Application Note

Radiation Tolerant Inverting Buck-Boost Converter with TPS7H4010-SEP

TEXAS INSTRUMENTS

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ABSTRACT

One common design challenge for space applications is the need to generate a negative voltage rail. This application note illustrates how to design an inverting buck-boost using the radiation tolerant TPS7H4010-SEP. Radiation tolerant devices are needed to shield against single event effects and dose effects in LEO™ applications. The TPS7H4010-SEP is rated for 30-krad (Si) for total ionizing dose and 43 MeV*cm2/mg for singe event latch-up immunity. This topology takes a positive input voltage and create a regulated negative output voltage. This application note details design considerations and simulation results, so that designers can scale the design to different requirements. The document also includes experimental results and configuration instructions to regulate voltage rails of -12 V, -6 V, and -1.8 V from a 12-V input and a 5-V input for the -6 V and -1.8 V rails.

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1 Introduction

1.1 Design Description

Implementing the TPS7H4010-SEP as an inverting buck-boost is similar to buck topology. In the buck topology, the positive connection of the output is connected to the inductor and the return is connected to the integrated circuit (IC) ground. In the inverting buck-boost configuration however, the IC ground is used as the negative output voltage and what used to be the positive output is connected to ground. The inverting buck-boost topology allows the output voltage to be inverted and lower than ground because Vin is typically referred to ground, but in the inverting buck-boost topology, Vin is referred to Vout. The input voltage range of the TPS7H4010-SEP in the inverting buck-boost is 3.5-V to 32-V (+ Vout), where Vout is a negative value. Since the input is switching from Vin all the way to Vout instead of ground, remember to pick adequately rated capacitors for the input. The maximum output current is reduced when going from buck to inverting buck-boost configuration. For this application, 3 A was the maximum current tested as exceeding 3 A is not recommended. Figure 1-1 shows the schematic for the inverting buck-boost topology.

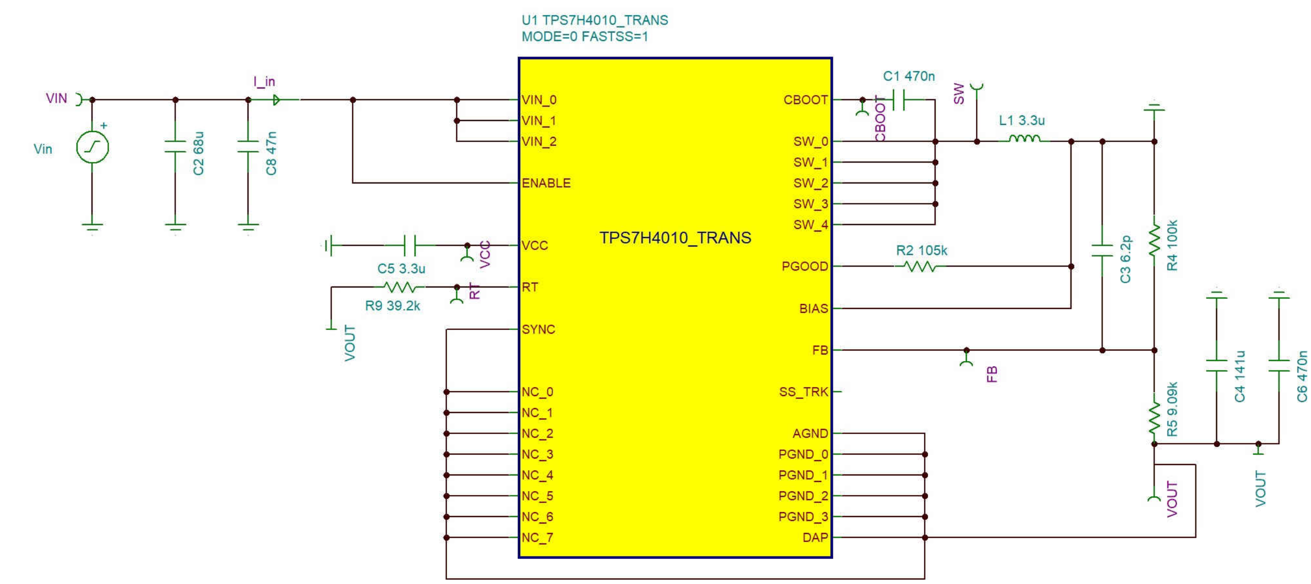

Figure 1-1. TPS7H4010-SEP Inverting Buck Boost Topology

1.2 Design Goals

Table 1-1. Design Goals

Input Voltage	Output Voltage	Tested Output Current	Switching Frequency
12 V	-12 V	3 A	1 MHz
12 V	-6 V	3 A	1 MHz
12 V	-1.8 V	3 A	1 MHz
5 V	-6 V	2.5 A	1 MHz
5 V	-1.8 V	3 A	1 MHz

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2 Detailed Design Procedure

For this application note, the inverting buck-boost is implemented using the TPS7H4010EVM. The TPS7H4010EVM has two TPS7H4010-SEP devices on the board. One device is configured to output 3.3V and the other is configured to output 1.8V. The following instructions on how to configure the TPS7H4010EVM in an inverting buck-boost topology is referred to the 1.8 V rail on the EVM (Figure 2-1). The first step is to ground the output labeled as VOUT_A (TP1, J1, top of J20) on the board. Then for the output and load, connect that to the EVM ground labeled GND_A (TP9, J2, bottom of J20). The input voltage is still connected across PVIN_A (TP5, J3) and VOUT_A (TP1, J1, top of J20) since this is what the ground is tied to. This process configures the EVM into the inverting buck-boost configuration.

Table 2-1. Passive Component Changes

Vout	L1 (L3) (uH)	Cout	R2(R12) (Ω)	R4(R14)(Ω)	R6(R16)(Ω)
-12 V	3.3 uH	141 uF	100 k	9.1 k	39.2 k
-6 V	3.3 uH	141 uF	100 k	20 k	39.2 k
-1.8 V	1.8 uH	400 uF	100 k	124 k	39.2 k

The design considerations for each of the different rails tested is discussed. For the TPS7H4010-SEP inverting buck-boost topology, a switching frequency of 1 MHz was set. For these changes to be made on the TPS7H4010EVM, some passive component values were changed on what was originally the 3.3 V rail to convert to the -12 V and -6 V rails and on the original 1.8 V to convert to -1.8 V. To do this, first on both the 3.3 V rail and the 1.8 V rail of the EVM R16 (R6 on the 1.8-V rail) was replaced with a 39.2-k resistor to change the switching frequency to the desired 1-MHz switching frequency. Then to change the output voltage value of the 3.3 V rail, the feedback resistor R14 was changed to regulate to -12 V and -6 V. Table 2-1 shows the passive values used for the design of each of the output rails tested for the inverting buck-boost application. The table includes two numbers for each of the passive values corresponding to the number on the schematic based on the initial 1.8 V rail (3.3 V rail) schematic. Both resistors that need to be changed are highlighted in Figure 2-1 of the TPS7H4010EVM. The remainder of the passive values have stayed the same for the testing performed. Note that other passive values can be changed to optimize for the specific output regulation required.

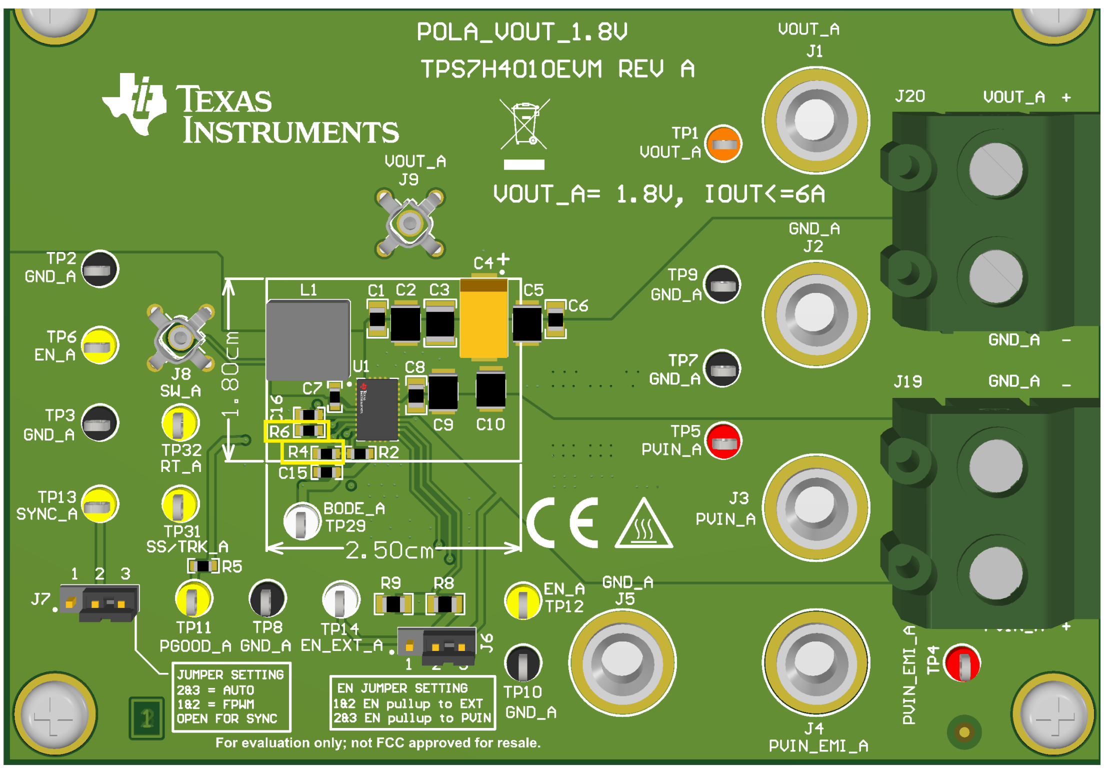

Figure 2-1. TPS7H4010EVM 3.3-V Layout

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3 Testing Results

Testing was done at -12 V, -6 V, and -1.8 V to show the range that the inverting buck-boost topology for the TPS7H4010-SEP is capable of. Testing for the -6-V rail and -1.8 V was done with a 5-V input voltage on top of the 12-V input to show behaviors at a lower input voltage as well. Typical waveforms and testing results for each of the rails tested are shown in the following figures. Note that each of the rails except for the 5 Vin to -6 Vout were tested up to 3 A. For the 5 Vin to -6 Vout rail, waveforms were captured at 2 A because with the EVM the regulation started to become unstable past 2.5 A. This can be optimized by changing capacitance and inductance values as mentioned in the design section. The schematic for the -1.8 V rail from the TPS7H4010EVM is shown in Figure 3-1.

Traditional methods for AC response were taken, but found to be inaccurate, thus the traditional methods were not included. The transient responses show that the device in the inverting buck-boost topology is still stable under the test conditions.

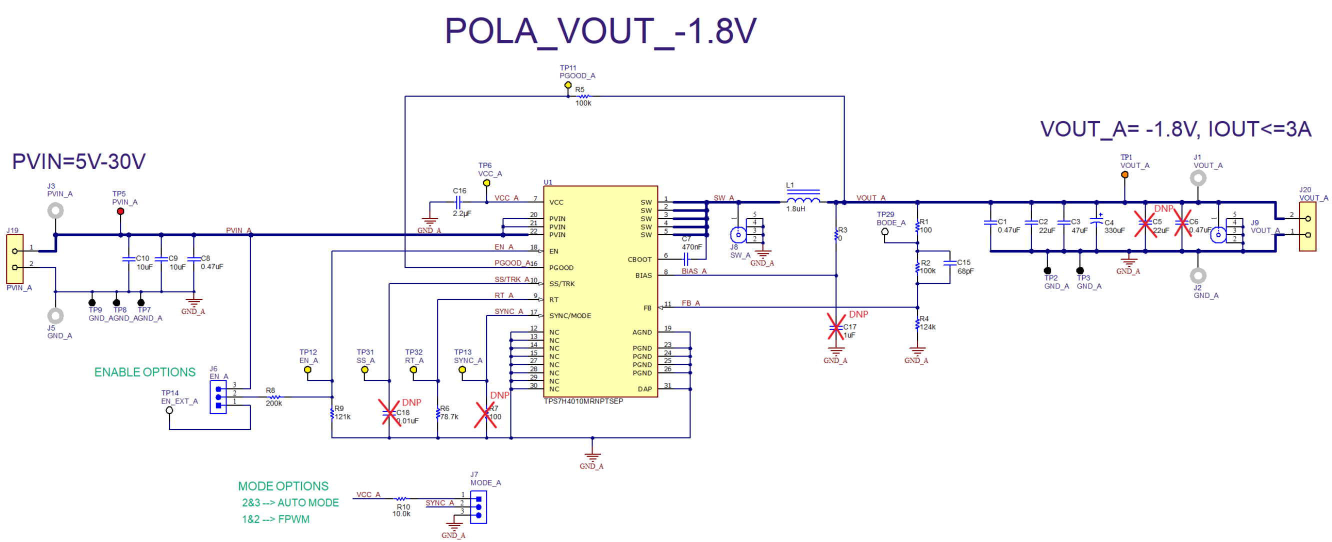

Figure 3-1. TPS7H4010EVM 1.8-V Rail Schematic

Figure 3-2 shows the tested efficiency for the 12 V in and the -12 V out from 100 mA to 3 A.

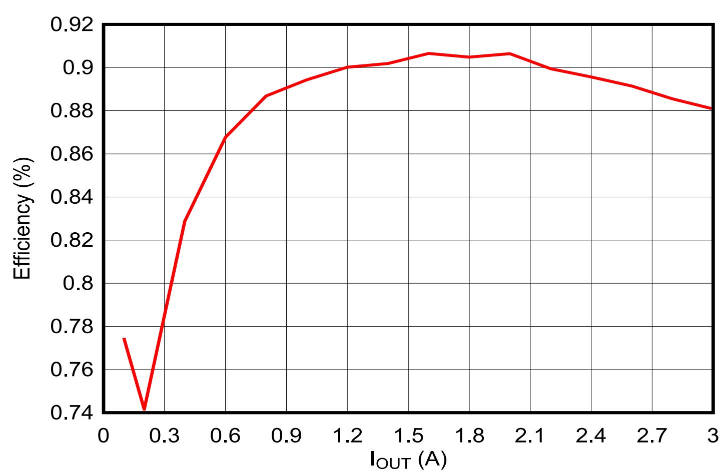

Figure 3-2. 12 V to -12 V Efficiency

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Figure 3-3 shows the transient response for 12 V in and -12 V out. The output current steps from 280 mA to 2.76 A. On the positive edge of the load step, the peak of the transient is 236 mV. On the negative edge, the valley of the transient is -204 mV.

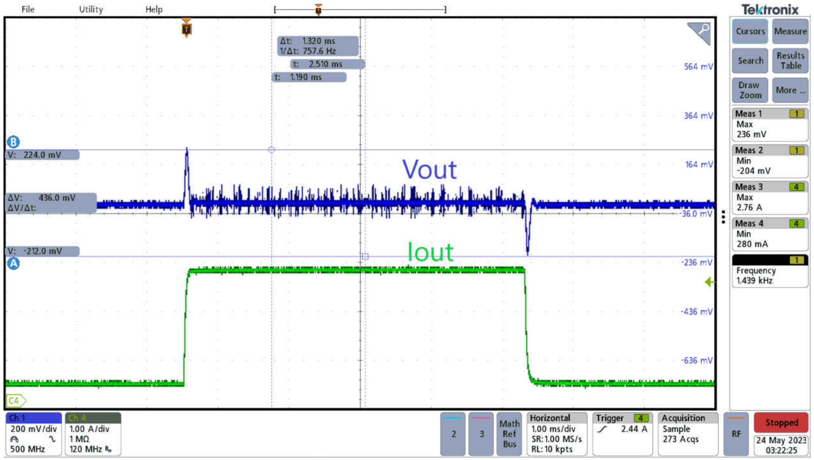

Figure 3-3. 12 V to -12 V Load Transient

Figure 3-4 shows the switch node for 12 V in and -12 V at a load current of 3 A. Switching frequency is 999.5 kHz

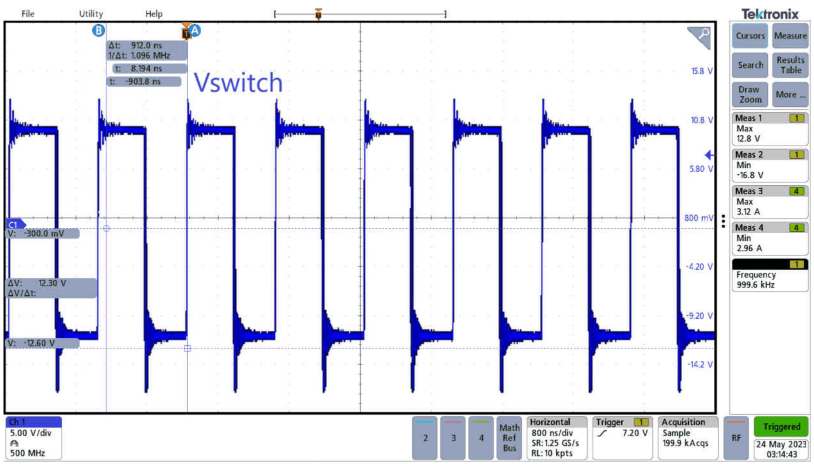

Figure 3-4. 12 V to -12 V (3-A Switch Node)

Figure 3-5 shows the input ripple for 12 V in and -12 V at a load current of 3 A which is 396 mV.

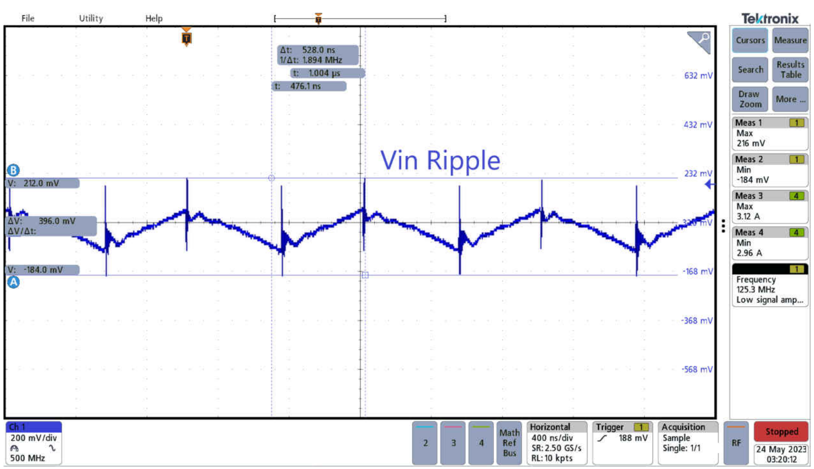

Figure 3-5. 12 V to -12 V Input Ripple 3 A

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Figure 3-6 shows the output ripple for 12 V in and -12 V at a load current of 3 A which is 115 mV.

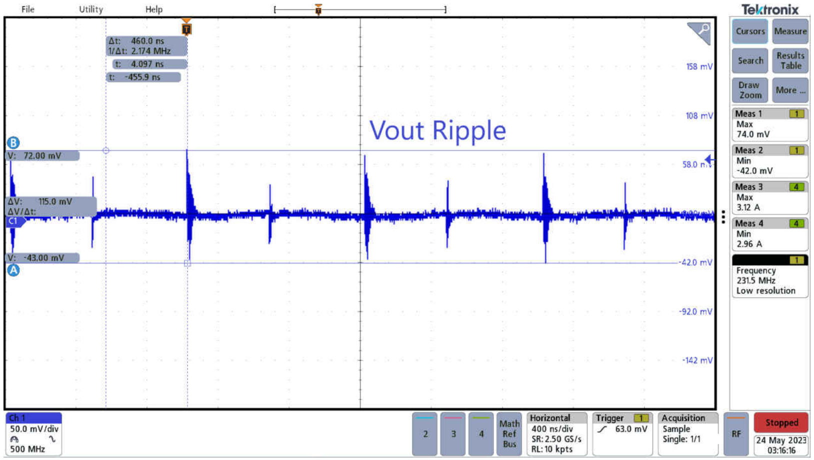

Figure 3-6. 12 V to -12 V (3-A Output Ripple)

Figure 3-7 shows the start-up waveforms of Vin and Vout. Vin takes 12.1 ms to get to 12 V and Vout takes 7.76 ms to get to -12 V.

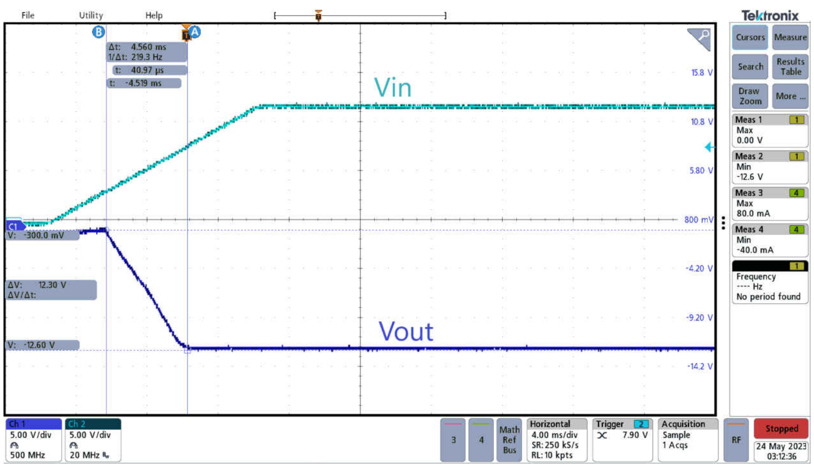

Figure 3-7. -12 V Start-up

Figure 3-8 shows the tested efficiency for the 12 V in and the -6 V out from 100 mA to 3 A.

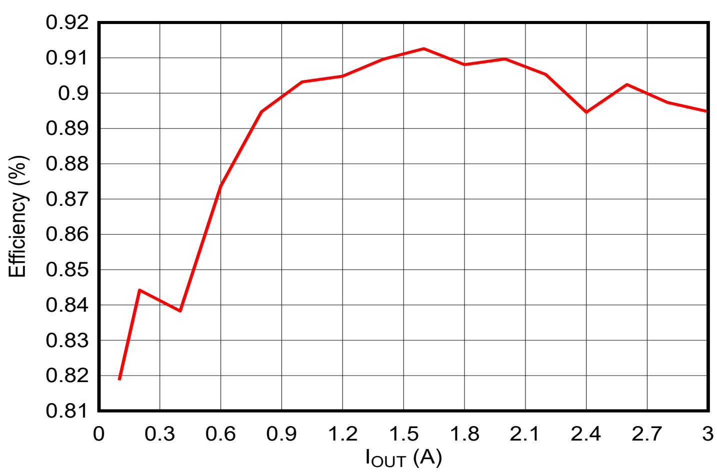

Figure 3-8. 12 V to -6 V Efficiency

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Figure 3-9 shows the transient response for 12 V in and -6 V out. The output current steps from 320 mA to 2.84 A. On the positive edge of the load step, the peak of the transient is 132 mV. On the negative edge, the valley of the transient is -60 mV.

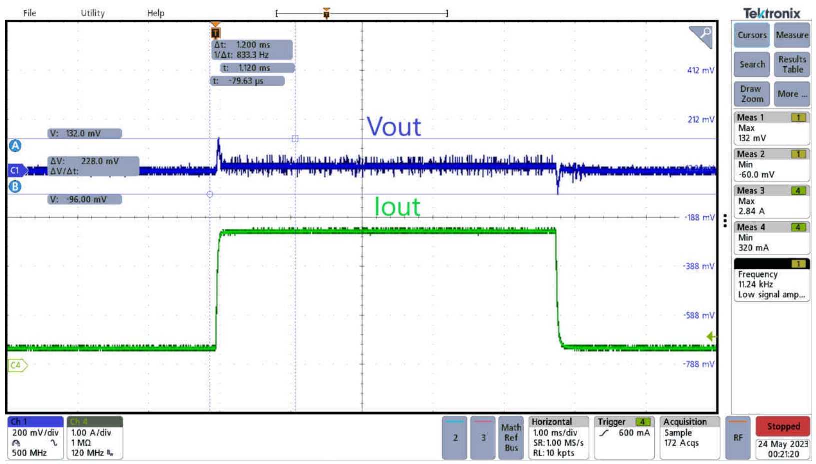

Figure 3-9. 12 V to -6 V Load Transient

Figure 3-10 shows the switch node for 12 V in and -6 V at a load current of 3 A. Switching frequency is 999.8 kHz.

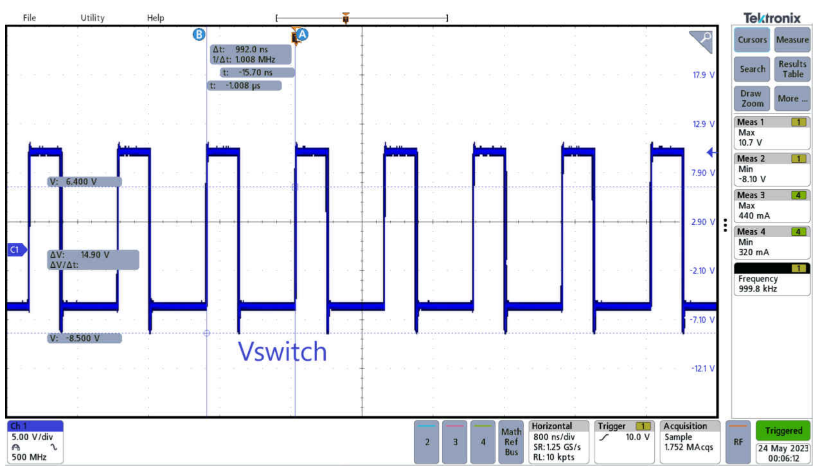

Figure 3-10. 12 V to -6 V Switch Node 3 A

Figure 3-11 shows the input ripple for 12 V in and -6 V at a load current of 3 A which is 214 mV.

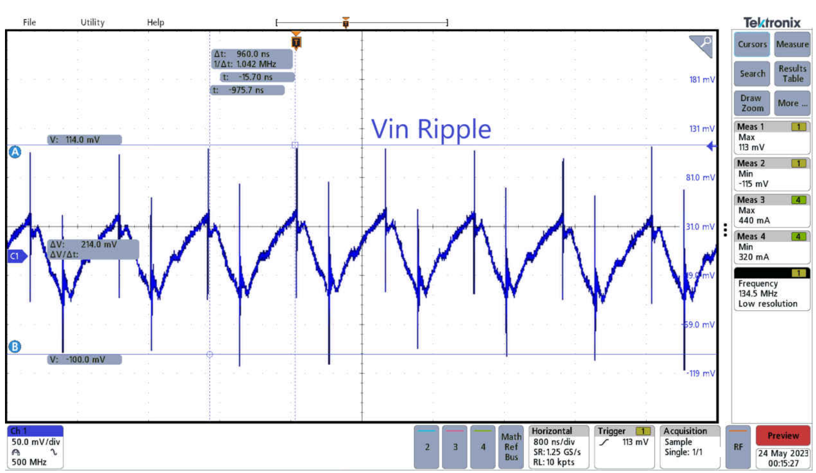

Figure 3-11. 12 V to -6 V Input Ripple 3-A

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Figure 3-12 shows the output ripple for 12 V in and -6 V at a load current of 3 A which is 94 mV.

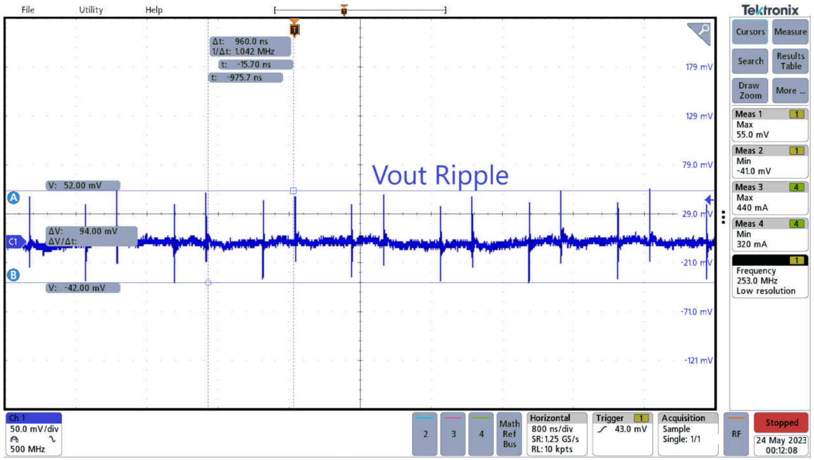

Figure 3-12. 12 V to -6 V Output Ripple 3-A

Figure 3-13 shows the start-up waveforms of Vin and Vout. Vin takes 11.48 ms to get to 12 V and Vout takes 7.48 ms to get to -6 V.

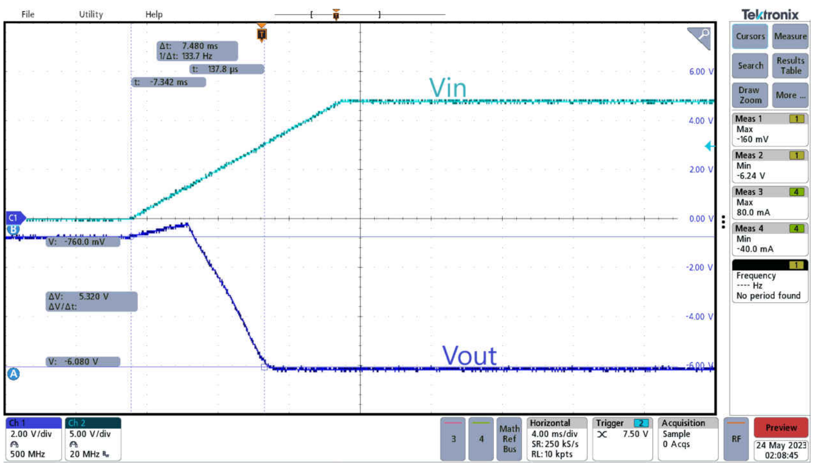

Figure 3-13. 12 V to -6 V Start-up

Figure 3-14 shows the tested efficiency for the 5 V in and the -6 V out from 100 mA to 3 A.

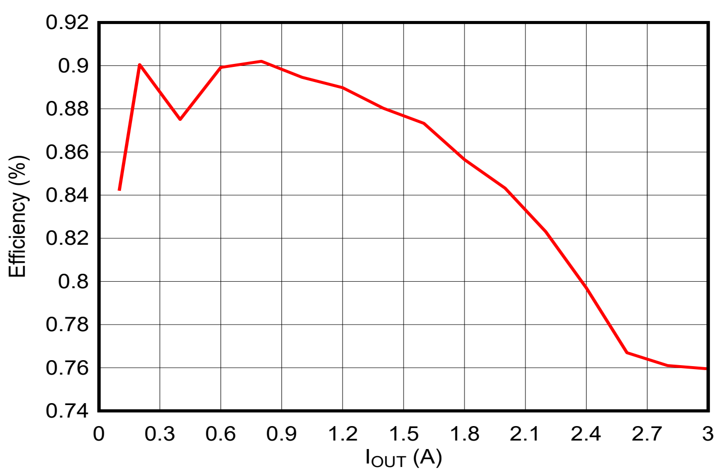

Figure 3-14. 5 V to -6 V Efficiency

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Figure 3-15 shows the transient response for 5 V in and -6 V out. The output current steps from 310 mA to 1.83 A. On the positive edge of the load step, the peak of the transient is 132 mV. On the negative edge, the valley of the transient is -68 mV.

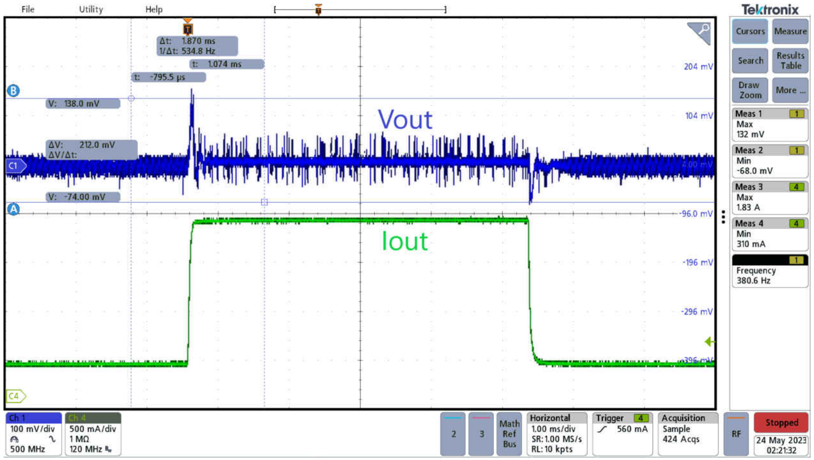

Figure 3-15. 5 V to -6 V Load Transient

Figure 3-16 shows the switch node for 5 V in and -6 V at a load current of 2 A. Switching frequency is 999.8 kHz.

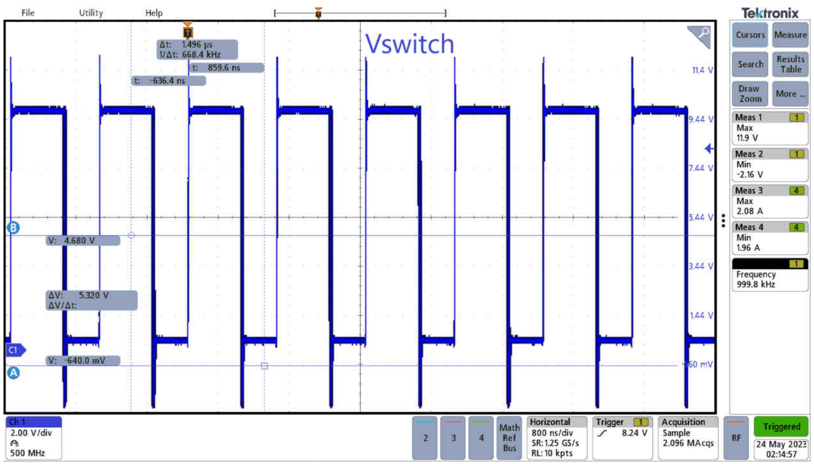

Figure 3-16. 5 V to -6 V Switch Node 2 A

Figure 3-17 shows the input ripple for 5 V in and -6 V at a load current of 2 A which is 224 mV.

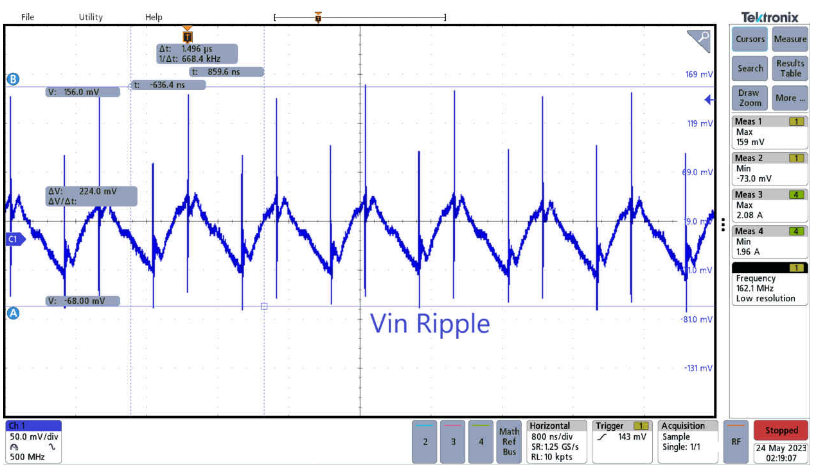

Figure 3-17. 5 V to -6 V Input Ripple 2 A

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Figure 3-18 shows the output ripple for 5 V in and -6 V at a load current of 2 A which is 97 mV.

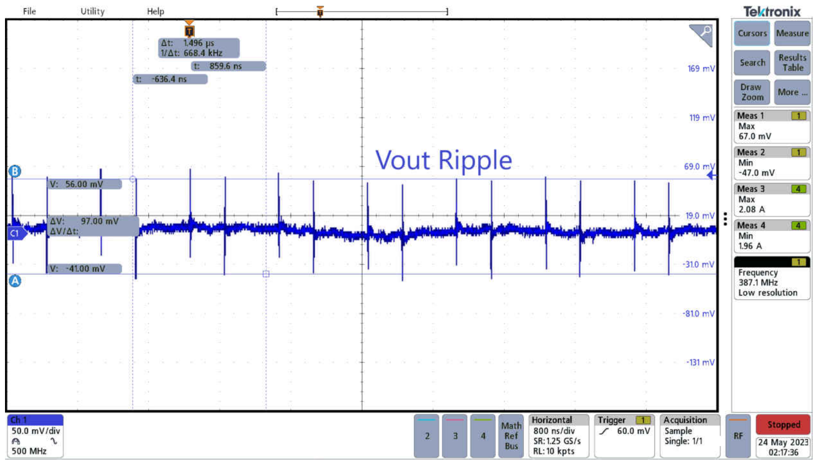

Figure 3-18. 5 V to -6 V Output Ripple 2 A

Figure 3-19 shows the start-up waveforms of Vin and Vout. Vin takes 4.5 ms to get to 5 V and Vout takes 7.7 ms to get to -6 V.

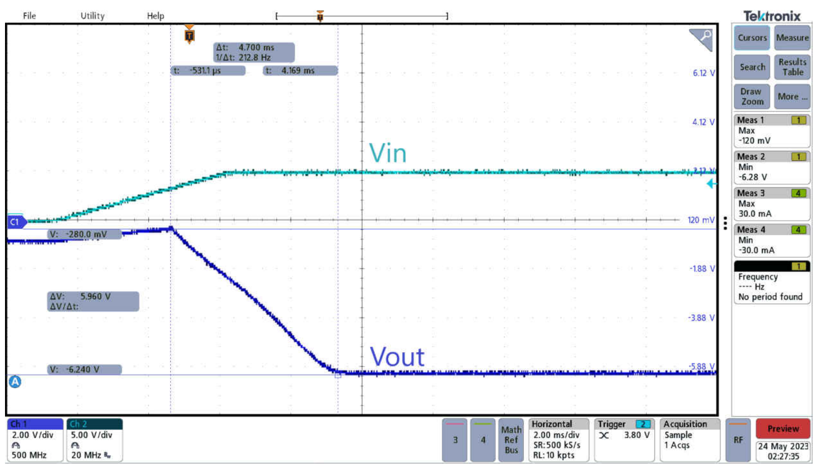

Figure 3-19. 5 V to -6 V Start-up

Figure 3-20 shows the tested efficiency for the 12 V in and the -1.8 V out from 100 mA to 3 A.

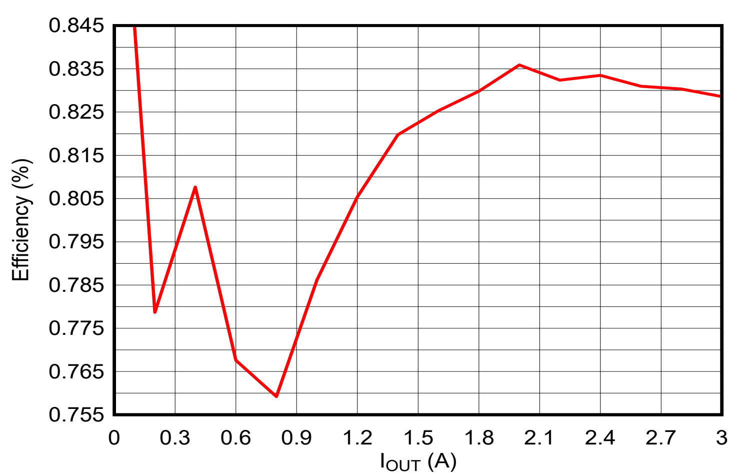

Figure 3-20. 12 V to -1.8 V Efficiency

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Figure 3-21 shows the transient response for 12 V in and -1.8 V out. The output current steps from 320 mA to 2.76 A. On the positive edge of the load step, the peak of the transient is 42 mV. On the negative edge, the valley of the transient is -12 mV

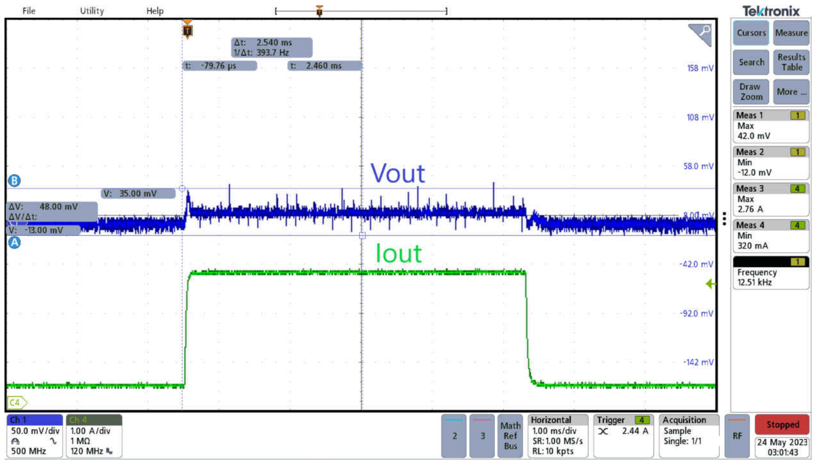

Figure 3-21. 12 V to -1.8 V Load Transient

Figure 3-22 shows the switch node for 12 V in and -1.8 V at a load current of 3 A. Switching frequency is 1.008 MHz.

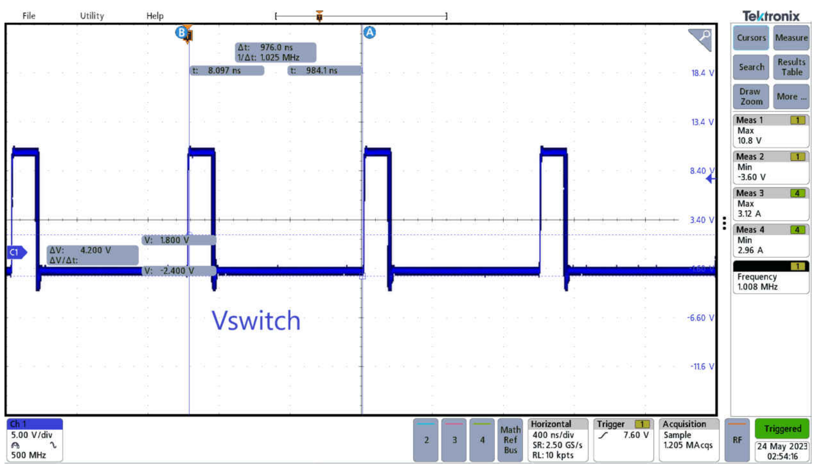

Figure 3-22. 12 V to -1.8 V (Switch Node 3-A)

Figure 3-23 shows the input ripple for 12 V in and -1.8 V at a load current of 3 A which is 190 mV.

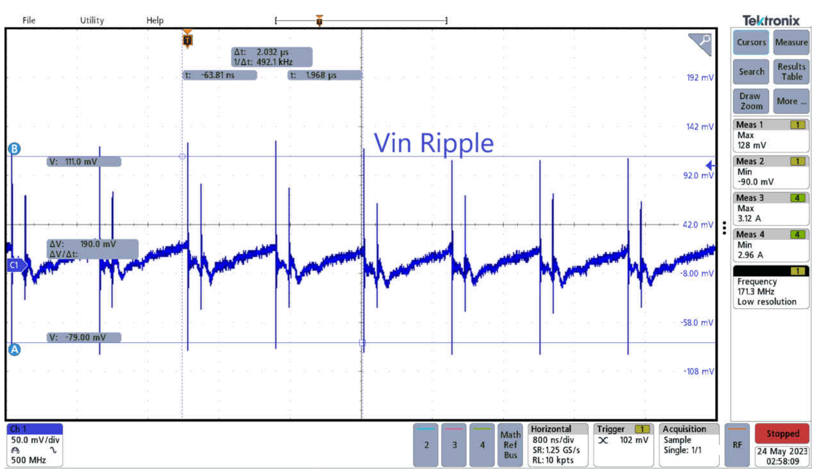

Figure 3-23. 12 V to -1.8 V Input Ripple 3-A

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Figure 3-24 shows the output ripple for 12 V in and -1.8 V at a load current of 3 A which is 48 mV.

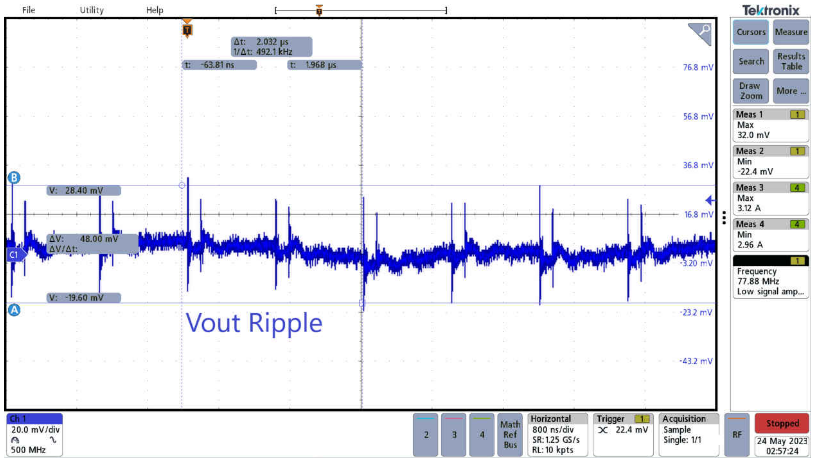

Figure 3-24. 12 V to -1.8 V Output Ripple 3-A

Figure 3-25 shows the start-up waveforms of Vin and Vout. Vin takes 12.2 ms to get to 12 V and Vout takes 7.22 ms to get to -1.8 V.

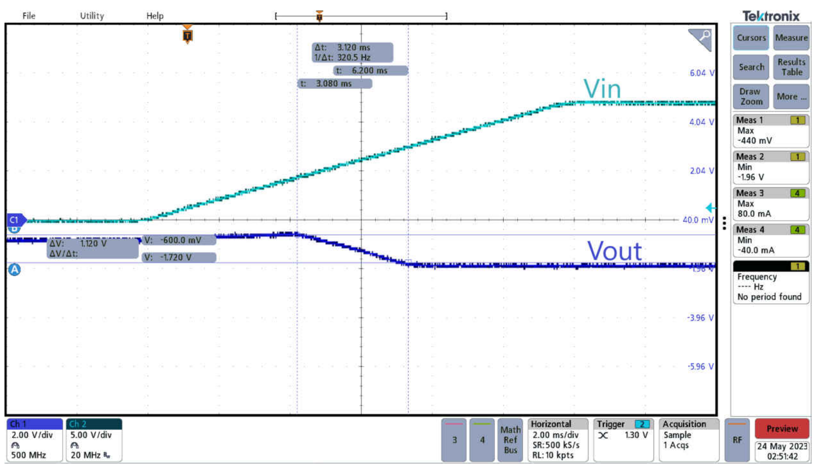

Figure 3-25. 12 V to -1.8 V Start-up

Figure 3-26 shows the tested efficiency for the 5 V in and the -1.8 V out from 100 mA to 3 A.

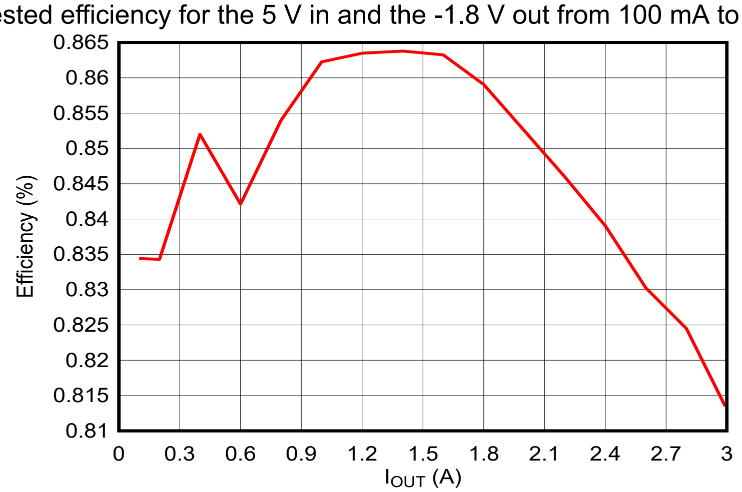

Figure 3-26. 5 V to -1.8 V Efficiency

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Figure 3-27 shows the transient response for 5 V in and -1.8 V out. The output current steps from 320 mA to 2.76 A. On the positive edge of the load step the peak of the transient is 48 mV. On the negative edge the valley of the transient is -16 mV.

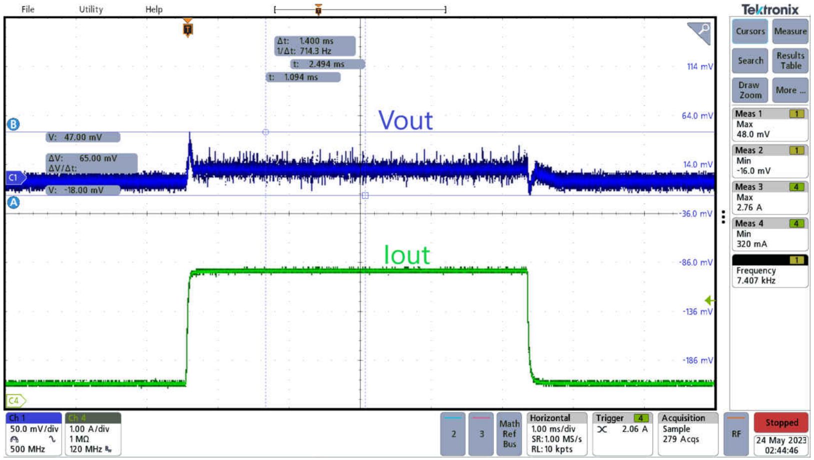

Figure 3-27. 5 V to -1.8 V Transient

Figure 3-28 shows the switch node for 5 V in and -1.8 V at a load current of 3 A. Switching frequency is 1.008 MHz.

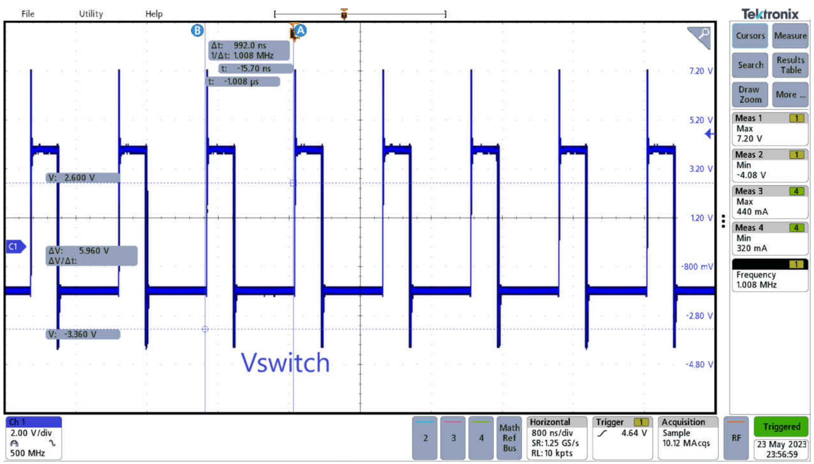

Figure 3-28. 5 V to -6 V Switch Node 3-A

Figure 3-29 shows the input ripple for 5 V in and -1.8 V at a load current of 3 A which is 264 mV.

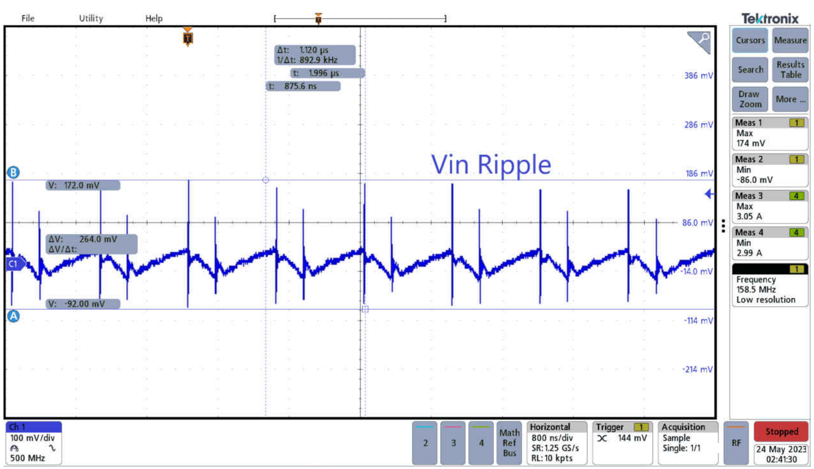

Figure 3-29. 5 V to -1.8 V Input Ripple 3-A

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Figure 3-30 shows the output ripple for 12 V in and -1.8 V at a load current of 3 A which is 80.8 mV.

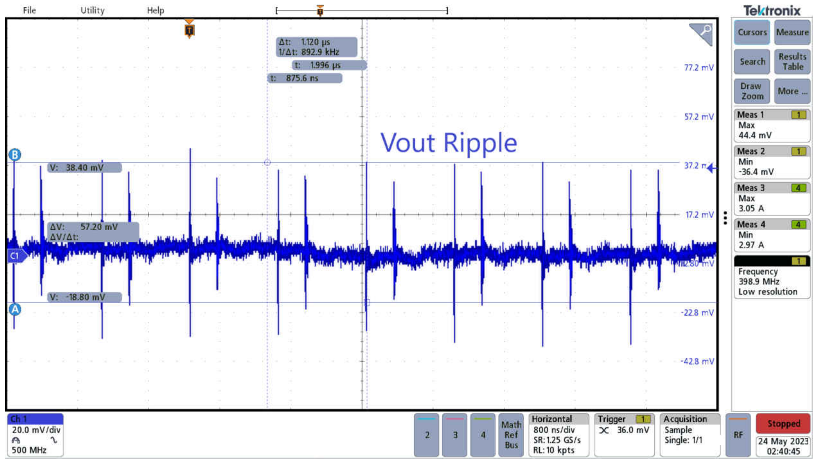

Figure 3-30. 5 V to -1.8 V Output Ripple 3-A

Figure 3-31 shows the start-up waveforms of Vin and Vout. Vin takes 4.4 ms to get to 12 V, and Vout takes 7.6 ms to get to -1.8 V.

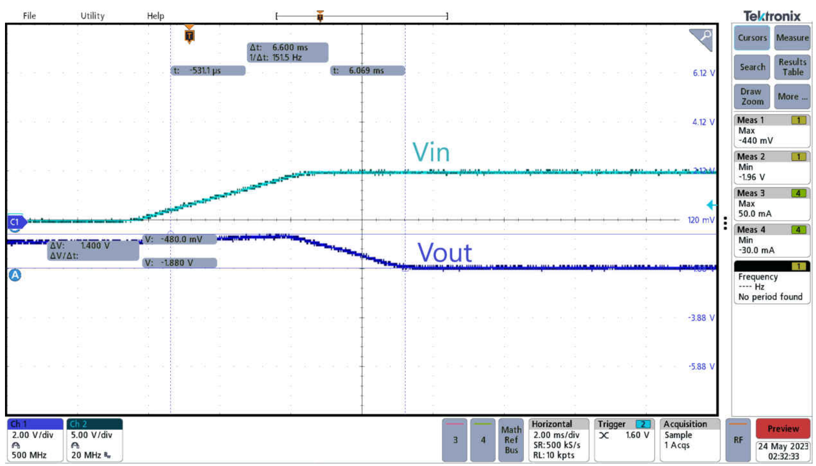

Figure 3-31. 5 V to -1.8 V Start-up (Dark Blue Vout, Light Blue Vin)

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4 Summary

The TPS7H4010-SEP can be configured as an inverting buck-boost converter to generate a negative output voltage. The inverting buck-boost topology changes some system characteristics, such as input voltage range and maximum output current. The TPS7H4010EVM can be reconfigured and modified to test the different characteristics in the inverting buck-boost topology. Measured data from the TPS7H4010EVM is provided to support the device functions with a variety of inputs and outputs in the inverting buck-boost topology.

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5 References

1. Texas Instruments, *TPS7H4010EVM User's Guide*, user's guide.
2. Texas Instruments, *TPS7H4010-SEP Radiation Hardened 3.5-V to 32-V, 6-A Synchronous Step-Down Voltage Converter in Space Enhanced Plastic*, data sheet.
3. Texas Instruments, *Using the TPS629210-Q1 in an Inverting Buck – Boost Topology*, application note.
4. Texas Instruments, *TPS7H4010-SEP Total Ionizing Dose (TID) Radiation Report*, radiation and reliability report
5. Texas Instruments, *Single-Event Effects Test Report of the TPS7H4010-SEP (Rev. A)*, radiation and reliability report.

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