

65-W USB Type-C® ZVS-Flyback Reference Design



1 Description

This reference design is a low-cost, high-density USB adapter that uses the UCC28782 active-clamp flyback controller and UCC5304 isolated driver in a ZVS-flyback topology. The maximum power rating is 65 W at 20-V output but is adjustable for 20-, 15-, 9-, and 5-V output voltage and 3 A. This design reaches a peak efficiency of 93.4%. The average efficiency and standby power levels are designed to meet DoE level VI and CoC Tier 2 limits. The compact design has dimensions of 44 mm × 54 mm × 20 mm (48cc open frame).

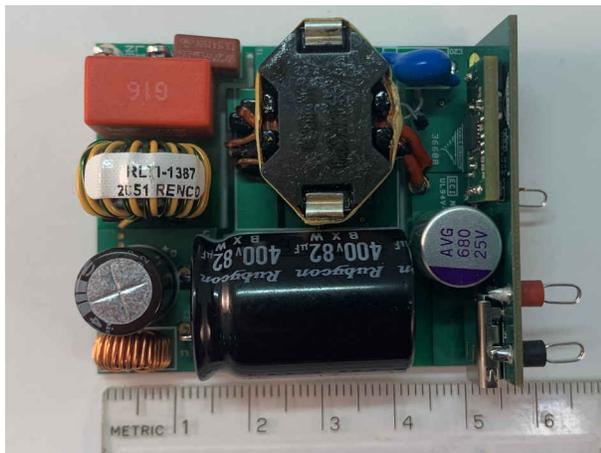


Figure 1-1. Top View of Assembly

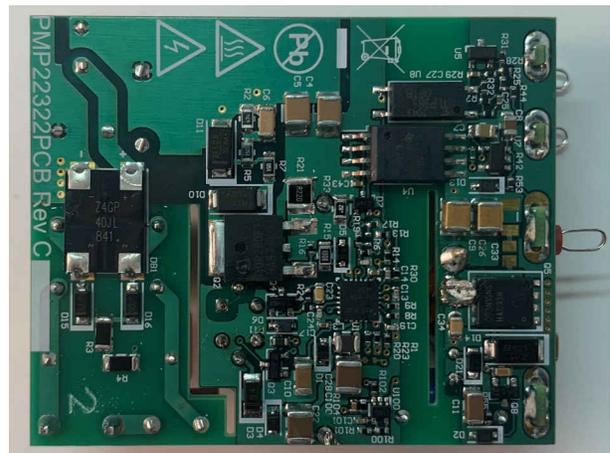


Figure 1-2. Bottom View of Assembly

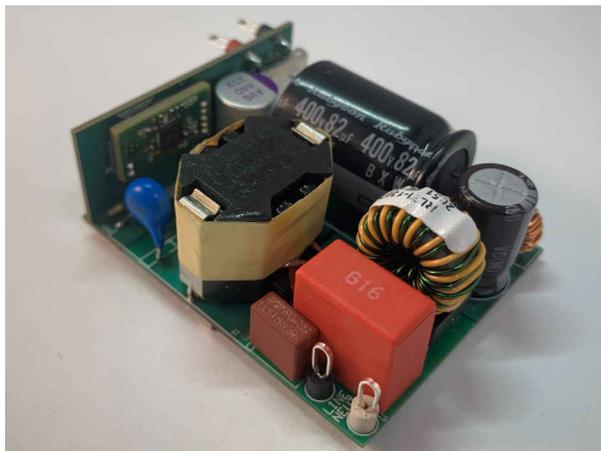


Figure 1-3. Angle View of Assembly



Figure 1-4. Angle View of Assembly

2 Test Prerequisites

2.1 Voltage and Current Requirements

Table 2-1. Voltage and Current Requirements

Parameter	Specifications
Input voltage range	90 VAC–265 VAC, 50 Hz, 60 Hz
Output voltage range	5 V–20 V
Maximum output current	3.25 A
Maximum output power	65 W

2.2 Dimensions

44 mm × 54 mm × 20 mm

3 Testing and Results

3.1 Switching Frequency

The switching frequency of the UCC28782 is variable due to the transition mode method of control. Frequency increases with decreasing load, and is higher with higher input voltages. The maximum frequency is limited at lighter loads by the adaptive burst mode of operation.

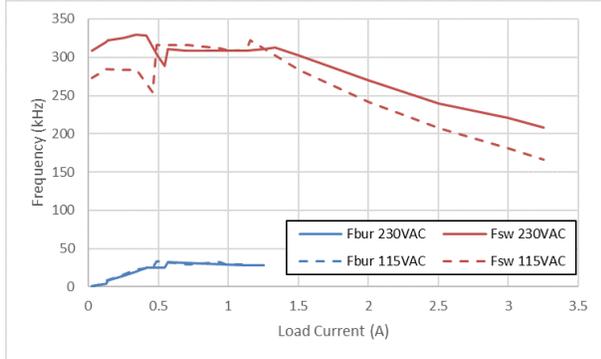


Figure 3-1. 20-V Switching and Burst Frequencies

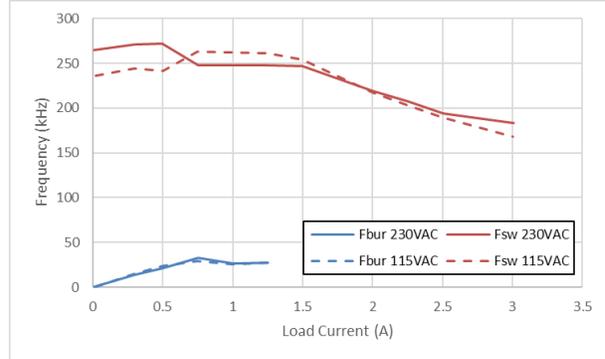


Figure 3-2. 15-V Switching and Burst Frequencies

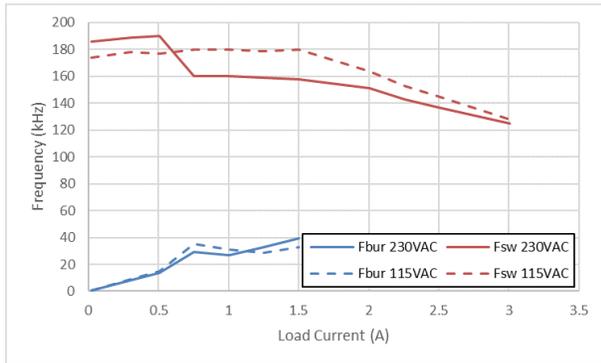


Figure 3-3. 9-V Switching and Burst Frequencies

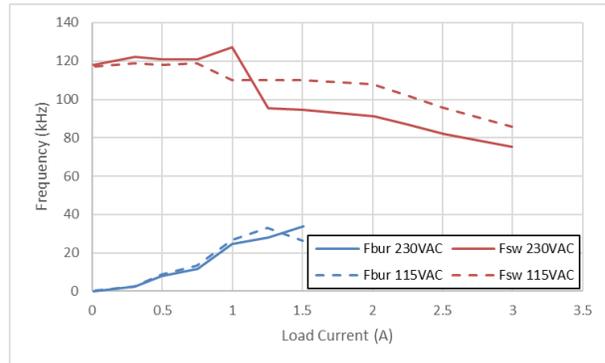


Figure 3-4. 5-V Switching and Burst Frequencies

3.2 Standby Power Consumption

For standby mode, the output cable was unplugged and the input power was measured.

V _{IN} (VAC)	Line Frequency (Hz)	P _{IN} (mW)
115	60	33.8
230	50	36.5

3.3 Tiny Load Power Consumption

For a tiny load, the output voltage was set to 20 V and loaded with 250 mW, and the input power was measured.

V _{IN} (VAC)	Line Frequency (Hz)	P _{IN} (mW)	Efficiency (%)
115	60	399	62.7
230	50	424	59.0

3.4 Average and 10% Load Efficiency

Average efficiency is the average of four efficiency measurements taken at 25%, 50%, 75%, and 100% rated load current.

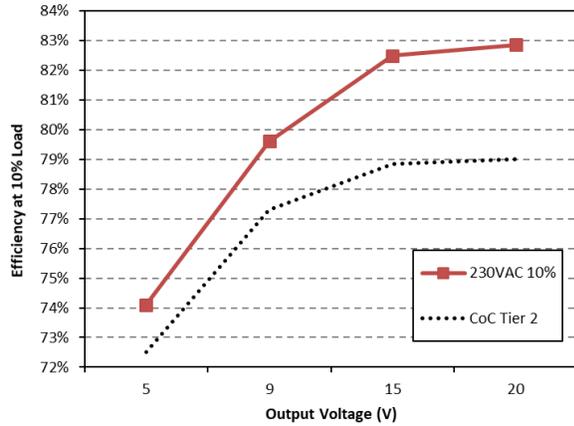


Figure 3-5. 10% Load Efficiency

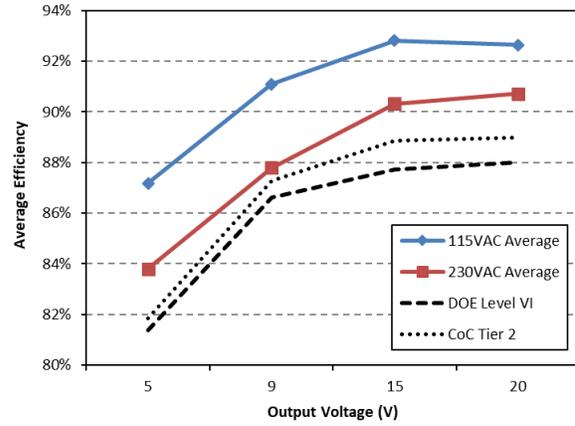


Figure 3-6. Average Efficiency

3.5 Efficiency Graphs

Efficiency and power loss for different output voltages are shown in the following images.

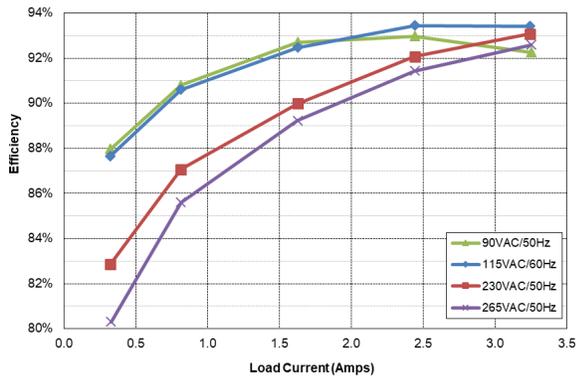


Figure 3-7. 20-V Output Efficiency

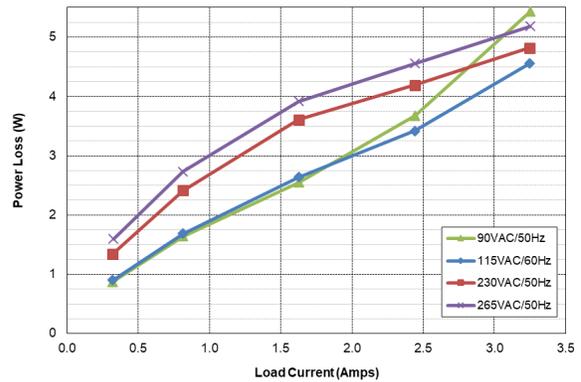


Figure 3-8. 20-V Output Power Loss

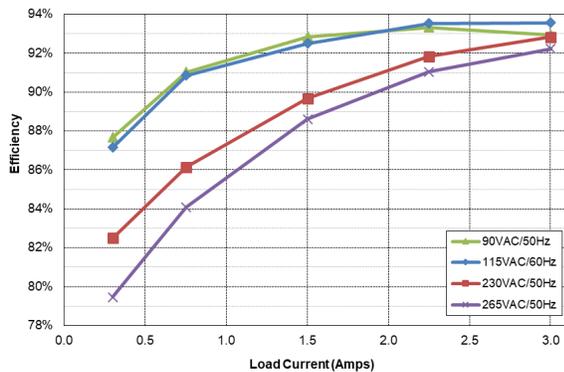


Figure 3-9. 15-V Output Efficiency

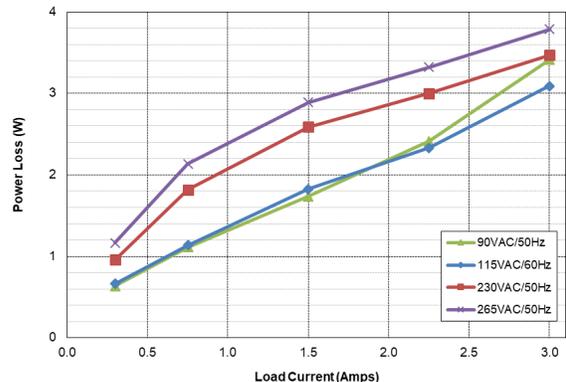


Figure 3-10. 15-V Output Power Loss

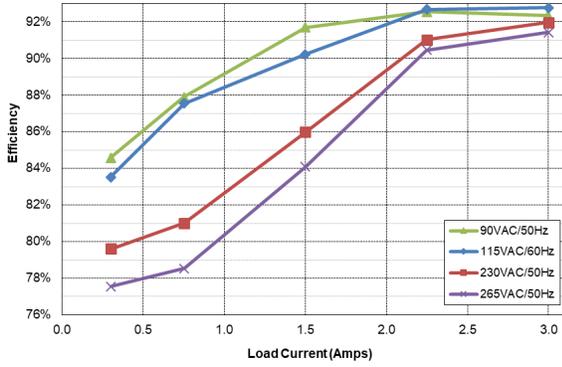


Figure 3-11. 9-V Output Efficiency

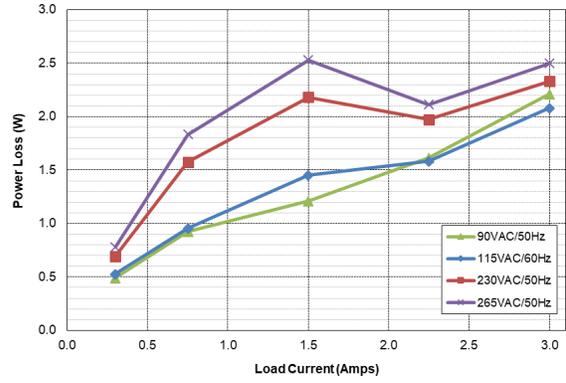


Figure 3-12. 9-V Output Power Loss

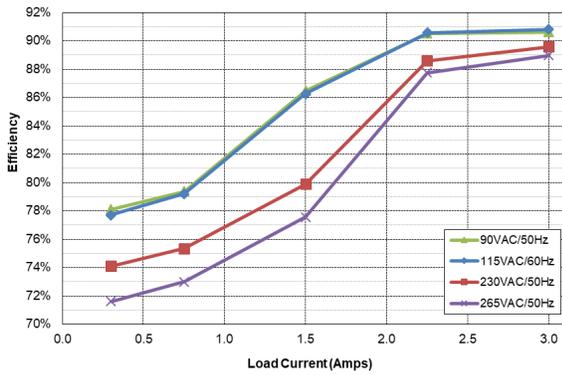


Figure 3-13. 5-V Output Efficiency

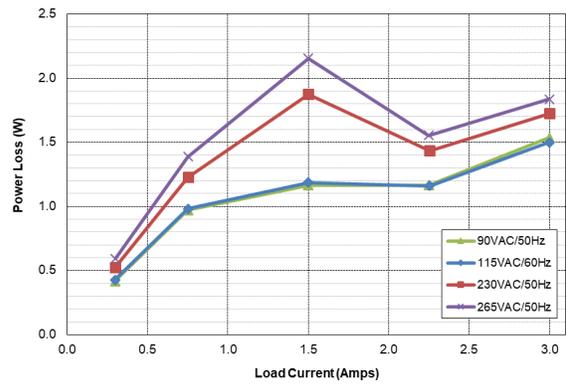


Figure 3-14. 5-V Output Power Loss

3.6 Thermal Images

All images captured with the UUT enclosed in a 30 cm × 45 cm × 20 cm plexiglass box, 25°C ambient, after a 30-minute warm up. The output was set to 20 V and loaded with 3.25 A.



Figure 3-15. 90 VAC, 50-Hz Input, Top View

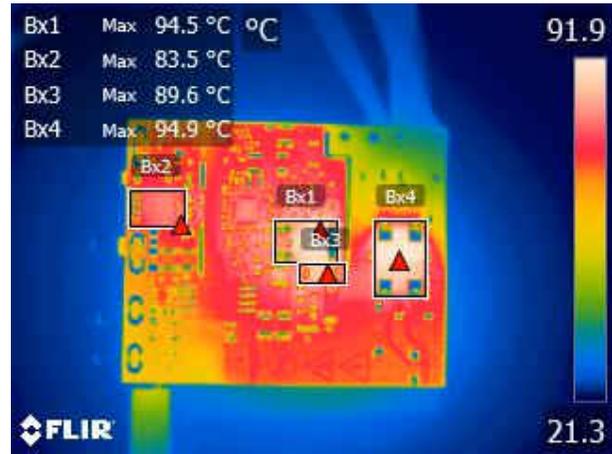


Figure 3-16. 90 VAC, 50-Hz Input, Bottom View

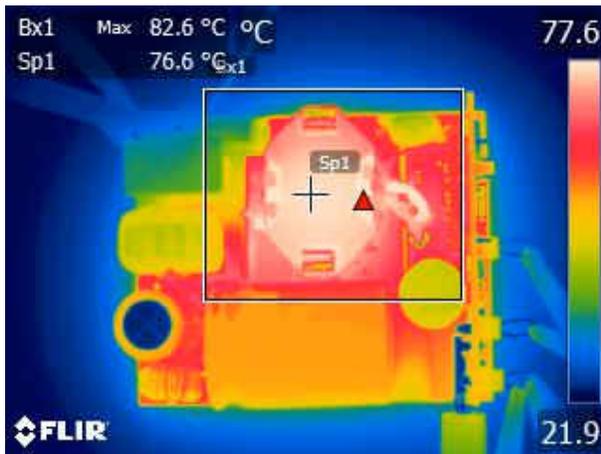


Figure 3-17. 115 VAC, 60-Hz Input, Top View

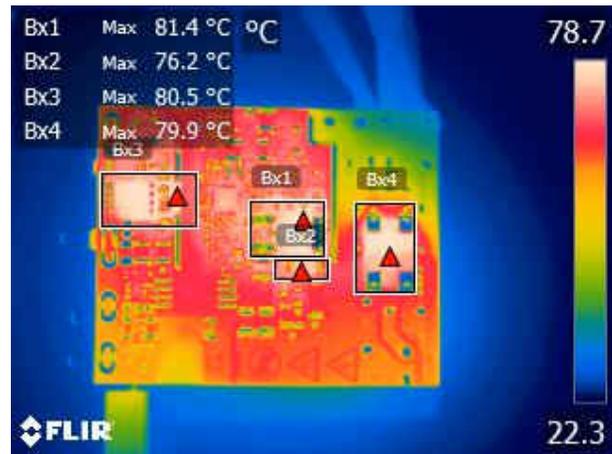


Figure 3-18. 115 VAC, 60-Hz Input, Bottom View

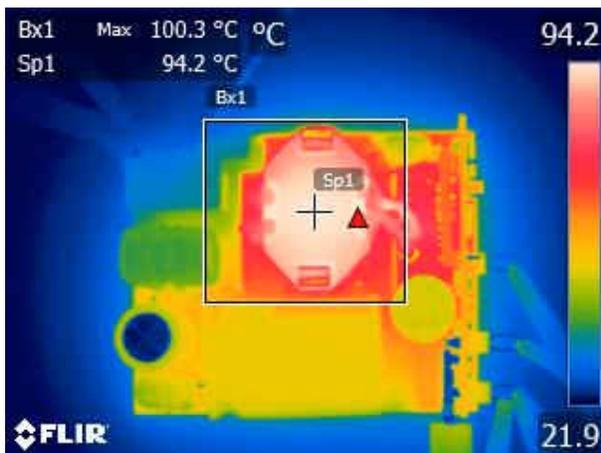


Figure 3-19. 230 VAC, 50-Hz Input, Top View

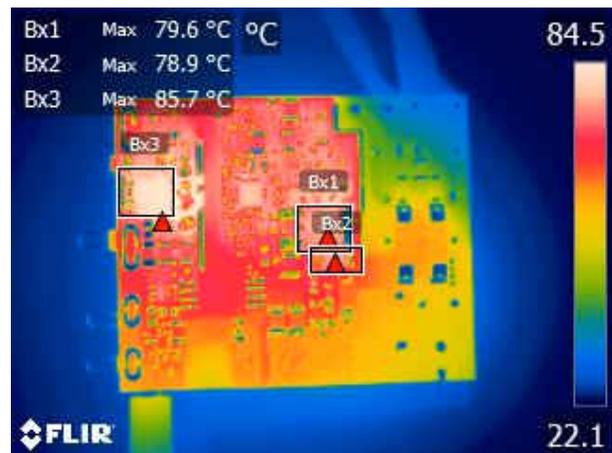


Figure 3-20. 230 VAC, 50-Hz Input, Bottom View

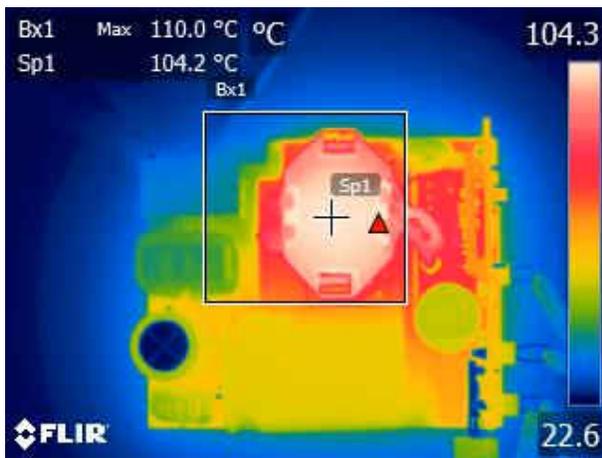


Figure 3-21. 265 VAC, 50-Hz Input, Top View

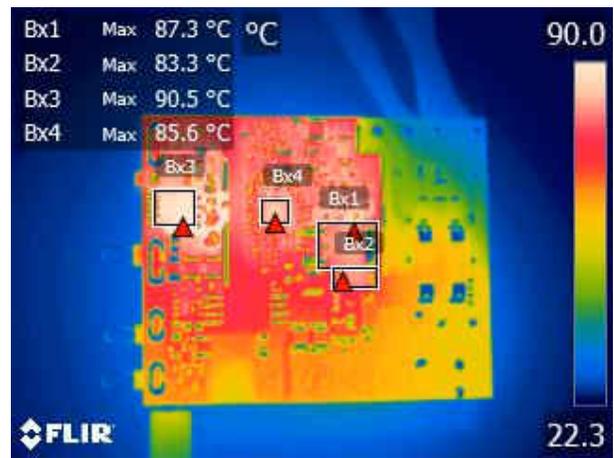
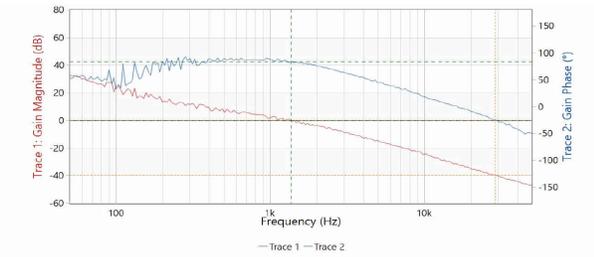


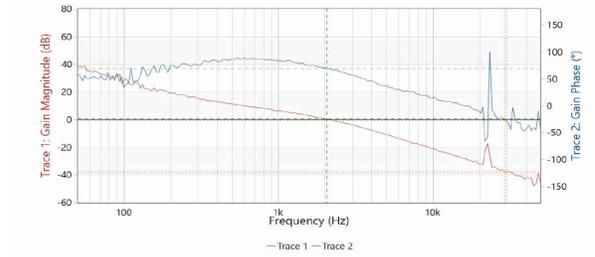
Figure 3-22. 265 VAC, 50-Hz Input, Bottom View

3.7 Bode Plots



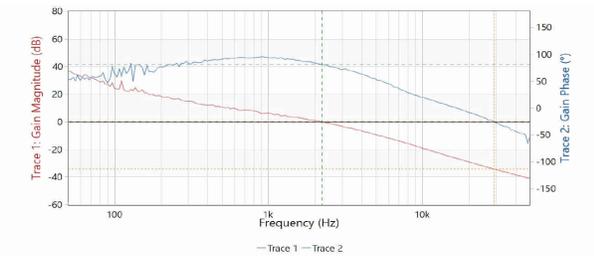
	Cursor 1	Cursor 2	Delta C2-C1
Frequency	1.363 kHz	28.966 kHz	27.602 kHz
Trace 1	Magnitude (dB)	Magnitude (dB)	Magnitude (dB)
Measurement	-121.122 mdB	-40.057 dB	-39.936 dB
Trace 2	Phase (°)	Phase (°)	Phase (°)
Measurement	84.291 °	-25.223 °	-109.614 °

Figure 3-23. 20 V, 3.25-A Output, 115 VAC, 60-Hz Input



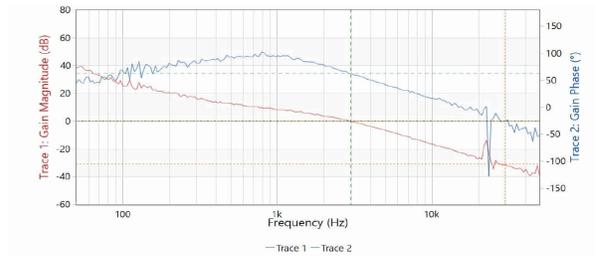
	Cursor 1	Cursor 2	Delta C2-C1
Frequency	2.042 kHz	29.595 kHz	27.553 kHz
Trace 1	Magnitude (dB)	Magnitude (dB)	Magnitude (dB)
Measurement	415.239 mdB	-37.861 dB	-38.276 dB
Trace 2	Phase (°)	Phase (°)	Phase (°)
Measurement	70.128 °	-26.763 °	-96.891 °

Figure 3-24. 20 V, 3.25-A Output, 230 VAC, 50-Hz Input



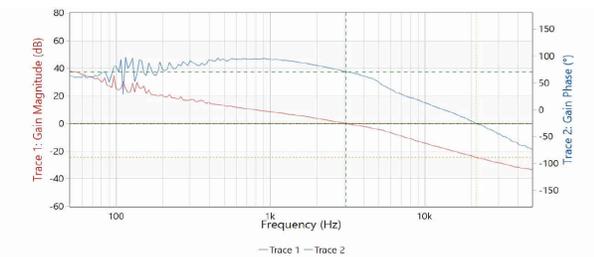
	Cursor 1	Cursor 2	Delta C2-C1
Frequency	2.225 kHz	29.09 kHz	26.865 kHz
Trace 1	Magnitude (dB)	Magnitude (dB)	Magnitude (dB)
Measurement	262.966 mdB	-34.064 dB	-34.327 dB
Trace 2	Phase (°)	Phase (°)	Phase (°)
Measurement	81.201 °	-25.289 °	-106.49 °

Figure 3-25. 15 V, 3-A Output, 115 VAC, 60-Hz Input



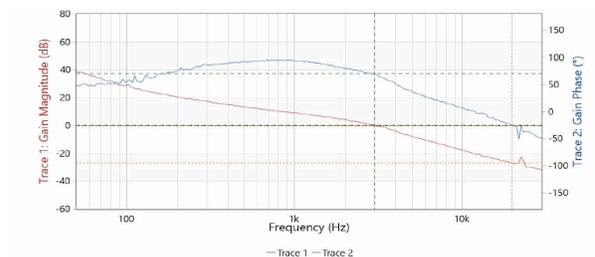
	Cursor 1	Cursor 2	Delta C2-C1
Frequency	2.993 kHz	29.722 kHz	26.729 kHz
Trace 1	Magnitude (dB)	Magnitude (dB)	Magnitude (dB)
Measurement	-158.664 mdB	-30.966 dB	-30.807 dB
Trace 2	Phase (°)	Phase (°)	Phase (°)
Measurement	62.458 °	-26.066 °	-88.524 °

Figure 3-26. 15 V, 3-A Output, 230 VAC, 50-Hz Input



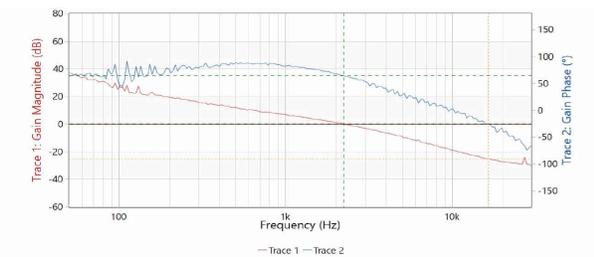
	Cursor 1	Cursor 2	Delta C2-C1
Frequency	3.085 kHz	21.531 kHz	18.446 kHz
Trace 1	Magnitude (dB)	Magnitude (dB)	Magnitude (dB)
Measurement	78.996 mdB	-24.321 dB	-24.4 dB
Trace 2	Phase (°)	Phase (°)	Phase (°)
Measurement	71.07 °	-25.06 °	-96.131 °

Figure 3-27. 9 V, 3-A Output, 115 VAC, 60-Hz Input



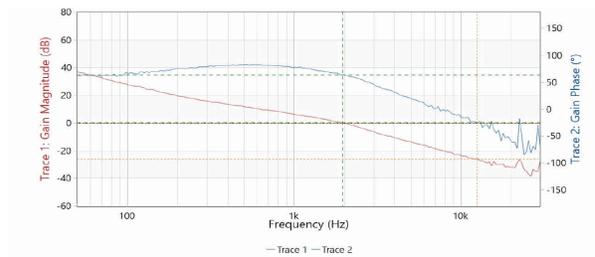
	Cursor 1	Cursor 2	Delta C2-C1
Frequency	2.993 kHz	19.83 kHz	16.837 kHz
Trace 1	Magnitude (dB)	Magnitude (dB)	Magnitude (dB)
Measurement	322.802 mdB	-26.956 dB	-27.279 dB
Trace 2	Phase (°)	Phase (°)	Phase (°)
Measurement	70.981 °	-26.097 °	-97.078 °

Figure 3-28. 9 V, 3-A Output, 230 VAC, 50-Hz Input



	Cursor 1	Cursor 2	Delta C2-C1
Frequency	2.23 kHz	16.578 kHz	14.348 kHz
Trace 1	Magnitude (dB)	Magnitude (dB)	Magnitude (dB)
Measurement	139.779 mdB	-25.217 dB	-25.357 dB
Trace 2	Phase (°)	Phase (°)	Phase (°)
Measurement	65.076 °	-25.088 °	-90.164 °

Figure 3-29. 5 V, 3-A Output, 115 VAC, 60-Hz Input



	Cursor 1	Cursor 2	Delta C2-C1
Frequency	1.955 kHz	12.546 kHz	10.591 kHz
Trace 1	Magnitude (dB)	Magnitude (dB)	Magnitude (dB)
Measurement	126.623 mdB	-25.878 dB	-26.004 dB
Trace 2	Phase (°)	Phase (°)	Phase (°)
Measurement	64.078 °	-25.92 °	-89.998 °

Figure 3-30. 5 V, 3-A Output, 230 VAC, 50-Hz Input

3.8 EMI

Conducted EMI measured with a 20 V, 3.25-A output are shown in the following figures. The output was tied to Earth ground.

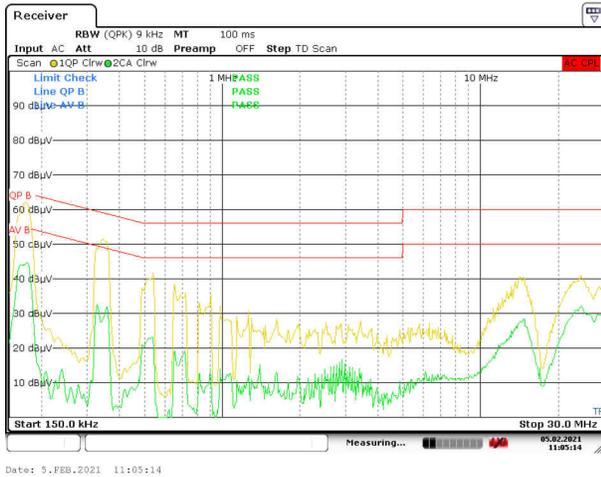


Figure 3-31. 115 VAC, 60-Hz Input

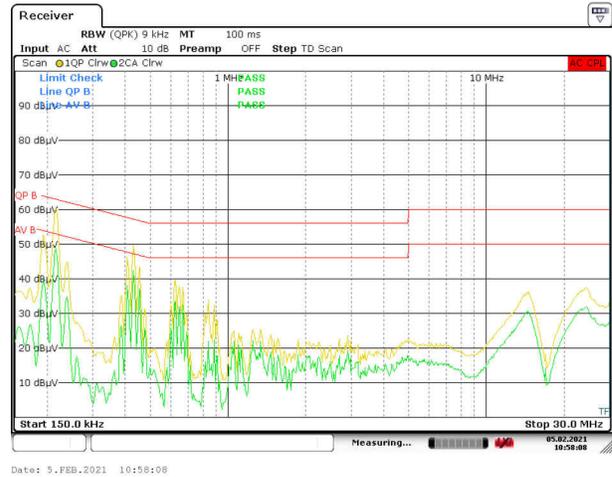


Figure 3-32. 230 VAC, 50-Hz Input

4 Waveforms

4.1 Switching

Switching behavior at 265 VAC, 50-Hz input is shown in the following figures. The highest voltage stress on both primary and secondary FETs occurs at highest input voltage and highest output voltage conditions. The voltage stress is highest on the synchronous rectifier (SR) FET during light loads when the UCC28782 disables ZVS operation to improve light load efficiency. At this condition, the non-ZVS results in a low-energy, high frequency spike on the drain of the SR FET.

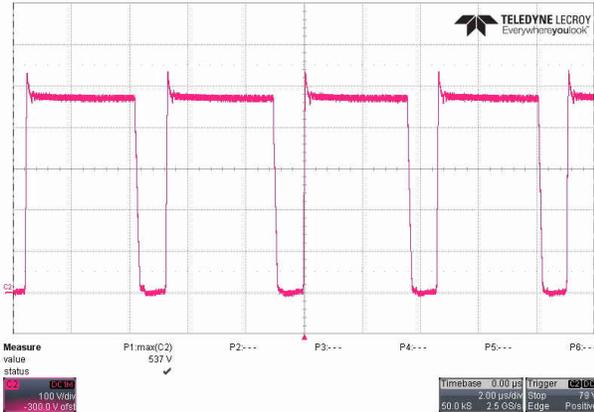


Figure 4-1. Primary FET (Q2) Drain-Source Voltage at 20 V, 3.25-A Output

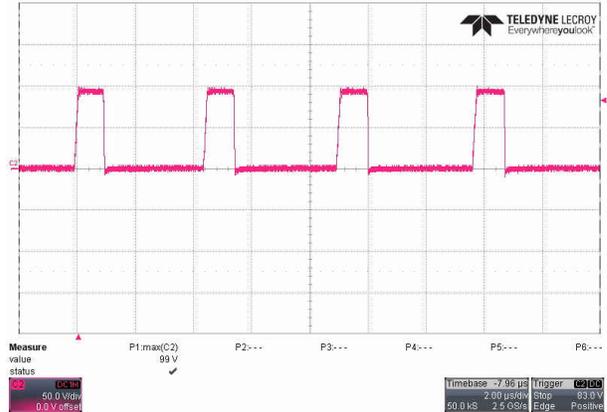


Figure 4-2. SR FET (Q5) Drain-Source Voltage at 20 V, 3.25-A Output

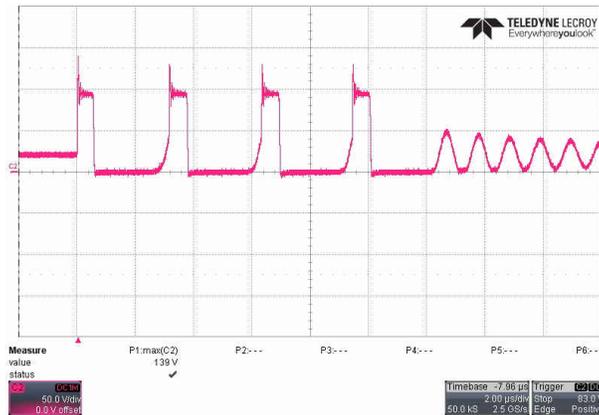


Figure 4-3. SR FET (Q5) Drain-Source Voltage at 20 V, 0-A Output

4.2 Output Voltage Ripple

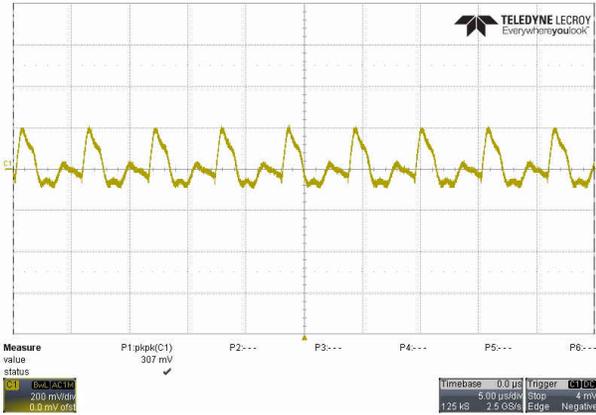


Figure 4-4. 20 V, 3.25-A Output, 115 VAC, 60-Hz Input

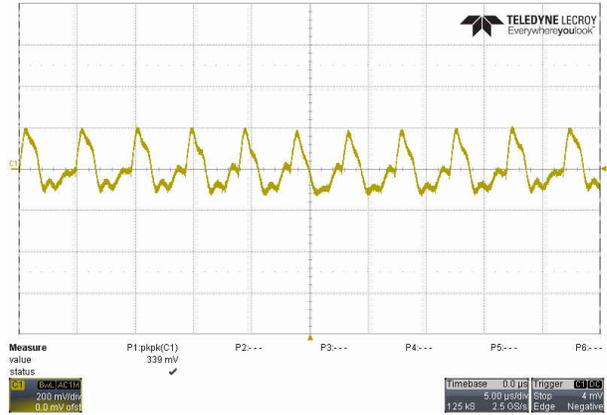


Figure 4-5. 20 V, 3.25-A Output, 230 VAC, 50-Hz Input

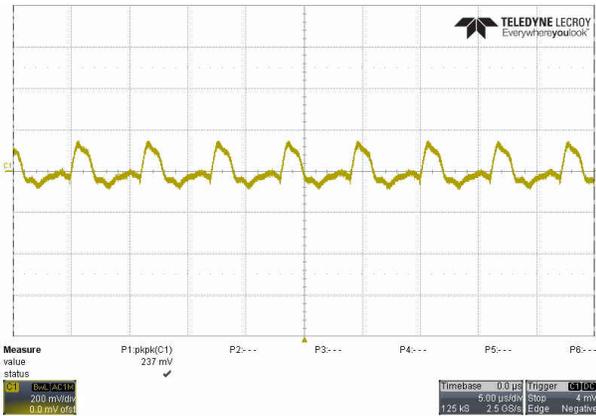


Figure 4-6. 15 V, 3-A Output, 115 VAC, 60-Hz Input

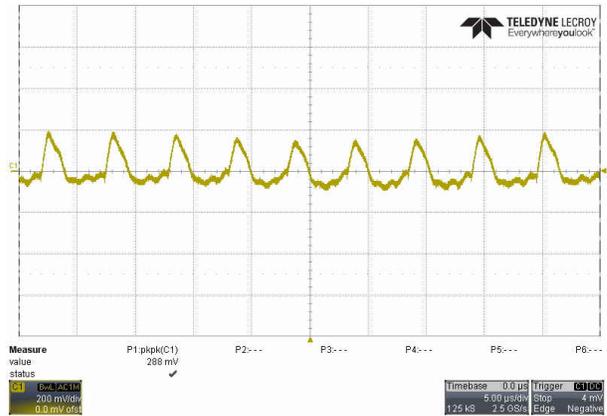


Figure 4-7. 15 V, 3-A Output, 230 VAC, 50-Hz Input

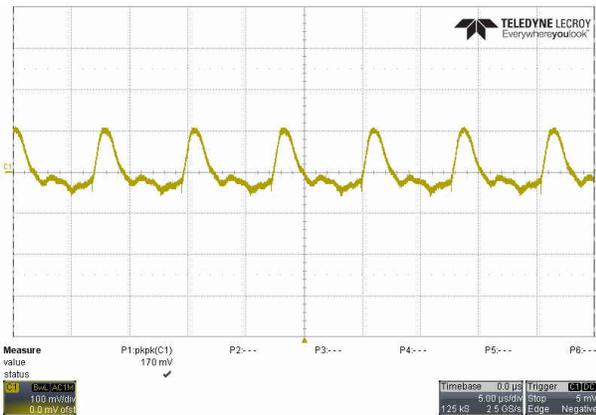


Figure 4-8. 9 V, 3-A Output, 115 VAC, 60-Hz Input

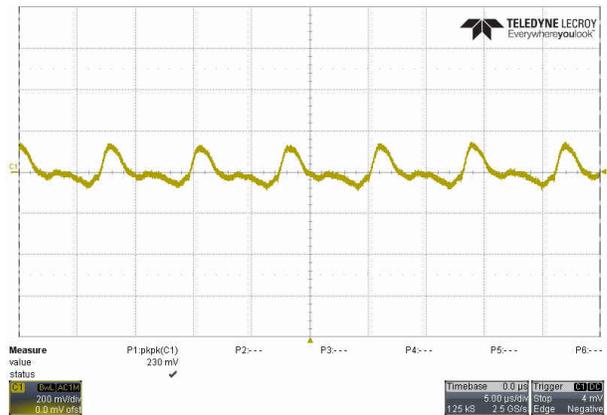


Figure 4-9. 9 V, 3-A Output, 230 VAC, 50-Hz Input

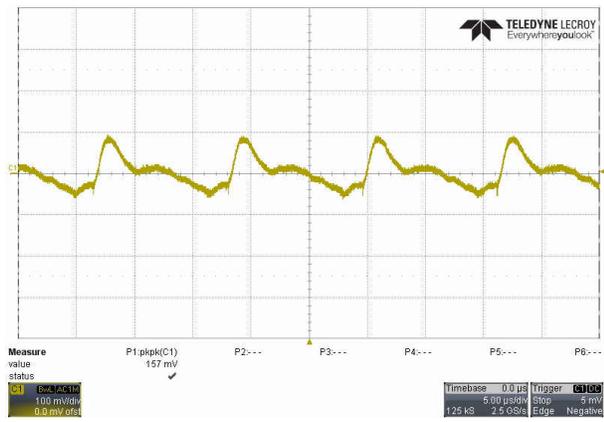


Figure 4-10. 5 V, 3-A Output, 115 VAC, 60-Hz Input

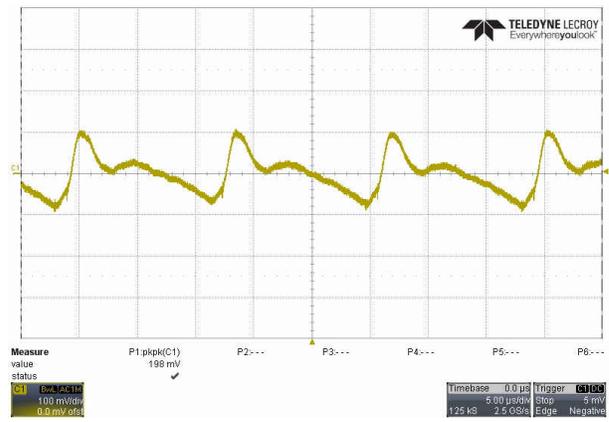


Figure 4-11. 5 V, 3-A Output, 230 VAC, 50-Hz Input

4.3 Load Transients

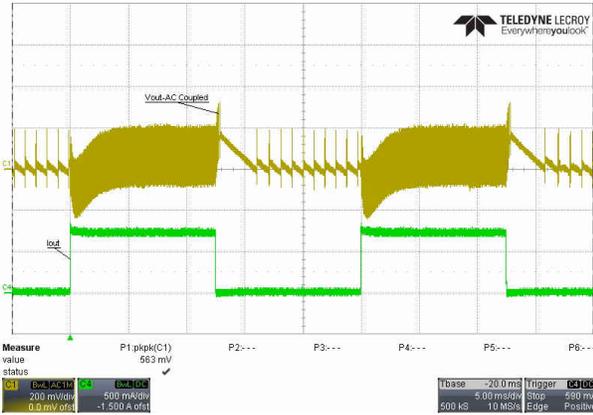


Figure 4-12. 20-V Output, 0 A to 0.75 A, 115 VAC, 60 Hz

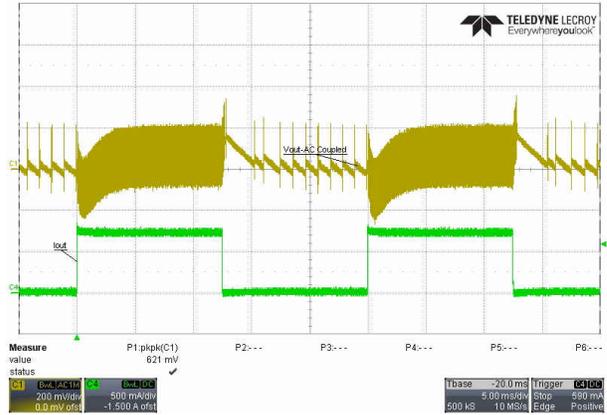


Figure 4-13. 20-V Output, 0 A to 0.75 A, 230 VAC, 50 Hz

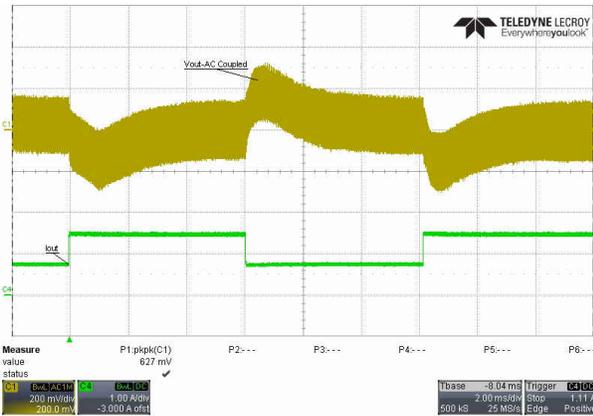


Figure 4-14. 20-V Output, 0.75 A to 1.5 A, 115 VAC, 60 Hz

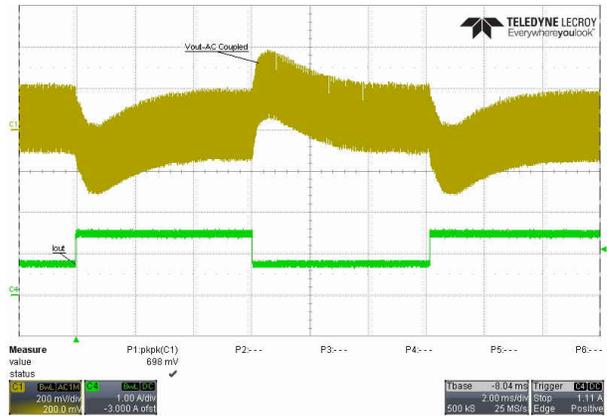


Figure 4-15. 20-V Output, 0.75 A to 1.5 A, 230 VAC, 50 Hz

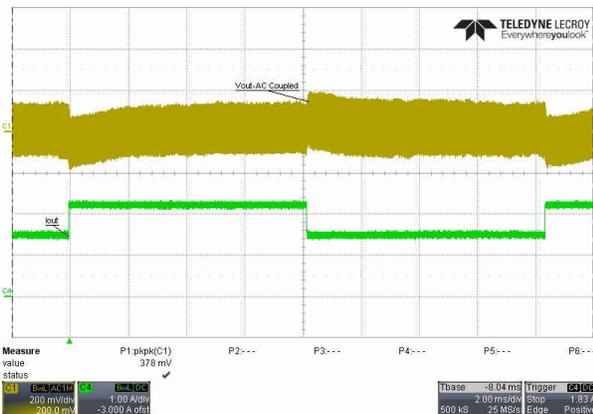


Figure 4-16. 20-V Output, 1.5 A to 2.25 A, 115 VAC, 60 Hz

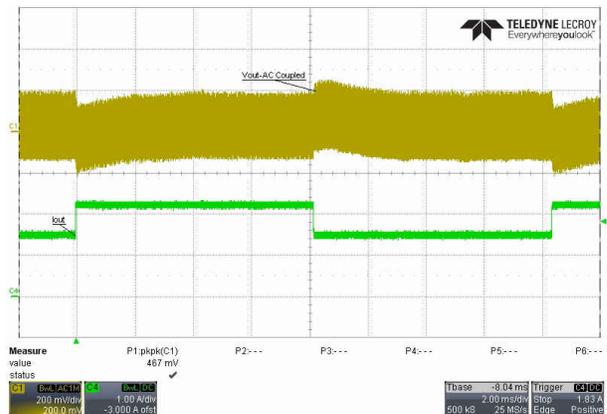


Figure 4-17. 20-V Output, 1.5 A to 2.25 A, 230 VAC, 50 Hz

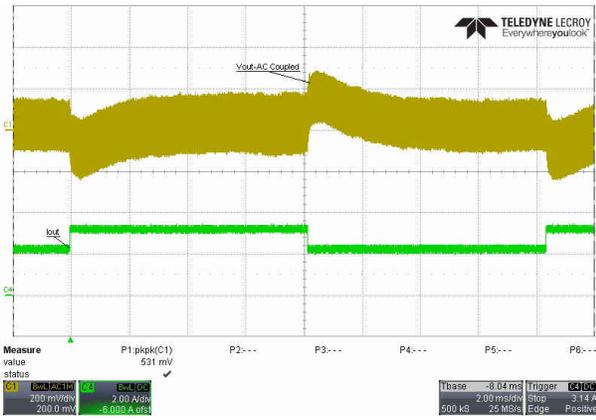


Figure 4-18. 20-V Output, 2.25 A to 3.25 A, 115 VAC, 60 Hz

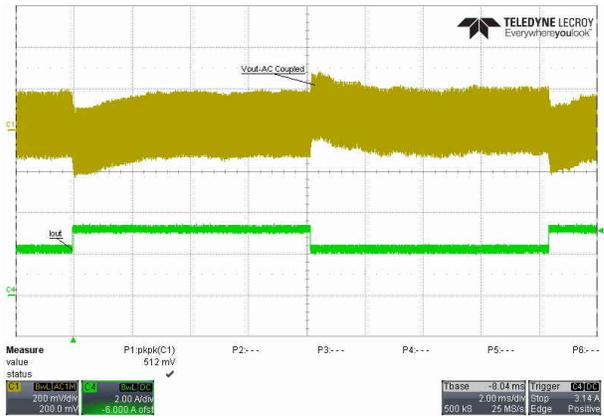


Figure 4-19. 20-V Output, 2.25 A to 3.25 A, 230 VAC, 50 Hz

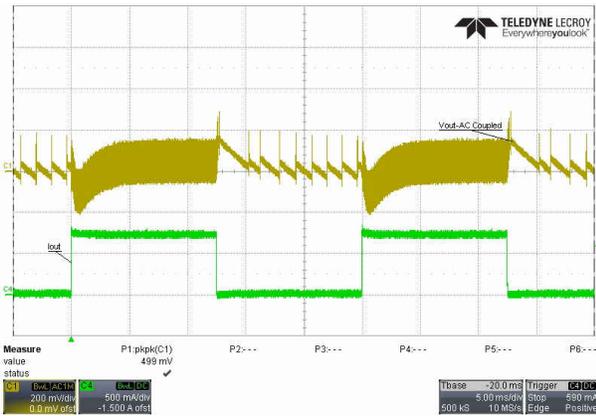


Figure 4-20. 15-V Output, 0 A to 0.75 A, 115 VAC, 60 Hz

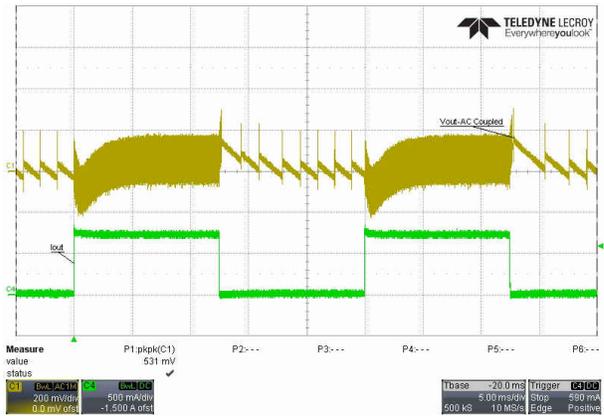


Figure 4-21. 15-V Output, 0 A to 0.75 A, 230 VAC, 50 Hz

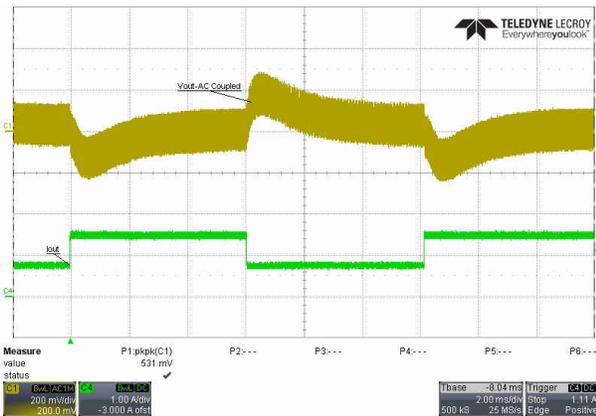


Figure 4-22. 15-V Output, 0.75 A to 1.5 A, 115 VAC, 60 Hz

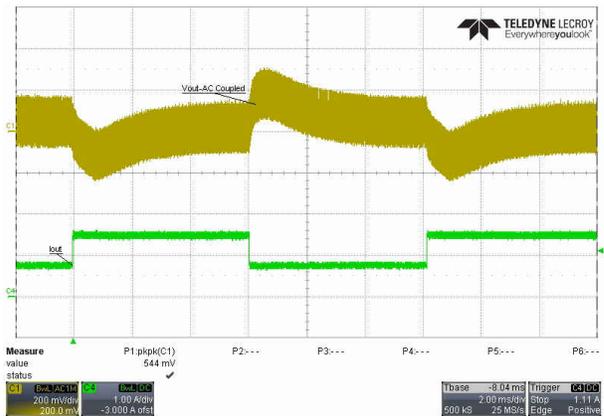


Figure 4-23. 15-V Output, 0.75 A to 1.5 A, 230 VAC, 50 Hz

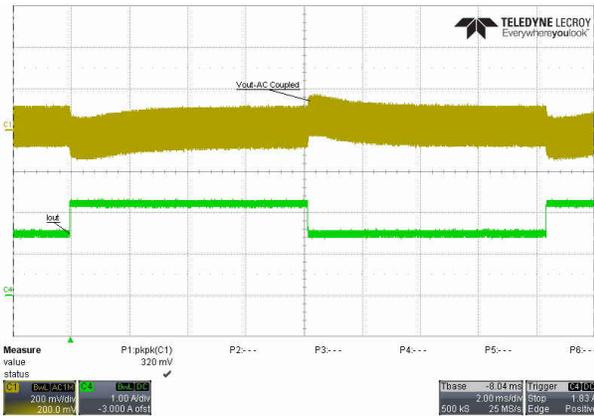


Figure 4-24. 15-V Output, 1.5 A to 2.25 A, 115 VAC, 60 Hz

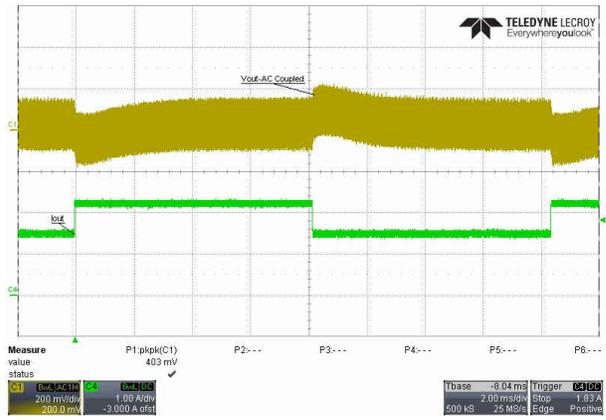


Figure 4-25. 15-V Output, 1.5 A to 2.25 A, 230 VAC, 50 Hz

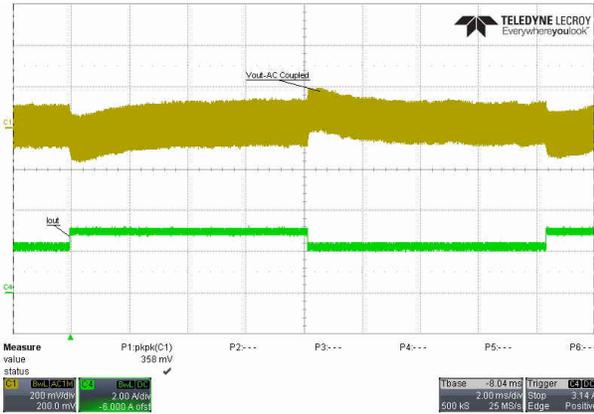


Figure 4-26. 15-V Output, 2.25 A to 3 A, 115 VAC, 60 Hz

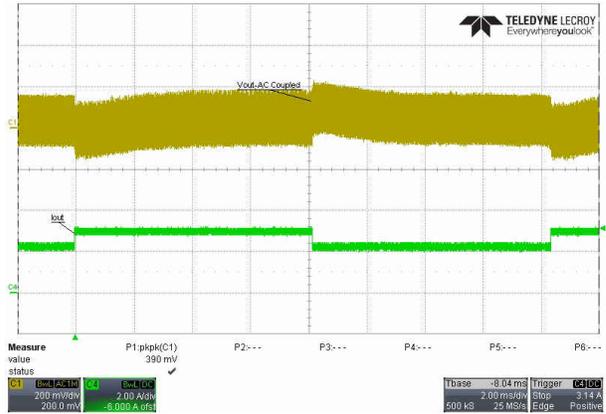


Figure 4-27. 15-V Output, 2.25 A to 3 A, 230 VAC, 50 Hz

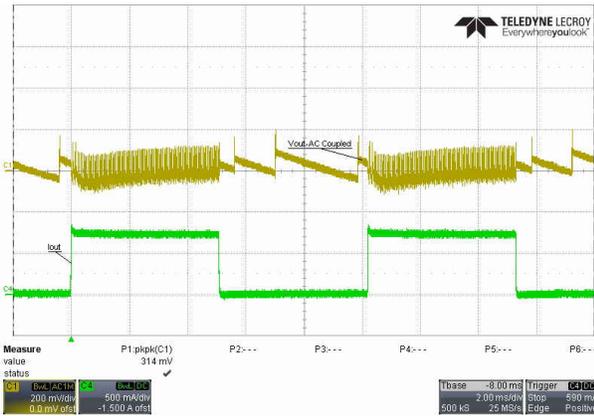


Figure 4-28. 9-V Output, 0 A to 0.75 A, 115 VAC, 60 Hz

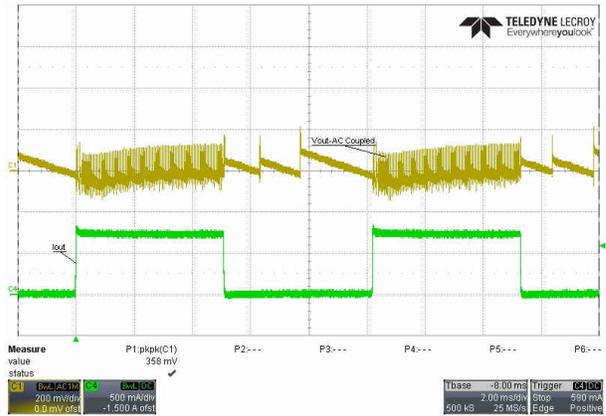


Figure 4-29. 9-V Output, 0 A to 0.75 A, 230 VAC, 50 Hz

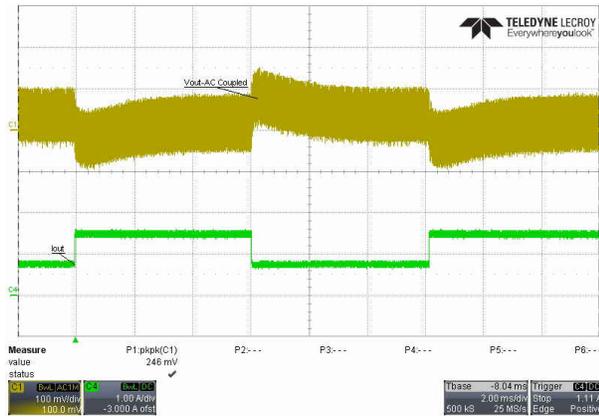


Figure 4-30. 9-V Output, 0.75 A to 1.5 A, 115 VAC, 60 Hz

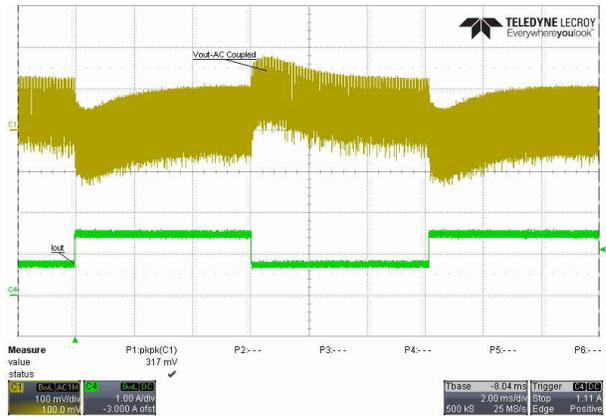


Figure 4-31. 9-V Output, 0.75 A to 1.5 A, 230 VAC, 50 Hz

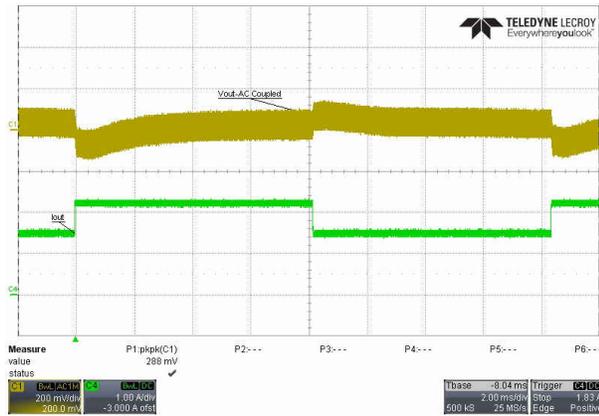


Figure 4-32. 9-V Output, 1.5 A to 2.25 A, 115 VAC, 60 Hz

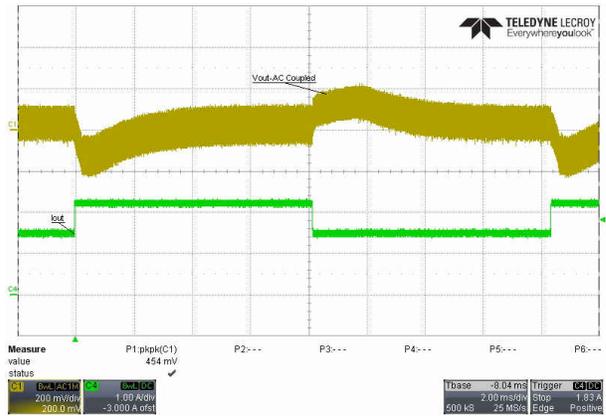


Figure 4-33. 9-V Output, 1.5 A to 2.25 A, 230 VAC, 50 Hz

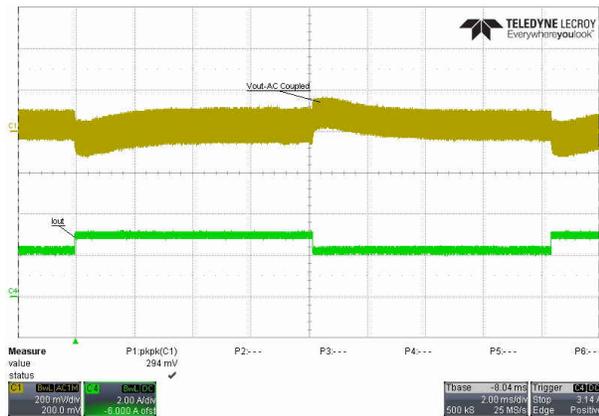


Figure 4-34. 9-V Output, 2.25 A to 3 A, 115 VAC, 60 Hz

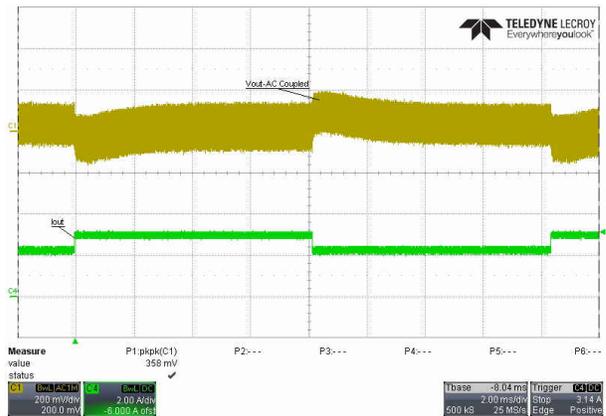


Figure 4-35. 9-V Output, 2.25 A to 3 A, 230 VAC, 50 Hz

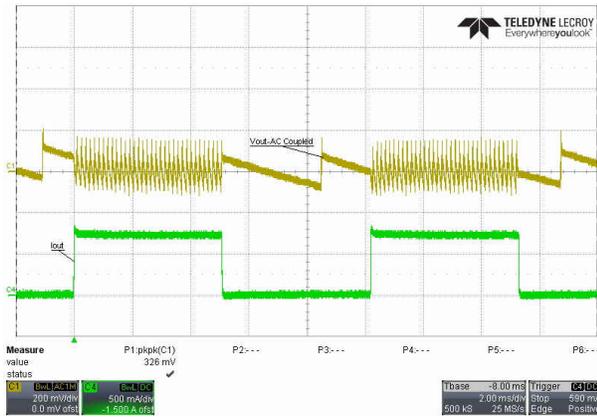


Figure 4-36. 5-V Output, 0 A to 0.75 A, 115 VAC, 60 Hz

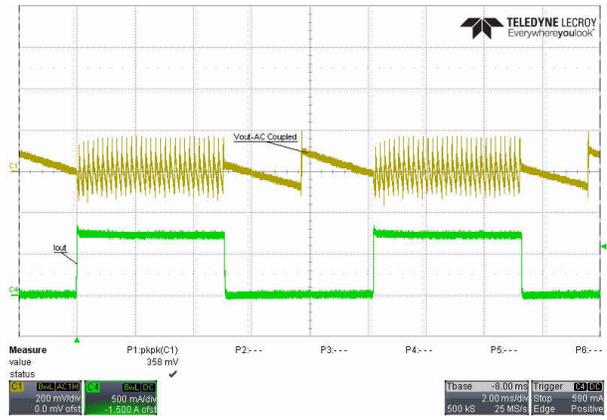


Figure 4-37. 5-V Output, 0 A to 0.75 A, 230 VAC, 50 Hz

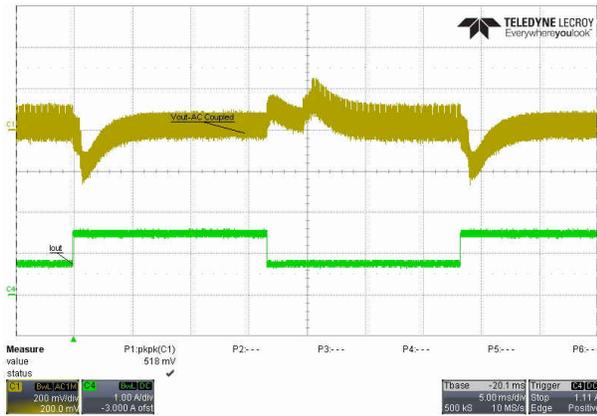


Figure 4-38. 5-V Output, 0.75 A to 1.5 A, 115 VAC, 60 Hz

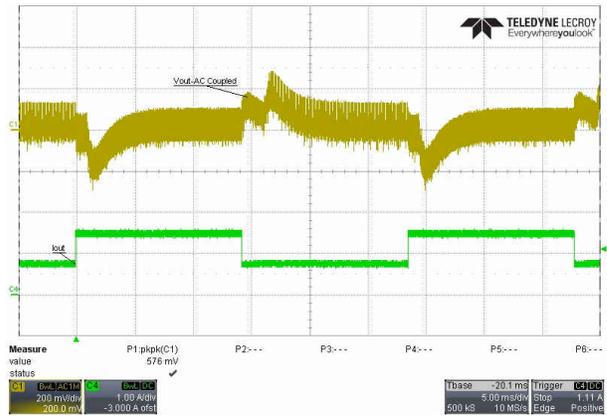


Figure 4-39. 5-V Output, 0.75 A to 1.5 A, 230 VAC, 50 Hz

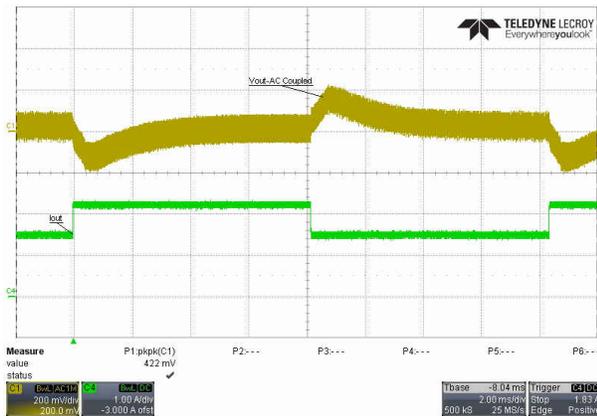


Figure 4-40. 5-V Output, 1.5 A to 2.25 A, 115 VAC, 60 Hz

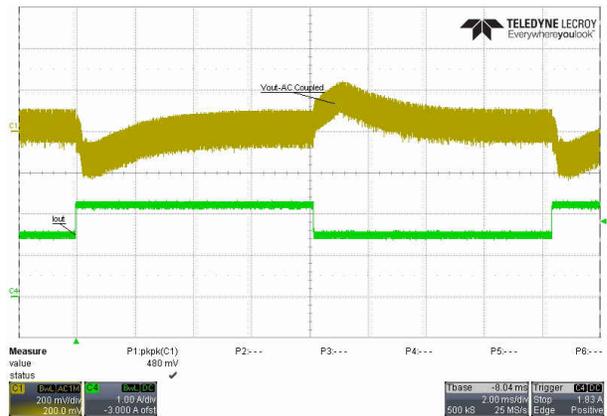


Figure 4-41. 5-V Output, 1.5 A to 2.25 A, 230 VAC, 50 Hz

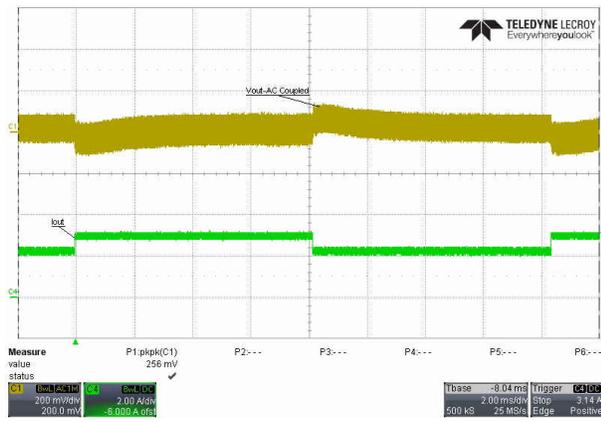


Figure 4-42. 5-V Output, 2.25 A to 3 A,
115 VAC, 60 Hz

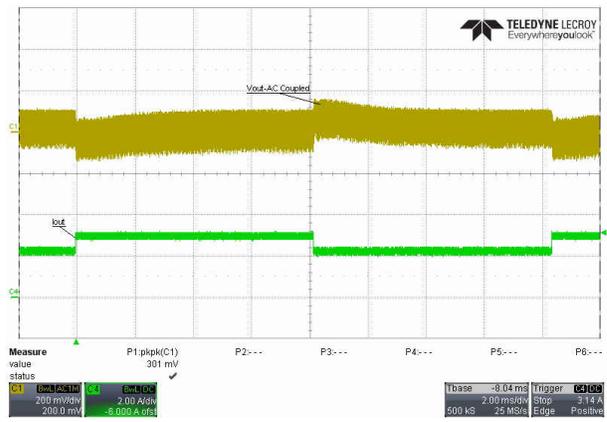


Figure 4-43. 5-V Output, 2.25 A to 3 A,
230 VAC, 50 Hz

4.4 Voltage Transitions

The output voltage during USB Type-C voltage transitions are shown in the following images. The input was 115 VAC, 60 Hz and the output was unloaded. This behavior is not dependent on input voltage.

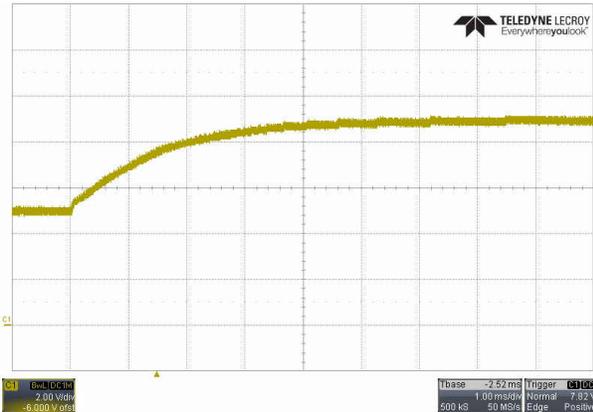


Figure 4-44. 5-V to 9-V Transition

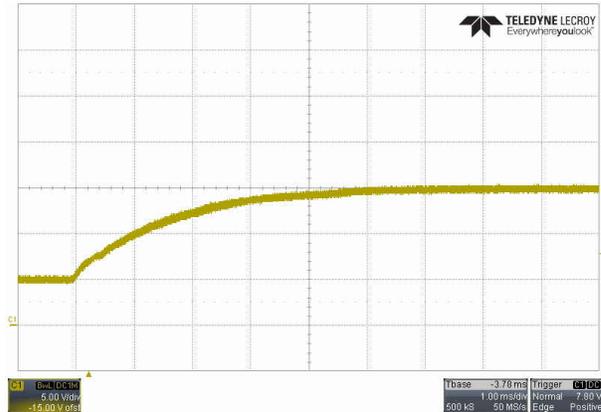


Figure 4-45. 5-V to 15-V Transition

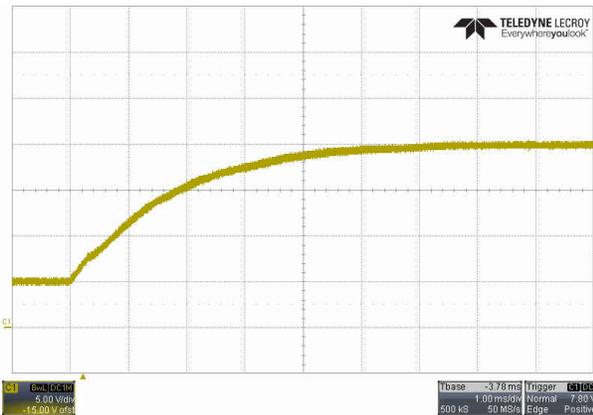


Figure 4-46. 5-V to 20-V Transition

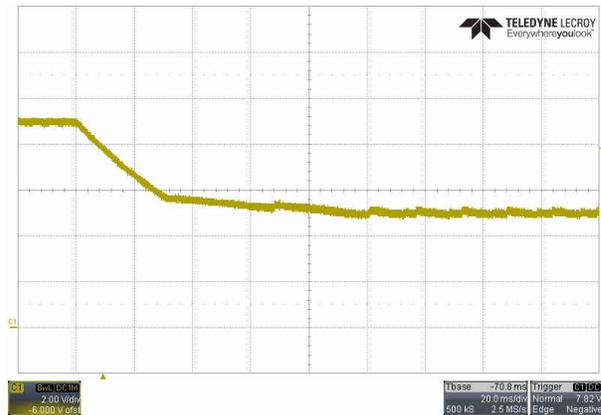


Figure 4-47. 9-V to 5-V Transition



Figure 4-48. 9-V to 15-V Transition

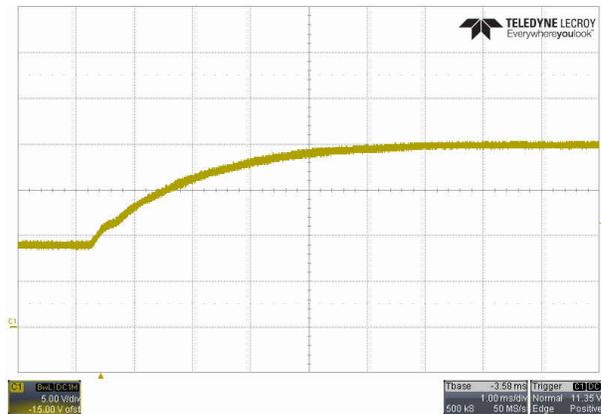


Figure 4-49. 9-V to 20-V Transition

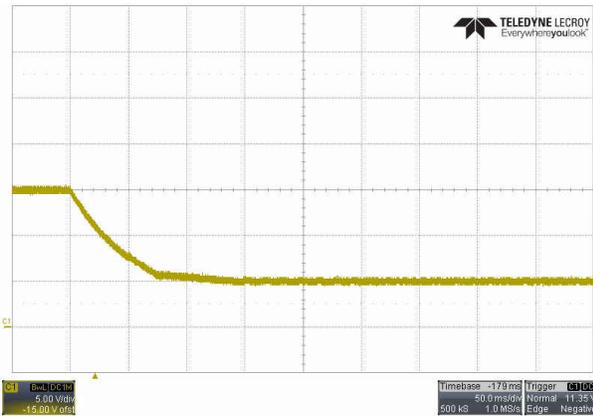


Figure 4-50. 15-V to 5-V Transition

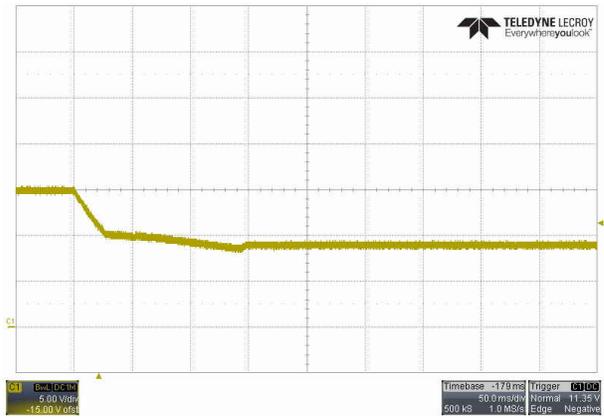


Figure 4-51. 15-V to 9-V Transition

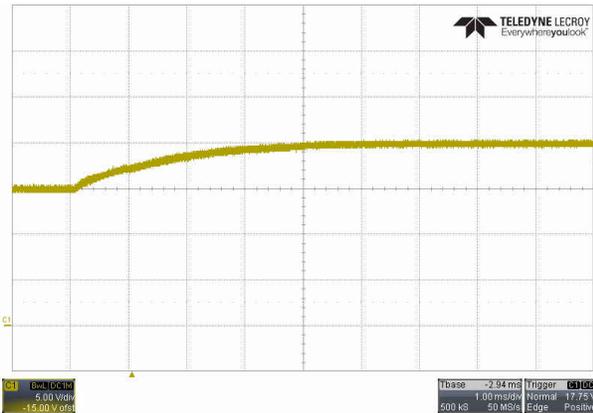


Figure 4-52. 15-V to 20-V Transition



Figure 4-53. 20-V to 5-V Transition

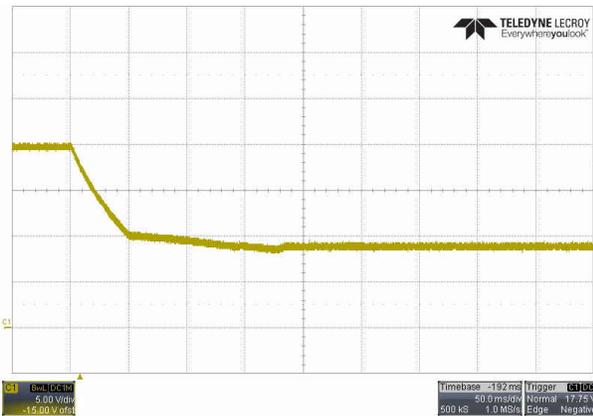


Figure 4-54. 20-V to 9-V Transition

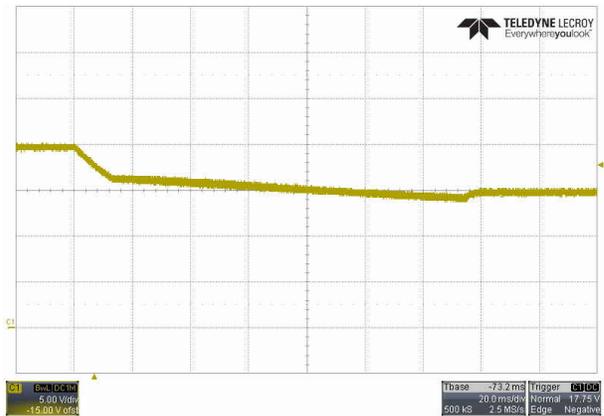


Figure 4-55. 20-V to 15-V Transition

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5 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (April 2021) to Revision A (July 2021)	Page
• Updated <i>Angle View of Assembly</i> image.....	1

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