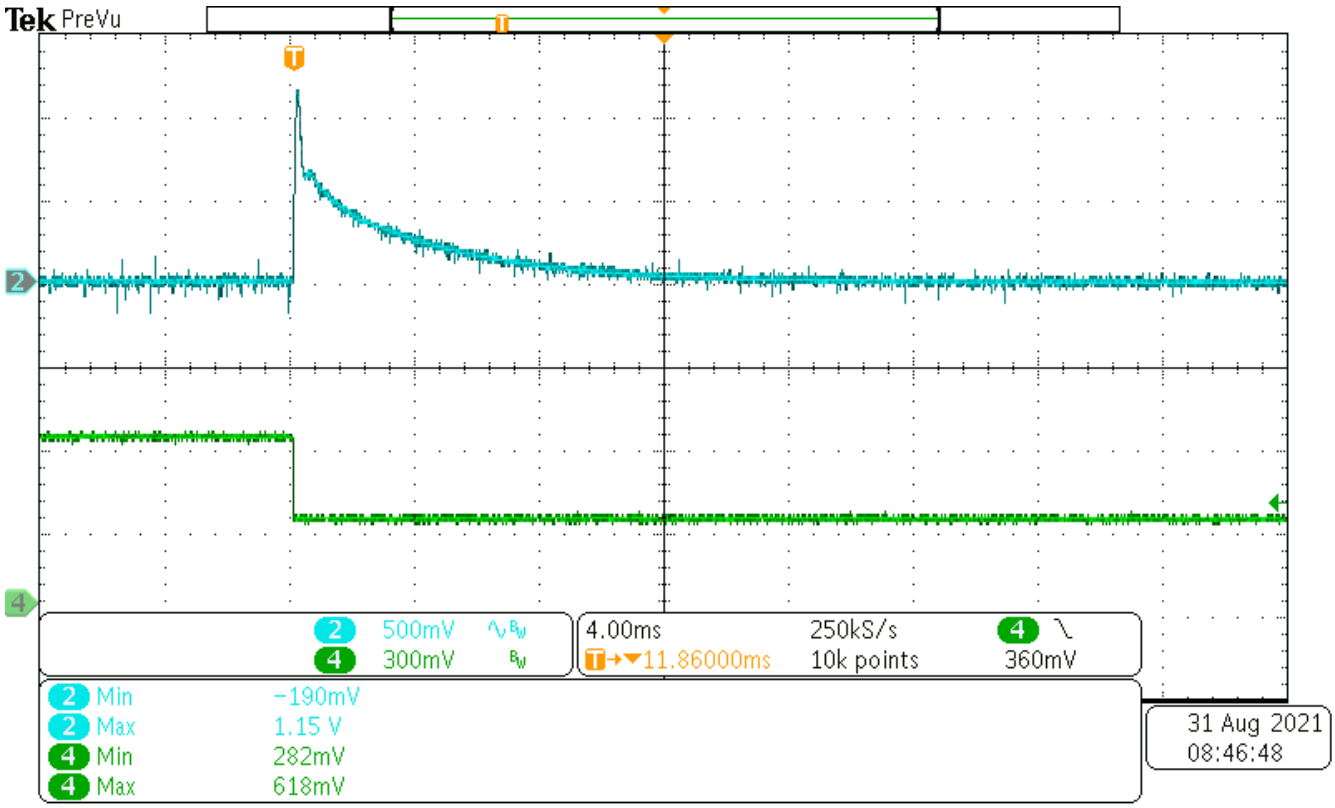
3.4 Load Transients

Load transient response waveforms are shown in Figure 3-5 and Figure 3-6.



Ch2: AC-coupled output voltage at 12.0 V_{IN}, bw limited (20 MHz) [scale: 500 mV/div, 4.0 ms/div]
Ch4: Load transient from 30.0 A to 60.0 A, slew rate 1.0 A/µs [scale: 30.0 A/div, 4.0 ms/div]

Figure 3-5. Load Transient - Rising Edge

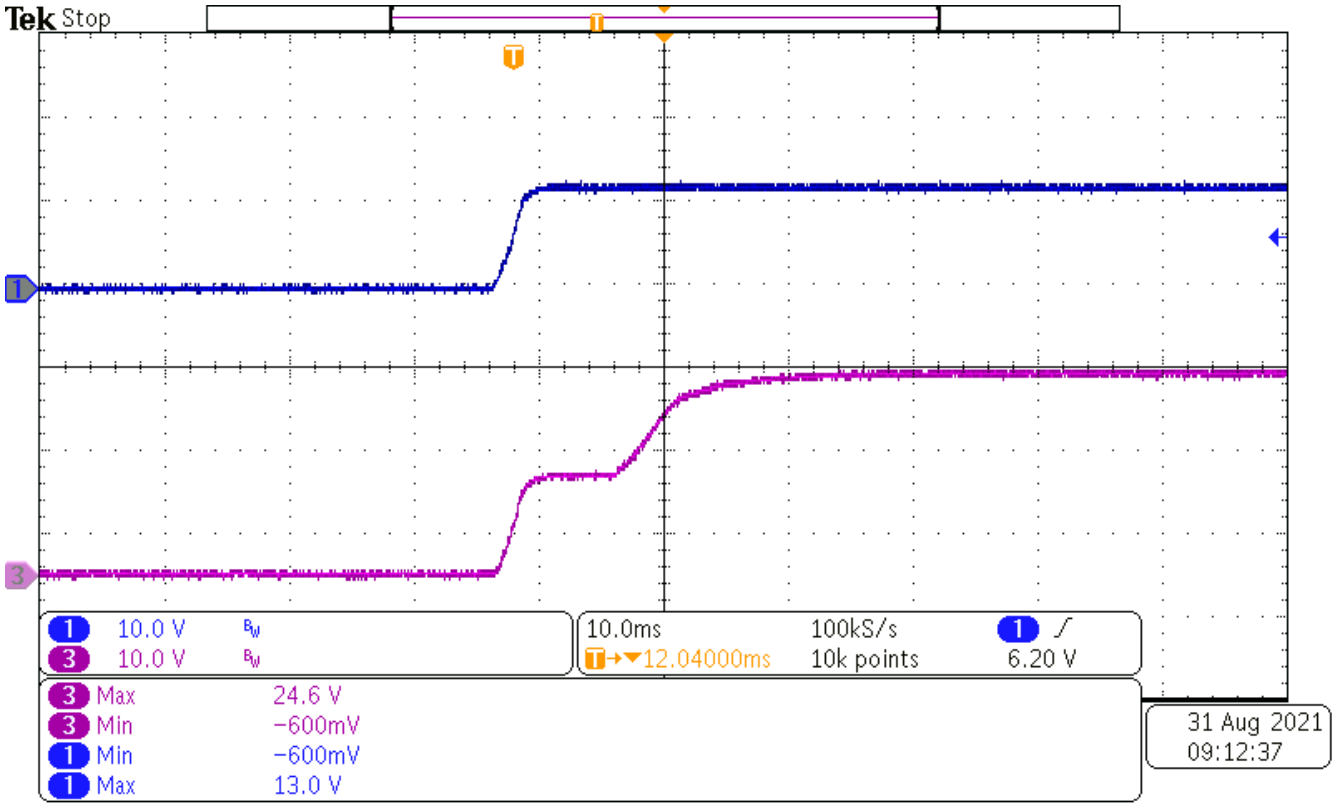


Ch2: AC-coupled output voltage at 12.0 V_{IN}, bw limited (20 MHz) [scale: 500.0 mv/div, 4.0 ms/div]
Ch4: Load transient from 60.0 A to 30.0 A, slew rate 1 A/µs [scale: 30.0 A/div, 4.0 ms/div]

Figure 3-6. Load Transient - Falling Edge

3.5 Start-up Sequence

Figure 3-7 shows the start-up behavior.

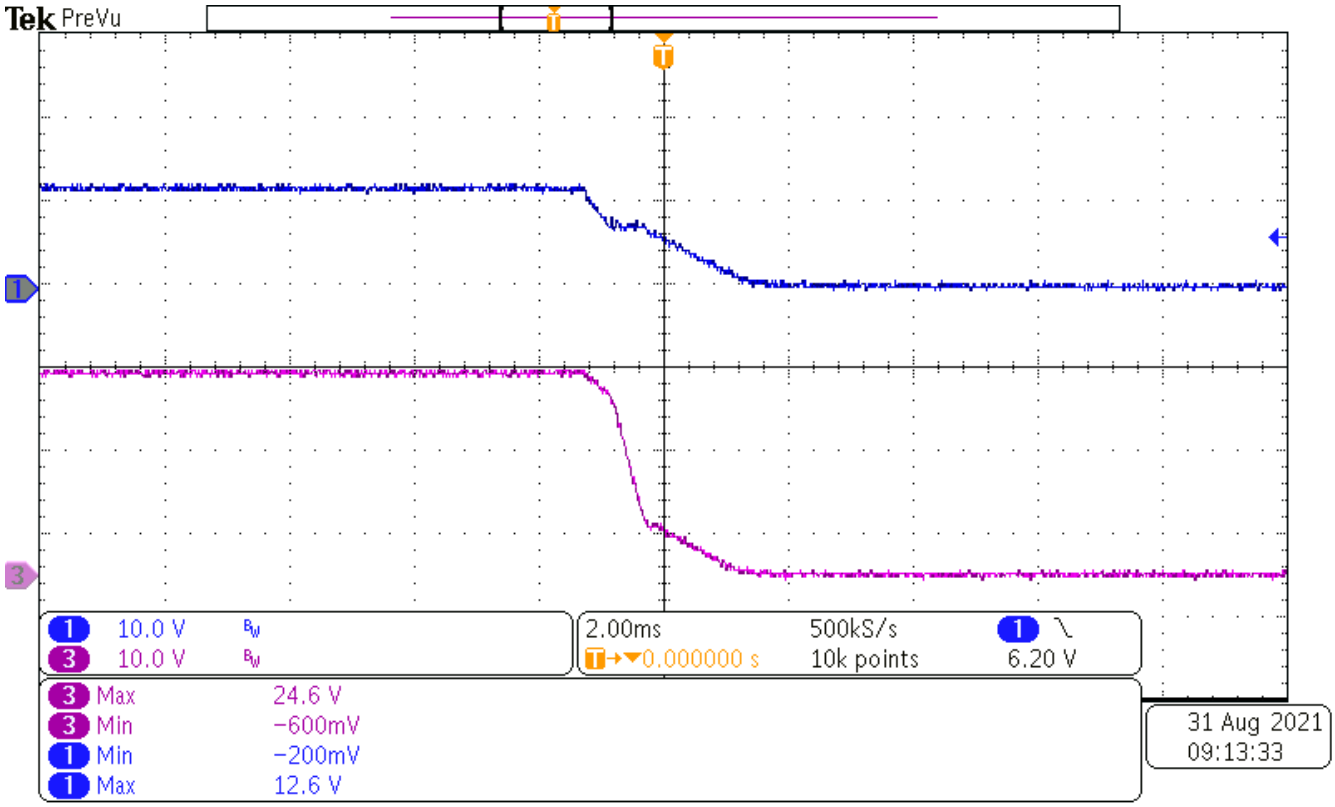


Ch1: Input voltage at 12.0 V_{IN} and 60.0-A load current [scale: 10.0 V/div, 10.0 ms/div]
Ch3: Output voltage at 12.0 V_{IN} and 60.0-A load current [scale: 10.0 V/div, 10.0 ms/div]

Figure 3-7. Start-up

3.6 Undervoltage Protection

Figure 3-8 shows the undervoltage protection waveform.



Ch1: Input voltage at 12.0 V_{IN} and 60.0-A load current [scale: 10 V/div, 2.0 ms/div]
Ch3: Output voltage at 12.0 V_{IN} and 60.0-A load current [scale: 10.0 V/div, 2.0 ms/div]

Figure 3-8. Undervoltage Protection

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), 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, regulatory 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 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.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265