65W USB-PD certified reference design based on ST-ONE

Introduction

The EVLONE65W is one of the best power density USB PD boards with a single USB Type-C® port supporting a Programmable Power Supply (PPS). The design supports a wide range of input voltages and can deliver five fixed PDOs and two APDOs.

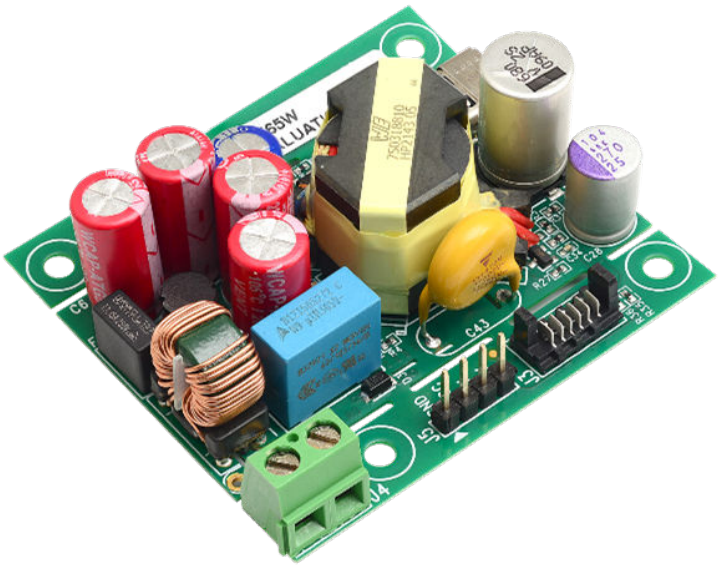
This board is based on ST-ONE, the world's first digital controller embedding Arm® Cortex® M0+ core, an offline programmable controller with synchronous rectification, and USB PD PHY in a single package.

Such a system is specifically designed to control ZVS non-complementary active clamp flyback converters to create high power density chargers and adapters with USB PD interface.

The device includes an active clamp flyback controller and its HV startup on the primary side, a microcontroller and all the peripherals required to control the conversion and the USB PD communication on the secondary side. The two sides are connected through an embedded galvanically isolated dual communication channel.

High switching frequency operations in companion with a MasterGaN4 power stage allows use of small size magnetic components while reaching a very high efficiency.

Figure 1. EVLONE65W board



Related document

Additional informations and details about ST-ONE and parameters can be found in the following documents:

- ST-ONE - Fully integrated controller for smart chargers (see www.st.com)
- ST-ONE parameter description (see www.st.com)

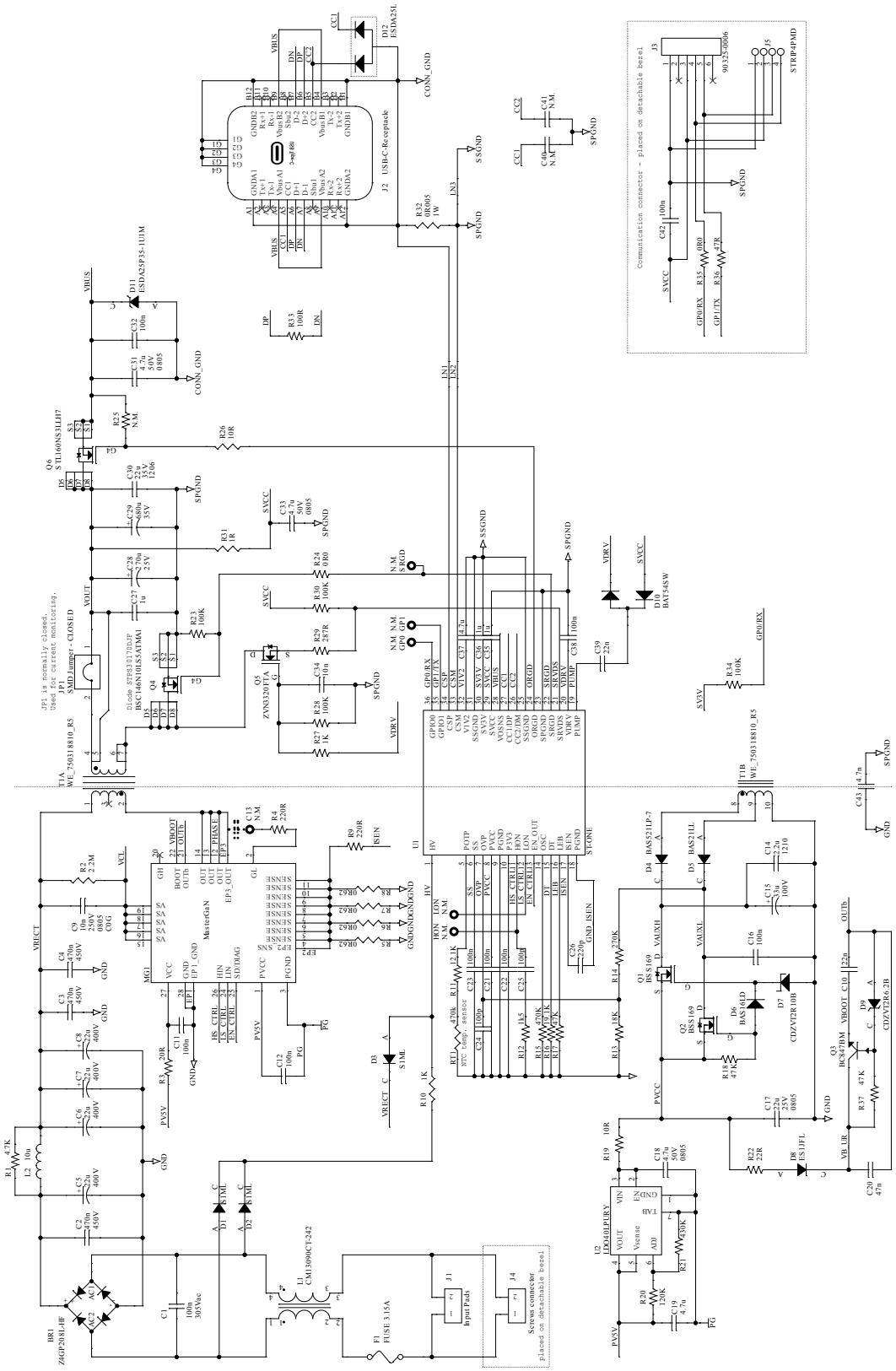
1 Main characteristics

The main features of the EVLONE65W board are listed below:

- Universal input mains range: 90 Vac to 265 Vac - Frequency 47 ÷ 63 Hz
- Maximum output power: 65 W
- Dimensions: 58x32x20 mm, (L x W x H)
- Power density: 30 W/in^3
- Efficiency: > 93 % @ full load
- Constant current output: 3.75 A max.
- Output voltage range: 3.3 ÷ 21 Vdc
- PD output:
  - Five fixed PDOs: 5 V@3.75 A, 9 V@3.75 A, 12 V@3.75 A, 15 V@3.75 A, 20 V@3.25 A
  - Two APDOs (PPS): 3.3 V÷16 V@3.75 A, 3.3 V÷21 V@3.25 A
- PPS mode: 20 mV step for CV, 50 mA step for CC
- Certified USB Power Delivery 3.1.1.2 power brick
- Feedback loops: constant current and constant voltage
- Protections: brown out, over current protection, over temperature protection, over voltage protection, under voltage protection.

2 Schematic diagram

Figure 2. **EVLONE65W schematic diagram**



3 Startup

The startup phase of the device is shown in the following figures at 90 Vac/60 Hz, 115 Vac/60 Hz, 230 Vac/50 Hz and 265 Vac/50 Hz under no load and full load conditions. The output voltage has been set to 5 V (fixed power configuration).

The output voltage starts increasing after a short delay from the presence of the input voltage (< 250 ms). There are no considerable oscillations in the output waveform.

In Figure 3, Figure 4, Figure 5 and Figure 6:

- Blue = V_{AC} 100 V/div
- Green = V_{OUT} 2 V/div
- Yellow = I_{OUT} 2 A/div

Figure 3. Startup at 90 V_{AC}, V_{OUT} 5 V, no load

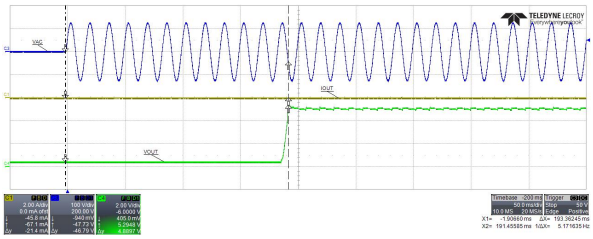


Figure 4. Startup at 90 V_{AC}, V_{OUT} 5 V, load 3.75 A

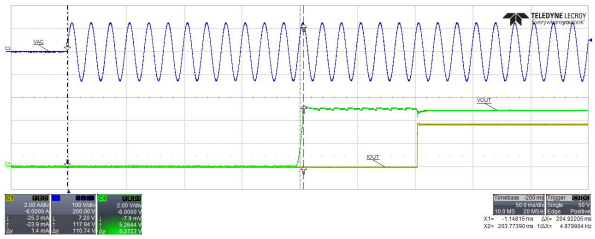


Figure 5. Startup at 115 V_{AC}, V_{OUT} 5 V, no load

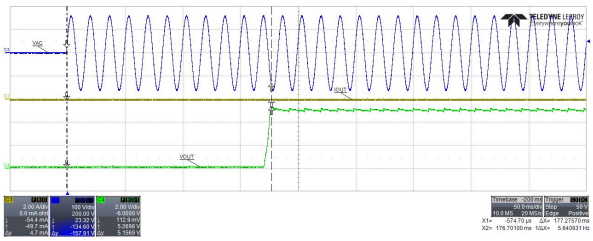
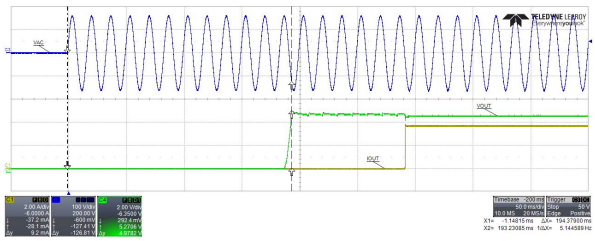


Figure 6. Startup at 115 V_{AC}, V_{OUT} 5 V, load 3.75 A



In Figure 7, Figure 8, Figure 9 and Figure 10:

- Blue = V_{IN} 200 V/div
- Green = V_{OUT} 2 V/div
- Yellow = I_{OUT} 2 A/div

Figure 7. Startup at 230 V_{AC}, V_{OUT} 5 V, no load

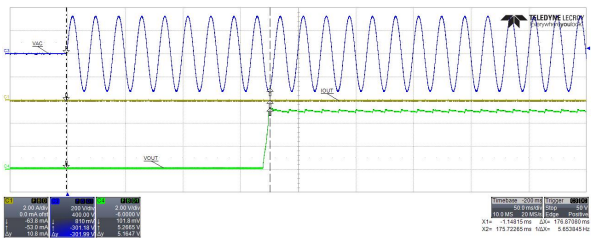


Figure 8. Startup at 230 V_{AC}, V_{OUT} 5 V, load 3.75 A

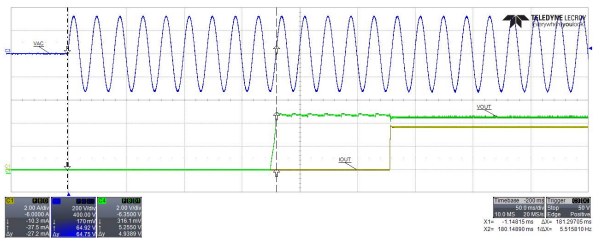


Figure 9. Startup at 265 V_{AC}, V_{OUT} 5 V, no load

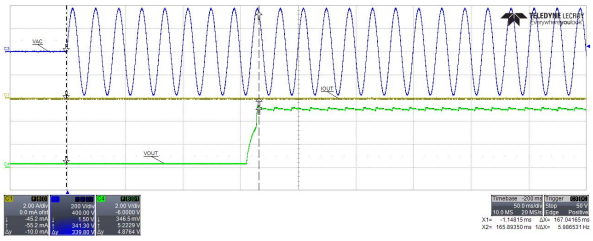
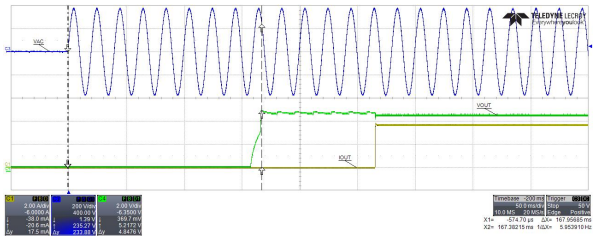


Figure 10. Startup at 265 V_{AC}, V_{OUT} 5 V, load 3.75 A



4 Output voltage regulation for dynamic load variation

The following figures show the load transient response waveforms of the active clamp flyback converter when subjected to repetitive dynamic load transitions from zero to full load at 115 V_{AC}/60 Hz and 230 V_{AC}/50 Hz. The transition period is 100 ms with a 50% duty cycle and a slew rate of 2.5 A/µs.

There are no abnormal oscillations in the output voltage and the overshoot and undershoot are acceptable.

From Figure 11 to Figure 22:

- Green = V_{OUT} 500 mV/div
- Yellow = I_{OUT} 1 A/div

Figure 11. Dynamic load from 0% to 25% of 3.75 A, V_{OUT} 3.3 V, V_{IN} = 115 V_{AC}

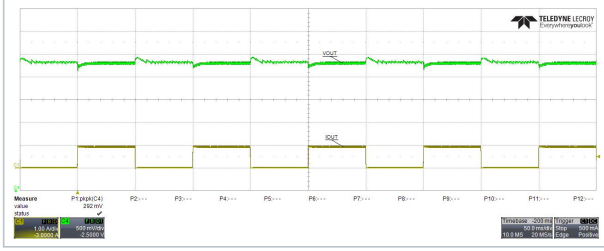


Figure 12. Dynamic load from 0% to 25% of 3.75 A, V_{OUT} 3.3 V, V_{IN} = 230 V_{AC}

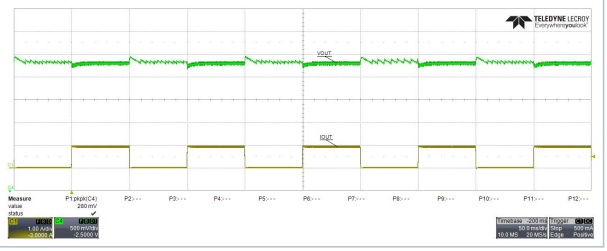


Figure 13. Dynamic load from 25% to 50% of 3.75 A, V_{OUT} 3.3 V, V_{IN} = 115 V_{AC}

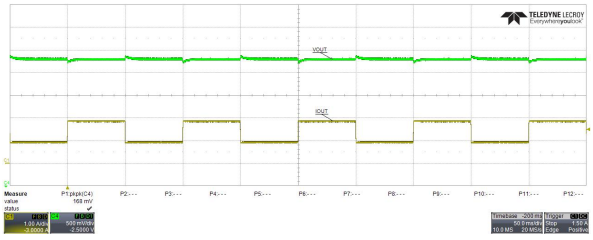


Figure 14. Dynamic load from 25% to 50% of 3.75 A, V_{OUT} 3.3 V, V_{IN} = 230 V_{AC}

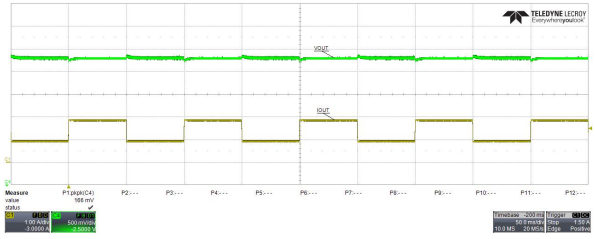


Figure 15. Dynamic load from 50% to 75% of 3.75 A, V_{OUT} 3.3 V, V_{IN} = 115 V_{AC}

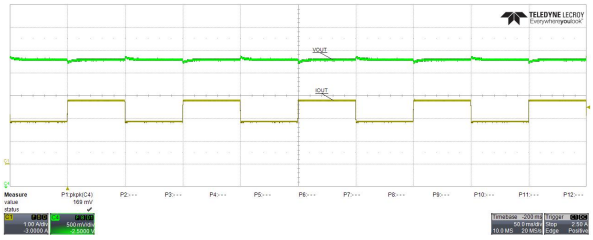


Figure 16. Dynamic load from 50% to 75% of 3.75 A, V_{OUT} 3.3 V, V_{IN} = 230 V_{AC}

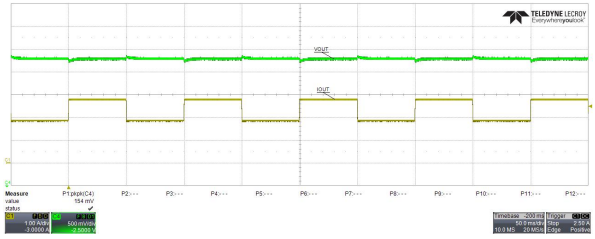


Figure 17. Dynamic load from 75% to 100% of 3.75 A, V_{OUT} 3.3 V, V_{IN} = 115 V_{AC}

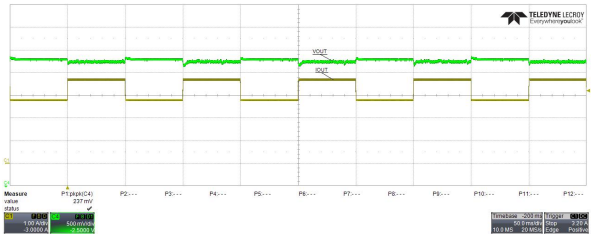


Figure 18. Dynamic load from 75% to 100% of 3.75 A, V_{OUT} 3.3 V, V_{IN} = 230 V_{AC}

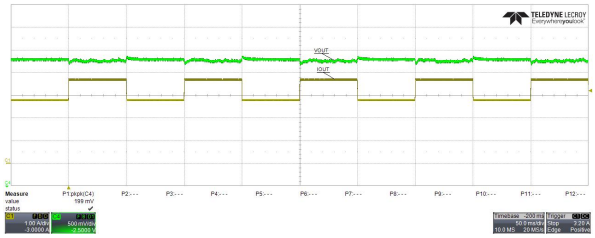


Figure 19. Dynamic load from 0 to 3.75 A, V_{OUT} 5 V, V_{IN} = 115 V_{AC}

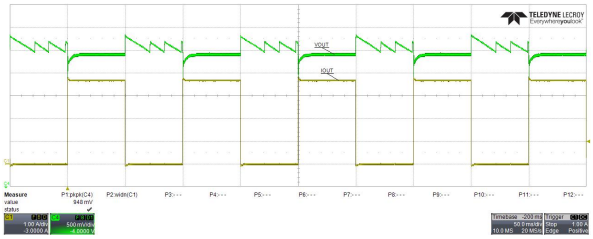


Figure 20. Dynamic load from 0 to 3.75 A, V_{OUT} 5 V, V_{IN} = 230 V_{AC}

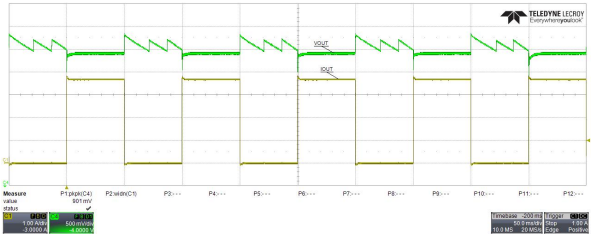


Figure 21. Dynamic load from 0 to 3.75 A, V_{OUT} 9 V, V_{IN} = 115 V_{AC}

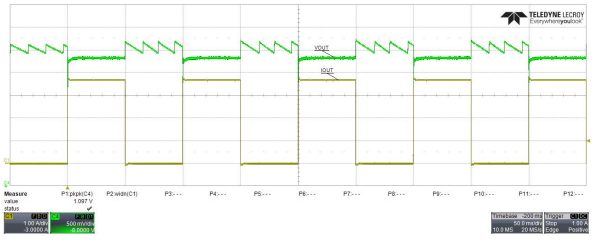
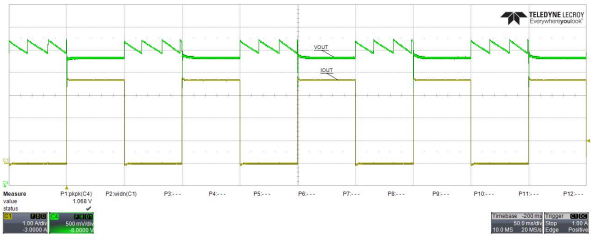


Figure 22. Dynamic load from 0 to 3.75 A, V_{OUT} 9 V, V_{IN} = 230 V_{AC}



In Figure 23 and Figure 24:

- Green = V_{OUT} 1 V/div
- Yellow = I_{OUT} 1 A/div

Figure 23. Dynamic load from 0 to 3.75 A, V_{OUT} 12 V, V_{IN} = 115 V_{AC}

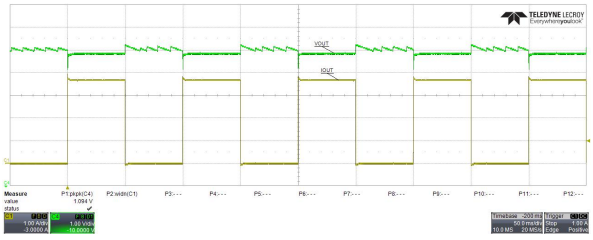
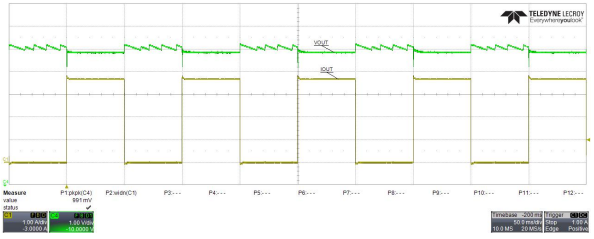


Figure 24. Dynamic load from 0 to 3.75 A, V_{OUT} 12 V, V_{IN} = 230 V_{AC}



From Figure 25 to Figure 28:

- Green = V_{OUT} 2 V/div
- Yellow = I_{OUT} 1 A/div

Figure 25. Dynamic load from 0 to 3.75 A, V_{OUT} 15 V, V_{IN} = 115 V_{AC}

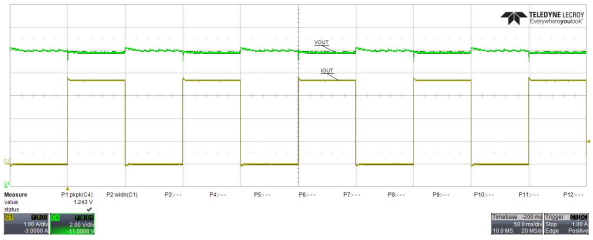


Figure 26. Dynamic load from 0 to 3.75 A, V_{OUT} 15 V, V_{IN} = 230 V_{AC}

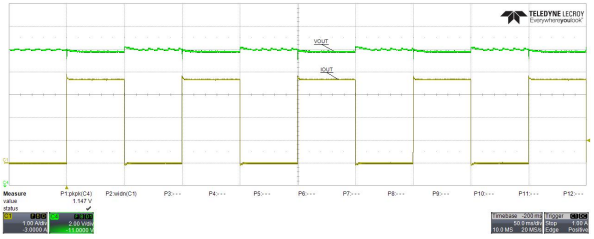


Figure 27. Dynamic load from 0 to 3.25 A, V_{OUT} 20 V, V_{IN} = 115 V_{AC}

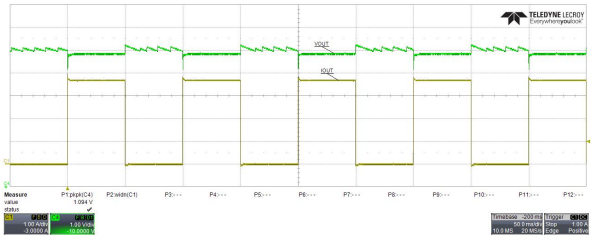
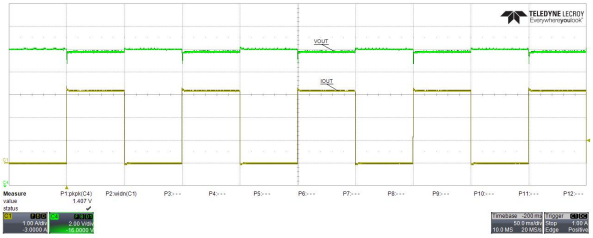


Figure 28. Dynamic load from 0 to 3.25 A, V_{OUT} 20 V, V_{IN} = 230 V_{AC}



5 Line transient

The following figures show the output voltage at line transient from 115 V_{AC}/60 Hz to 230 V_{AC}/50 Hz. The test has been performed with 1 Hz and 10 Hz frequencies.

In Figure 29 and Figure 30:

- Blue = V_{AC} 100 V/div
- Green = V_{OUT} 1 V/div

Figure 29. Line transient between 115 V_{AC} and 230 V_{AC} at 1 Hz

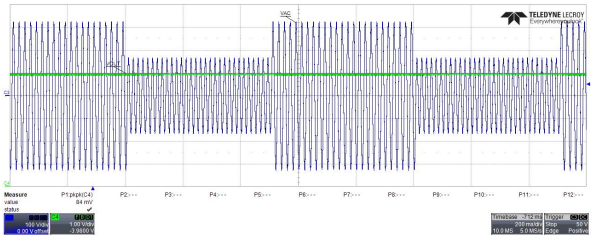
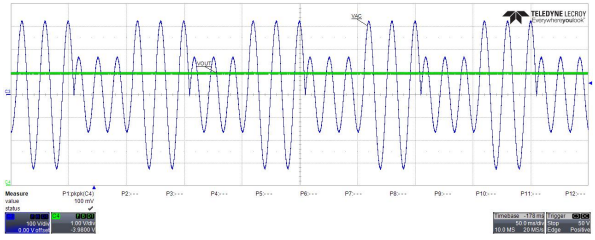


Figure 30. Line transient between 115 V_{AC} and 230 V_{AC} at 10 Hz



6 Output voltage ripple

The output voltage ripple has been measured through an oscilloscope at different output voltages with two different loads (0 A and maximum available current). In order to set the different output voltages, a sink tool has been used. The different loads have been set using a DC active load.

Tests have been performed at two input voltages:

- 115 V_{AC}/60 Hz
- 230 V_{AC}/50 Hz

From Figure 31 to Figure 42:

- Green = V_{OUT} 50 mV/div

Figure 31. Ripple at 115 V_{AC}, V_{OUT} 3.3 V, 0 A load

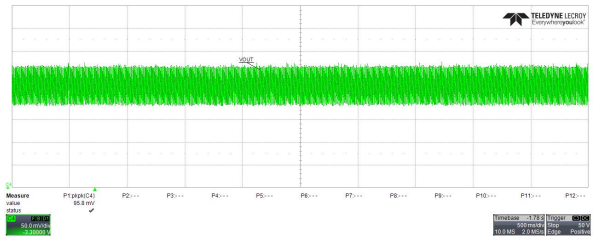


Figure 32. Ripple at 230 V_{AC}, V_{OUT} 3.3 V, 0 A load

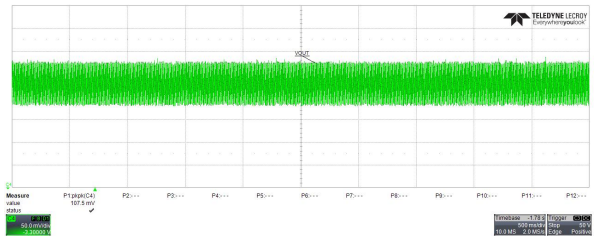


Figure 33. Ripple at 115 V_{AC}, V_{OUT} 3.3 V, 3.75 A load

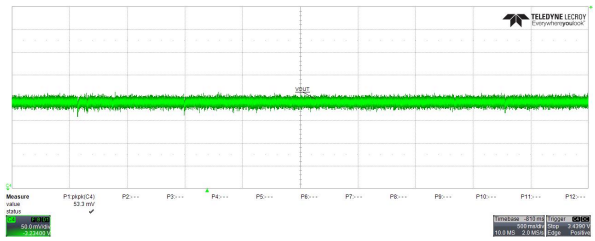


Figure 34. Ripple at 230 V_{AC}, V_{OUT} 3.3 V, 3.75 A load

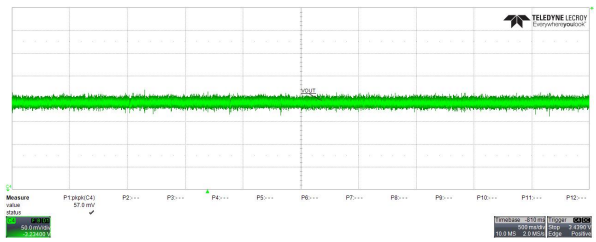


Figure 35. Ripple at 115 V_{AC}, V_{OUT} 5 V, 0 A load

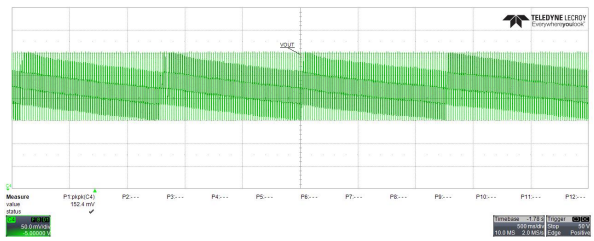


Figure 36. Ripple at 230 V_{AC}, V_{OUT} 5 V, 0 A load

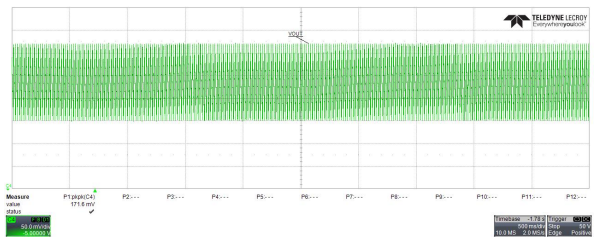


Figure 37. Ripple at 115 V_{AC}, V_{OUT} 5 V, 3.75 A load

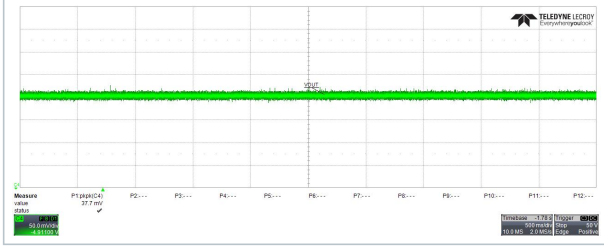


Figure 38. Ripple at 230 V_{AC}, V_{OUT} 5 V, 3.75 A load

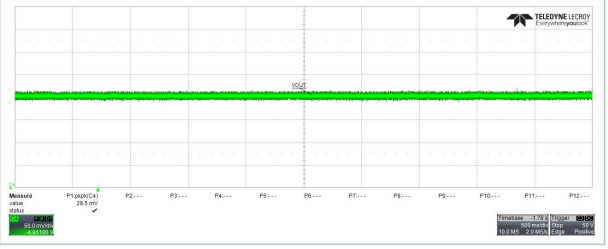


Figure 39. Ripple at 115 V_{AC}, V_{OUT} 9 V, 0 A load

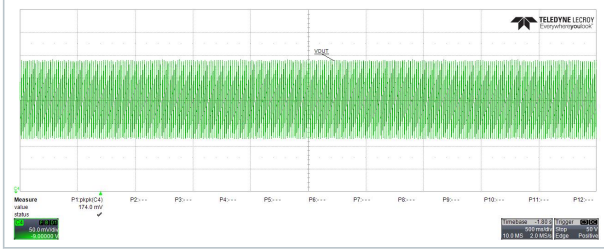


Figure 40. Ripple at 230 V_{AC}, V_{OUT} 9 V, 0 A load

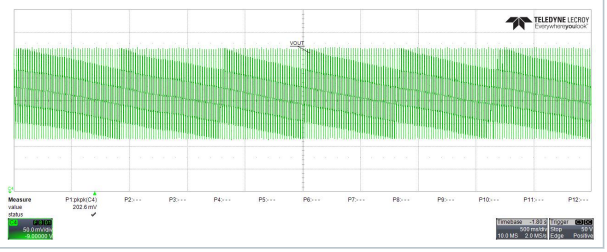


Figure 41. Ripple at 115 V_{AC}, V_{OUT} 9 V, 3.75 A load

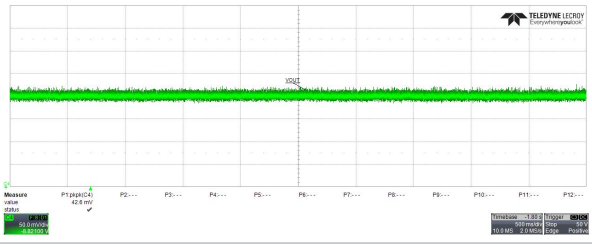
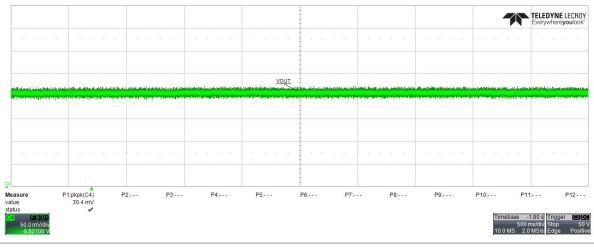


Figure 42. Ripple at 230 V_{AC}, V_{OUT} 9 V, 3.75 A load



From Figure 43 to Figure 46:

- Green = V_{OUT} 1 V/div

Figure 43. Ripple at 115 V_{AC}, V_{OUT} 12 V, 0 A load

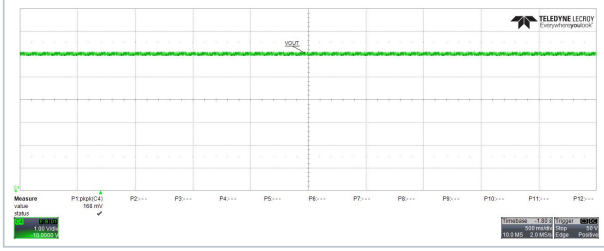


Figure 44. Ripple at 230 V_{AC}, V_{OUT} 12 V, 0 A load

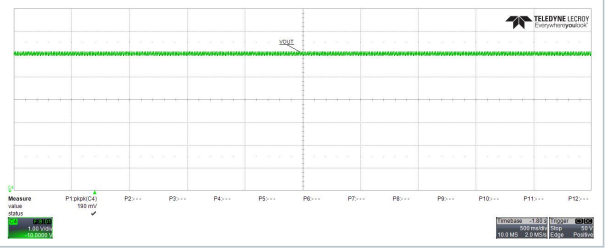


Figure 45. Ripple at 115 V_{AC}, V_{OUT} 12 V, 3.75 A load

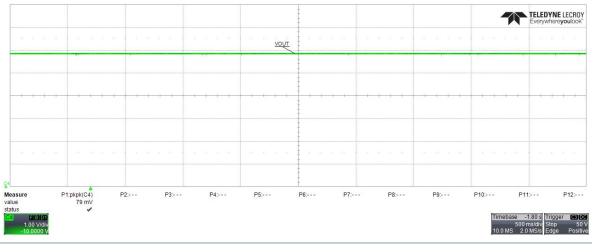
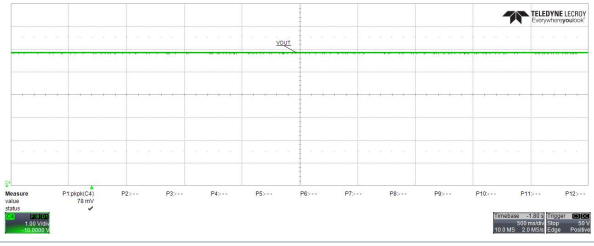


Figure 46. Ripple at 230 V_{AC}, V_{OUT} 12 V, 3.75 A load



From Figure 47 to Figure 54:

- Green = V_{OUT} 1.5 V/div

Figure 47. Ripple at 115 V_{AC}, V_{OUT} 15 V, 0 A load

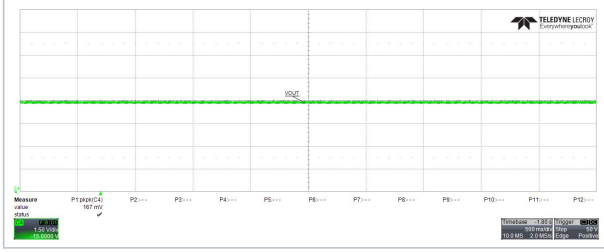


Figure 48. Ripple at 230 V_{AC}, V_{OUT} 15 V, 0 A load

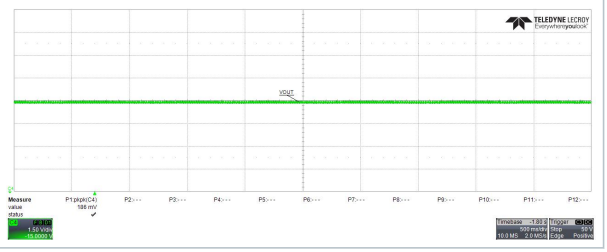


Figure 49. Ripple at 115 V_{AC}, V_{OUT} 15 V, 3.75 A load

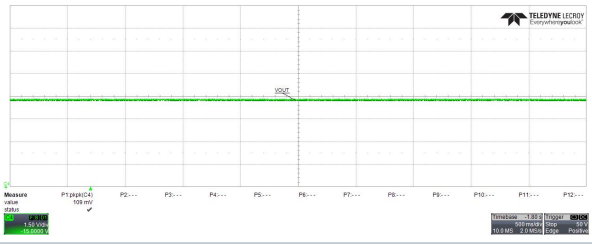


Figure 50. Ripple at 230 V_{AC}, V_{OUT} 15 V, 3.75 A load

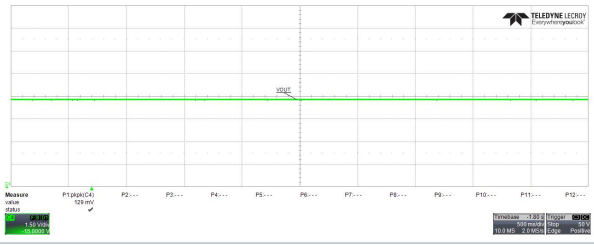


Figure 51. Ripple at 115 V_{AC}, V_{OUT} 20 V, 0 A load

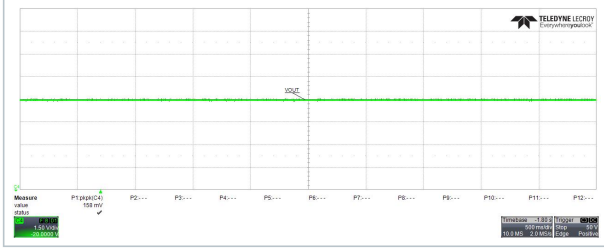


Figure 52. Ripple at 230 V_{AC}, V_{OUT} 20 V, 0 A load

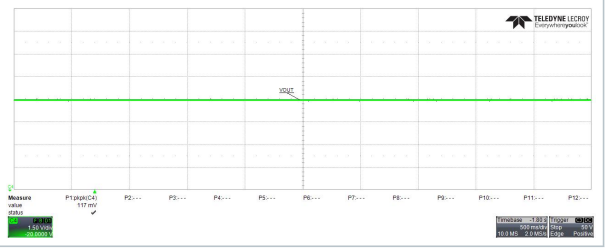


Figure 53. Ripple at 115 V_{AC}, V_{OUT} 20 V, 3.25 A load

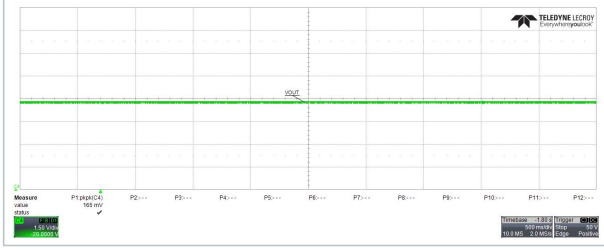


Figure 54. Ripple at 230 V_{AC}, V_{OUT} 20 V, 3.25 A load

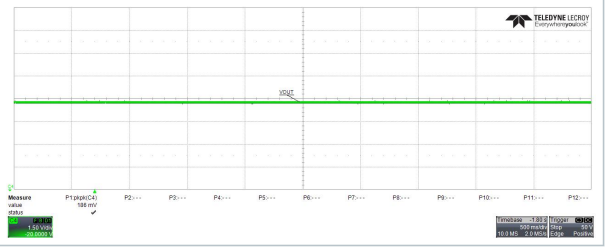


Table 1. Output voltage ripple test results

V_{AC} [V]	V_{OUT} [V]	Load [A]	Ripple [mV]	Max. ripple [mV] allowed by USB PD specification
115 V_{AC} @ 60 Hz	3.3	0	± 95.8	± 165
	3.3	3.75	± 53.3	± 165
	5	0	± 152.4	± 250
	5	3.75	± 37.7	± 250
	9	0	± 174.0	± 450
	9	3.75	± 42.6	± 450
	12	0	± 168.0	± 600
	12	3.75	± 79.0	± 600
	15	0	± 167.0	± 750
	15	3.75	± 109.0	± 750
	20	0	± 158.0	± 1000
	20	3.25	± 165.0	± 1000
230 V_{AC} @ 50 Hz	3.3	0	± 107.5	± 165
	3.3	3.75	± 57.0	± 165
	5	0	± 171.6	± 250
	5	3.75	± 28.5	± 250
	9	0	± 202.6	± 450
	9	3.75	± 30.4	± 450
	12	0	± 190.0	± 600
	12	3.75	± 78.0	± 600
	15	0	± 186.0	± 750
	15	3.75	± 129.0	± 750
	20	0	± 117.0	± 1000
	20	3.25	± 186.0	± 1000

7 Voltage transitions across all profiles

The following figures show all the output voltage transitions between PDO and APDO profiles acquired through an oscilloscope.

All the transitions respect USB PD requirements (transitions time < 275 ms, maximum voltage in addition to the new voltage value during the transition = ±500 mV).

All the tests have been performed at two different input voltages:

- 115 V_{AC}/60 Hz
- 230 V_{AC}/50 Hz

From Figure 55 to Figure 62:

- Green = V_{OUT} 500 mV/div

Figure 55. Voltage transition from 3.3 V to 5 V at 115 V_{AC} – no load

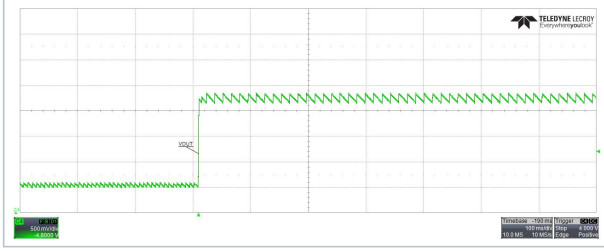


Figure 56. Voltage transition from 3.3 V to 5 V at 230 V_{AC} – no load

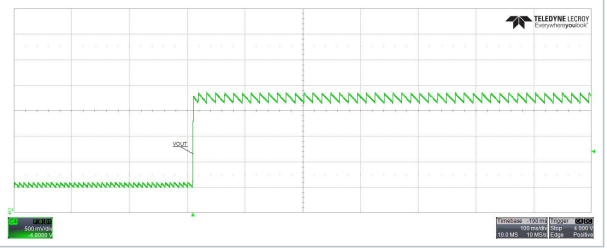


Figure 57. Voltage transition from 3.3 V to 5 V at 115 V_{AC} – 3.75 A load

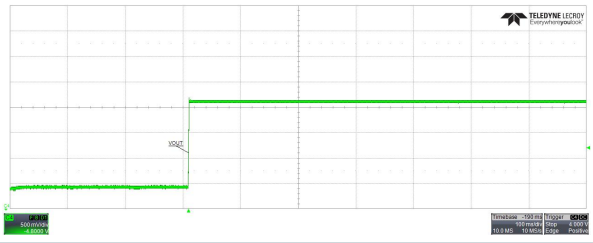


Figure 58. Voltage transition from 3.3 V to 5 V at 230 V_{AC} – 3.75 A load

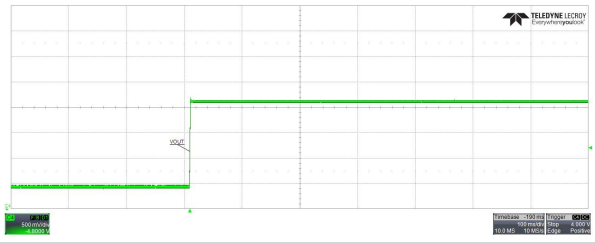


Figure 59. Voltage transition from 5 V to 3.3 V at 115 V_{AC} – no load

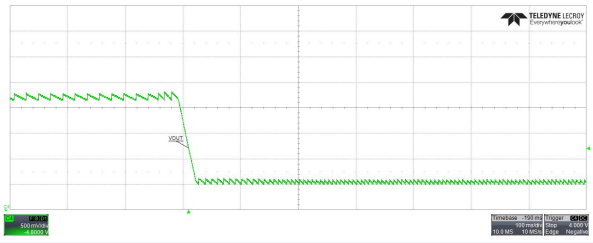


Figure 60. Voltage transition from 5 V to 3.3 V at 230 V_{AC} – no load

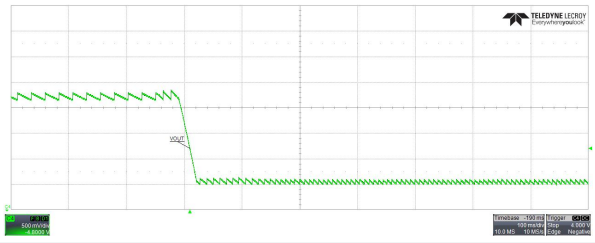


Figure 61. Voltage transition from 5 V to 3.3 V at 115 V_{AC} – 3.75 A load

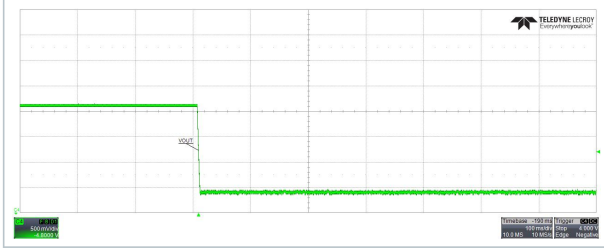
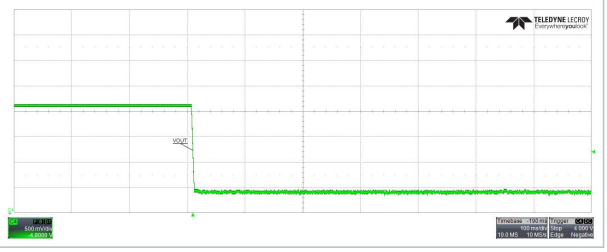


Figure 62. Voltage transition from 5 V to 3.3 V at 230 V_{AC} – 3.75 A load



From Figure 63 to Figure 70:

- Green = V_{OUT} 1 V/div

Figure 63. Voltage transition from 3.3 V to 9 V at 115 V_{AC} – no load

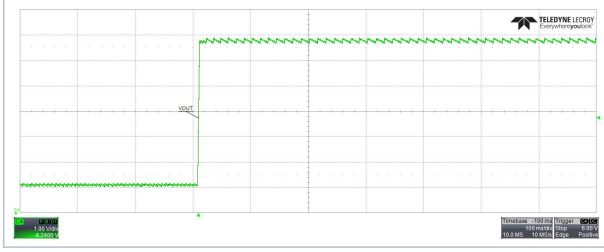


Figure 64. Voltage transition from 3.3 V to 9 V at 230 V_{AC} – no load

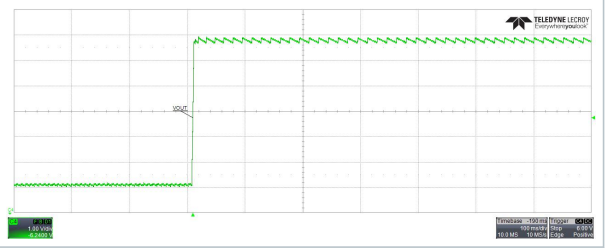


Figure 65. Voltage transition from 3.3 V to 9 V at 115 V_{AC} – 3.75 A load

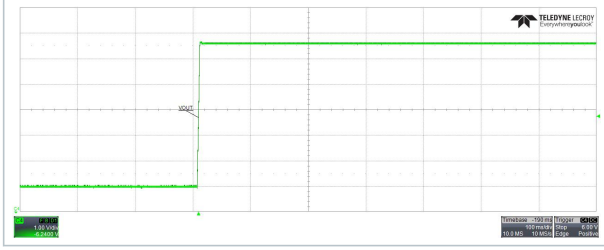


Figure 66. Voltage transition from 3.3 V to 9 V at 230 V_{AC} – 3.75 A load

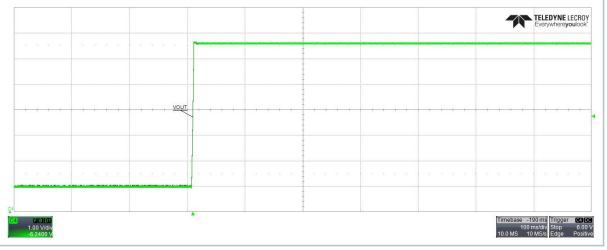


Figure 67. Voltage transition from 9 V to 3.3 V at 115 V_{AC} – no load

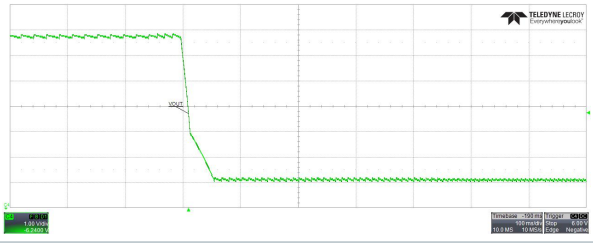


Figure 68. Voltage transition from 9 V to 3.3 V at 230 V_{AC} – no load

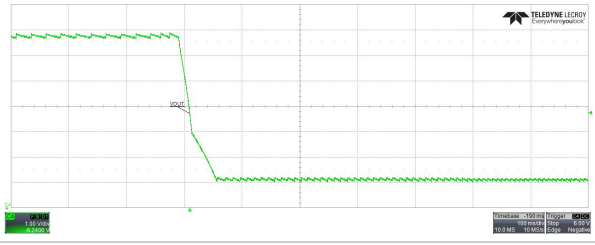


Figure 69. Voltage transition from 9 V to 3.3 V at 115 V_{AC} – 3.75 A load

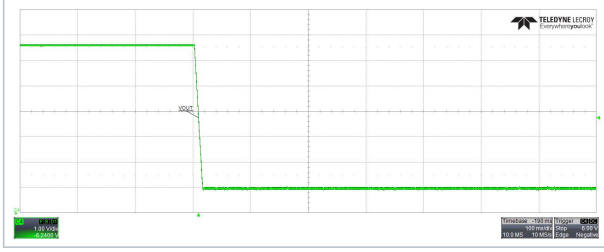
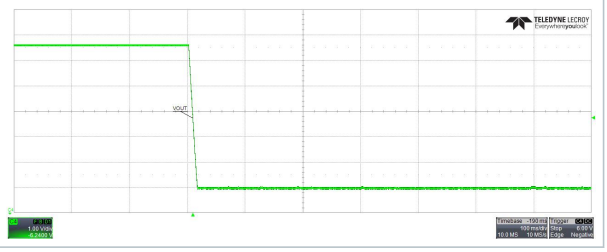


Figure 70. Voltage transition from 9 V to 3.3 V at 230 V_{AC} – 3.75 A load



From Figure 71 to Figure 86:

- Green = V_{OUT} 2 V/div

Figure 71. Voltage transition from 3.3 V to 12 V at 115 V_{AC} – no load

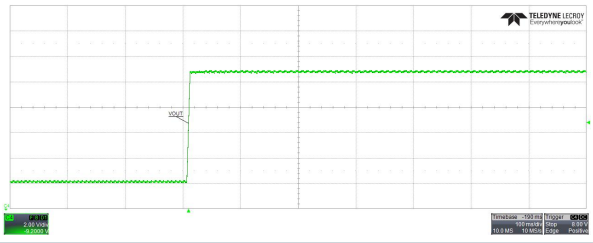


Figure 72. Voltage transition from 3.3 V to 12 V at 230 V_{AC} – no load

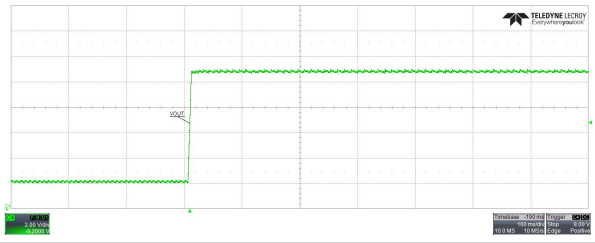


Figure 73. Voltage transition from 3.3 V to 12 V at 115 V_{AC} – 3.75 A load

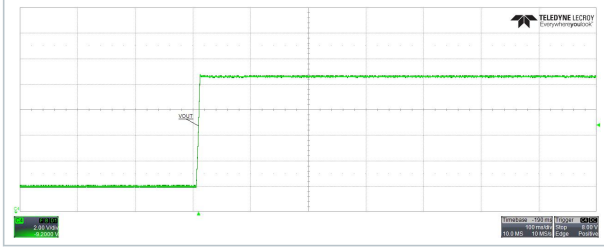


Figure 74. Voltage transition from 3.3 V to 12 V at 230 V_{AC} – 3.75 A load

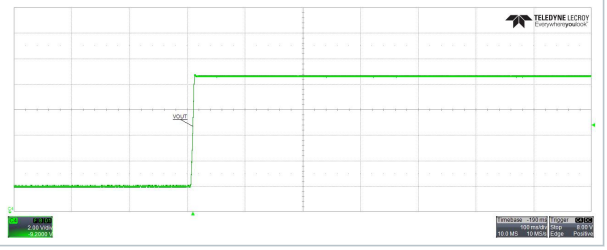


Figure 75. Voltage transition from 12 V to 3.3 V at 115 V_{AC} – no load

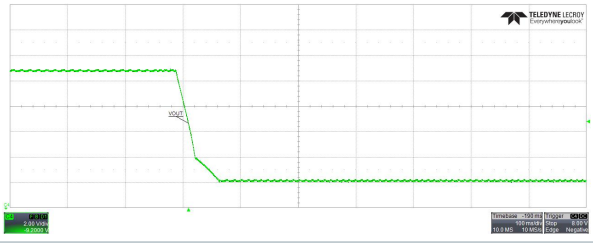


Figure 76. Voltage transition from 12 V to 3.3 V at 230 V_{AC} – no load

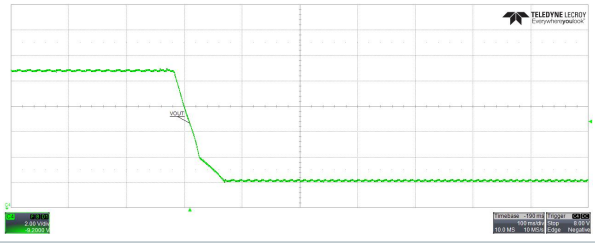


Figure 77. Voltage transition from 12 V to 3.3 V at 115 V_{AC} – 3.75 A load

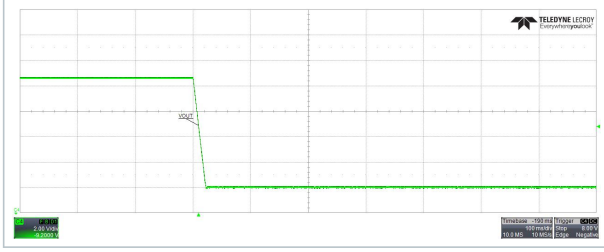


Figure 78. Voltage transition from 12 V to 3.3 V at 230 V_{AC} – 3.75 A load

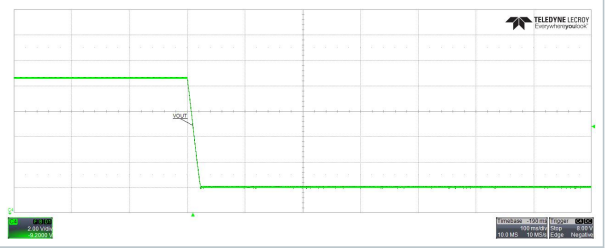


Figure 79. Voltage transition from 3.3 V to 15 V at 115 V_{AC} – no load

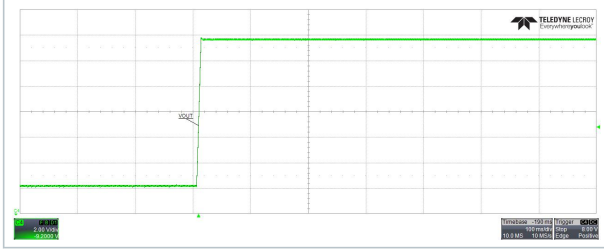


Figure 80. Voltage transition from 3.3 V to 15 V at 230 V_{AC} – no load

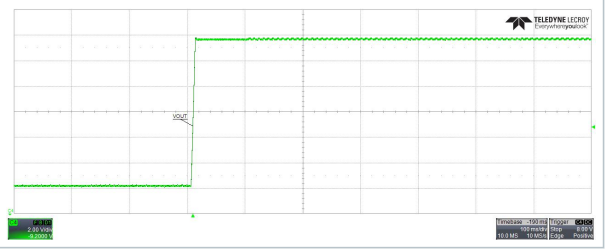


Figure 81. Voltage transition from 3.3 V to 15 V at 115 V_{AC} – 3.75 A load

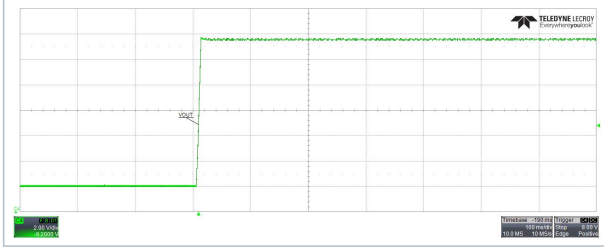


Figure 82. Voltage transition from 3.3 V to 15 V at 230 V_{AC} – 3.75 A load

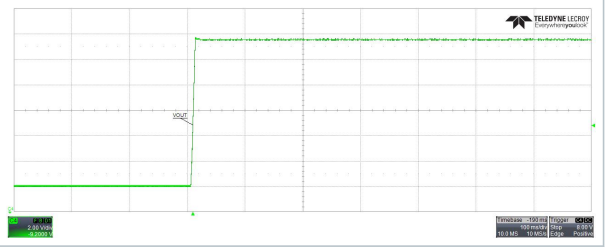


Figure 83. Voltage transition from 15 V to 3.3 V at 115 V_{AC} – no load

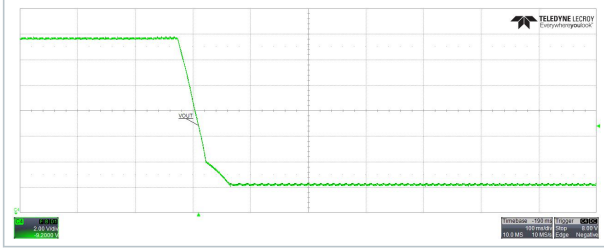


Figure 84. Voltage transition from 15 V to 3.3 V at 230 V_{AC} – no load

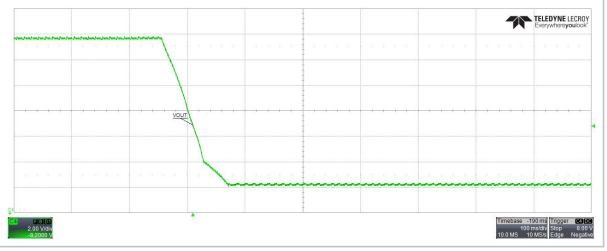


Figure 85. Voltage transition from 15 V to 3.3 V at 115 V_{AC} – 3.75 A load

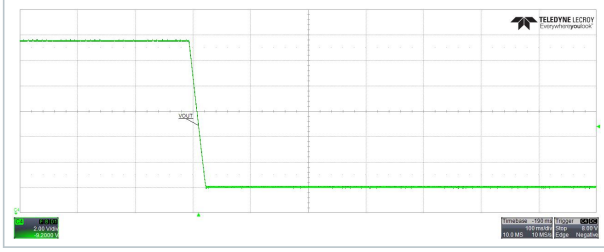
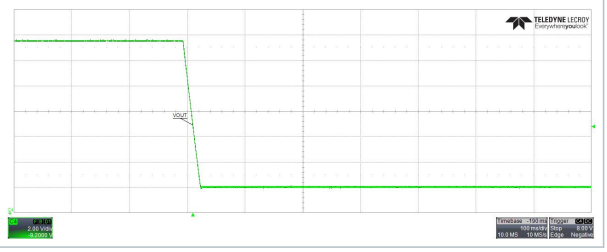


Figure 86. Voltage transition from 15 V to 3.3 V at 230 V_{AC} – 3.75 A load



From Figure 87 to Figure 94:

- Green = V_{OUT} 3 V/div

Figure 87. Voltage transition from 3.3 V to 20 V at 115 V_{AC} – no load

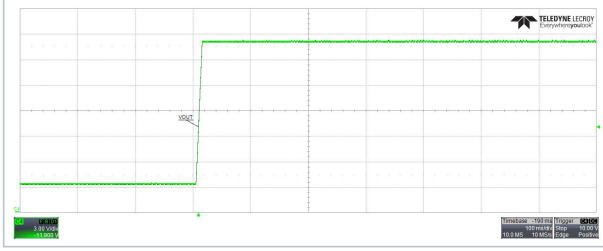


Figure 88. Voltage transition from 3.3 V to 20 V at 230 V_{AC} – no load

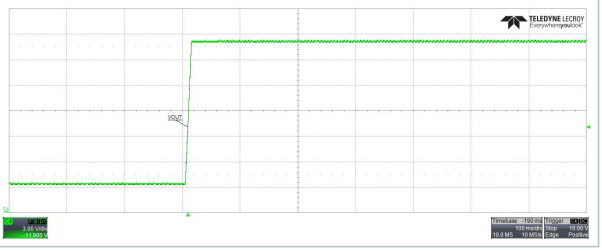


Figure 89. Voltage transition from 3.3 V to 20 V at 115 V_{AC} – 3.25 A load

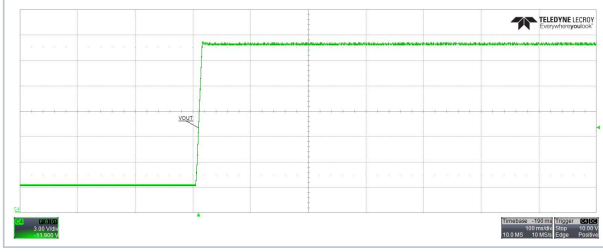


Figure 90. Voltage transition from 3.3 V to 20 V at 230 V_{AC} – 3.25 A load

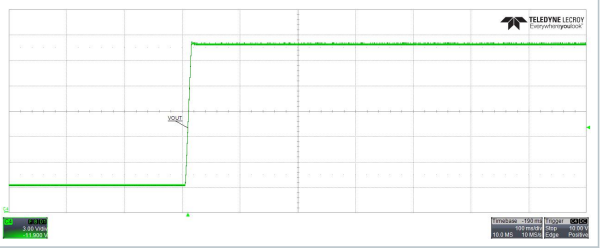


Figure 91. Voltage transition from 20 V to 3.3 V at 115 V_{AC} – no load

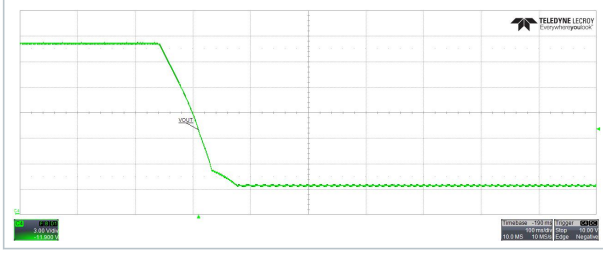


Figure 92. Voltage transition from 20 V to 3.3 V at 230 V_{AC} – no load

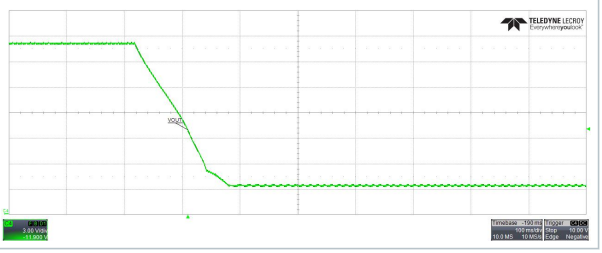
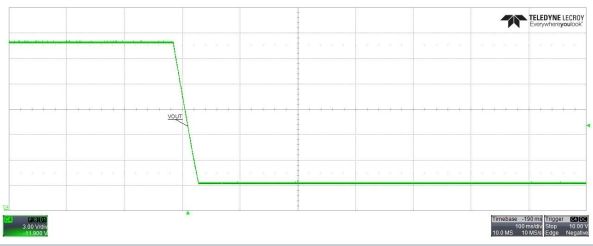


Figure 93. Voltage transition from 20 V to 3.3 V at 115 V_{AC} – 3.25 A load

Figure 94. Voltage transition from 20 V to 3.3 V at 230 V_{AC} – 3.25 A load



From Figure 95 to Figure 110:

- Green = V_{OUT} 1 V/div

Figure 95. Voltage transition from 5 V to 9 V at 115 V_{AC} – no load

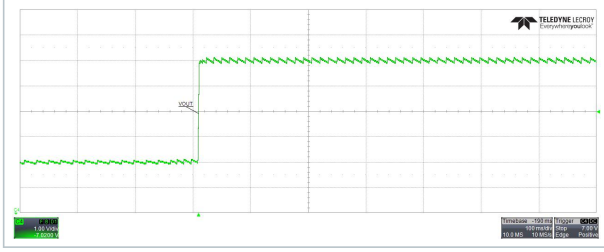


Figure 96. Voltage transition from 5 V to 9 V at 230 V_{AC} – no load

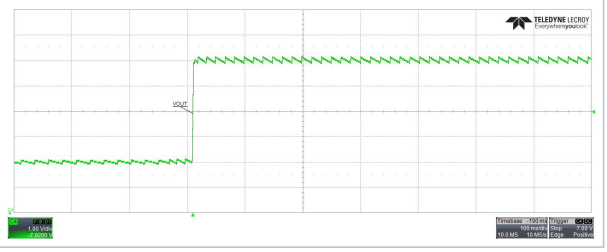


Figure 97. Voltage transition from 5 V to 9 V at 115 V_{AC} – 3.75 A load

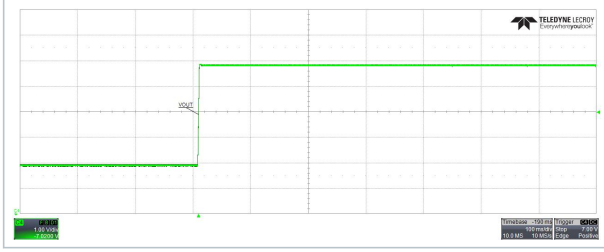


Figure 98. Voltage transition from 5 V to 9 V at 230 V_{AC} – 3.75 A load

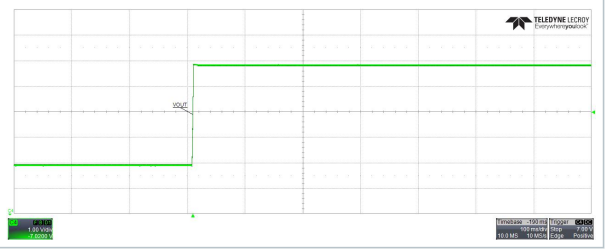


Figure 99. Voltage transition from 9 V to 5 V at 115 V_{AC} – no load

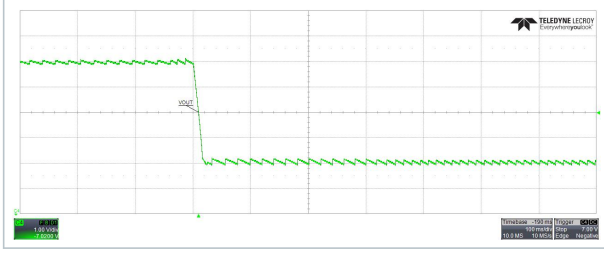


Figure 100. Voltage transition from 9 V to 5 V at 230 V_{AC} – no load

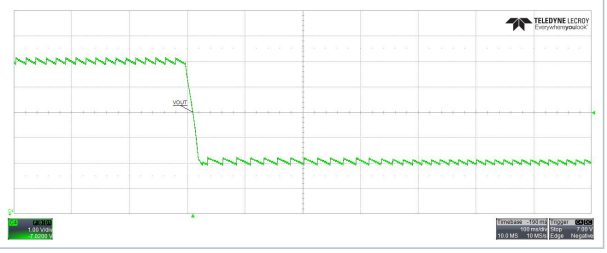


Figure 101. Voltage transition from 9 V to 5 V at 115 V_{AC} – 3.75 A load

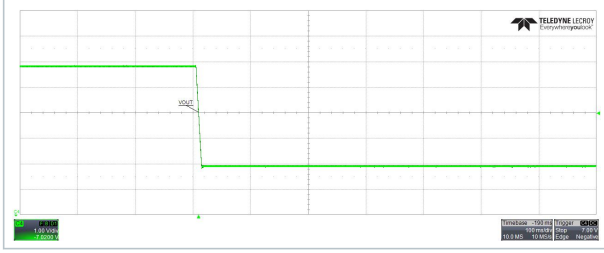


Figure 102. Voltage transition from 9 V to 5 V at 230 V_{AC} – 3.75 A load

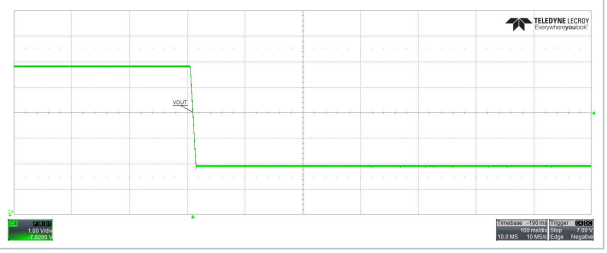


Figure 103. Voltage transition from 5 V to 12 V at 115 V_{AC} – no load

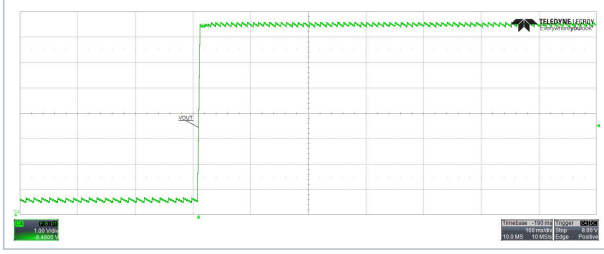


Figure 104. Voltage transition from 5 V to 12 V at 230 V_{AC} – no load

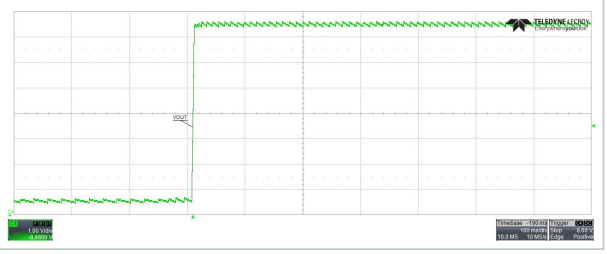


Figure 105. Voltage transition from 5 V to 12 V at 115 V_{AC} – 3.75 A load

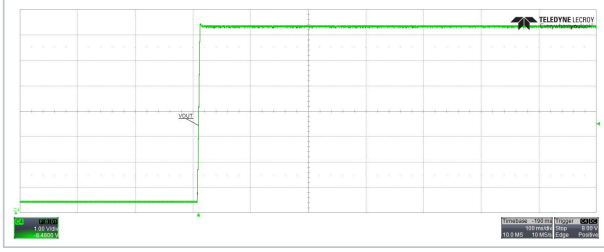


Figure 106. Voltage transition from 5 V to 12 V at 230 V_{AC} – 3.75 A load

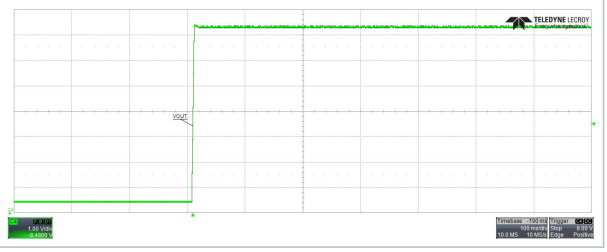


Figure 107. Voltage transition from 12 V to 5 V at 115 V_{AC} – no load

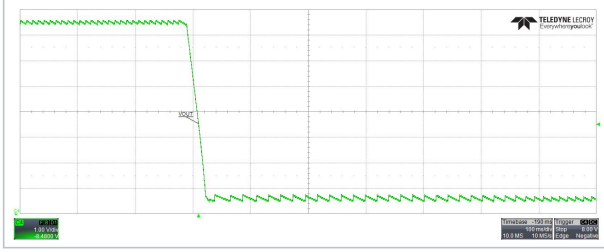


Figure 108. Voltage transition from 12 V to 5 V at 230 V_{AC} – no load

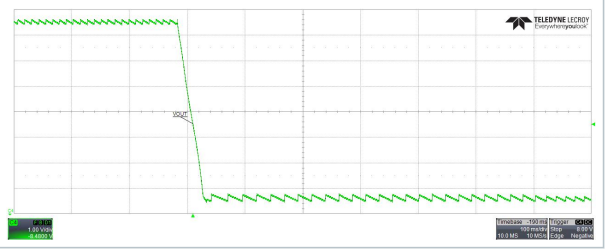


Figure 109. Voltage transition from 12 V to 5 V at 115 V_{AC} – 3.75 A load

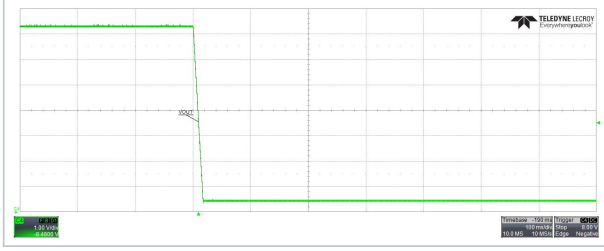
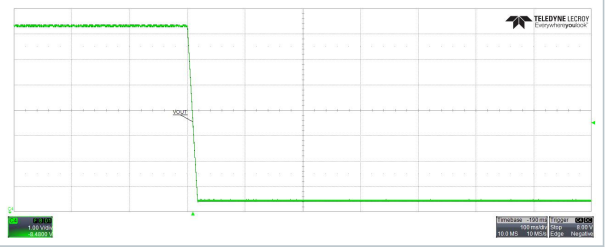


Figure 110. Voltage transition from 12 V to 5 V at 230 V_{AC} – 3.75 A load



From Figure 111 to Figure 118:

- Green = V_{OUT} 2 V/div

Figure 111. Voltage transition from 5 V to 15 V at 115 V_{AC} – no load

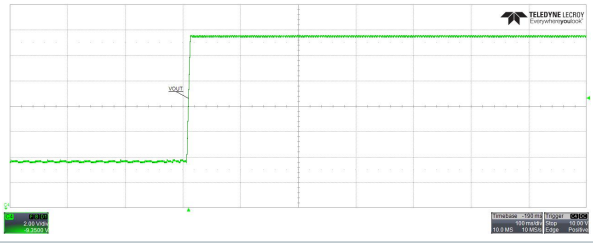


Figure 112. Voltage transition from 5 V to 15 V at 230 V_{AC} – no load

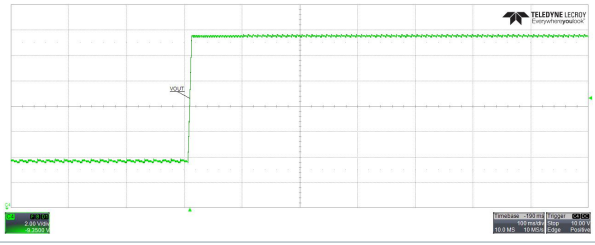


Figure 113. Voltage transition from 5 V to 15 V at 115 V_{AC} – 3.75 A load

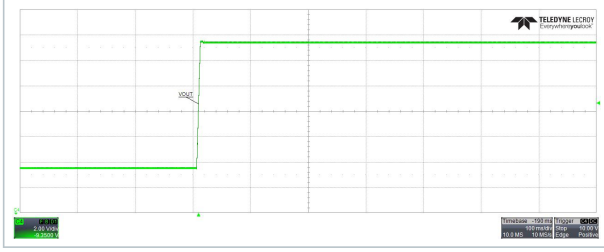


Figure 114. Voltage transition from 5 V to 15 V at 230 V_{AC} – 3.75 A load

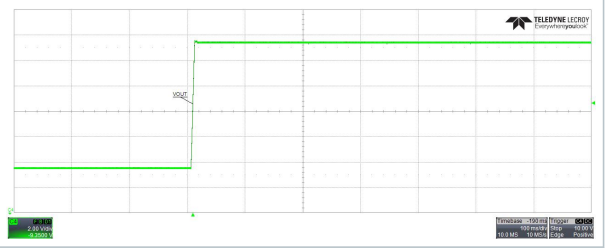


Figure 115. Voltage transition from 15 V to 5 V at 115 V_{AC} – no load

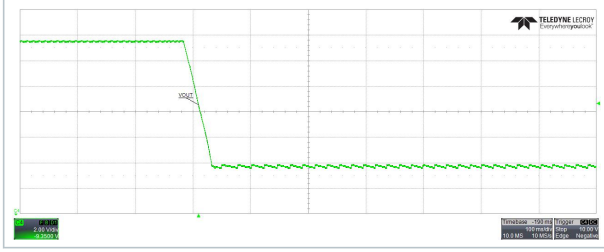


Figure 116. Voltage transition from 15 V to 5 V at 230 V_{AC} – no load

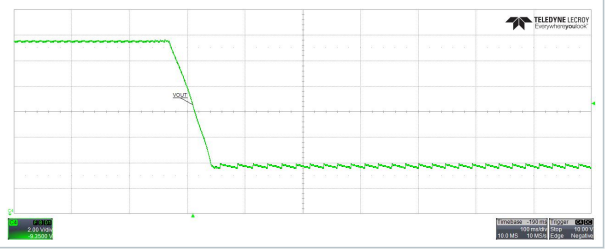


Figure 117. Voltage transition from 15 V to 5 V at 115 V_{AC} – 3.75 A load

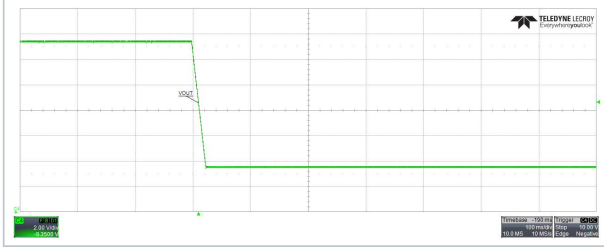
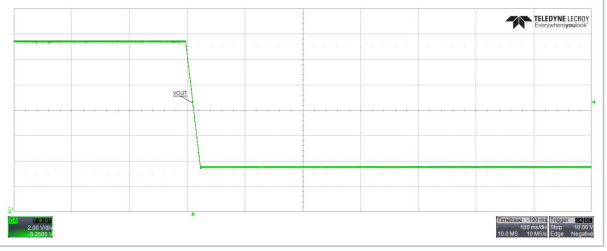


Figure 118. Voltage transition from 15 V to 5 V at 230 V_{AC} – 3.75 A load



From Figure 119 to Figure 126:

- Green = V_{OUT} 3 V/div

Figure 119. Voltage transition from 5 V to 20 V at 115 V_{AC} – no load

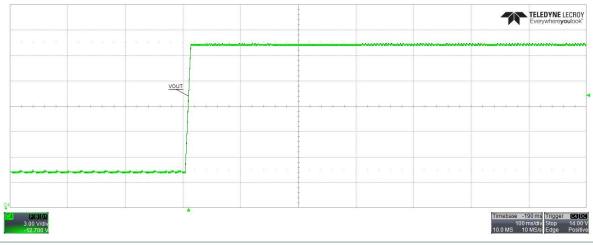


Figure 120. Voltage transition from 5 V to 20 V at 230 V_{AC} – no load

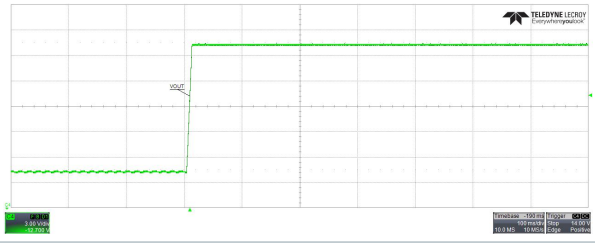


Figure 121. Voltage transition from 5 V to 20 V at 115 V_{AC} – 3.25 A load

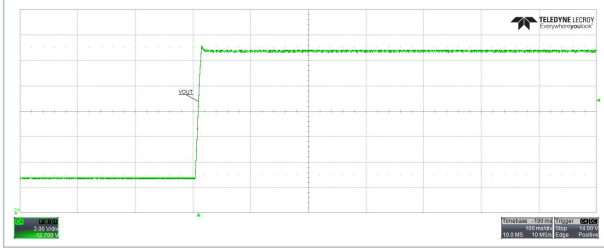


Figure 122. Voltage transition from 5 V to 20 V at 230 V_{AC} – 3.25 A load

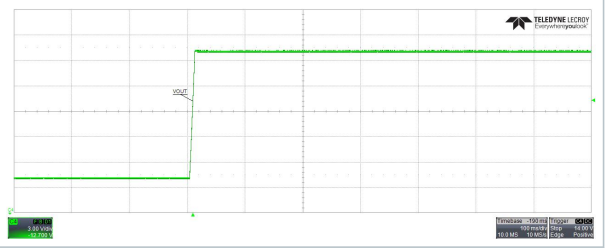


Figure 123. Voltage transition from 20 V to 5 V at 115 V_{AC} – no load

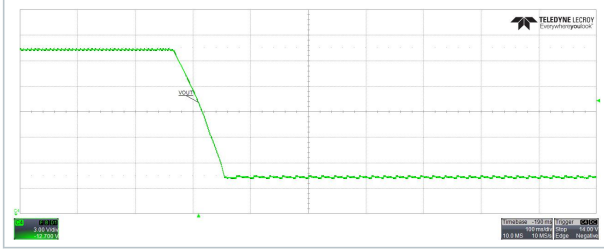


Figure 124. Voltage transition from 20 V to 5 V at 230 V_{AC} – no load

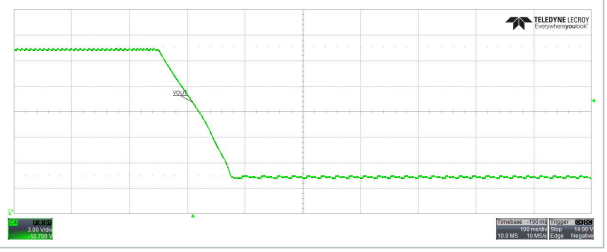


Figure 125. Voltage transition from 20 V to 5 V at 115 V_{AC} – 3.25 A load

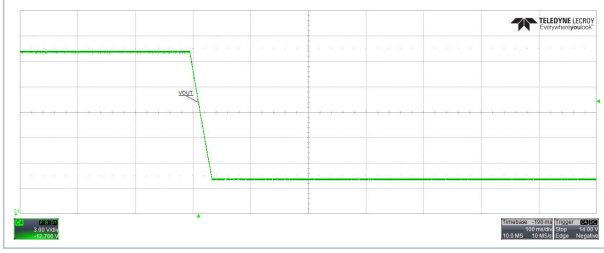
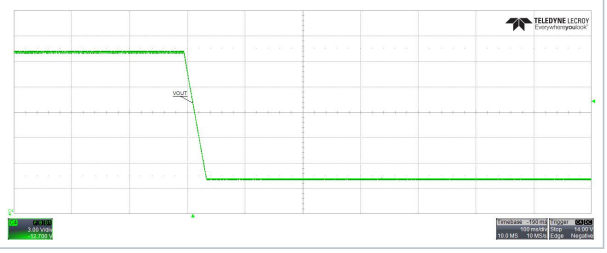


Figure 126. Voltage transition from 20 V to 5 V at 230 V_{AC} – 3.25 A load



From Figure 127 to Figure 134:

- Green = V_{OUT} 1 V/div

Figure 127. Voltage transition from 9 V to 12 V at 115 V_{AC} – no load

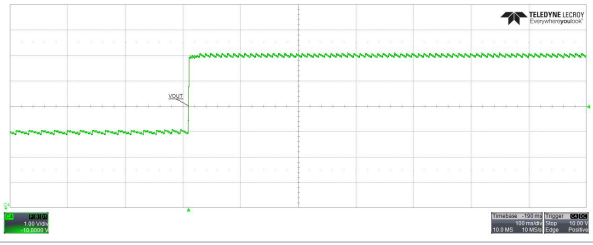


Figure 128. Voltage transition from 9 V to 12 V at 230 V_{AC} – no load

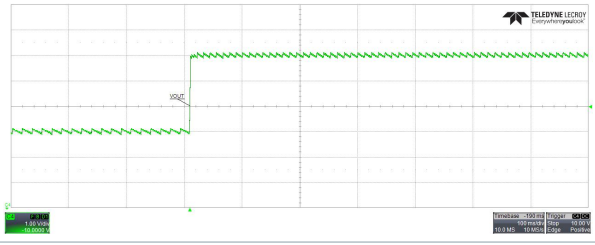


Figure 129. Voltage transition from 9 V to 12 V at 115 V_{AC} – 3.75 A load

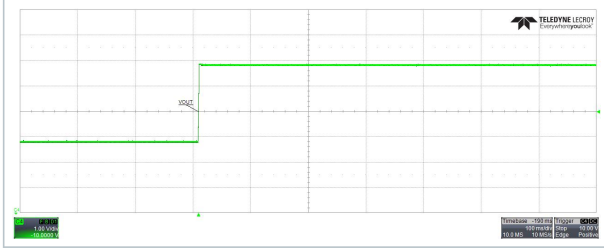


Figure 130. Voltage transition from 9 V to 12 V at 230 V_{AC} – 3.75 A load

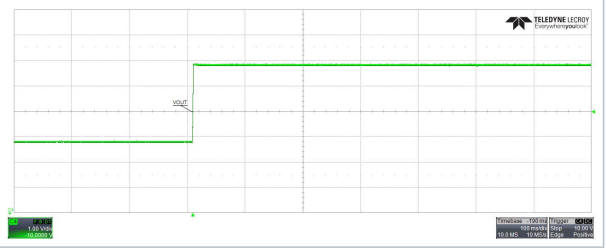


Figure 131. Voltage transition from 12 V to 9 V at 115 V_{AC} – no load

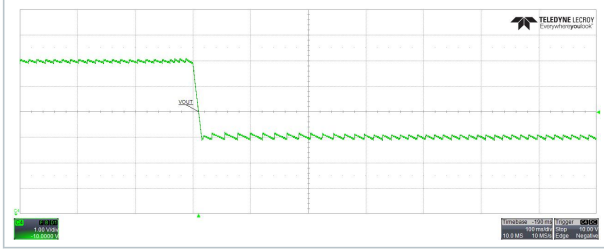


Figure 132. Voltage transition from 12 V to 9 V at 230 V_{AC} – no load

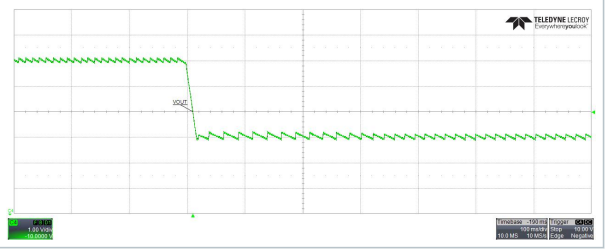


Figure 133. Voltage transition from 12 V to 9 V at 115 V_{AC} – 3.75 A load

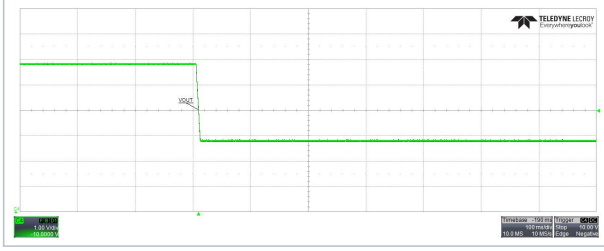
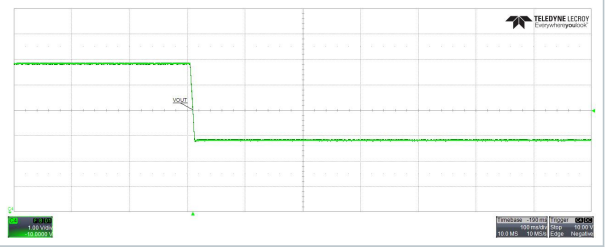


Figure 134. Voltage transition from 12 V to 9 V at 230 V_{AC} – 3.75 A load



From Figure 135 to Figure 174:

- Green = V_{OUT} 2 V/div

Figure 135. Voltage transition from 9 V to 15 V at 115 V_{AC} – no load

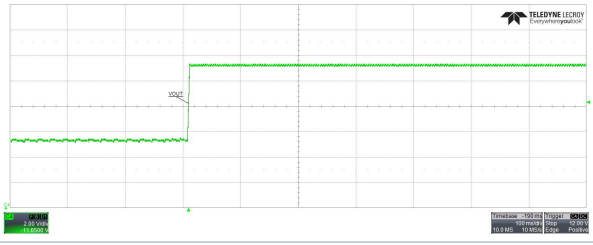


Figure 136. Voltage transition from 9 V to 15 V at 230 V_{AC} – no load

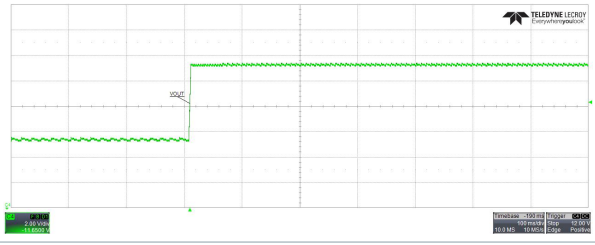


Figure 137. Voltage transition from 9 V to 15 V at 115 V_{AC} – 3.75 A load

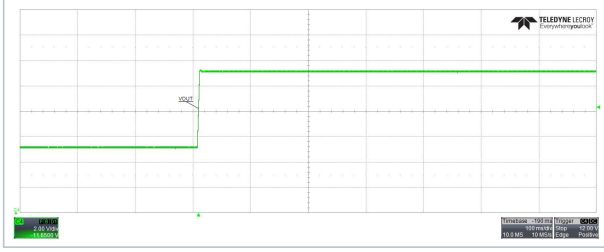


Figure 138. Voltage transition from 9 V to 15 V at 230 V_{AC} – 3.75 A load

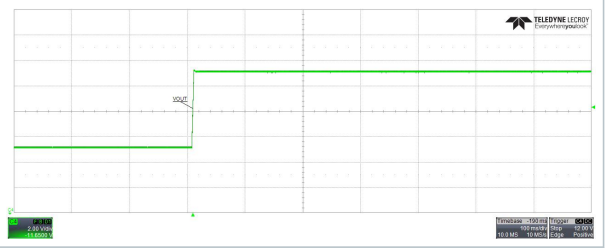


Figure 139. Voltage transition from 15 V to 9 V at 115 V_{AC} – no load

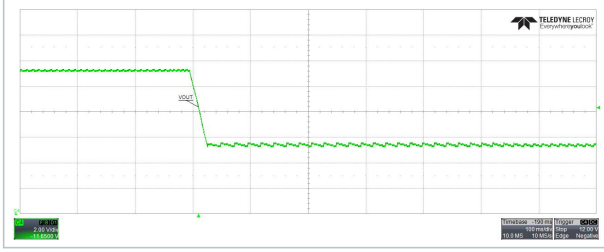


Figure 140. Voltage transition from 15 V to 9 V at 230 V_{AC} – no load

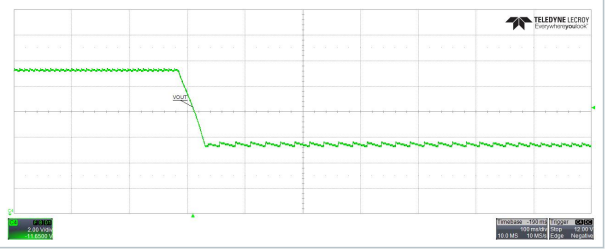


Figure 141. Voltage transition from 15 V to 9 V at 115 V_{AC} – 3.75 A load

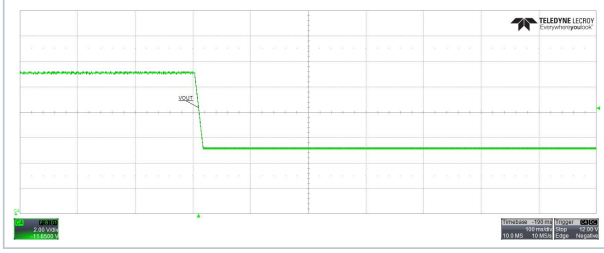


Figure 142. Voltage transition from 15 V to 9 V at 230 V_{AC} – 3.75 A load

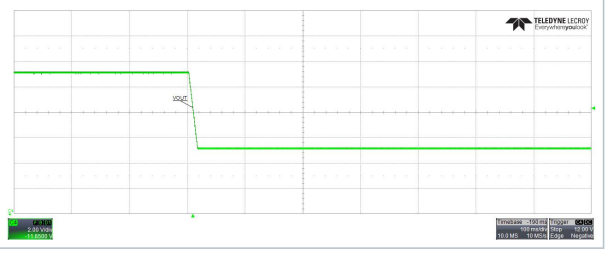


Figure 143. Voltage transition from 9 V to 20 V at 115 V_{AC} – no load

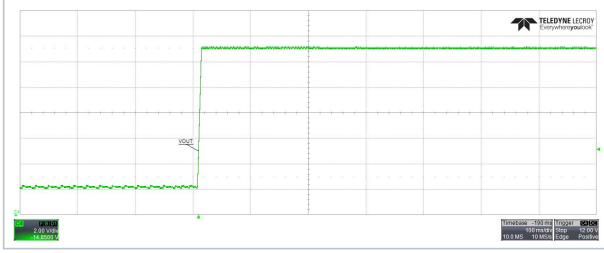


Figure 144. Voltage transition from 9 V to 20 V at 230 V_{AC} – no load

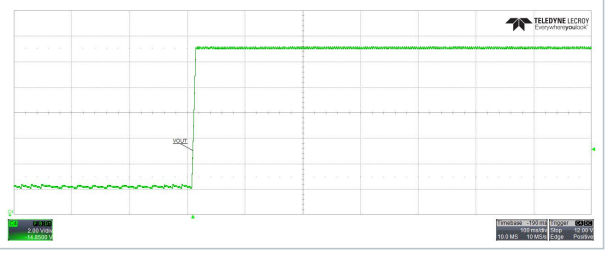


Figure 145. Voltage transition from 9 V to 20 V at 115 V_{AC} – 3.25 A load

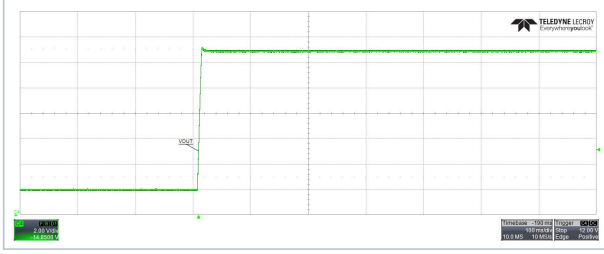


Figure 146. Voltage transition from 9 V to 20 V at 230 V_{AC} – 3.25 A load

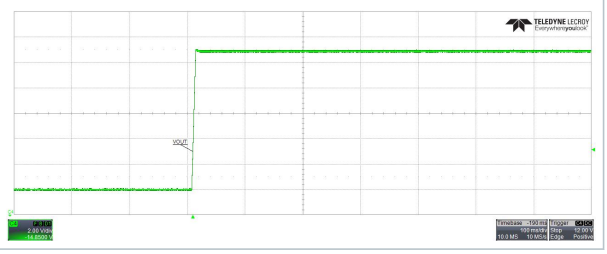


Figure 147. Voltage transition from 20 V to 9 V at 115 V_{AC} – no load

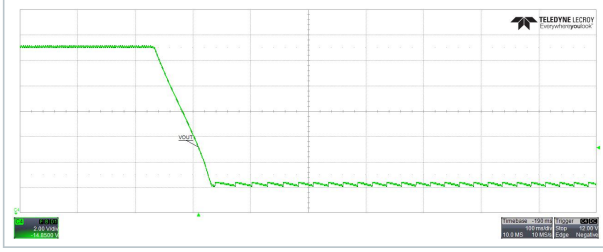


Figure 148. Voltage transition from 20 V to 9 V at 230 V_{AC} – no load

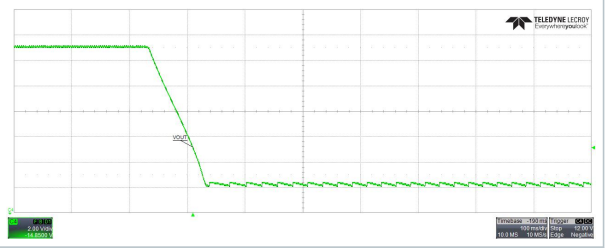


Figure 149. Voltage transition from 20 V to 9 V at 115 V_{AC} – 3.25 A load

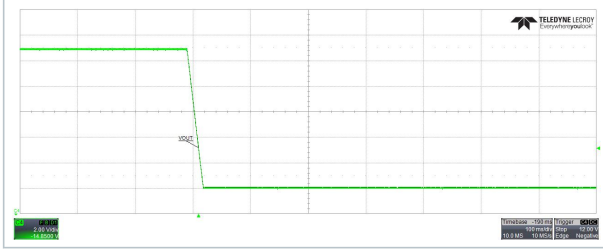


Figure 150. Voltage transition from 20 V to 9 V at 230 V_{AC} – 3.25 A load

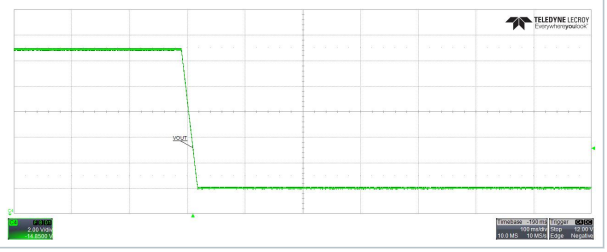


Figure 151. Voltage transition from 12 V to 15 V at 115 V_{AC} – no load

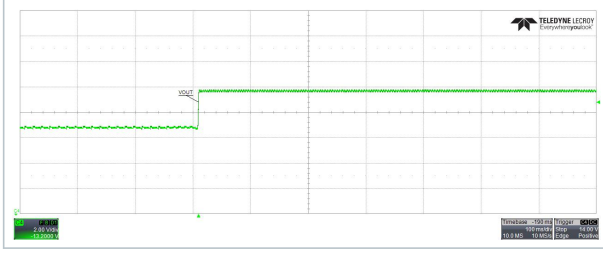


Figure 152. Voltage transition from 12 V to 15 V at 230 V_{AC} – no load

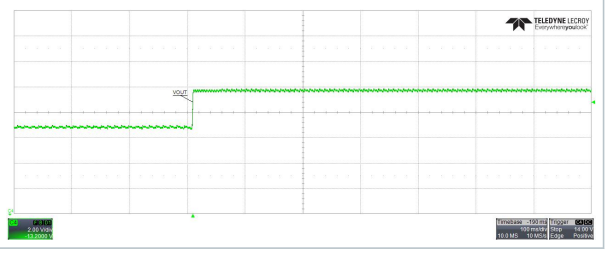


Figure 153. Voltage transition from 12 V to 15 V at 115 V_{AC} – 3.75 A load

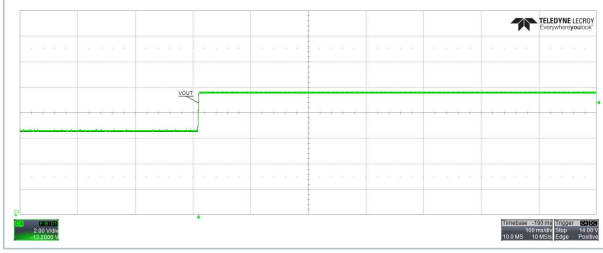


Figure 154. Voltage transition from 12 V to 15 V at 230 V_{AC} – 3.75 A load

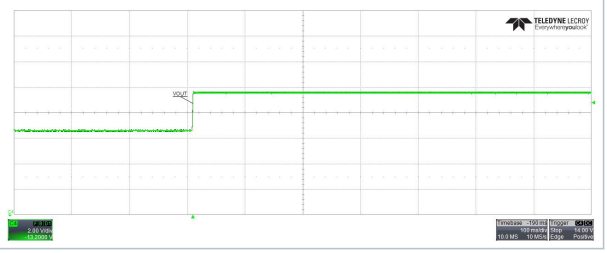


Figure 155. Voltage transition from 15 V to 12 V at 115 V_{AC} – no load

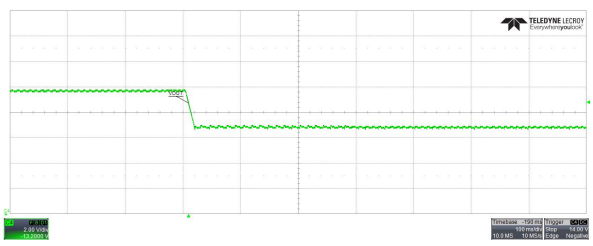


Figure 156. Voltage transition from 15 V to 12 V at 230 V_{AC} – no load

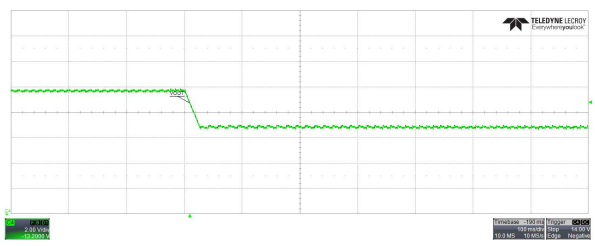


Figure 157. Voltage transition from 15 V to 12 V at 115 V_{AC} – 3.75 A load

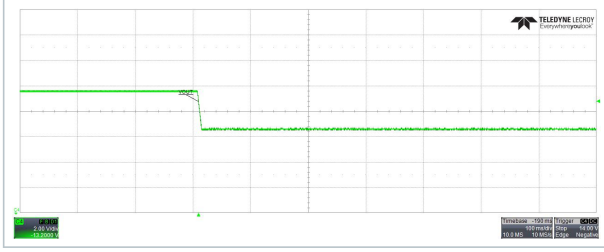


Figure 158. Voltage transition from 15 V to 12 V at 230 V_{AC} – 3.75 A load

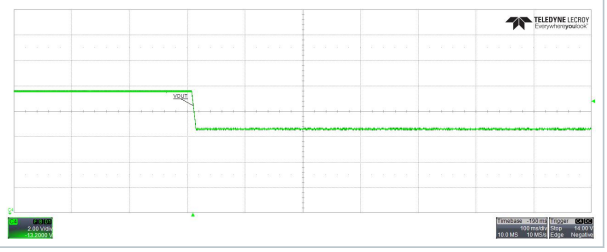


Figure 159. Voltage transition from 12 V to 20 V at 115 V_{AC} – no load

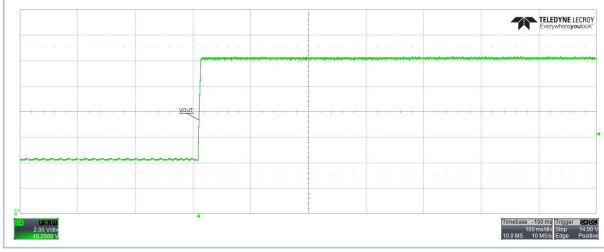


Figure 160. Voltage transition from 12 V to 20 V at 230 V_{AC} – no load

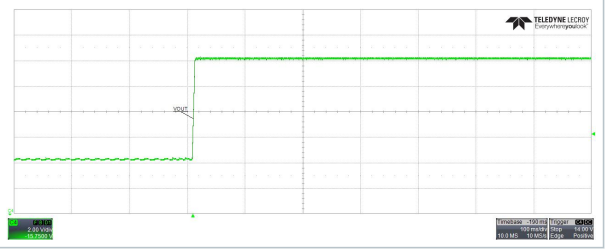


Figure 161. Voltage transition from 12 V to 20 V at 115 V_{AC} – 3.25 A load

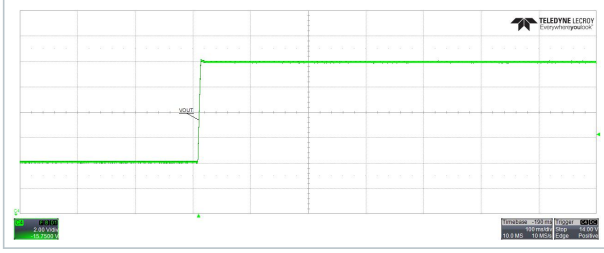


Figure 162. Voltage transition from 12 V to 20 V at 230 V_{AC} – 3.25 A load

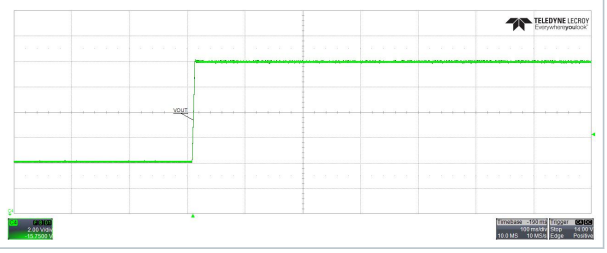


Figure 163. Voltage transition from 20 V to 12 V at 115 V_{AC} – no load

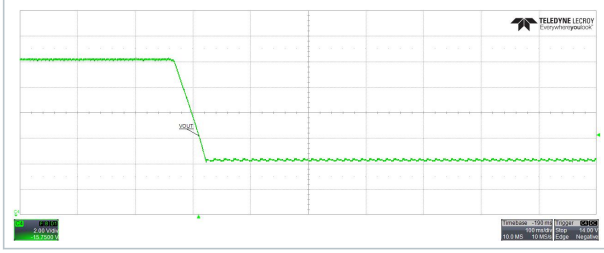


Figure 164. Voltage transition from 20 V to 12 V at 230 V_{AC} – no load

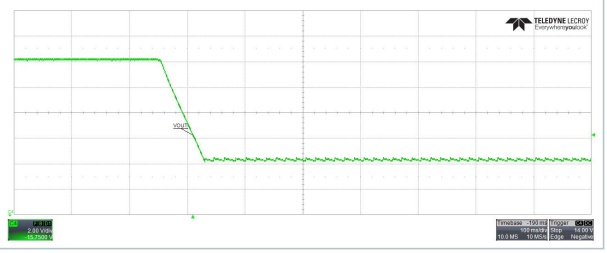


Figure 165. Voltage transition from 20 V to 12 V at 115 V_{AC} – 3.25 A load

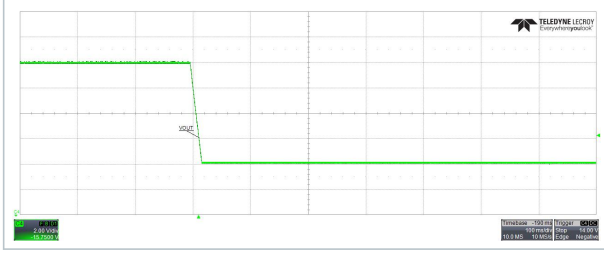


Figure 166. Voltage transition from 20 V to 12 V at 230 V_{AC} – 3.25 A load

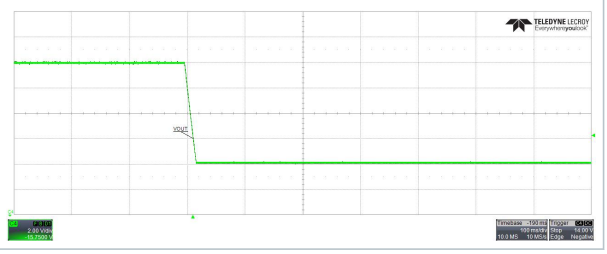


Figure 167. Voltage transition from 15 V to 20 V at 115 V_{AC} – no load

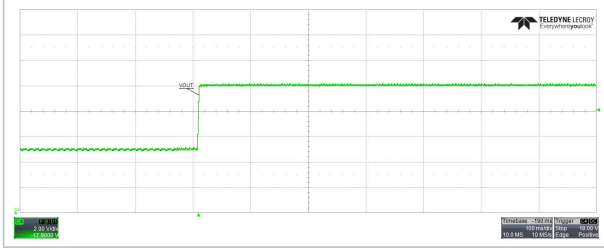


Figure 168. Voltage transition from 15 V to 20 V at 230 V_{AC} – no load

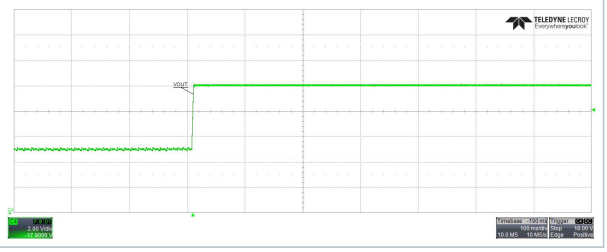


Figure 169. Voltage transition from 15 V to 20 V at 115 V_{AC} – 3.25 A load

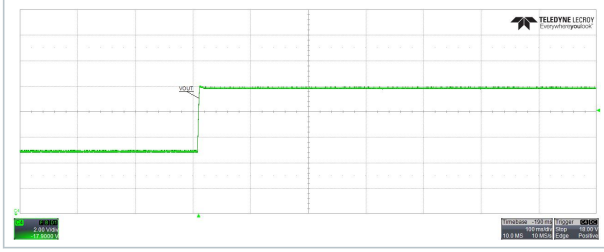


Figure 170. Voltage transition from 15 V to 20 V at 230 V_{AC} – 3.25 A load

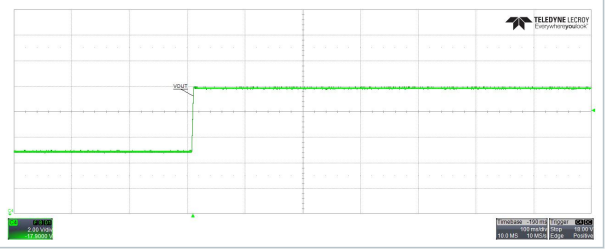


Figure 171. Voltage transition from 20 V to 15 V at 115 V_{AC} – no load

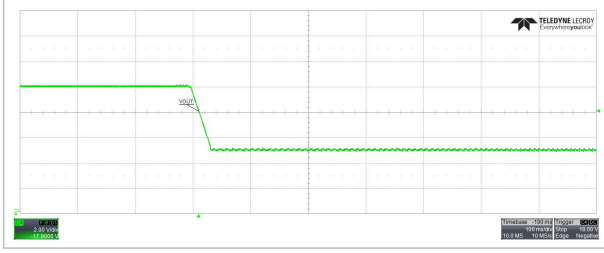


Figure 172. Voltage transition from 20 V to 15 V at 230 V_{AC} – no load

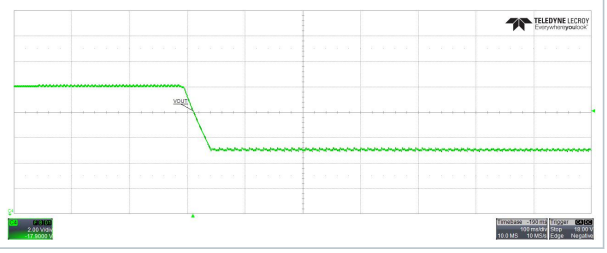


Figure 173. Voltage transition from 20 V to 15 V at 115 V_{AC} – 3.25 A load

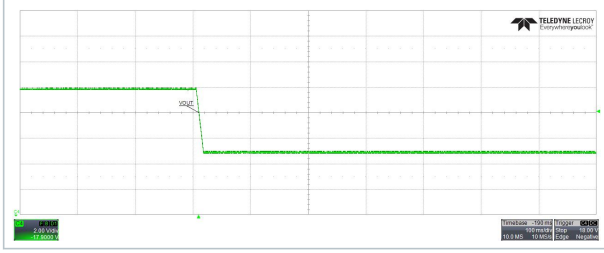
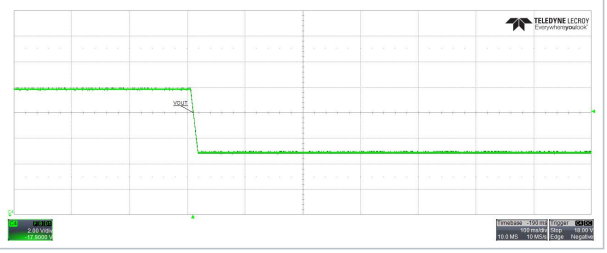


Figure 174. Voltage transition from 20 V to 15 V at 230 V_{AC} – 3.25 A load



8 Voltage stress on the main power MOSFET

The following figures show the voltage phase on the primary side and the current sense pin voltage. The measures have been performed with 90 V_{AC}/60 Hz and 265 V_{AC}/50 Hz input voltages under full load condition. Different output voltages have been selected (3.3 V-APDO, 5 V-PDO, 9 V-PDO, 12 V-PDO, 15 V-PDO and 20 V-PDO).

Figure 175. Primary side phase waveform with 3.3 V output at 90 V_{AC} – 3.75 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 50 V/div
- $V_{PHASEmax}$ = 164.4 V

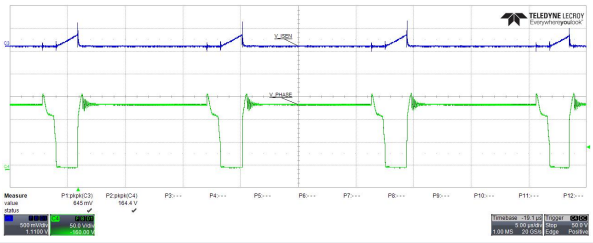


Figure 176. Primary side phase waveform with 3.3 V output at 265 V_{AC} – 3.75 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 100 V/div
- $V_{PHASEmax}$ = 406.8 V

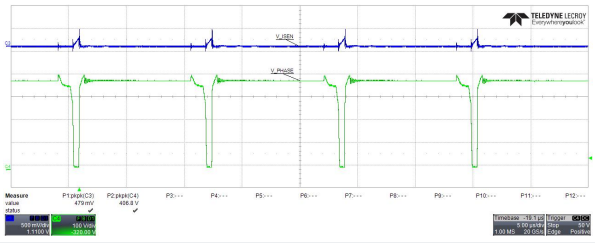


Figure 177. Primary side phase waveform with 5 V output at 90 V_{AC} – 3.75 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 50 V/div
- $V_{PHASEmax}$ = 172.7 V

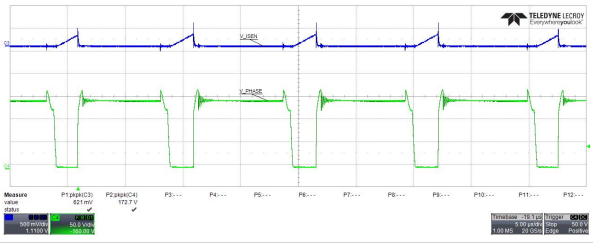


Figure 178. Primary side phase waveform with 5 V output at 265 V_{AC} – 3.75 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 100 V/div
- $V_{PHASEmax}$ = 419.2 V

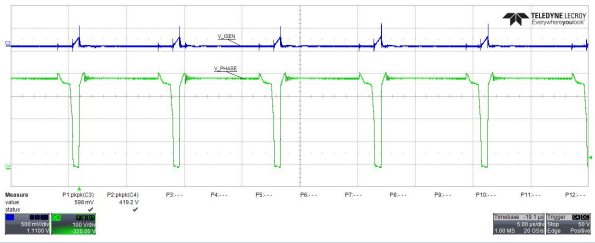


Figure 179. Primary side phase waveform with 9 V output at 90 V_{AC} – 3.75 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 50 V/div
- $V_{PHASEmax}$ = 195.7 V

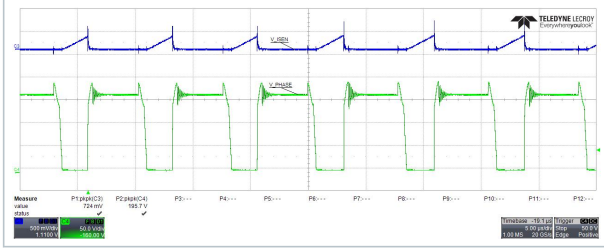


Figure 180. Primary side phase waveform with 9 V output at 265 V_{AC} – 3.75 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 100 V/div
- $V_{PHASEmax}$ = 444.7 V

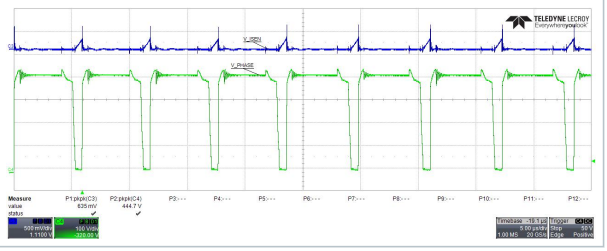


Figure 181. Primary side phase waveform with 12 V output at 90 V_{AC} – 3.75 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 50 V/div
- $V_{PHASEmax}$ = 207.6 V

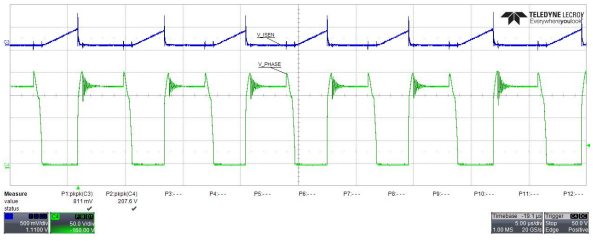


Figure 182. Primary side phase waveform with 12 V output at 265 V_{AC} – 3.75 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 100 V/div
- $V_{PHASEmax}$ = 458.5 V

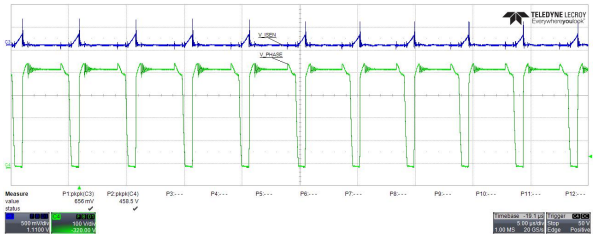


Figure 183. Primary side phase waveform with 15 V output at 90 V_{AC} – 3.75 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 50 V/div
- $V_{PHASEmax}$ = 221.1 V

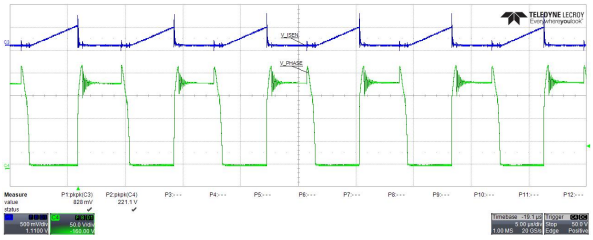


Figure 184. Primary side phase waveform with 15 V output at 265 V_{AC} – 3.75 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 100 V/div
- $V_{PHASEmax}$ = 483.8 V

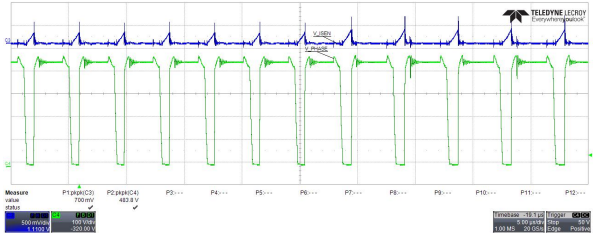


Figure 185. Primary side phase waveform with 20 V output at 90 V_{AC} – 3.25 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 50 V/div
- $V_{PHASEmax}$ = 268.2 V

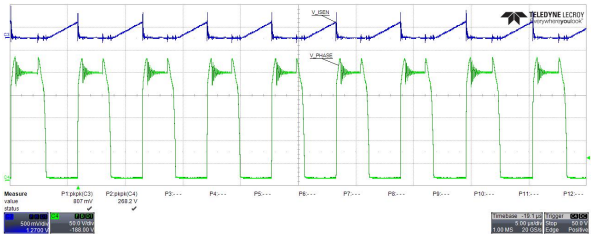
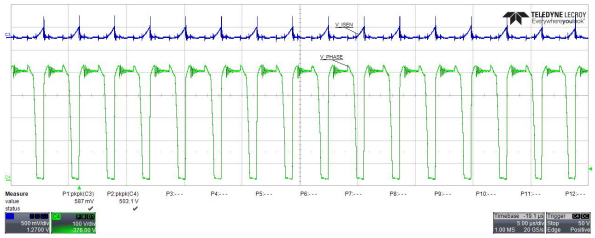


Figure 186. Primary side phase waveform with 20 V output at 265 V_{AC} – 3.25 A load

- Blue = V_{ISEN} 500 mV/div
- Green = V_{PHASE} 100 V/div
- $V_{PHASEmax}$ = 503.1 V



The figures below show the V_{DS} voltages of the synchronous rectifier (SR) on the secondary side of the device. The measures have been performed with 90 V_{AC}/60 Hz and 265 V_{AC}/50 Hz input voltages under full load condition. Different output voltages have been selected (3.3 V-APDO, 5 V-PDO, 9 V-PDO, 12 V-PDO, 15 V-PDO and 20 V-PDO).

Figure 187. Secondary side phase waveform with 3.3 V output at 90 V_{AC} – 3.75 A load

- Green = V_{DS} of SR 10 V/div
- V_{DSmax} = 23.79 V

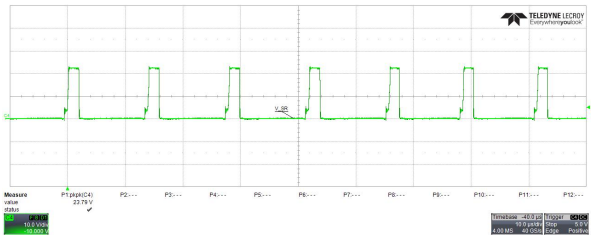


Figure 188. Secondary side phase waveform with 3.3 V output at 265 V_{AC} – 3.75 A load

- Green = V_{DS} of SR 20 V/div
- V_{DSmax} = 62.25 V

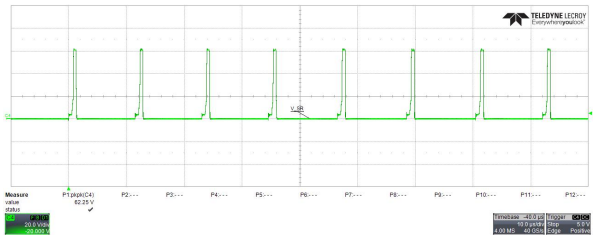


Figure 189. Secondary side phase waveform with 5 V output at 90 V_{AC} – 3.75 A load

- Green = V_{DS} of SR 10 V/div
- V_{DSmax} = 24.80 V

Figure 190. Secondary side phase waveform with 5 V output at 265 V_{AC} – 3.75 A load

- Green = V_{DS} of SR 20 V/div
- V_{DSmax} = 63.42 V

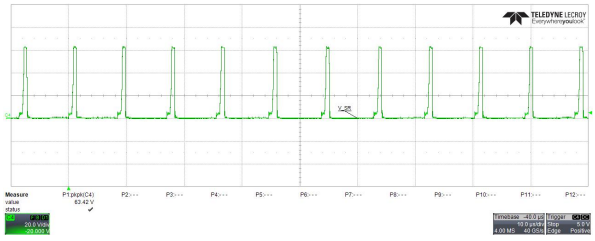


Figure 191. Secondary side phase waveform with 9 V output at 90 V_{AC} – 3.75 A load

- Green = V_{DS} of SR 10 V/div
- V_{DSmax} = 27.34 V

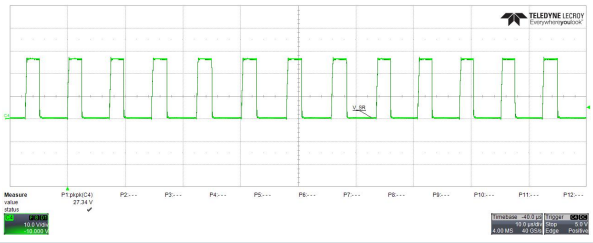


Figure 192. Secondary side phase waveform with 9 V output at 265 V_{AC} – 3.75 A load

- Green = V_{DS} of SR 20 V/div
- V_{DSmax} = 66.67 V

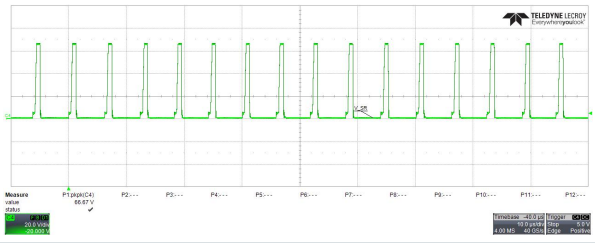


Figure 193. Secondary side phase waveform with 12 V output at 90 V_{AC} – 3.75 A load

- Green = V_{DS} of SR 10 V/div
- V_{DSmax} = 28.84 V

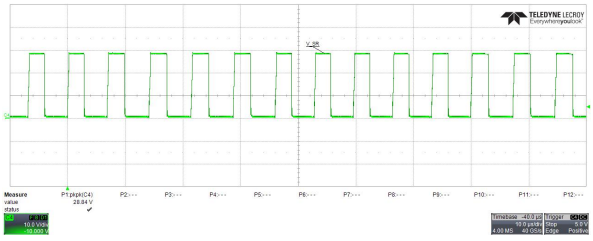


Figure 194. Secondary side phase waveform with 12 V output at 265 V_{AC} – 3.75 A load

- Green = V_{DS} of SR 20 V/div
- V_{DSmax} = 69.97 V

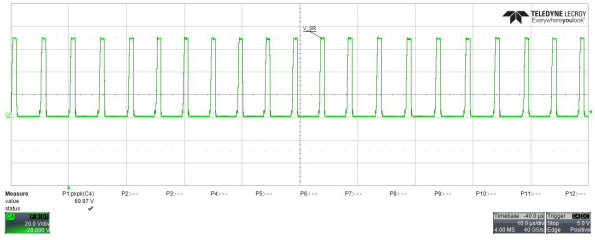


Figure 195. Secondary side phase waveform with 15 V output at 90 V_{AC} – 3.75 A load

- Green = V_{DS} of SR 10 V/div
- V_{DSmax} = 26.33 V

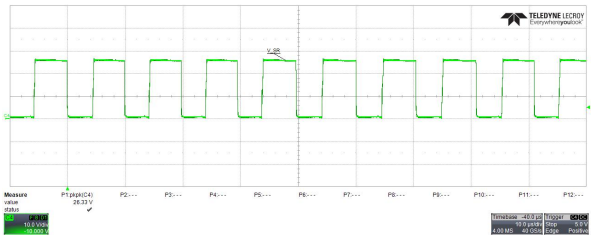


Figure 196. Secondary side phase waveform with 15 V output at 265 V_{AC} – 3.75 A load

- Green = V_{DS} of SR 20 V/div
- V_{DSmax} = 70.32 V

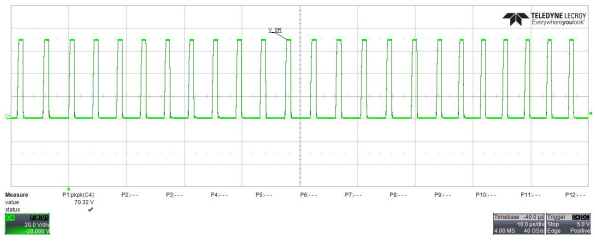


Figure 197. Secondary side phase waveform with 20 V output at 90 V_{AC} – 3.25 A load

- Green = V_{DS} of SR 10 V/div
- V_{DSmax} = 35.45 V

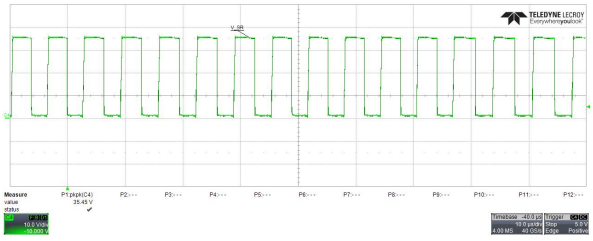
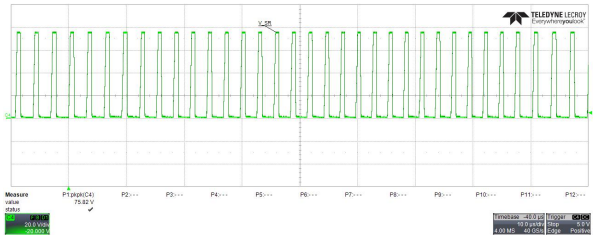


Figure 198. Secondary side phase waveform with 20 V output at 265 V_{AC} – 3.25 A load

- Green = V_{DS} of SR 20 V/div
- V_{DSmax} = 75.82 V



9 PPS voltage transitions

The EVLONE65W is designed to provide PPS profiles to control the output voltage, ensuring 20 mV steps during constant voltage operation and 50 mA steps during constant current operation. The test below shows a PPS voltage transition from 3.3 V to 21 V. A dedicated tool (Quadramax) performs a sequence of voltage requests from the minimum to the maximum value of the requested APDO with different voltage steps:

- 20 mV
- 100 mV
- 500 mV

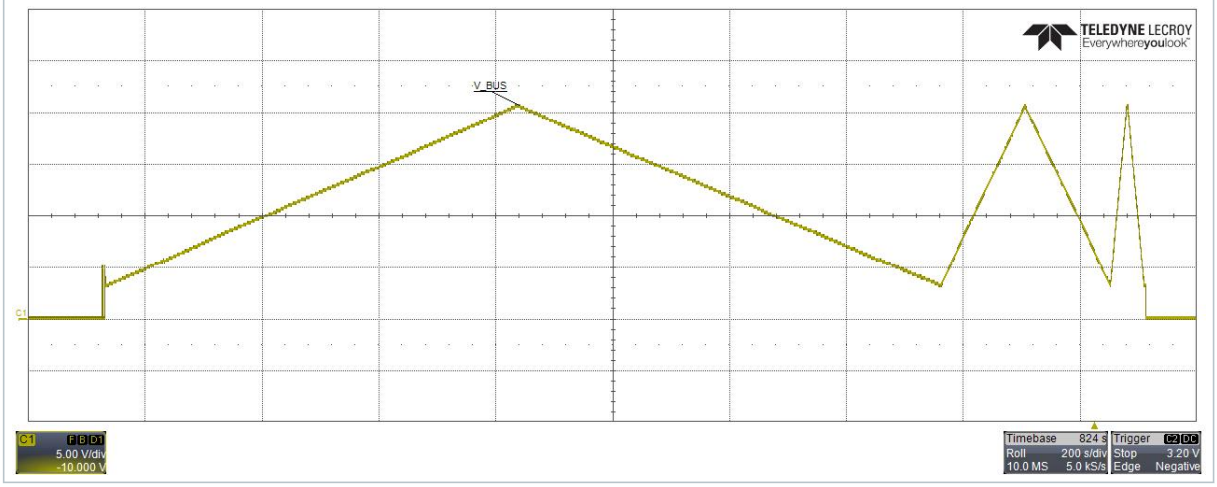
The current requested during the test is equal to 1.7 A, that is calculated by the following equation as required by the test specifications:

$$0.8 \times \left(\frac{APDO\ maximum\ current}{2} + 500\ mA\right)$$

In the figure below:

- Yellow = V_{BUS} 5 V/div

Figure 199. PPS voltage transition from 3.3 V to 21 V at 230 V_{AC} - 1.7 A



10 PPS current limit

When the load overcomes the operating current, the system enters Current Limit mode. To perform this test the following conditions have been applied:

- Operating current:
  - 1 A
  - (Current APDO max. current/2) + 500 mA
  - Current APDO max. current
- Operating voltage:
  - APDO min. voltage
  - (APDO min. voltage + APDO max voltage)/2
  - APDO max. voltage
- Current step:
  - 50 mA

The following figures show the Current Limit mode and data related to the two higher operating voltages. The minimum operating voltage condition is negligible for the board performance evaluation. Due to the low voltages requested by the tester, small load increases quickly activate Current Limit mode. All the data have been collected using an oscilloscope in XY configuration (X=I_{OUT}, Y=V_{BUS}) and a commercial tool, working as a sink. All the tests have been performed with input voltage at 230 V_{AC}/50 Hz.

Figure 200. PPS current limit APDO (3.3V÷16V), operating voltage = 9.65 V, operating current = 1 A

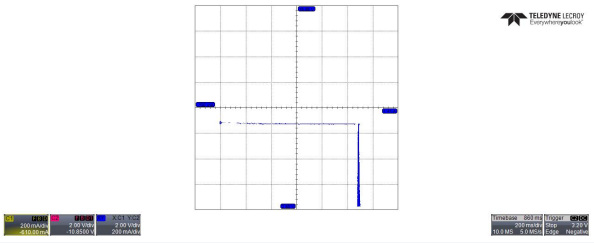


Figure 201. PPS current limit APDO (3.3V÷16V), operating voltage = 9.65 V, operating current = 2.35 A

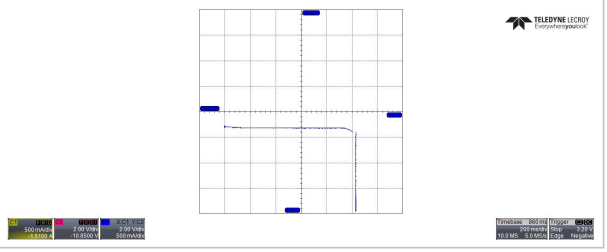


Figure 202. PPS current limit APDO (3.3V÷16V), operating voltage = 9.65 V, operating current = 3.75 A

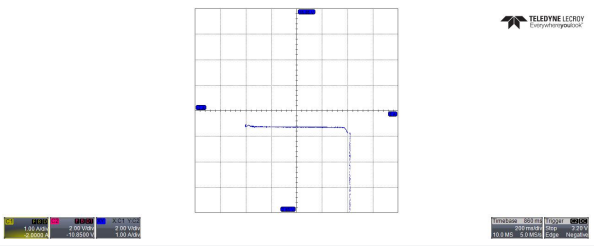


Figure 203. PPS current limit APDO (3.3V÷16V), operating voltage = 16 V, operating current = 1 A

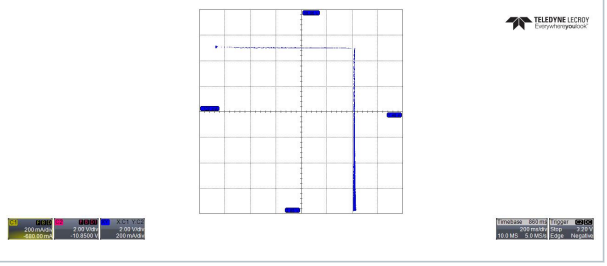


Figure 204. PPS current limit APDO (3.3V÷16V), operating voltage = 16 V, operating current = 2.35 A

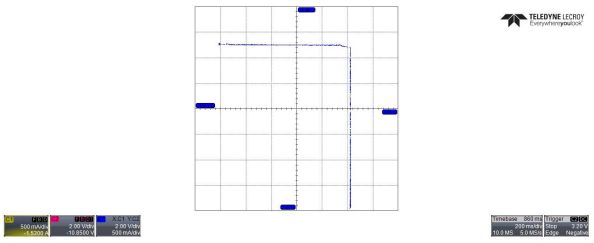


Figure 205. PPS current limit APDO (3.3V÷16V), operating voltage = 16 V, operating current = 3.75 A

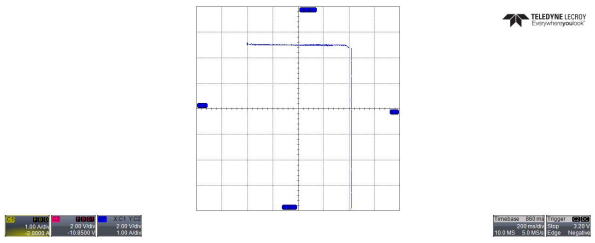


Figure 206. PPS current limit APDO (3.3V÷21V), operating voltage = 12.15 V, operating current = 1 A

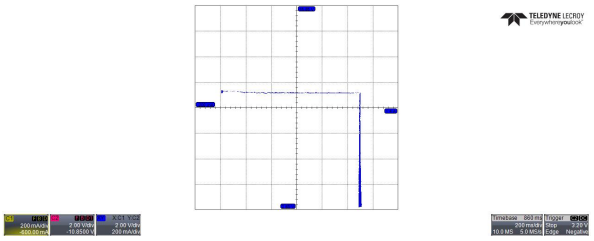


Figure 207. PPS current limit APDO (3.3V÷21V), operating voltage = 12.15 V, operating current = 2.1 A

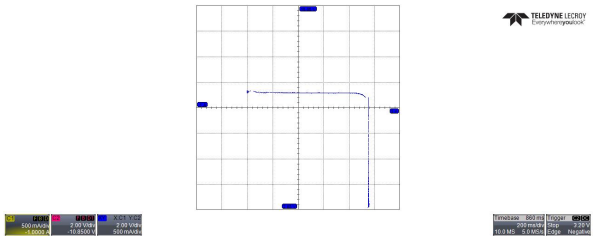


Figure 208. PPS current limit APDO (3.3V÷21V), operating voltage = 12.15 V, operating current = 3.25 A

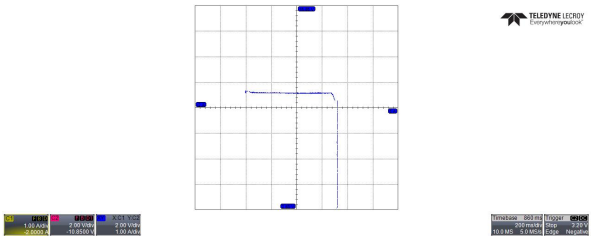


Figure 209. PPS current limit APDO (3.3V÷21V), operating voltage = 20 V, operating current = 1 A

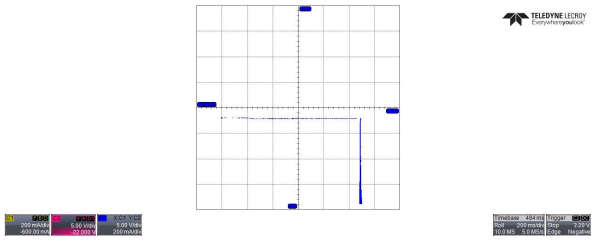


Figure 210. PPS current limit APDO (3.3V÷21V), operating voltage = 20 V, operating current = 2.1 A

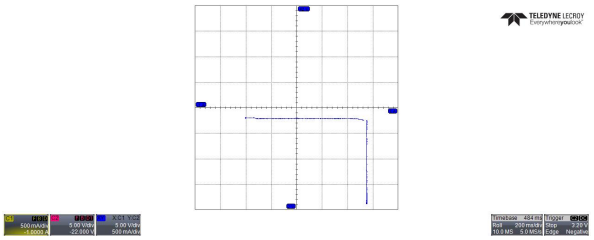
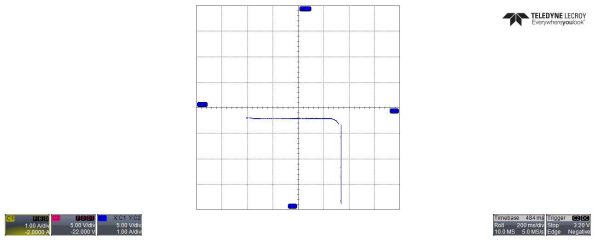


Figure 211. PPS current limit APDO (3.3V÷21V), operating voltage = 20 V, operating current = 3.25 A



11 Operation modes

The following figures show the operation mode of the device under different conditions. The test has been performed with 230 V_{AC}/50 Hz input voltage and setting two different outputs:

- 5 V at 3.75 A load
- 20 V at 3.25 A load

To change the mode of operation the maximum load has been slowly decreased until the minimum load value (0 A), and viceversa. Starting from maximum load it is possible to observe the CCM/DCM mode, then, decreasing the load, the system enters in valley skipping mode and finally at very low load the device is in burst mode, and the reverse when the load is increased. The following waveforms show the secondary side phase at the different operation modes. In the following figures:

- Blue = V_phase_secondary_side 20 V/div

Figure 212. CCM/DCM operation mode at 230 V_{AC} with 5 V output

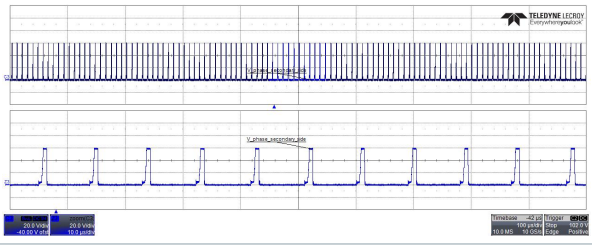


Figure 213. Valley skipping operation mode at 230 V_{AC} with 5 V output

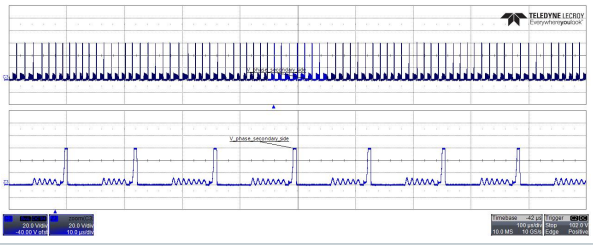


Figure 214. Burst operation mode at 230 V_{AC} with 5 V output

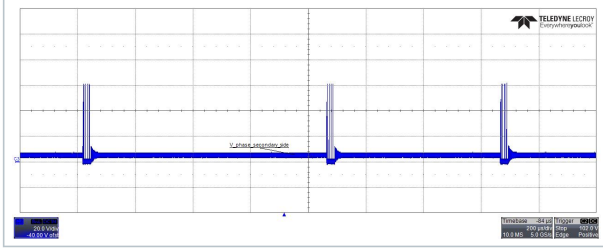


Figure 215. CCM/DCM operation mode at 230 V_{AC} with 20 V output

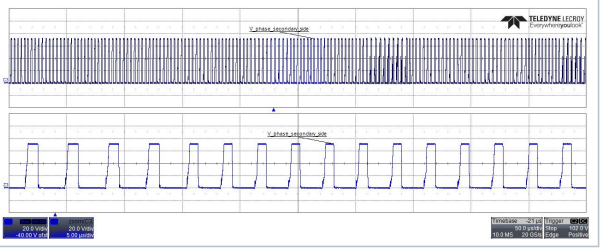


Figure 216. Valley skipping operation mode at 230 V_{AC} with 20 V output

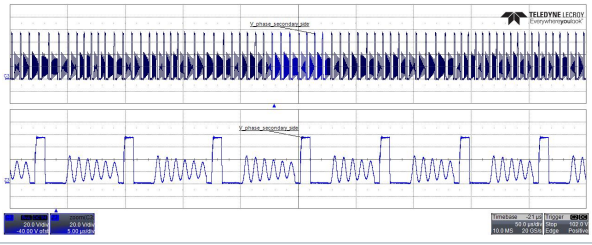
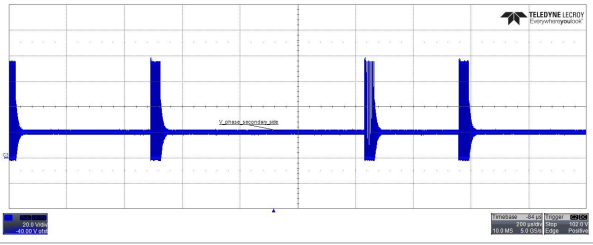


Figure 217. Burst operation mode at 230 V_{AC} with 20 V output



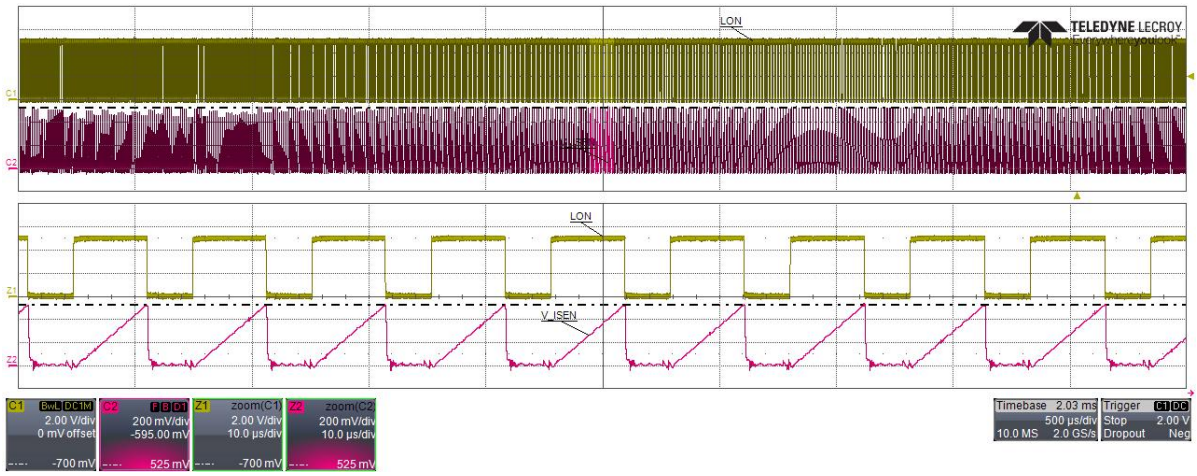
12 Protections

12.1 OC1 protection on primary side

To verify the correct behavior of the OC1 protection on the primary side, the current load is increased until V_{ISEN} reaches the $V_{IPKCLAMP}$ (equal to 525 mV). Every time that the voltage on the current sense pin bypasses this limit, the LON signal is turned off. In the next figure:

- Yellow = LON 2 V/div
- Purple = V_{ISEN} 200 mV/div

Figure 218. OC1 protection on primary side – 20 V output at 90 V_{AC}

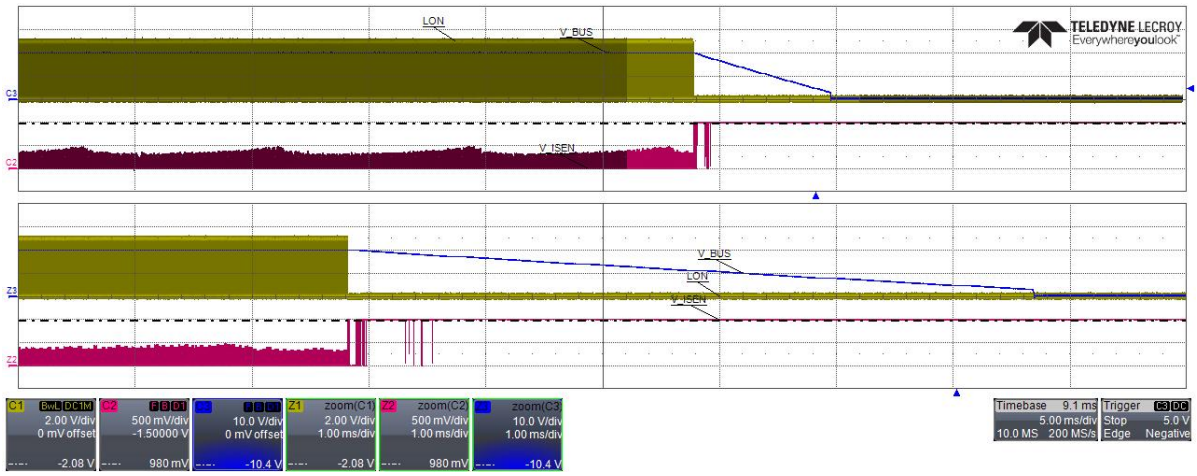


12.2 OC2 protection on primary side

To test this kind of protection, a function waveform generator is connected to the ISEN pin through a diode. A DC offset is set to trigger the OC2 level protection. When the voltage on the current sense pin bypasses the V_{OCTH} (equal to 900 mV) the LON and V_{BUS} are turned off. In the following figure:

- Yellow = LON 2 V/div
- Purple = V_{ISEN} 500 mV/div
- Blue = V_{BUS} 10 V/div

Figure 219. OC2 protection on primary side – 20 V output at 90 V_{AC}

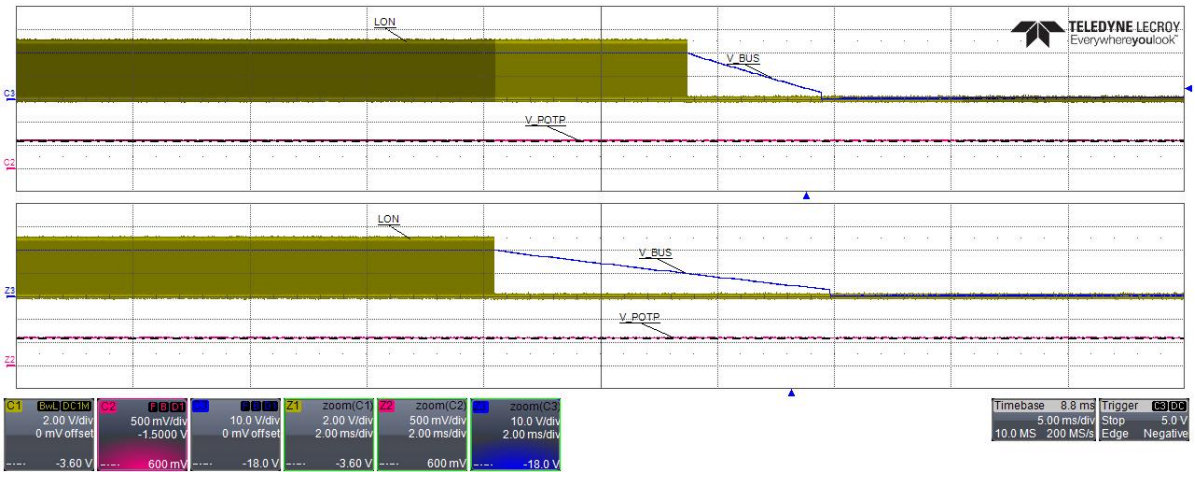


12.3 POTP protection on primary side

To check the POTP protection on the primary side, R11 is changed with a resistance of 1 kΩ. In this way it is possible to trigger the protection at a lower temperature. The output is set to 20 V full load. When the voltage on the POTP pin bypasses the V_{POVTH} (equal to 600 mV) the VBUS and LON are turned off. In the following figure:

- Yellow = LON 2 V/div
- Purple = V_{POTP} 500 mV/div
- Blue = V_{BUS} 10 V/div

Figure 220. POTP protection on primary side – 20 V output at 90 V_{AC}



12.4 OCP protection on secondary side

To verify the OCP protection on the secondary side, an extra current load is requested. The test is performed for all the PDO profiles. When the output current load exceeds the maximum PDO current value by 5.5%, the V_{BUS} is turned off. The test has been performed with 115 V_{AC}/60 Hz and 230 V_{AC}/50 Hz input voltages. In Figure 221 and Figure 222:

- Yellow = I_{OUT} 200 mA/div
- Purple = V_{BUS} 2 V/div

Figure 221. OCP protection on secondary side – 5 V output at 115 V_{AC}

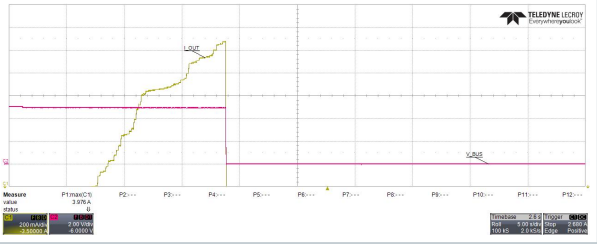
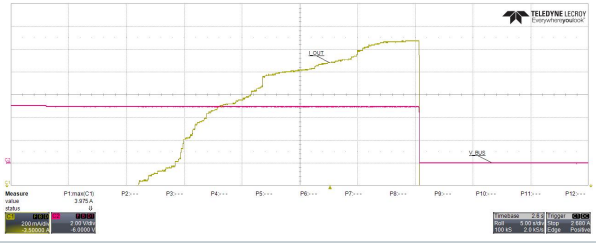


Figure 222. OCP protection on secondary side – 5 V output at 230 V_{AC}



From Figure 223 to Figure 230:

- Yellow = I_{OUT} 200 mA/div
- Purple = V_{BUS} 5 V/div

Figure 223. OCP protection on secondary side – 9 V output at 115 V_{AC}

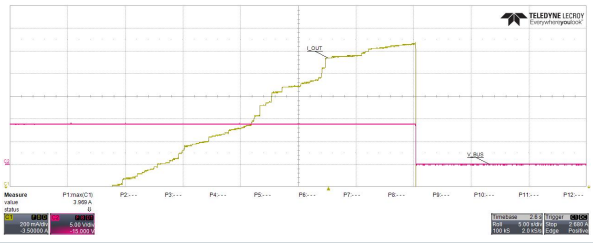


Figure 224. OCP protection on secondary side – 9 V output at 230 V_{AC}

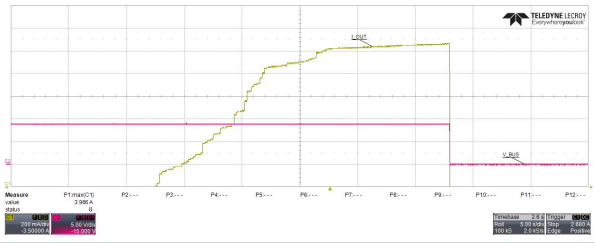


Figure 225. OCP protection on secondary side – 12 V output at 115 V_{AC}

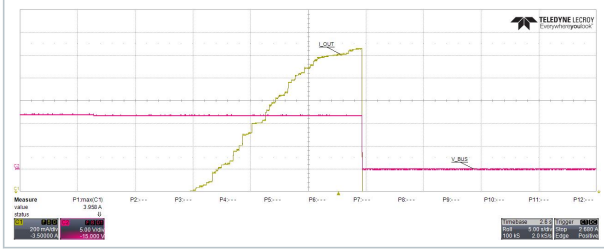


Figure 226. OCP protection on secondary side – 12 V output at 230 V_{AC}

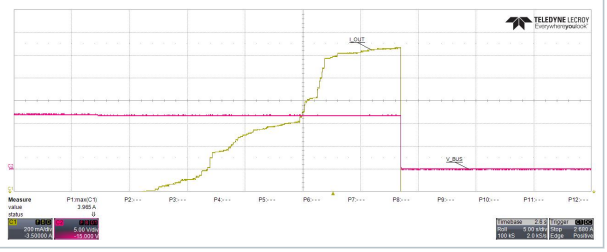


Figure 227. OCP protection on secondary side – 15 V output at 115 V_{AC}

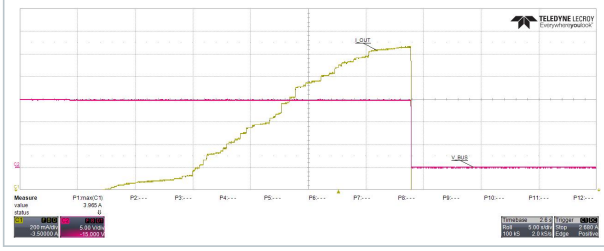


Figure 228. OCP protection on secondary side – 15 V output at 230 V_{AC}

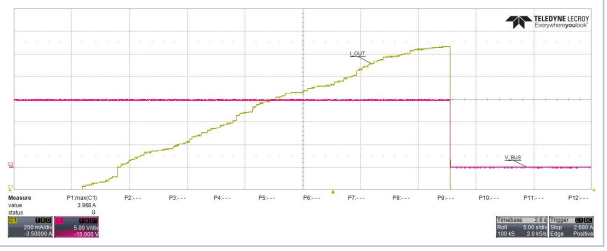


Figure 229. OCP protection on secondary side – 20 V output at 115 V_{AC}

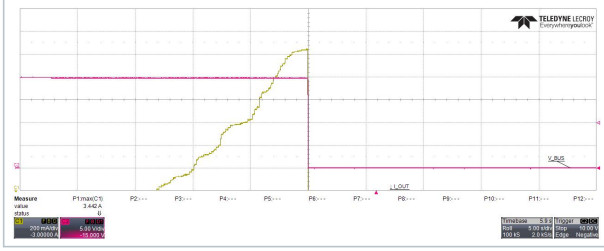
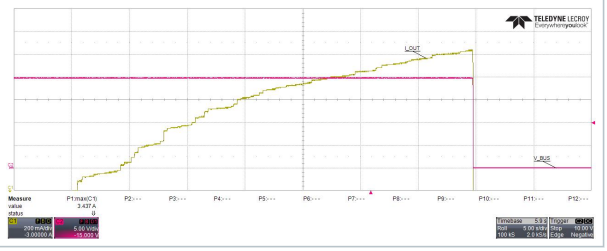


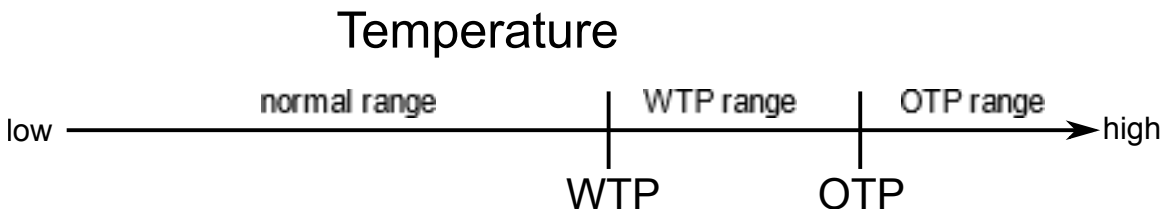
Figure 230. OCP protection on secondary side – 20 V output at 230 V_{AC}



12.5 SOTP protection on secondary side

In general, when over temperature on secondary side occurs, the HARD_RESET message is sent out and the next capability proposed is only 5 V at 500 mA. In case the OTP (Over Temperature Protection) is confirmed for 10 seconds, the V_{BUS} voltage is switched off. The V_{BUS} voltage is provided only when the secondary side temperature returns below OTP-10 ºC. There is also a WTP (Warning Temperature Protection) range between WTP point and OTP point (see Figure 231).When the temperature enters the WTP range an Alarm message is sent, but no other action is performed. Only in case of new capability request or new contract, the next capability message limits the current/power, depending on the setup on the configuration area.

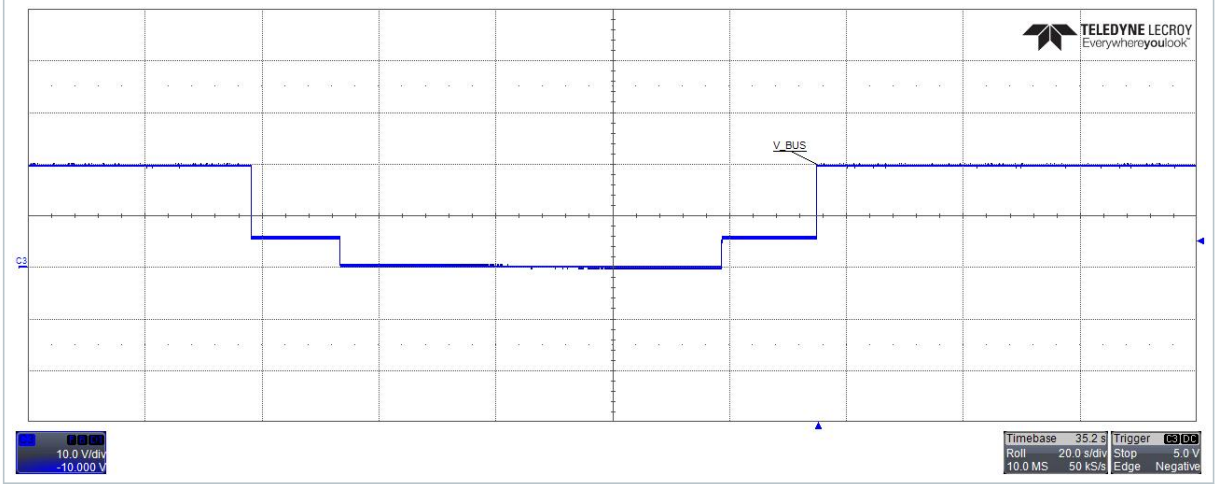
Figure 231. **Secondary side OTP management**



In this case, to check the correct behavior of the SOTP protection on the secondary side, the board is heated and, watching the trend of V_{BUS}, it is possible to observe that the device touches the OTP limit (V_{BUS} decreased to 5V). Then, when OTP is triggered for more than 10 seconds the V_{BUS} is switched off. After turning off the heat source, it is possible to understand from V_{BUS} that ST-ONE exits from OTP status and V_{BUS} is turned on again (5V output) waiting for a new PDO request (20V in this case). In the next figure:

- Blue = V_{BUS} 10 V/div

Figure 232. **SOTP protection on secondary side – 20 V output at 90 V_{AC}**

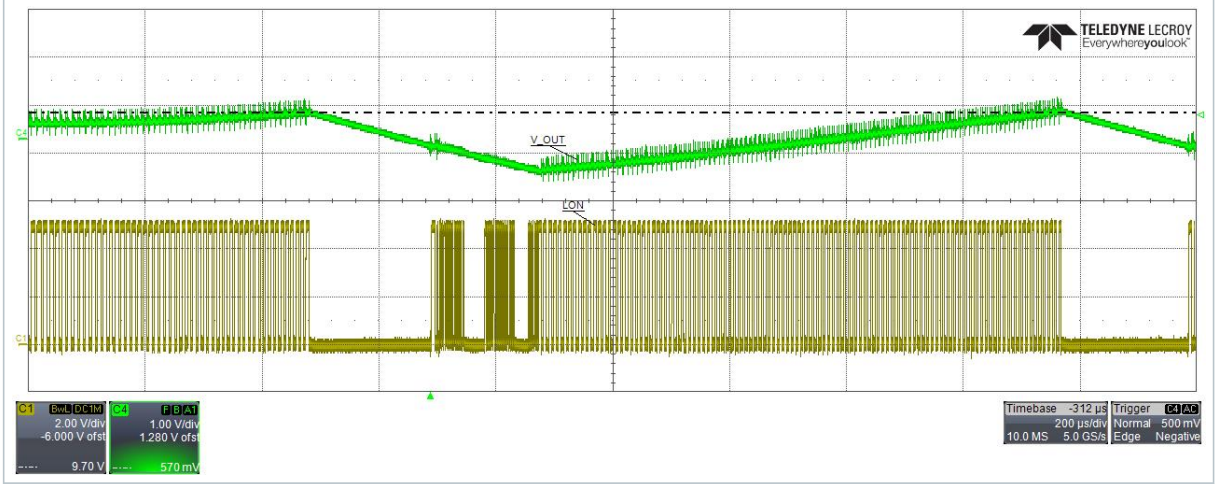


12.6 OVP protection on secondary side

To test the OVP protection on the secondary side, the value of the PID_P_CV parameter is set to 60 through GUI interface, and the output is set to 20 V full load. The V_{OUT} is measured with the oscilloscope in AC mode, so it is easier to observe the output voltage oscillation. When V_{OUT} reaches $V_{OVPthreshold} = \left(V_{OUT} + \frac{2.7}{100} \cdot V_{OUT}\right) + 29.2\,mV$, it starts to decrease until the system enters burst mode. In the following figure:

- Yellow = LON 2 V/div
- Green = V_{OUT} 1 V/div

Figure 233. **OVP protection on secondary side – 20 V output at 90 V_{AC}**



13 Efficiency measurements

In this section the efficiencies of all the PDO profiles and the efficiency with APDO at 3.3 V output are reported. The output voltage has been measured at the board end (on top of capacitor C31), while the current is measured from the DC active load. The input power has been captured using a digital power meter, while the output power has been calculated as the product between V_{OUT} and I_{OUT}. Measurements have been performed starting from full load condition with a burn-in period of 20 minutes. The following tables show the efficiencies with different input voltages:

- 90 V_{AC}/60 Hz
- 115 V_{AC}/60 Hz
- 230 V_{AC}/50 Hz
- 265 V_{AC}/50 Hz

Different output loads have been set for each input voltage:

- 10% of maximum load
- 25% of maximum load
- 50% of maximum load
- 75% of maximum load
- 100% of maximum load

Table 2. Efficiency at 90 V_{AC}

Output load [%]	V_{OUT} [V]	I_{OUT} [A]	P_{OUT} [W]	P_{IN} [W]	η [%]
3.3 V output					
10%	3.316	0.373	1.237	1.430	86.49%
25%	3.309	0.936	3.097	3.461	89.49%
50%	3.306	1.873	6.192	6.858	90.29%
75%	3.297	2.811	9.268	10.292	90.05%
100%	3.258	3.713	12.097	13.641	88.68%
Average (100, 75, 50, 25%) =					89.63%
5 V output					
10%	5.025	0.374	1.879	2.152	87.33%
25%	5.019	0.936	4.698	5.187	90.57%
50%	5.016	1.874	9.400	10.275	91.48%
75%	5.003	2.811	14.063	15.369	91.51%
100%	4.993	3.748	18.714	20.666	90.55%
Average (100, 75, 50, 25%) =					91.03%
9 V output					
10%	9.035	0.373	3.370	3.799	88.71%
25%	9.032	0.936	8.454	9.255	91.34%
50%	9.026	1.873	16.906	18.335	92.20%
75%	9.016	2.810	25.335	27.375	92.55%
100%	8.997	3.748	33.721	36.811	91.61%
Average (100, 75, 50, 25%) =					91.93%
12 V output					
10%	12.063	0.373	4.499	5.112	88.02%
25%	12.060	0.936	11.288	12.422	90.87%
50%	12.049	1.873	22.568	24.517	92.05%
75%	12.042	2.810	33.838	36.642	92.35%
100%	12.023	3.748	45.062	49.334	91.34%
Average (100, 75, 50, 25%) =					91.65%
15 V output					
10%	15.057	0.373	5.616	6.422	87.45%
25%	15.053	0.936	14.090	15.556	90.57%
50%	15.049	1.873	28.187	30.707	91.79%
75%	15.031	2.811	42.252	45.933	91.99%
100%	15.002	3.748	56.227	62.008	90.68%
Average (100, 75, 50, 25%) =					91.26%
20 V output					
10%	20.069	0.323	6.482	7.566	85.68%
25%	20.066	0.811	16.274	18.139	89.72%
50%	20.060	1.623	32.557	35.748	91.07%
75%	20.055	2.436	48.854	53.318	91.63%
100%	20.035	3.248	65.074	71.719	90.73%
Average (100, 75, 50, 25%) =					90.79%

Table 3. Efficiency at 115 V_{AC}

Output load [%]	V_{OUT} [V]	I_{OUT} [A]	P_{OUT} [W]	P_{IN} [W]	η [%]
3.3 V output					
10%	3.317	0.373	1.237	1.441	85.86%
25%	3.309	0.936	3.097	3.470	89.26%
50%	3.306	1.873	6.192	6.873	90.09%
75%	3.298	2.811	9.271	10.282	90.16%
100%	3.256	3.713	12.090	13.562	89.14%
Average (100, 75, 50, 25%) =					89.66%
5 V output					
10%	5.025	0.373	1.874	2.155	86.98%
25%	5.019	0.936	4.698	5.188	90.55%
50%	5.016	1.873	9.395	10.259	91.58%
75%	5.006	2.811	14.072	15.329	91.80%
100%	4.996	3.748	18.725	20.571	91.03%
Average (100, 75, 50, 25%) =					91.24%
9 V output					
10%	9.036	0.373	3.370	3.779	89.19%
25%	9.033	0.936	8.455	9.187	92.03%
50%	9.028	1.873	16.909	18.218	92.82%
75%	9.014	2.810	25.329	27.191	93.15%
100%	8.996	3.748	33.717	36.421	92.58%
Average (100, 75, 50, 25%) =					92.64%
12 V output					
10%	12.063	0.373	4.499	5.093	88.35%
25%	12.060	0.936	11.288	12.342	91.46%
50%	12.050	1.873	22.570	24.388	92.54%
75%	12.041	2.810	33.835	36.311	93.18%
100%	12.031	3.748	45.092	48.682	92.63%
Average (100, 75, 50, 25%) =					92.45%
15 V output					
10%	15.059	0.373	5.617	6.406	87.68%
25%	15.056	0.936	14.092	15.492	90.97%
50%	15.047	1.873	28.183	30.541	92.28%
75%	15.037	2.811	42.269	45.453	92.99%
100%	15.014	3.748	56.272	60.934	92.35%
Average (100, 75, 50, 25%) =					92.15%
20 V output					
10%	20.064	0.323	6.481	7.536	86.00%
25%	20.062	0.811	16.270	18.064	90.07%
50%	20.060	1.623	32.557	35.541	91.61%
75%	20.046	2.436	48.832	52.862	92.38%
100%	20.036	3.248	65.077	70.531	92.27%
Average (100, 75, 50, 25%) =					91.58%

Table 4. Efficiency at 230 V_{AC}

Output load [%]	V_{OUT} [V]	I_{OUT} [A]	P_{OUT} [W]	P_{IN} [W]	η [%]
3.3 V output					
10%	3.317	0.373	1.237	1.614	76.66%
25%	3.309	0.936	3.097	3.615	85.68%
50%	3.305	1.873	6.190	7.153	86.54%
75%	3.299	2.811	9.273	10.654	87.04%
100%	3.269	3.713	12.138	13.819	87.83%
Average (100, 75, 50, 25%) =					86.77%
5 V output					
10%	5.024	0.373	1.874	2.269	82.59%
25%	5.016	0.936	4.695	5.313	88.37%
50%	5.015	1.873	9.393	10.514	89.34%
75%	5.005	2.811	14.069	15.601	90.18%
100%	4.997	3.748	18.729	20.648	90.70%
Average (100, 75, 50, 25%) =					89.65%
9 V output					
10%	9.037	0.373	3.371	3.824	88.15%
25%	9.033	0.936	8.455	9.246	91.44%
50%	9.028	1.873	16.909	18.311	92.35%
75%	9.014	2.810	25.329	27.272	92.88%
100%	9.002	3.747	33.730	36.226	93.11%
Average (100, 75, 50, 25%) =					92.44%
12 V output					
10%	12.066	0.373	4.501	5.096	88.32%
25%	12.063	0.936	11.291	12.297	91.82%
50%	12.057	1.873	22.583	24.307	92.91%
75%	12.048	2.811	33.867	36.279	93.35%
100%	12.041	3.748	45.130	48.236	93.56%
Average (100, 75, 50, 25%) =					92.91%
15 V output					
10%	15.060	0.373	5.617	6.398	87.80%
25%	15.058	0.936	14.094	15.382	91.63%
50%	15.049	1.873	28.187	30.344	92.89%
75%	15.034	2.811	42.261	45.273	93.35%
100%	15.032	3.748	56.340	60.103	93.74%
Average (100, 75, 50, 25%) =					92.90%
20 V output					
10%	20.079	0.323	6.486	7.569	85.69%
25%	20.063	0.811	16.271	18.004	90.37%
50%	20.065	1.623	32.565	35.366	92.08%
75%	20.050	2.436	48.842	52.691	92.69%
100%	20.036	3.248	65.077	69.657	93.42%
Average (100, 75, 50, 25%) =					92.14%

Table 5. Efficiency at 265 V_{AC}

Output load [%]	V_{OUT} [V]	I_{OUT} [A]	P_{OUT} [W]	P_{IN} [W]	η [%]
3.3 V output					
10%	3.318	0.373	1.238	1.727	71.66%
25%	3.310	0.936	3.098	3.682	84.14%
50%	3.304	1.873	6.188	7.271	85.11%
75%	3.301	2.811	9.279	10.857	85.47%
100%	3.273	3.713	12.153	14.029	86.63%
Average (100, 75, 50, 25%) =					85.34%
5 V output					
10%	5.025	0.373	1.874	2.315	80.96%
25%	5.016	0.936	4.695	5.399	86.96%
50%	5.014	1.873	9.391	10.674	87.98%
75%	5.006	2.811	14.072	15.830	88.89%
100%	4.997	3.748	18.729	20.819	89.96%
Average (100, 75, 50, 25%) =					88.45%
9 V output					
10%	9.036	0.373	3.370	3.851	87.52%
25%	9.033	0.936	8.455	9.267	91.24%
50%	9.028	1.873	16.909	18.342	92.19%
75%	9.016	2.810	25.335	27.376	92.54%
100%	9.005	3.747	33.742	36.362	92.79%
Average (100, 75, 50, 25%) =					92.19%
12 V output					
10%	12.071	0.373	4.502	5.134	87.70%
25%	12.064	0.936	11.292	12.355	91.40%
50%	12.057	1.873	22.583	24.414	92.50%
75%	12.042	2.810	33.838	36.406	92.95%
100%	12.031	3.748	45.092	48.286	93.39%
Average (100, 75, 50, 25%) =					92.56%
15 V output					
10%	15.060	0.373	5.617	6.407	87.68%
25%	15.056	0.936	14.092	15.397	91.53%
50%	15.051	1.873	28.191	30.396	92.74%
75%	15.048	2.811	42.300	45.416	93.14%
100%	15.022	3.748	56.302	60.263	93.43%
Average (100, 75, 50, 25%) =					92.71%
20 V output					
10%	20.085	0.323	6.487	7.591	85.46%
25%	20.064	0.811	16.272	18.007	90.36%
50%	20.063	1.623	32.562	35.418	91.94%
75%	20.042	2.436	48.822	52.827	92.42%
100%	20.029	3.248	65.054	69.876	93.10%
Average (100, 75, 50, 25%) =					91.96%

The results of EVLONE65W no load consumption at 115 V_{AC} and 230 V_{AC} are now reported. The consumption has been measured 20 minutes after the power-on. Two kinds of measurements have been performed:

- Consumption in no load condition, a 3 A wire is connected to the USB Type-C® port
- Consumption in no load condition, nothing is connected to the USB Type-C® port

Table 6. EVLONE65W no load consumption - 3 A wire connected to the USB Type-C® port

No load consumption - 5V output	
115 V_{AC} / 60 Hz	230 V_{AC} / 50 Hz
P_{IN} [mW]	P_{IN} [mW]
54.539	59.665

Table 7. EVLONE65W no load consumption - nothing connected to the USB Type-C® port

No load consumption - 5V output	
115 V_{AC} / 60 Hz	230 V_{AC} / 50 Hz
P_{IN} [mW]	P_{IN} [mW]
54.414	59.422

14 Thermal measurements

A thermal analysis of the board has been performed using an infrared thermal imaging camera. The test was performed with the output voltage set to 20 V under full load condition. The board has been submitted to 115 V_{AC} and 230 V_{AC} as inputs. The following figures show the thermal results 30 minutes after switching on the board.

Figure 234. Thermal image at 115 V_{AC} – bottom view

Sp1=111.4°C, Sp2=107.0°C, Sp3=85.9°C, Sp4=88.1°C

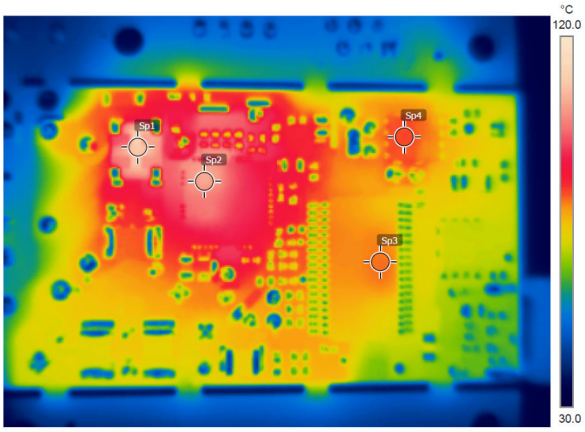


Figure 235. Thermal image at 115 V_{AC} – top view

Sp1=95.2°C, Sp2=88.8°C, Sp3=84.2°C, Sp4=103.8°C

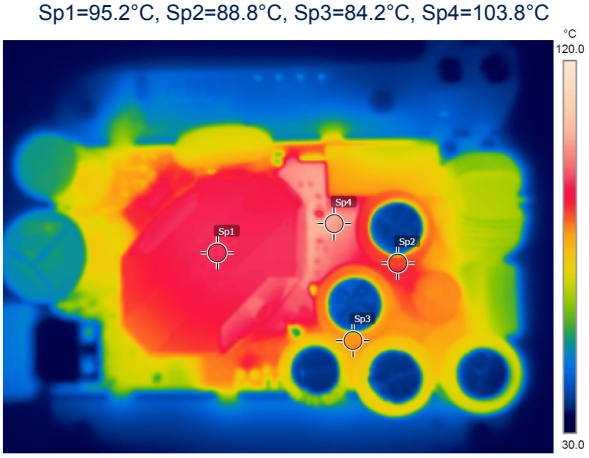


Table 8. Thermal map at 115 V_{AC}

Point	Reference	Description	Temperature at 115 V_{AC}
Bottom view			
Sp1	BR1	Bridge rectifier	111.4 °C
Sp2	MG1	MASTERGAN4	107.0 °C
Sp3	U1	ST-ONE	85.9 °C
Sp4	Q4	SR MOSFET	88.1 °C
Top view			
Sp1	T1	RM8 transformer	95.2 °C
Sp2	C5	Electrolytic capacitor	88.8 °C
Sp3	C8	Electrolytic capacitor	84.2 °C
Sp4	D8	SMD diode	103.8 °C

Figure 236. **Thermal image at 230 V_{AC} – bottom view**

Sp1=85.1°C, Sp2=97.2°C, Sp3=89.8°C, Sp4=88.3°C

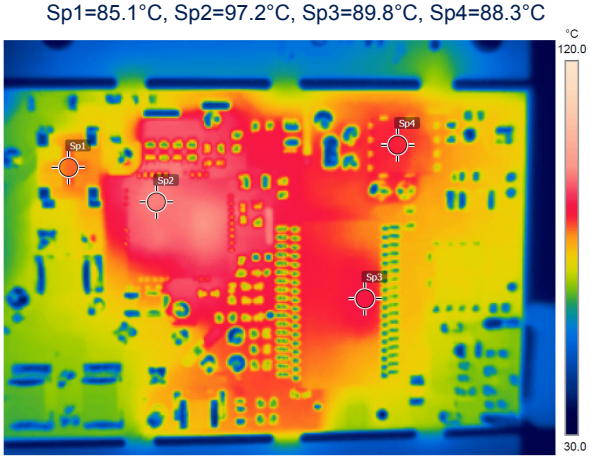


Figure 237. **Thermal image at 230 V_{AC} – top view**

Sp1=93.0°C, Sp2=69.9°C, Sp3=69.6°C, Sp4=88.6°C

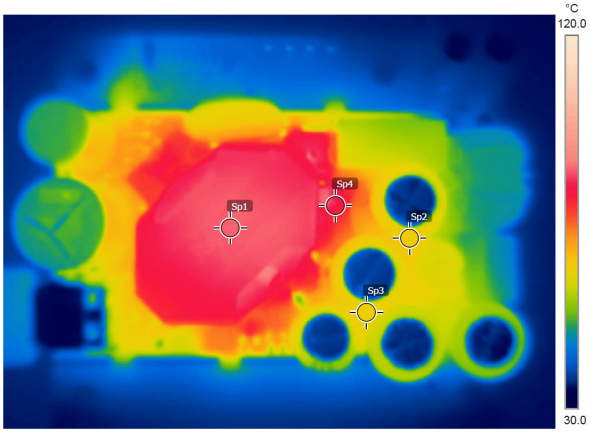


Table 9. **Thermal map at 230 V_{AC}**

Point	Reference	Description	Temperature at 230 V_{AC}
Bottom view			
Sp1	BR1	Bridge rectifier	85.1 °C
Sp2	MG1	MASTERGAN4	97.2 °C
Sp3	U1	ST-ONE	89.8 °C
Sp4	Q4	SR MOSFET	88.3 °C
Top view			
Sp1	T1	RM8 transformer	93.0 °C
Sp2	C5	Electrolytic capacitor	69.9 °C
Sp3	C8	Electrolytic capacitor	69.6 °C
Sp4	D8	SMD diode	88.6 °C

15 EMI measurements

The EVLONE65W has been tested to verify conducted noise emissions. The following figures show the results of the EMI tests with 115 V_{AC} and 230 V_{AC} as inputs. The limits shown in the diagrams are EN55022 Class-B, which is the most popular standard for domestic equipment and has more severe limits compared to Class-A, dedicated to IT technology equipment. The EN55022 Class-B limit relevant to average measurements is indicated in red on the diagrams, while the limit relevant to quasi-peak is indicated in yellow. In all conditions the measurements are below the limits.

Figure 238. EMI test at 115 V_{AC} (output: 20 V - 3 A)

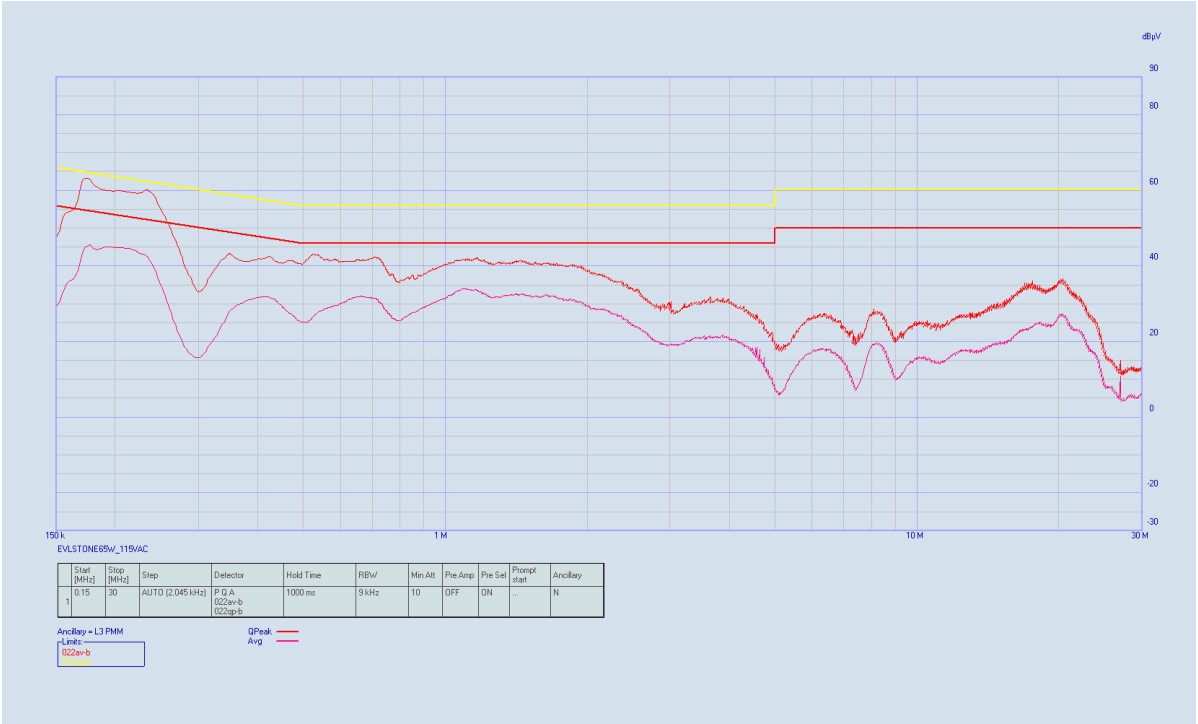
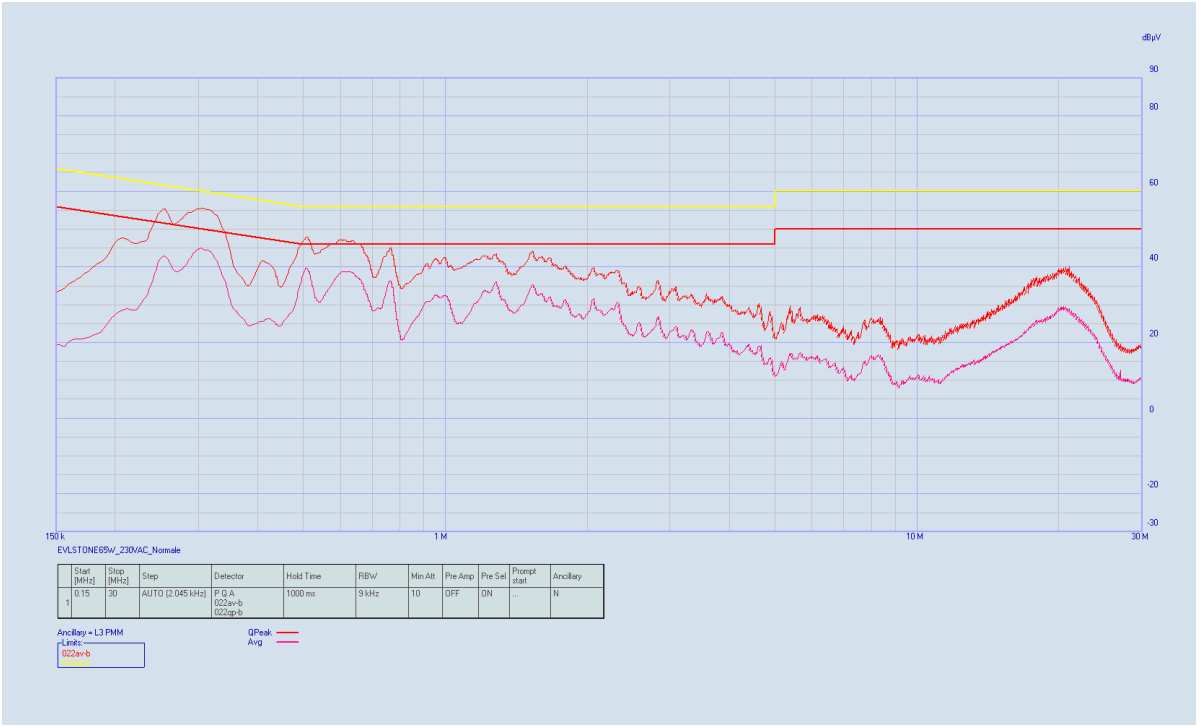
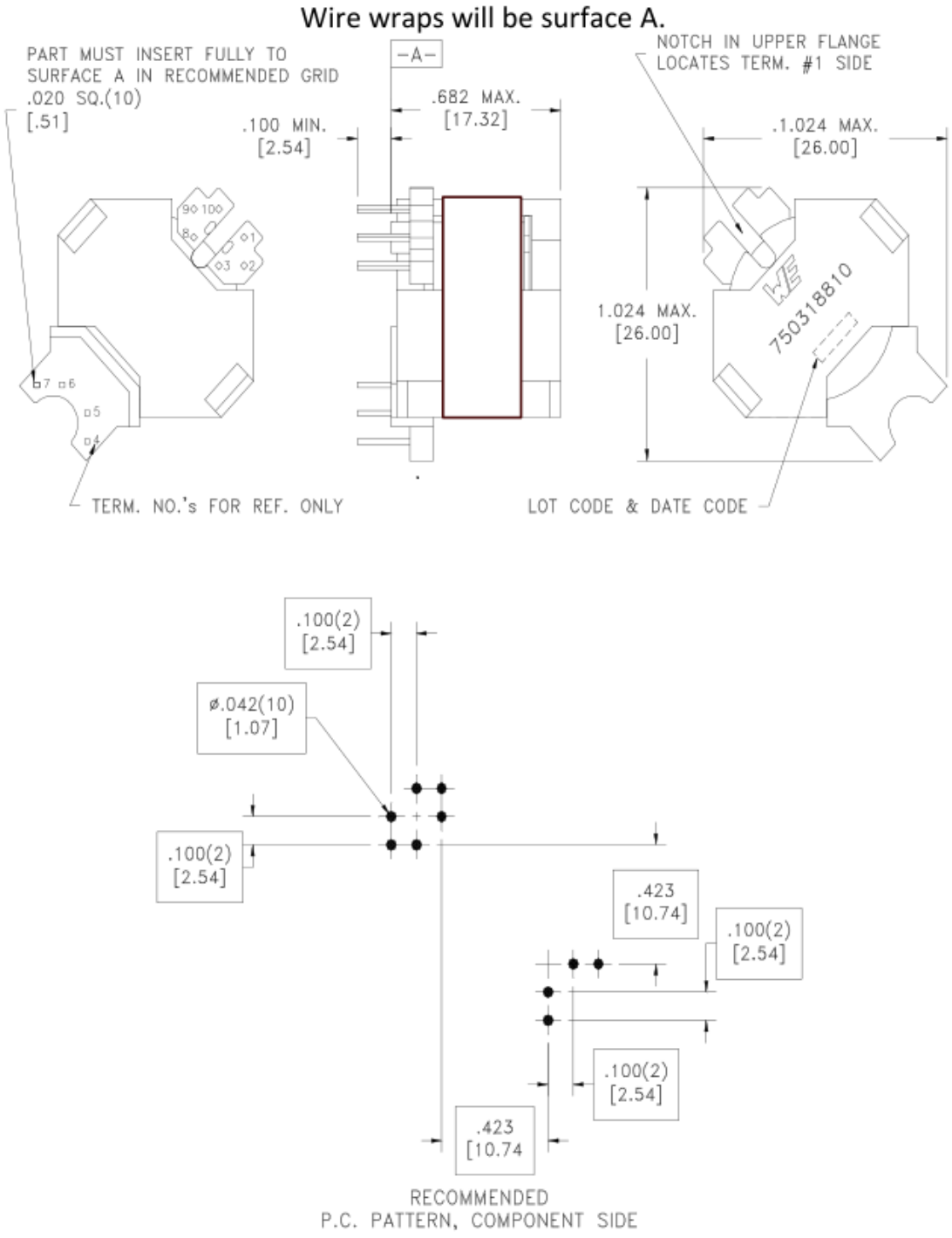


Figure 239. **EMI test at 230 V_{AC} (output: 20 V - 3 A)**



16 Magnetic specifications

Figure 240. **Coil mechanical aspect**



General description

- Operating temperature range: -40°C to +125°C including temperature rise
- Reinforced insulation for primary side circuit
- Maximum working voltage: 265 Vrms and 400 Vpeak
- In our application pin 3 is removed

Figure 241. **Coil electrical diagram**

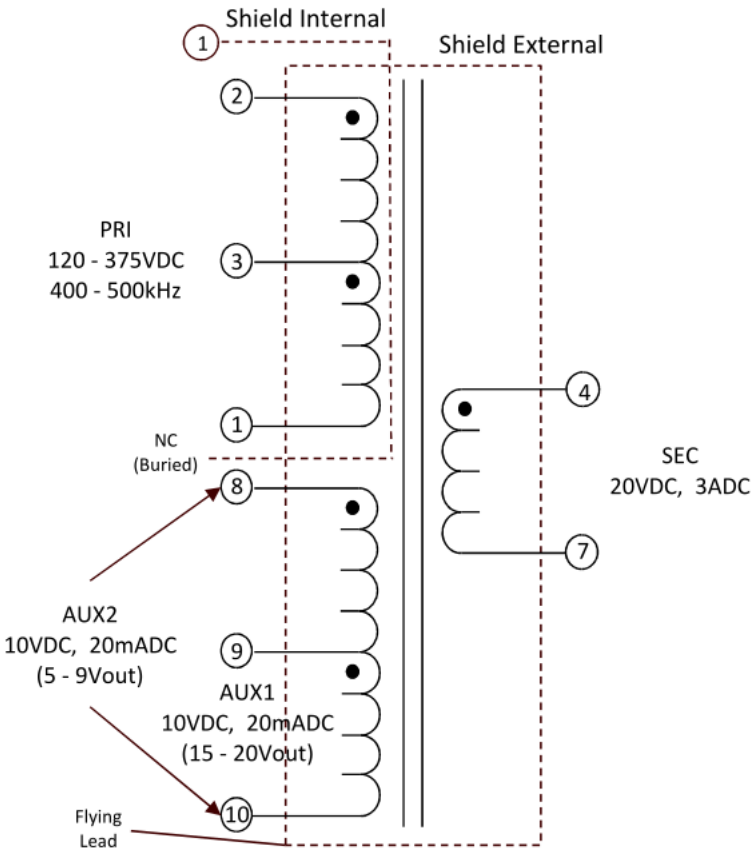


Table 10. **Electrical specifications @25 °C**

PARAMETER	TEST CONDITIONS	VALUE
D.C. RESISTANCE 2-1	@ 20 °C	0.130 ohms ±20%
D.C. RESISTANCE 8-9	@ 20 °C	0.340 ohms ±20%
D.C. RESISTANCE 9-10	@ 20 °C	0.250 ohms ±20%
D.C. RESISTANCE 4-7	@ 20 °C	0.009 ohms max.
INDUCTANCE 2-1	100kHz, 100mV, Ls	127µH ±10%
SATURATION CURRENT 2-1	20% roll off from initial	3.4A
LEAKAGE INDUCTANCE 2-1	tie(8+10,4+7),100kHz, 100mV, Ls	2.0µH typ, 3.5µH max.
DIELECTRIC 2-4	tie(1+8), 3750VAC, 1 second	3000VAC, 1 minute
DIELECTRIC 2-8	625VAC, 1 second	500VAC, 1 minute
TURNS RATIO	(2-1):(9-10)	4:1, ±1%
TURNS RATIO	(2-1):(8-10)	1.71:1, ±1%
TURNS RATIO	(2-1):(4-7)	6:1, ±1%

Manufacturer

- Würth Elektronik
- Inductor P/N: 750318810

17 Bill of material

Table 11. **EVLONE65W bill of material**

Reference	Part number	Value	Description	Package	Manufacturer
BR1	Z4GP208L-HF		RECT BRIDGE GP 800V 2A Z4	Z4	Comchip
C1	B32921C3104M	100 nF	Radial polypropylene film cap.	Plastic radial	TDK
C2, C3, C4	CGA8N4X7T2W474K230KA	470 nF	SMD multilayer ceramic cap.	1812	TDK
C5, C6, C7, C8	860021374027	22 µF	Aluminum electrolytic capacitor	D8, h16, pitch 3.5 mm	Würth
C9	C2012C0G2E103J125AA	10 nF	SMD multilayer ceramic cap.	0805	TDK
C10, C39	885012205052	22 nF	SMD multilayer ceramic cap.	0402	Würth
C11, C12, C21, C22, C23, C32, C38, C42	885012205085	100 nF	SMD multilayer ceramic cap.	0402	Würth
C13	DNM	N.M.	Not mounted		
C14	885012209071	2.2 µF	SMD multilayer ceramic cap.	1210	Würth
C15	ECA2AAM330X	33 µF	Aluminum electrolytic capacitor	D8, h11.5, pitch 3.5 mm	Panasonic
C16	885012206120	100 nF	SMD multilayer ceramic cap.	0603	Würth
C17	CL21A226MAQNNNE	22 µF	SMD multilayer ceramic cap.	0805	Samsung
C18, C31, C33	C2012X7R1H475K	4.7 µF	SMD multilayer ceramic cap.	0805	TDK
C19	885012107018	4.7 µF	SMD multilayer ceramic cap.	0805	Würth
C20	C1608X7R1H473K080AA	47 nF	SMD multilayer ceramic cap.	0603	TDK
C24, C25	885012205055	100 pF	SMD multilayer ceramic cap.	0402	Würth
C26	885012005063	220 pF	SMD multilayer ceramic cap.	0402	Würth
C27	UMK107AB7105KA-T	1 µF	SMD multilayer ceramic cap.	0603	Taiyo Yuden
C28	25SEK270M	270 µF	Aluminum polymer capacitor	Radial	Panasonic
C29	EEH-ZS1V681UP	680 µF	Aluminum polymer capacitor	10 mm SMD	Panasonic
C30	C3216X5R1V226M160AC	22 µF	SMD multilayer ceramic cap.	1206	TDK
C34	885012205050	10 nF	SMD multilayer ceramic cap.	0402	Würth

Reference	Part number	Value	Description	Package	Manufacturer
C35	C1005X5R1V105K050BC	1 µF	SMD multilayer ceramic cap.	0402	TDK
C36	885012105012	1 µF	SMD multilayer ceramic cap.	0402	Würth
C37	885012105008	4.7 µF	SMD multilayer ceramic cap.	0402	Würth
C40, C41		N.M.	SMD multilayer ceramic cap.	0402	
C43	VY1472M51Y5VQ63V0	4.7 nF	CAP CER 4700PF 500 VAC Y5 V RADIAL		Vishay
D1, D2, D3	S1ML R3G		SMD diode	DO-219AB	Taiwan Semiconductor
D4	BAS521LP-7		High-voltage switching diode	SOD-882	Nexperia
D5	BAS21LLYL		High-voltage switching diode	SOD-882	Nexperia
D6	BAS16LD		SMD fast switching rectifier	SOD-882	NXP
D7	CDZVT2R10B		SMD Zener diode	SOD-923	ROHM
D8	ES1JFL		SMD diode	SOD-123F	On Semiconductor
D9	CDZVT2R6.2B		SMD Zener diode	SOD-923	ROHM
D10	BAT54SWFILM		SMD Schottky rectifiers array	SOT-323	STMicroelectronics
D11	ESDA25P35-1U1M		TVS diode	QFN-1610	STMicroelectronics
D12	ESDA25L		SMD TVS diode	SOT23	STMicroelectronics
F1	39213150000	FUSE 3.15 A	Radial lead time lag fuse	8.5X4	LittelFuse
HON, LON, SRGD, GP0, GP1		N.M.	Test point pad		
J1		Input pads	Plated holes for cable.		
J2	2012670005		USB Type-C® receptacle		Molex
J3	90325-0006		Conn flat male 6 pins, straight, pitch 1.27 mm		Molex
J4	282837-2	Screws connector	Screw connector, single row, 5.08 pitch, 13.5 A	5.08 mm	TE Connectivity
J5	M20-9993645		Male strip 4 pins pitch 2.54 180°		Harwin Inc.
JP1		SMD Jumper / **CLOSED**	Jumper_SMD - **CLOSE with solder drop**	2 p medium	
L1	CM13090CT-242		Common mode choke		Bourns
L2	744779100	10 µH	Radial leaded wire wound inductor	Radial	Würth Elektronik
LN1, LN2, LN3		LINK	PCB link: ignore		
MG1	MASTERGAN4		GaN half-bridge w. driver	31VFQFPN 9 x 9 x 1.0	STMicroelectronics

Reference	Part number	Value	Description	Package	Manufacturer
Q1, Q2	BSS169H6327XTSA1		SMD N-ch MOSFET	SOT23	Infineon
Q3	BC847BM		NPN transistor general purpose	SOT883	Nexperia
Q4	BSC146N10LS5ATMA1		SMD N-ch power MOSFET	PowerFLAT	Infineon
Q5	ZVN3320FTA		SMD N-ch MOSFET	SOT23	Diodes Incorporated
Q6	STL160NS3LLH7		SMD N-ch power MOSFET	PowerFLAT	STMicroelectronics
R1		4.7 kΩ	SMD resistor	0603	
R2	RC0805FR-072M2L	2.2 MΩ	SMD resistor	0805	Yageo
R3	RC0603FR-0720RL	20 Ω	SMD resistor	0603	Yageo
R4, R9	RC0402FR-07220RL	220 Ω	SMD resistor	0402	Yageo
R5, R6, R7, R8	UCR03EVPFLR620	0.62 Ω	SMD current sense resistor	0603	ROHM
R10	RC0603FR-071KL	1 kΩ	SMD resistor	0603	Yageo
R11	CRCW04024K70FKEDC	12.1 kΩ	SMD resistor	0402	Vishay
R12	RC0402FR-071K5L	1.5 kΩ	SMD resistor	0402	Yageo
R13	RC0402FR-0718KL	18 kΩ	SMD resistor	0402	Yageo
R14	RC0402FR-07270KL	270 kΩ	SMD resistor	0402	Yageo
R15	RC0402FR-07470KL	470 kΩ	SMD resistor	0402	Yageo
R16	ERJ-2RKF1912X	19.1 kΩ	SMD resistor	0402	Panasonic
R17, R18, R37	RC0402FR-0747KL	47 kΩ	SMD resistor	0402	Yageo
R19, R26	CRCW040210R0JNED	10 Ω	SMD resistor	0402	Vishay
R20	RC0402FR-07120KL	120 kΩ	SMD resistor	0402	Yageo
R21	RC0402FR-07430KL	430 kΩ	SMD resistor	0402	Yageo
R22	RC0402FR-0722RL	22 Ω	SMD resistor	0402	Yageo
R23, R28, R30	RC0402FR-07100KL	100 kΩ	SMD resistor	0402	Yageo
R24, R35	MCR01MZPJ000	0 Ω	SMD resistor	0402	ROHM
R25		N.M.	SMD resistor	0402	
R27	RC0402JR-071KL	1 kΩ	SMD resistor	0402	Yageo
R29	RC0402FR-07287RL	287 Ω	SMD resistor	0402	Yageo
R31	RC0402FR-071RL	1 Ω	SMD resistor	0402	Yageo
R32	WSLP08055L000FEA18	5 mΩ	SMD very high power, low value resistor	0805	Vishay
R33	RC0402FR-07100RL	100 Ω	SMD resistor	0402	Yageo
R34	CRG0603F100K	100 kΩ	SMD resistor	0603	TE Connectivity
R36		47 Ω	SMD resistor	0402	
RT1	NCP15WM474J03RC	470 kΩ	SMD thermistor NTC	0402	Murata
T1	750318810_R5		RM8 extended rail transformer		Würth
U1	ST-ONE		Fully integrated controller for smart chargers	SSOP36	STMicroelectronics

Reference	Part number	Value	Description	Package	Manufacturer
U2	LDO40LPURY		Low drop-out regulator	6-DFN	STMicroelectronics

Revision history

Table 12. **Document revision history**

Date	Version	Changes
29-Jun-2022	1	Initial release.
29-Nov-2022	2	Add Section 16
06-Mar-2023	3	Title modification.

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