Test Report: PMP22817

Automotive SPI Programmable Gate Driver and Bias Supply With Integrated Transformer Reference Design

Description

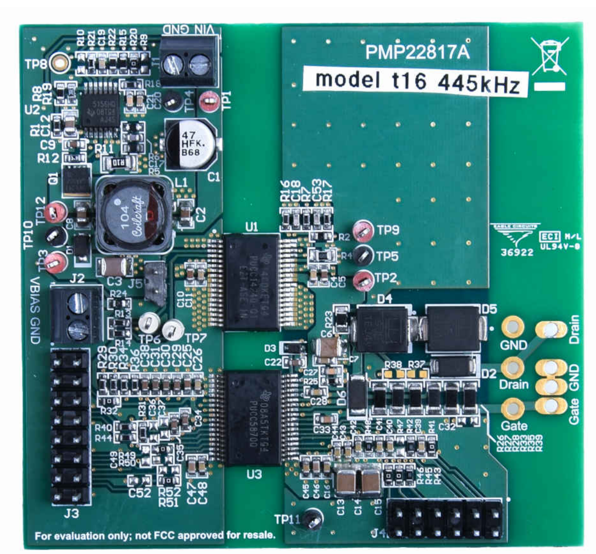
This reference design provides isolated bias supply and isolated gate drivers for power switches in traction inverters and onboard chargers. Both the bias power and driver provide the high isolation (3-kV$_{RMS}$ for 1 minute) needed for 800-V$_{DC}$ bus applications. The isolated bias provides from 24 V$_{DC}$ both the +15-V and –5-V gate drive biases. The isolated driver provides the high currents (up to 30-A peak) needed to rapidly turn on and off these high-power switches, and offers advanced protection features. This reference design also provides a tested DC/DC single-ended primary inductor converter SEPIC off automotive battery voltage (6 V to 42 V, including surges and dips) to provide the regulated 24 V.

Features

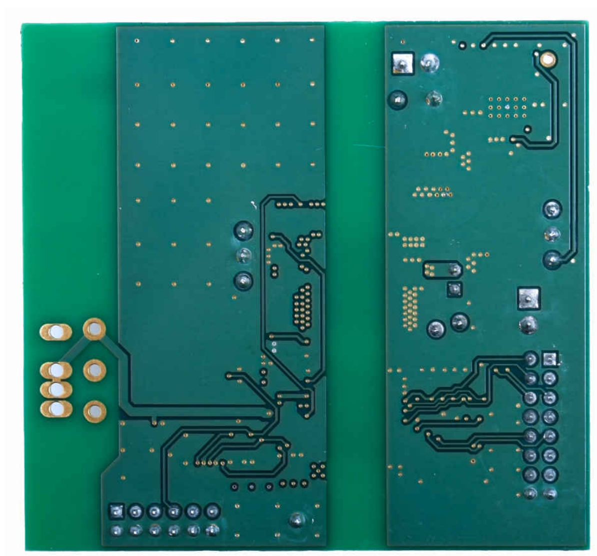
- Tested design providing isolated bias and isolated drive for high-power silicon carbide switches in traction inverters
- Advanced protection feature in the driver eases functional safety qualification
- High isolation of 3 kV$_{RMS}$ allows use in 800-V power trains
- Complete isolated conversion for +15 V and –5 V on a single IC
- Regulated simple 24-V converter off full automotive battery voltage range provided

Applications

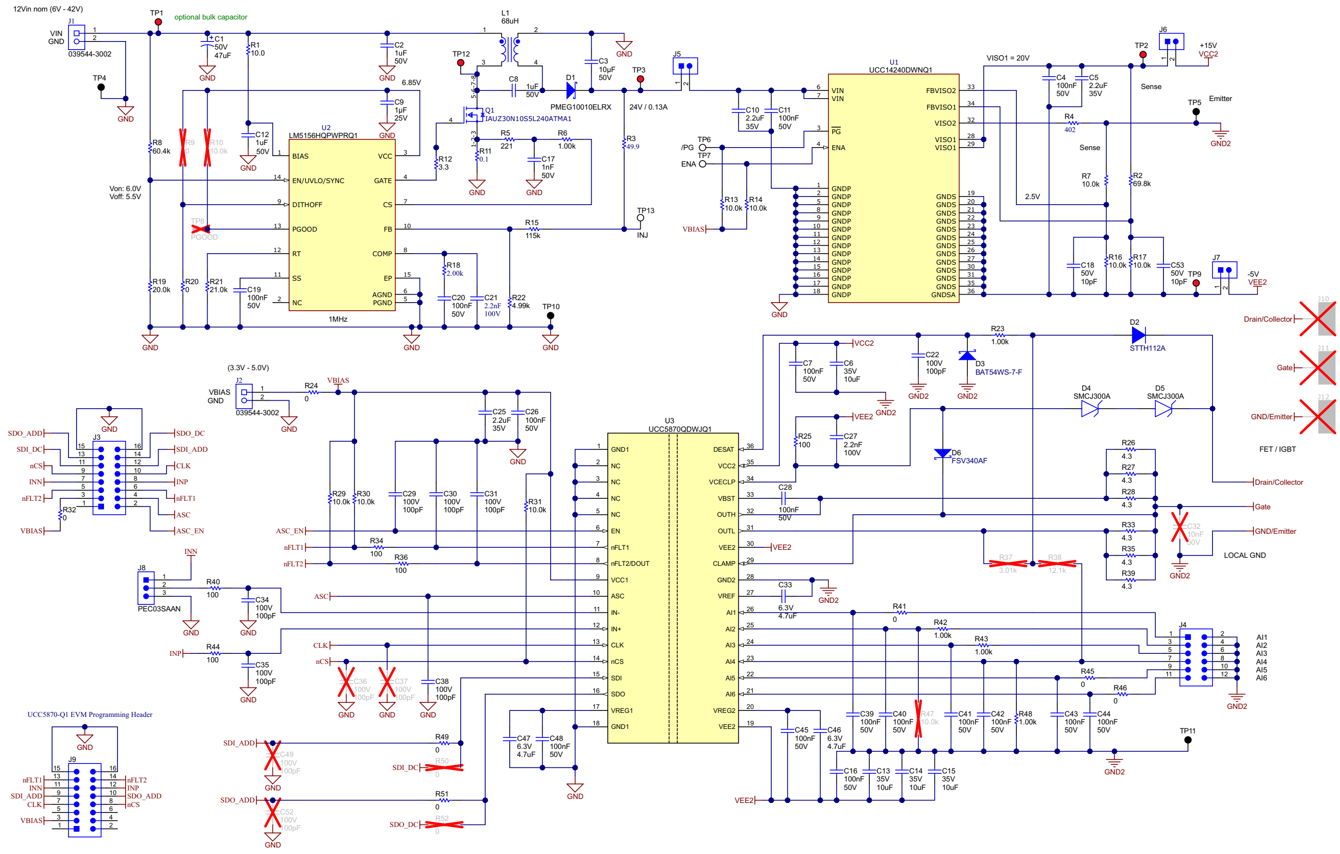
- Traction inverter motor control
- On-board (OBC) and wireless charger



Top of Board



Bottom of Board



Simplified Schematic

1 Test Prerequisites

This section provides the testing guide used in the detailed testing of the SEPIC and in verification of the overall operation of the board.

Table 1-1 and Table 1-2 detail the PMP22817 headers and test points.

Table 1-1. PMP22817 Headers

Header	Description
J1	V_{IN} to LM5156-Q1 SEPIC: 6 V to 42 V: Main power input
J2	Vbias: 3.3 V to 5 V
J5	Remove to power up the LM5156-Q1 SEPIC alone. Install to power all devices.
J3	Digital I/O on UCC5870-Q1. The UCC5870-Q1 EVM programmer can be connected to this header to use the UCC5870-Q1 EVM GUI to test the UCC5870-Q1 with a plug-in *PMP22817-adapterA* board. For more information, see Section 1.3.
J4	Optional analog inputs to UCC5870-Q1 referenced to target SiC source or IGBT emitter

Table 1-2. Test Points and Test Point Descriptions

Test Point	Description
TP1	V_{IN}
TP2	+15-V output from UCC14240-Q1
TP3	24-V output from LM5156-Q1 TP3 used as V_{OUT} for bode plot or loop stability of LM5156-Q1 SEPIC
TP4, TP10	Ground, primary TP10 used as ground for bode plot or loop stability of LM5156-Q1 SEPIC
TP5, TP11	Ground, secondary
TP6	Power good pin on UCC14240-Q1
TP7	ENA pin on UCC14240-Q1
TP8	Power good pin on LM5156-Q1, modified to be used as injection point for bode plot to evaluate loop stability
TP9	–5-V output from UCC14240-Q1
TP12	LM5156-Q1 switch node

1. **Powering the board**

   Two supplies are needed to power PMP22817, V_{IN} and Vbias. V_{IN} must be in the range of 9 V to 18 V. Vbias must be in the range of 3.3 V to 5 V. The order in which V_{IN} and Vbias are supplied and removed is not important.

2. **Once the board is properly powered up**

   Once V_{IN} and Vbias are supplied, then V_{IN} is present on TP1, the switch node on TP12 is switching at 445 kHz, TP3 measures 24 V, and 20 V is present between TP2 and TP9. TP6 reads high.

1.1 LM5156-Q1

1.1.1 Loading LM5156-Q1

To test the LM5156-Q1 by itself, remove J5 and connect a load to either pin 1 of J5 or TP3. Reference the load to the primary side ground. Connect V_{IN} to J1.

1.1.2 LM5156-Q1 SEPIC Bode Loop Testing

Complete the following for bode loop testing:

1. Cut the connection from R15 to TP3 (24 V). This cut is bridged with 49.9 Ω and is called *R100*.
2. On the PCB, cut the TP8 connection to U2–13. R10 (power good pullup) is not populated.
3. Populate TP8 with a green through-hole test point (Keystone 5116) and tie to a connection between *R100* and R115. TP8 becomes a signal injection point for the bode plot.
4. Use a network analyzer such as the Bode 100 from Omricon Lab with the following:
   - V1 measured between injection point TP8 and ground TP10
   - V2 measured between V_{OUT} TP3 and ground
   - Actual signal injection between TP8 and TP3

1.2 Loading UCC14240-Q1

To test the UCC14240-Q1, install J5 and connect a load between TP2 and TP9 (not between TP2 and TP5 or TP9 and TP5). Connect V_{IN} to J1, Vbias to J2, and power up. After testing, remove power and load.

1.3 UCC5870-Q1 and UCC5870-Q1 EVM GUI

This section shows how to evaluate the UCC5870-Q1 with the UCC5870-Q1 EVM GUI.

Use the *UCC5870QEVMGUI-044* MCU daughter board to communicate between PMP22817 port J3 and a Personal Computer (PC) with the *UCC5870-Q1 EVM GUI* software installed.

Ordering a UCC5870-Q1 EVM includes the *UCC5870QEVMGUI-044* and cable to connect from the *UCC5870QEVMGUI-044* to a USB port on the PC. The user's guide for the EVM includes instructions to download the GUI onto a PC, and then instructions to operate the UCC5870-Q1 on the PMP22817 after power up.

Use the *PMP22817-adapterA* to connect PMP22817 J3 to this *UCC5870QEVMGUI-044* J103. Both boards should plug into this adapter such that they do not overlap.

Table 1-3. Connections of This Plug-In Adapter

UCC5870QEVMGUI-044 J103 Pin Number	PMP22817 J3 Pin Number	PMP22817 Pin Name
9	12	SDI_ADD
10	13	SDO_ADD
8	9	nCS
14	5	nFLT2
3	3	Vbias
7	10	CLK
12	8	INP
13	6	nFLT1
15	15	GND

Also, use the USB A male-B micro to male 1-M cable from the same MCU daughter board *UCC5870QEVMGUI-044* to connect its J100 to any USB port on a PC with the *UCC5870-Q1 EVM GUI* software loaded.

Make sure the J5 jumper on the PMP22817 is in place to allow the 24 V from the SEPIC to power the UCC14020-Q1. Connect V_{IN} to J1, Vbias to J2, and power up. Once PMP22817 is powered up, follow the steps in the *power up* section of the *UCC5870QDWJEVM-026 Evaluation Module* users guide, after the step that creates the PWM waveforms, there is a –5 V to 15 V, 10 kHz, 50% duty cycle square wave present between the gate and GND pads.

1.4 Voltage and Current Requirements

Table 1-4. Voltage and Current Requirements

Parameter	Specifications
Input Voltage	9 V–18 V with dips to 6 V and surges to 42 V
Output Voltage	24 V
Output Current	130 mA
Switching Frequency	445 kHz (preferred) or 2 MHz

1.5 Required Equipment

- V_{IN} power supply (6 V to 42 V)
- Vbias power supply (3.3 V to 5 V)
- Electronic load
- Oscilloscope
- Digital multimeters

1.6 Considerations

Steady State Input Range: 9 V to 18 V

When testing for dips down to 6-V input or for surges to 42-V input for more than a few seconds, a fan blowing on the board is needed.

Testing focused on SEPIC using the LM5156; however, the performance of the UCC14240 and UCC5870 is described in the device data sheets.

1.7 Dimensions

Dimensions: 2.95 in × 2.75 in

2 Testing and Results

2.1 SEPIC Efficiency Graphs

The efficiency graphs are shown in the following figures.

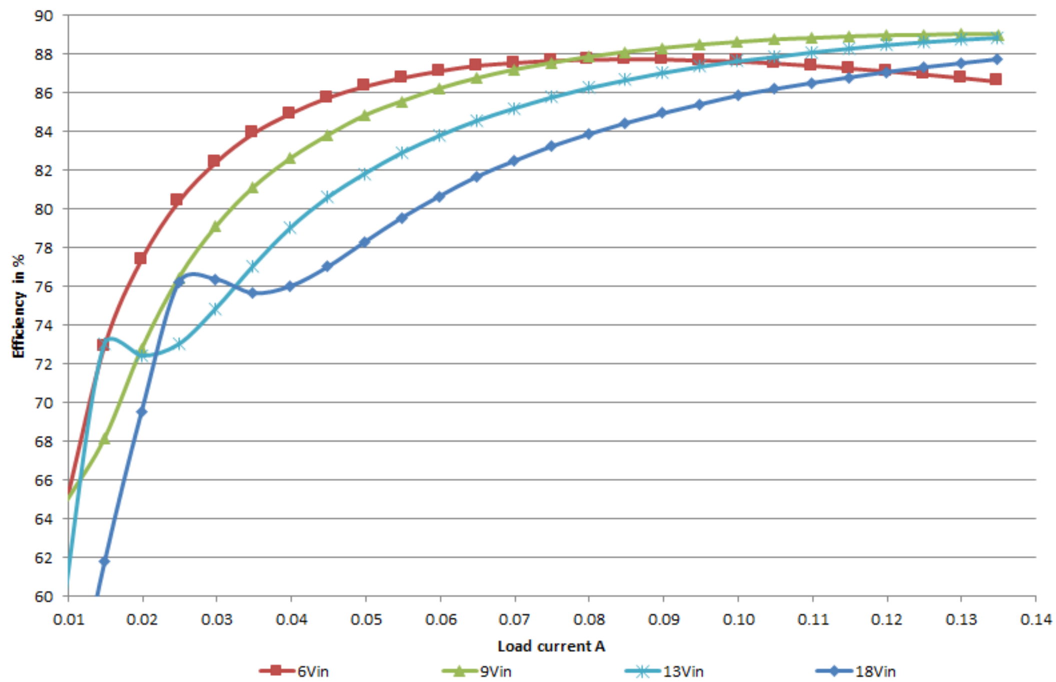


Figure 2-1. Efficiency of the PMP22817 SEPIC at 445 kHz

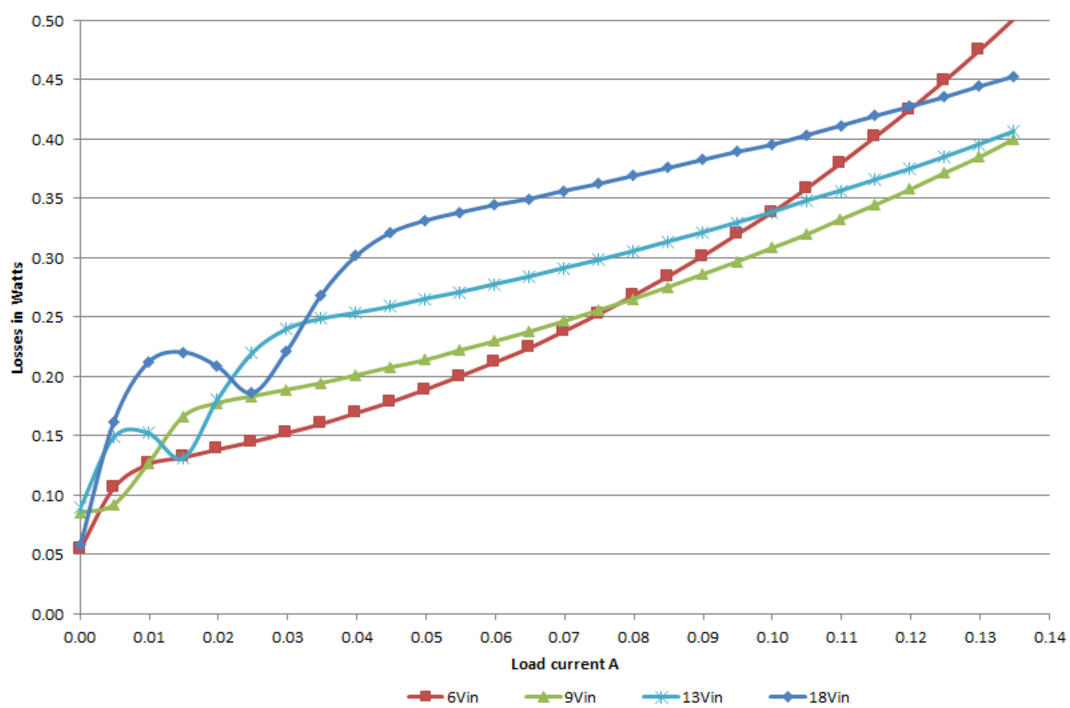


Figure 2-2. Power Loss of the PMP22817 SEPIC at 445 kHz

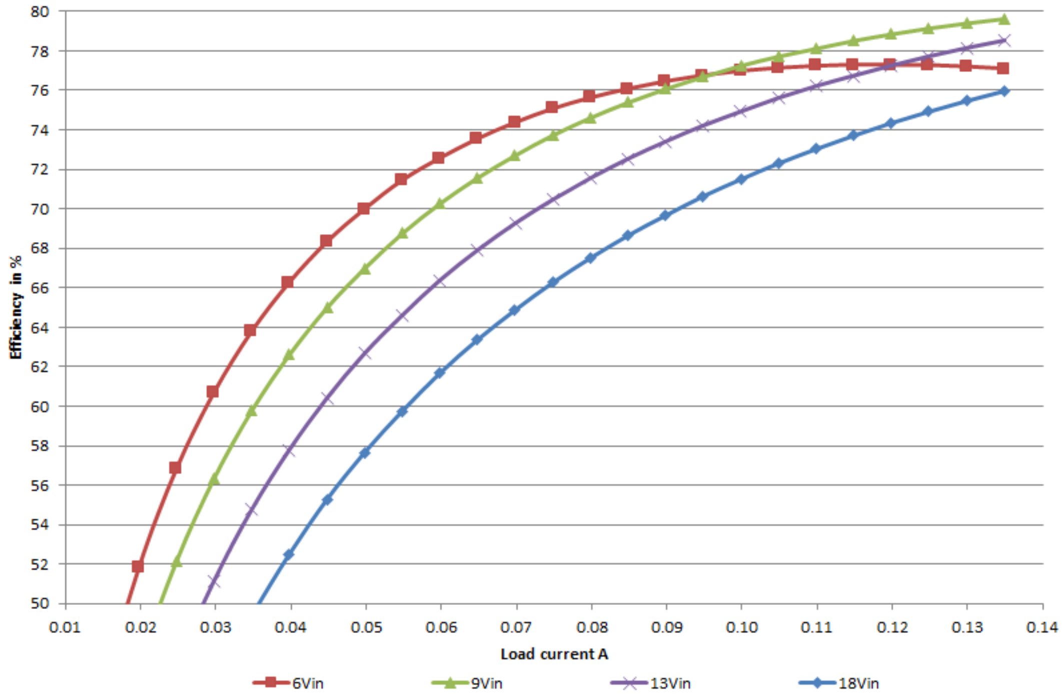


Figure 2-3. Efficiency of the PMP22817 SEPIC at 2 MHz

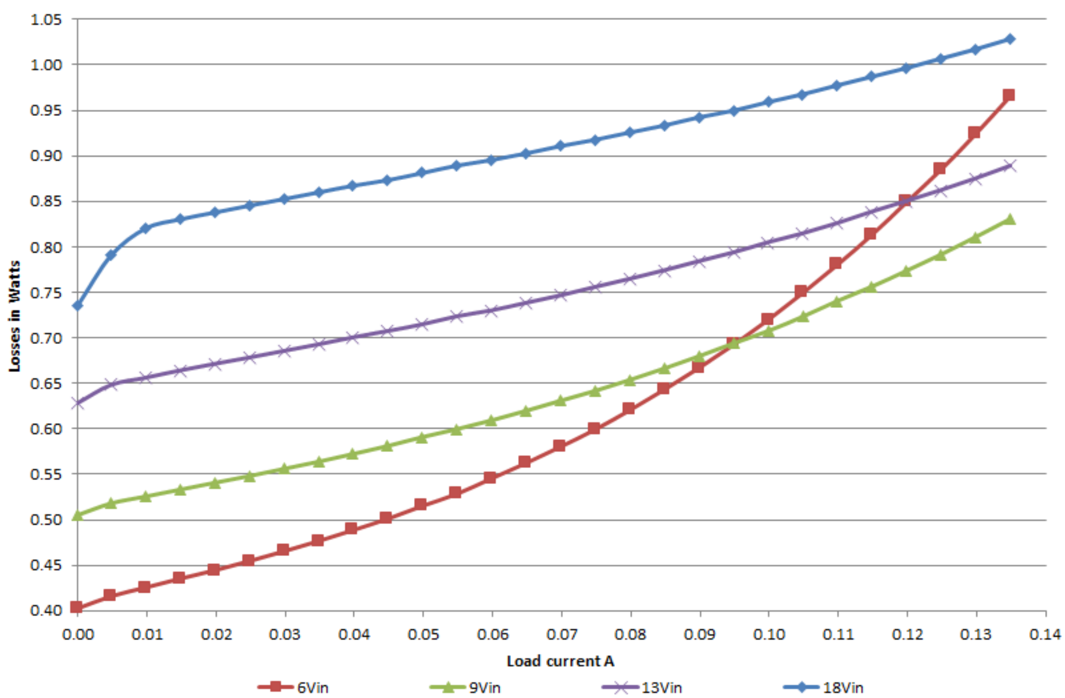


Figure 2-4. Power Loss of the PMP22817 SEPIC at 2 MHz

2.2 SEPIC Efficiency Data

Efficiency data is shown in the following tables.

Table 2-1. PMP22817 Efficiency, V_{IN} = 9 V, Switching Frequency = 445 kHz

V_{IN} V	I_{IN} A	V_{OUT}	I_{OUT} A	Efficiency %	Loss W
9.004	0.0095	24.02	0.0000	0.0	0.085
9.002	0.0231	24.02	0.0048	55.6	0.092
9.000	0.0403	24.02	0.0098	65.0	0.127
8.998	0.0581	24.02	0.0148	68.1	0.166
8.996	0.0727	24.02	0.0198	72.8	0.178
8.994	0.0867	24.02	0.0248	76.5	0.184
8.993	0.1007	24.02	0.0298	79.1	0.189
8.991	0.1147	24.02	0.0348	81.1	0.195
8.989	0.1288	24.02	0.0398	82.6	0.201
8.988	0.1429	24.02	0.0448	83.8	0.208
8.986	0.1571	24.02	0.0498	84.8	0.214
8.984	0.1713	24.02	0.0548	85.6	0.222
8.983	0.1856	24.02	0.0598	86.2	0.230
8.981	0.1999	24.02	0.0648	86.7	0.238
8.979	0.2143	24.02	0.0698	87.2	0.247
8.978	0.2287	24.02	0.0748	87.5	0.256
8.976	0.2432	24.02	0.0798	87.8	0.265
8.974	0.2578	24.02	0.0848	88.1	0.276
8.972	0.2723	24.02	0.0898	88.3	0.286
8.971	0.2871	24.02	0.0948	88.5	0.297
8.969	0.3018	24.02	0.0998	88.6	0.308
8.967	0.3165	24.02	0.1048	88.7	0.320
8.966	0.3314	24.02	0.1098	88.8	0.333
8.964	0.3463	24.02	0.1148	88.9	0.345
8.962	0.3612	24.02	0.1198	88.9	0.358
8.960	0.3762	24.02	0.1248	89.0	0.372
8.958	0.3912	24.02	0.1299	89.0	0.385
8.957	0.4064	24.02	0.1348	89.0	0.400

Table 2-2. PMP22817 Efficiency, V_{IN} = 13 V, Switching Frequency = 445 kHz

V_{IN} V	I_{IN} A	V_{OUT}	I_{OUT} A	Efficiency %	Loss W
13.00	0.0070	24.02	0.0000	0.0	0.090
13.00	0.0204	24.02	0.0048	43.7	0.149
13.00	0.0299	24.02	0.0098	60.7	0.153
12.99	0.0375	24.02	0.0148	73.0	0.132
12.99	0.0506	24.02	0.0198	72.4	0.181
12.99	0.0628	24.02	0.0248	73.0	0.220
12.99	0.0736	24.02	0.0298	74.9	0.240
12.99	0.0835	24.02	0.0348	77.1	0.249
12.99	0.0932	24.02	0.0398	79.0	0.254
12.98	0.1029	24.02	0.0448	80.6	0.259
12.98	0.1126	24.02	0.0498	81.8	0.266
12.98	0.1223	24.02	0.0548	82.9	0.271
12.98	0.1321	24.02	0.0598	83.8	0.278
12.98	0.1418	24.02	0.0648	84.6	0.284
12.98	0.1517	24.02	0.0698	85.2	0.292
12.98	0.1615	24.02	0.0748	85.8	0.298
12.98	0.1713	24.02	0.0798	86.3	0.306
12.98	0.1812	24.02	0.0848	86.7	0.314
12.98	0.1911	24.02	0.0898	87.0	0.321
12.98	0.2010	24.02	0.0948	87.4	0.330
12.97	0.2109	24.02	0.0998	87.6	0.338
12.97	0.2210	24.02	0.1048	87.9	0.348
12.97	0.2309	24.02	0.1099	88.1	0.356
12.97	0.2409	24.02	0.1149	88.3	0.366
12.97	0.2509	24.02	0.1199	88.5	0.375
12.97	0.2610	24.02	0.1249	88.6	0.385
12.97	0.2710	24.02	0.1298	88.8	0.395
12.97	0.2811	24.02	0.1348	88.9	0.406

Table 2-3. PMP22817 Efficiency, V_{IN} = 18 V, Switching Frequency = 445 kHz

V_{IN} V	I_{IN} A	V_{OUT}	I_{OUT} A	Efficiency %	Loss W
18.01	0.0032	24.02	0.0000	0.0	0.058
18.01	0.0154	24.02	0.0048	41.7	0.162
18.01	0.0249	24.02	0.0098	52.6	0.212
18.00	0.0321	24.02	0.0148	61.8	0.221
18.00	0.0380	24.02	0.0198	69.5	0.208
18.00	0.0435	24.02	0.0248	76.2	0.186
18.00	0.0521	24.02	0.0298	76.4	0.222
18.00	0.0614	24.02	0.0348	75.7	0.269
18.00	0.0699	24.02	0.0398	76.0	0.302
18.00	0.0777	24.02	0.0448	77.0	0.321
18.00	0.0849	24.02	0.0498	78.3	0.332
18.00	0.0920	24.02	0.0548	79.6	0.338
18.00	0.0990	24.02	0.0598	80.7	0.345
17.99	0.1060	24.02	0.0648	81.7	0.350
17.99	0.1130	24.02	0.0698	82.5	0.357
17.99	0.1201	24.02	0.0748	83.2	0.362
17.99	0.1271	24.02	0.0798	83.9	0.369
17.99	0.1342	24.02	0.0848	84.4	0.376
17.99	0.1412	24.02	0.0898	84.9	0.383
17.99	0.1483	24.02	0.0949	85.4	0.390
17.99	0.1554	24.02	0.0999	85.9	0.395
17.99	0.1625	24.02	0.1049	86.2	0.403
17.99	0.1696	24.02	0.1099	86.5	0.412
17.99	0.1767	24.02	0.1149	86.8	0.420
17.99	0.1839	24.02	0.1199	87.1	0.428
17.98	0.1910	24.02	0.1248	87.3	0.436
17.98	0.1982	24.02	0.1298	87.5	0.445
17.98	0.2053	24.02	0.1348	87.7	0.453

Table 2-4. PMP22817 Efficiency, V_{IN} = 13 V, Switching Frequency = 2 MHz

V_{IN} V	I_{IN} A	V_{OUT}	I_{OUT} A	Efficiency %	Loss W
12.99	0.0484	24.09	0.0000	0.0	0.628
12.99	0.0588	24.09	0.0048	15.2	0.648
12.99	0.0687	24.09	0.0098	26.5	0.656
12.99	0.0786	24.09	0.0148	35.0	0.664
12.99	0.0884	24.09	0.0198	41.5	0.671
12.99	0.0983	24.09	0.0248	46.9	0.678
12.99	0.1081	24.09	0.0298	51.2	0.686
12.98	0.1180	24.09	0.0348	54.8	0.693
12.98	0.1278	24.09	0.0398	57.8	0.700
12.98	0.1376	24.09	0.0448	60.4	0.707
12.98	0.1475	24.09	0.0498	62.7	0.715
12.98	0.1574	24.09	0.0548	64.6	0.723
12.98	0.1673	24.09	0.0598	66.4	0.730
12.98	0.1772	24.09	0.0648	67.9	0.738
12.98	0.1872	24.09	0.0698	69.3	0.747
12.98	0.1972	24.09	0.0748	70.5	0.756
12.97	0.2072	24.09	0.0798	71.5	0.765
12.97	0.2172	24.09	0.0848	72.5	0.774
12.97	0.2272	24.09	0.0898	73.4	0.784
12.97	0.2374	24.09	0.0948	74.2	0.794
12.97	0.2475	24.09	0.0998	74.9	0.805
12.97	0.2576	24.09	0.1049	75.6	0.815
12.97	0.2678	24.09	0.1099	76.2	0.826
12.97	0.2781	24.09	0.1148	76.7	0.838
12.97	0.2882	24.09	0.1198	77.3	0.850
12.96	0.2985	24.09	0.1249	77.7	0.862
12.96	0.3089	24.09	0.1298	78.1	0.875
12.96	0.3192	24.09	0.1349	78.5	0.889

2.3 SEPIC Bode Plots

Bode plots are shown in the following figures.

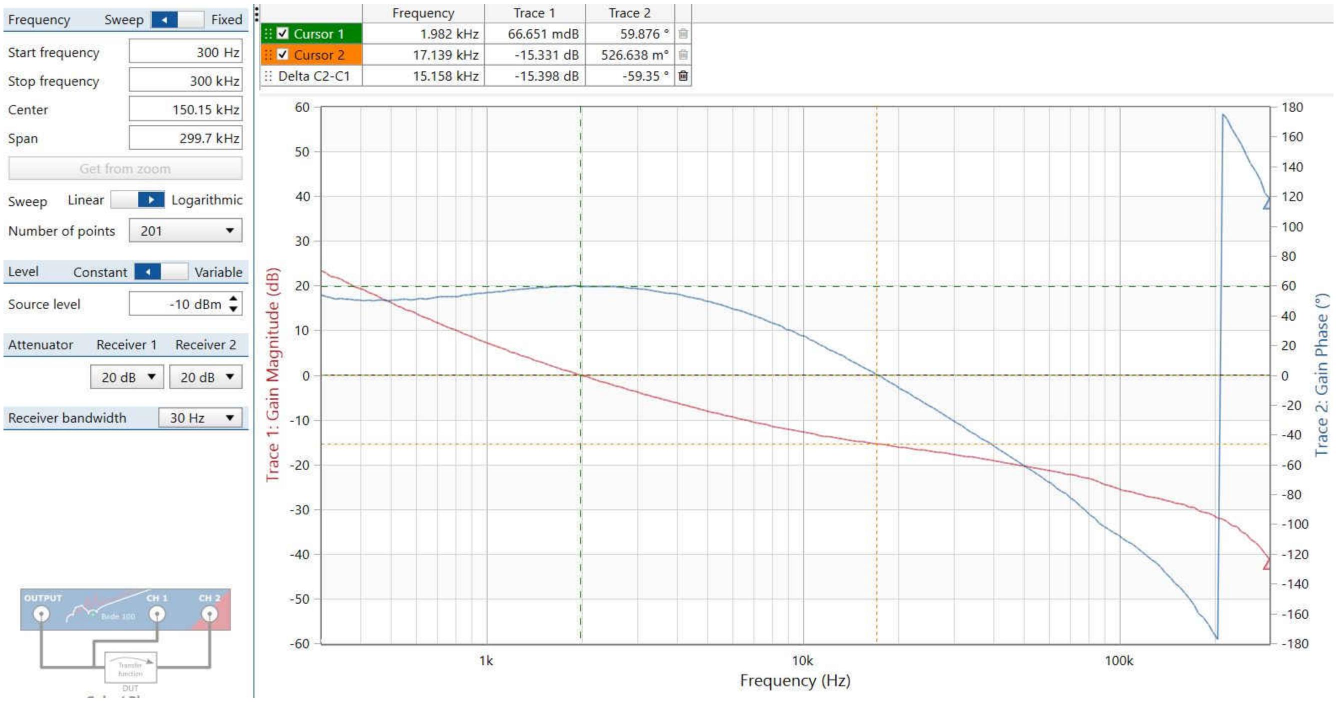


Figure 2-5. Bode Plot at 445-kHz Switching Frequency

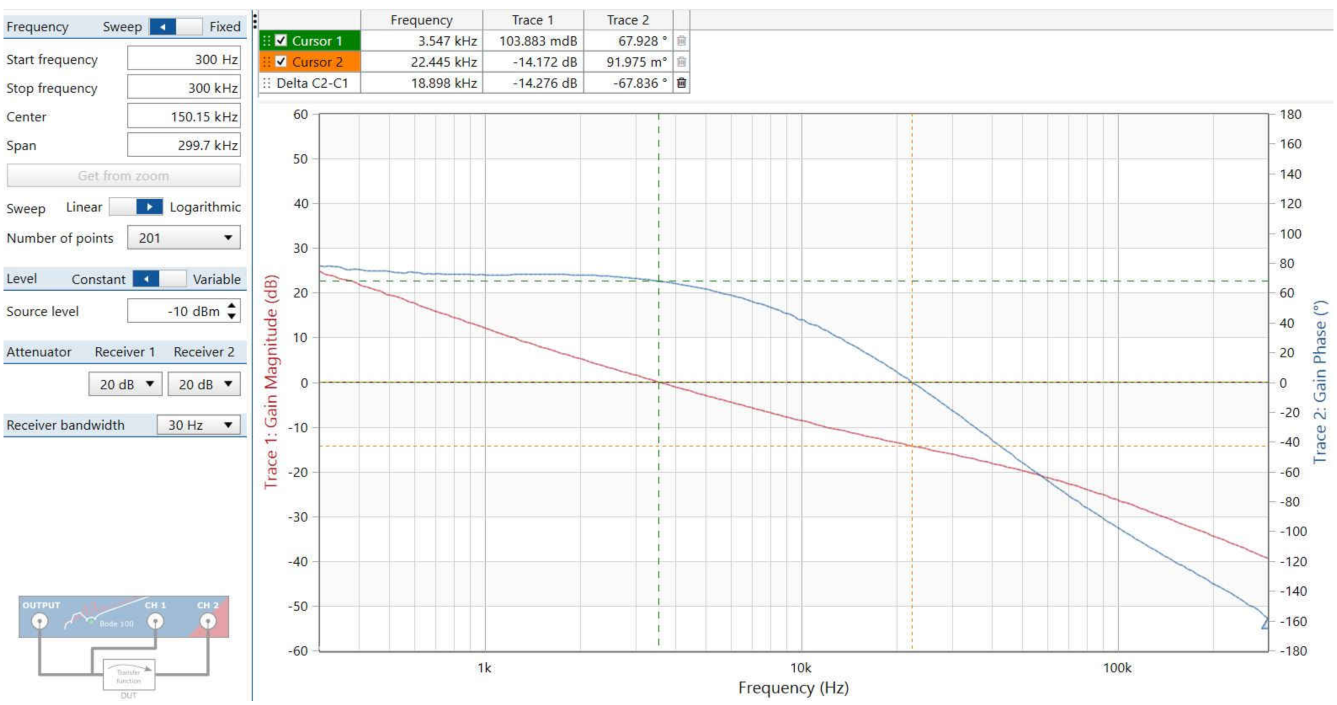


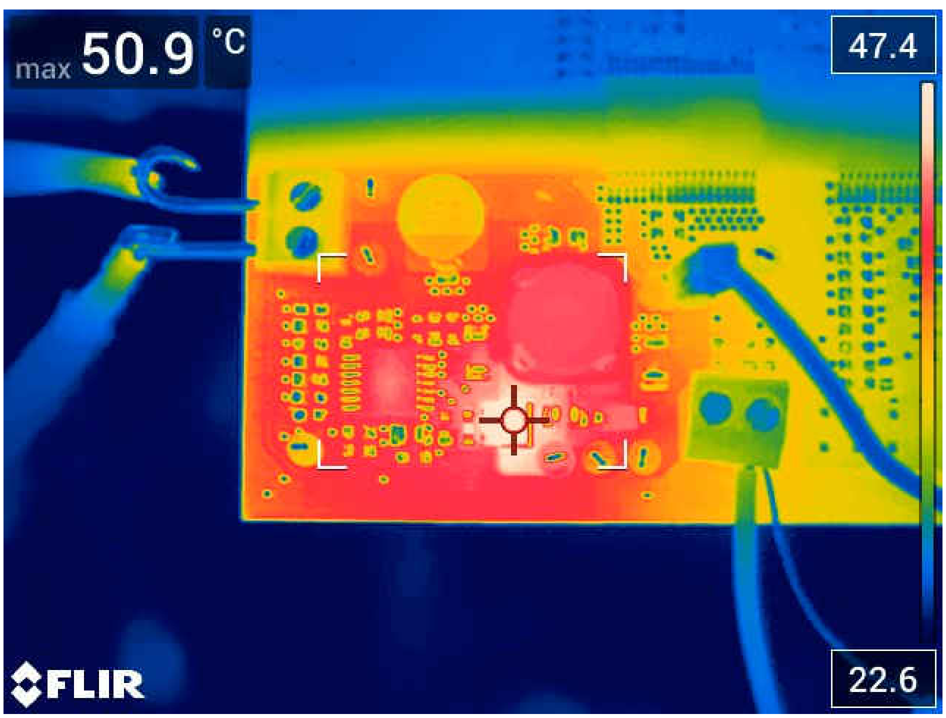
Figure 2-6. Bode Plot at 2-MHz Switching Frequency

2.4 Thermal Images

Thermal images are shown in the following figures.

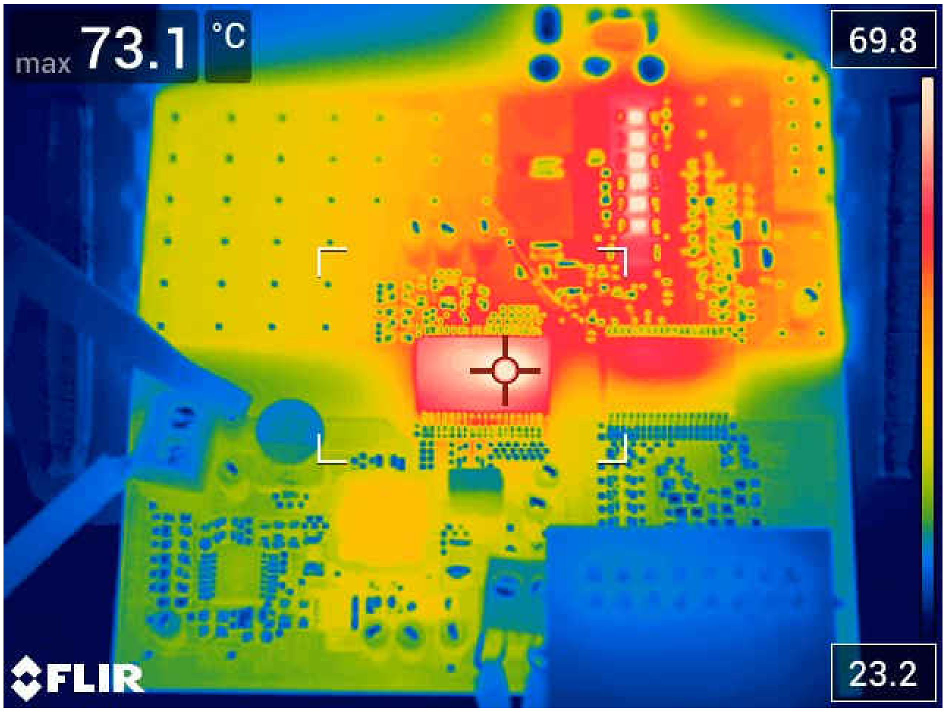
V_{IN} = 18 V_{IN}, V_{OUT} = 24 V_{OUT} at 130 mA
The SEPIC inductor is the hottest item.

Figure 2-7. SEPIC Thermals at 445-kHz Switching Frequency



V_{IN} = 18V, V_{OUT} = 24 V_{OUT} at 130 mA
The SEPIC switch is the hottest item.

Figure 2-8. SEPIC Thermals at 2-MHz Switching Frequency



12 V_{IN} to SEPIC, 24 V from SEPIC, +15 V, –5 V from isolated DC/DC. Isolated driver run at 40 kHz, 50% duty into 0.1-µF load for 2 µC per cycle or 80 mA, 1.6-W average current, power draw from isolated DC/DC. Ambient 21°C to 23°C with no fan.
Isolated DC/DC at 73°C, gate driver at 56°C and gate drive resistors up to 76°C

Figure 2-9. Isolated DC/DC and Driver Thermals at 40 kHz, 50% Duty, PWM 100 nF on Gate

3 Waveforms

3.1 SEPIC Switching

Switching behavior is shown in the following figures.

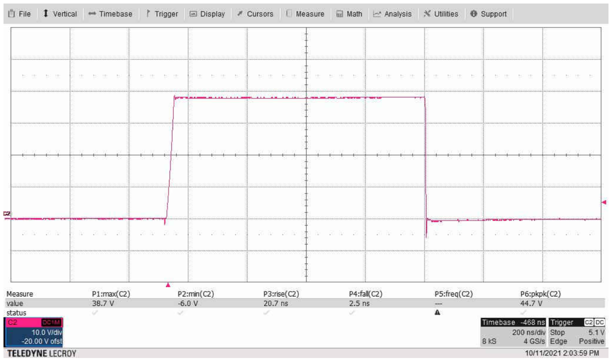


Figure 3-1. Switching at 18-V_{IN} Q1 Drain Full Load at 445 kHz Showing Only 1 Pulse

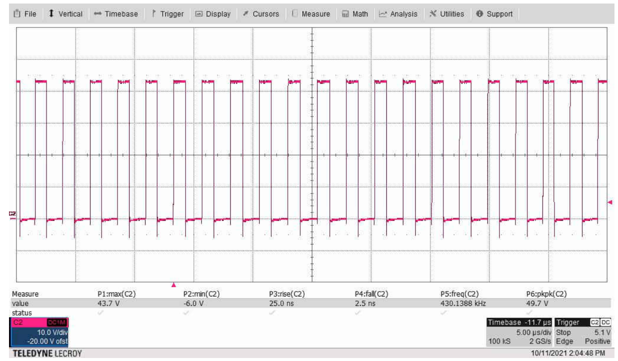


Figure 3-2. Switching at 18-V_{IN} Q1 Drain Full Load at 445 kHz Showing 22 Cycles

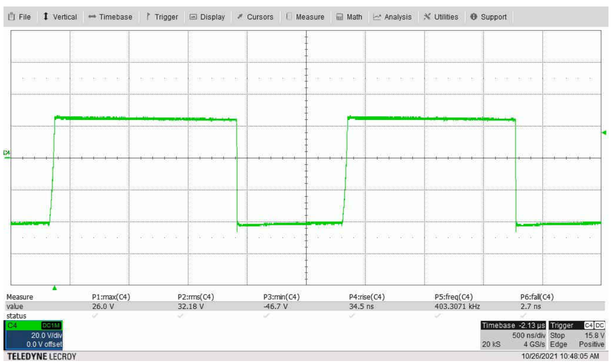


Figure 3-3. Switching at 42-V_{IN} D1 Anode Full Load at 445 kHz Showing 2 Cycles

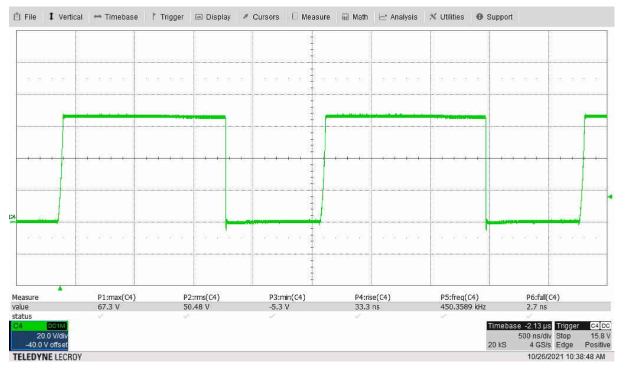


Figure 3-4. Switching 42-V_{IN} Q1 Drain Full Load at 445 kHz Showing Two Cycles

3.2 SEPIC Output Voltage Ripple

Output voltage ripple is shown in the following figures.

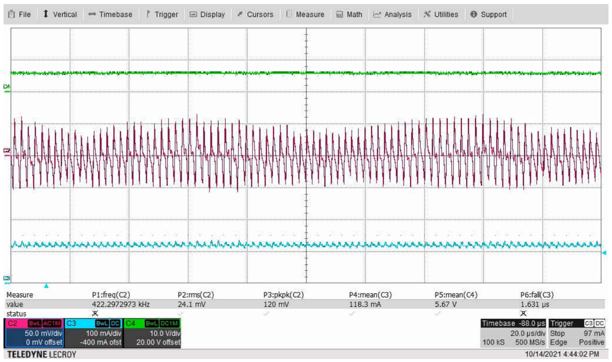


Figure 3-5. Output Voltage Ripple With 445-kHz Switching Frequency

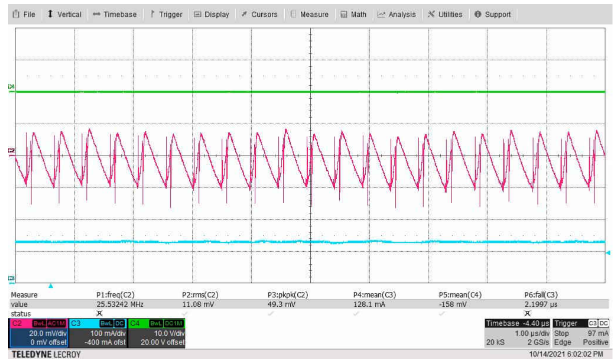
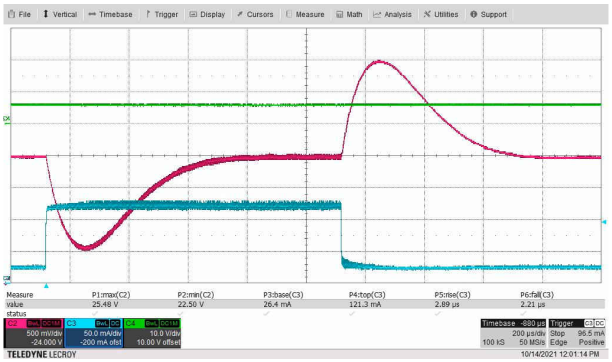


Figure 3-6. Output Voltage Ripple With 2-MHz Switching Frequency

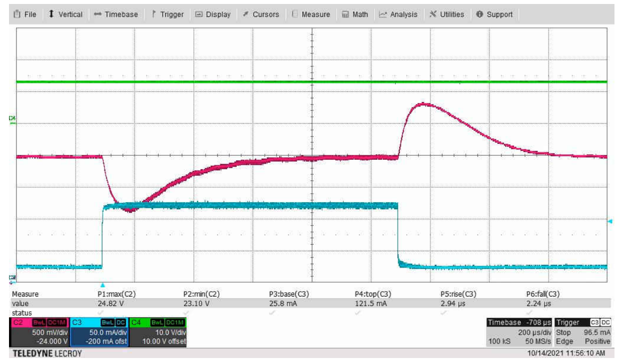
3.3 SEPIC Load Transients

Load transient response is shown in the following figures.



Green = V_{IN}, Pink = V_{OUT}, Blue = Load Current

Figure 3-7. Load Transients, , V_{IN} = 6 V, Switching Frequency = 445 kHz



Green = V_{IN}, Pink = V_{OUT}, Blue = Load Current

Figure 3-8. Load Transient, V_{IN} = 13 V, Switching Frequency = 445 kHz

Green = V_{IN}, Pink = V_{OUT}, Blue = Load Current

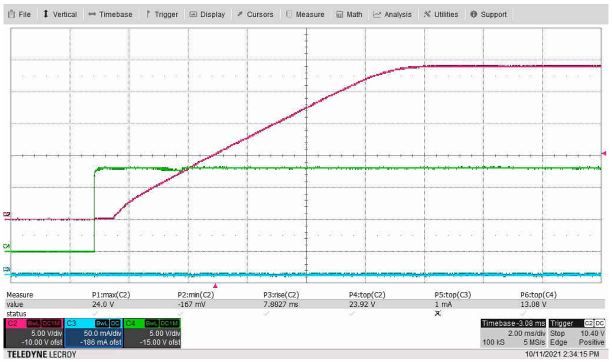
Figure 3-9. Load Transient, V_{IN} = 13 V, Switching Frequency = 2 MHz

Green = V_{IN}, Pink = V_{OUT}, Blue = Load Current

Figure 3-10. Load Transient, V_{IN} = 6 V, Switching Frequency = 2 MHz

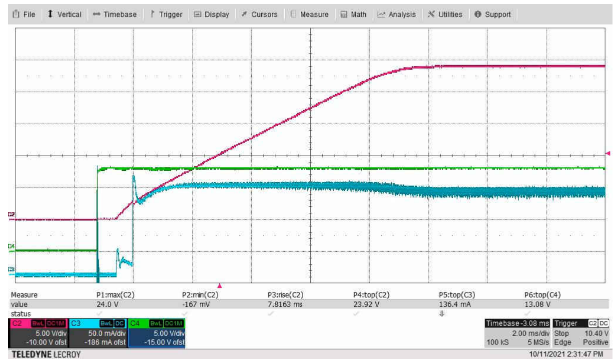
3.4 SEPIC Start-Up Sequence

Start-up behavior is shown in the following figures.



Green = V_{IN}, Pink = V_{OUT}

Figure 3-11. Start-Up, V_{IN} = 13-V No Load

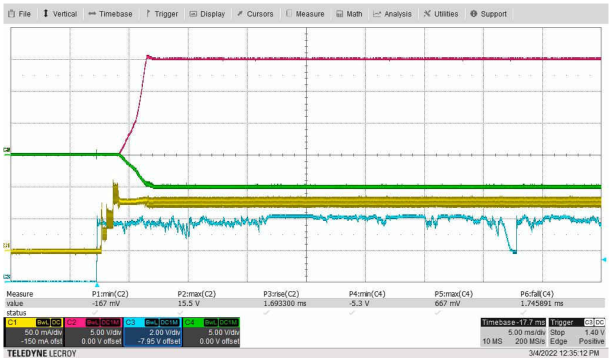


Green = V_{IN}, Pink = V_{OUT}, Blue = Load Current

Figure 3-12. Start-Up, V_{IN} = 13-V Load

3.5 Isolated Bias Supply Start Up and Shutdown

Isolated bias supply start-up and shutdown waveforms are shown in this section. The focus of these tests was on proper ramp up and ramp down of outputs with abrupt and noisy loading and with a noisy and bouncing enable signal.



24 VDC into isolated DC/DC:

75-mA load between +15-V and –5-V output

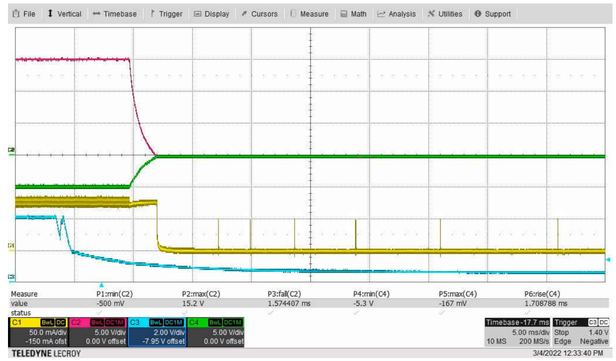
Scope channel 1 (yellow) is load current off DC/DC (noisy)

Scope channel 2 (red) is the +15-V output with 0.5-V overshoot

Scope channel 3 (blue) is the enable signal

Scope channel 4 (green) is the –5-V output.

Figure 3-13. Isolated DC/DC Turn On by Rising Enable Signal



24 VDC into isolated DC/DC:

75-mA load between +15-V and –5-V output

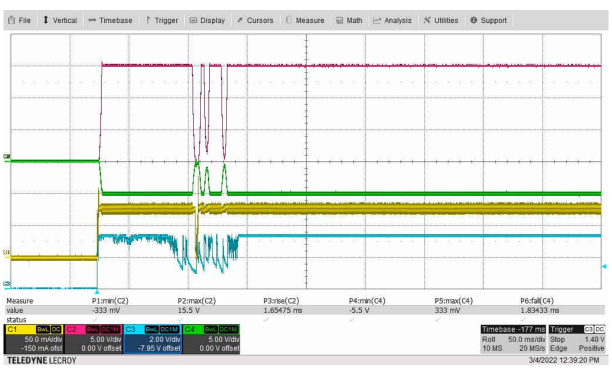
Scope channel 1 (yellow) is load current off DC/DC (noisy)

Scope channel 2 (red) is the +15-V output

Scope channel 3 (blue) is the enable signal

Scope channel 4 (green) is the –5-V output.

Figure 3-14. Isolated DC/DC Turn Off by Falling Enable Signal



24 VDC into isolated DC/DC:

75-mA load between +15-V and –5-V output

Scope channel 1 (yellow) is load current off DC/DC (noisy)

Scope channel 2 (red) is the +15-V output with 0.5-V overshoot

Scope channel 3 (blue) is the enable signal

Scope channel 4 (green) is the –5-V output

Figure 3-15. Isolated DC/DC Turn On by Rising Enable Signal With Switch Bounce

24 VDC ramped up into isolated DC/DC:

75-mA load between +15-V and –5-V output. Enable is always high.

Scope channel 1 (yellow) is load current off DC/DC (noisy)

Scope channel 2 (red) is the +15-V output with 0.5-V overshoot

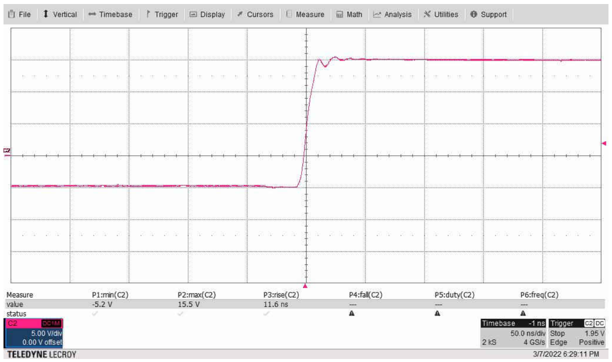
Scope channel 3 (blue) is ramping up main V_{IN}

Scope channel 4 (green) is the –5-V output.

Figure 3-16. Isolated DC/DC Turn On by Rising Main V_{IN} to 24 V

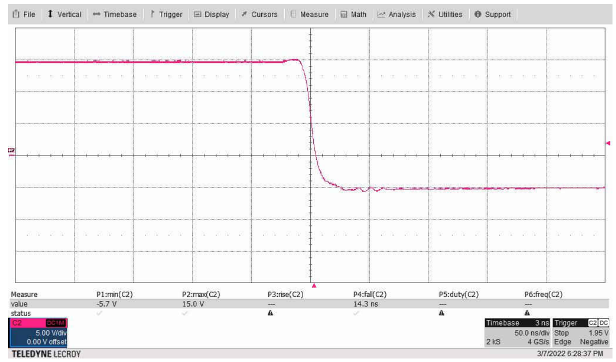
3.6 Isolated Gate Drive

Isolated gate drive waveforms are shown in this section.



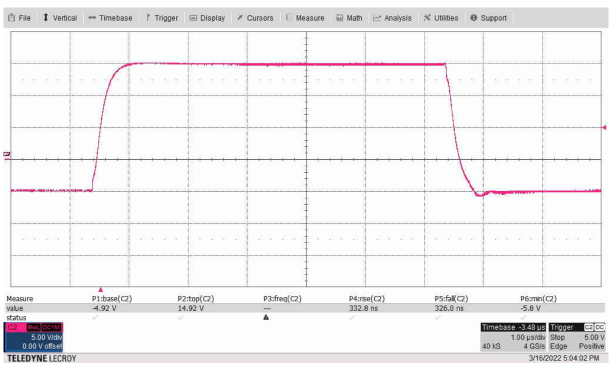
+15 V, –5 V to isolated driver, model t16 used
Scope at full 500-MHz bandwidth
Scope channel two red showing gate voltage versus isolated side ground
Rising (10% to 90%) in 12 ns

Figure 3-17. Rising Waveform - No Load



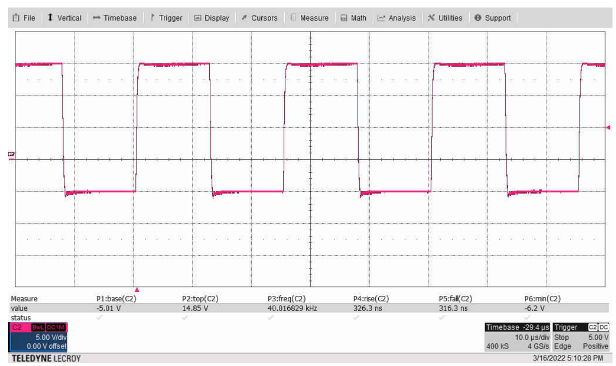
+15 V, –5 V to isolated driver, model t16 used
Scope at full 500-MHz bandwidth
Scope channel two red showing gate voltage versus isolated side ground
Falling (90% to 10%) in 14 ns

Figure 3-18. Falling Waveform - No Load



+15 V, –5 V to isolated driver, model t11 used
Scope at 200-MHz bandwidth
Scope channel two red showing gate voltage versus isolated side ground
Rising (10% to 90%) in 333 ns and falling (90% to 10%) in 326 ns

Figure 3-19. Gate Loaded With 100 nF, 2-µC Charge: One 6-µs Pulse



+15 V, –5 V to isolated driver, model t11 used
Scope at 200-MHz bandwidth
Scope channel two red showing gate voltage versus isolated side ground

Figure 3-20. Gate Loaded With 100 nF, 2-µC Charge: 40 kHz, 50% Duty, 4 Cycles