**Test Report: PMP22087**  
*336-W Auxless AC/DC Power Supply Reference Design With 80 PLUS Platinum Compatible Performance*

**Description**

This reference design is an AC to DC power supply design with critical conduction mode (CRM) PFC and half-bridge LLC series resonant converter that provides 24V, 240W continuous, 336W peak output from universal input AC voltage (90VAC to 264VAC). This design uses UCC28056 CRM/DCM PFC controller, UCC256404 enhanced LLC controller, and UCC24612-2 synchronous rectifier controller with burst mode enabled for low standby power losses. 87mW @ 115VAC and 124mW @ 230VAC is achieved in this design. Moreover, 93.4% peak efficiency at 115-Vac input and 95.3% peak efficiency at 230-Vac input are achieved in this design. The efficiency and power factor numbers also meet both 115-V and 230-V internal 80 PLUS Platinum specifications and DoE level VI requirement.
1 System Specification

1.1 Board Dimension:
75mm x 180mm x 30mm.

1.2 Input Characteristics

1.2.1 AC Input Voltage and Frequency Limitations:

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Nominal</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAC</td>
<td>90</td>
<td>100~240</td>
<td>265</td>
</tr>
<tr>
<td>Hz</td>
<td>47</td>
<td>50~60</td>
<td>63</td>
</tr>
</tbody>
</table>

1.2.2 AC Input Current:
- 4A Max. at 100VAC.
- 2A Max. at 200VAC.
- Current total harmonic distortion should be less than 20% from 5A to 10A load.

1.2.3 Power Factor:
Power factor should be greater than 0.95 at 50% load with either 115VAC/60Hz or 230VAC/50Hz input.

1.2.4 Inrush Current:
- Cold start: <50A at both 100VAC and 230VAC input and 25degC ambient temperature.
- Hot start: no component damage.

1.3 Output Characteristics
The power supply unit should be able to supply 24V+/−5%, 240W output power continuously and 24V+/−5%, 336W peak power for 20second with 10% duty cycle.
2 Testing and Results

2.1 Board Photos
The photographs below show the top and bottom view of the PMP22087Rev A board. PMP22087Rev A circuit is built on PMP21160Rev B PCB board.

2.1.1 Top Side

2.1.2 Bottom Side
2.2 Efficiency Data
4-point average efficiency: 92.38% @ 115VAC/60Hz and 94.16% @ 230VAC/50Hz

![Total Efficiency Graph](chart)

2.2.1 100VAC/60Hz Efficiency Measurement

<table>
<thead>
<tr>
<th>Vin (V)</th>
<th>Iin (A)</th>
<th>Pin (W)</th>
<th>P.F.</th>
<th>THD (%)</th>
<th>Vout (V)</th>
<th>Iout (A)</th>
<th>Pout(W)</th>
<th>Efficiency (%)</th>
</tr>
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<tbody>
<tr>
<td>100.09</td>
<td>0.288</td>
<td>15.71</td>
<td>0.546</td>
<td>19.31</td>
<td>23.92</td>
<td>0.493</td>
<td>11.79</td>
<td>75.07%</td>
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<td>100.06</td>
<td>0.391</td>
<td>29.56</td>
<td>0.754</td>
<td>18.01</td>
<td>23.92</td>
<td>1.002</td>
<td>23.97</td>
<td>81.08%</td>
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<tr>
<td>100.05</td>
<td>0.439</td>
<td>42.17</td>
<td>0.961</td>
<td>8.26</td>
<td>23.92</td>
<td>1.496</td>
<td>35.78</td>
<td>84.86%</td>
</tr>
<tr>
<td>100.02</td>
<td>0.561</td>
<td>54.65</td>
<td>0.974</td>
<td>9.36</td>
<td>23.92</td>
<td>1.989</td>
<td>47.58</td>
<td>87.06%</td>
</tr>
<tr>
<td>100.11</td>
<td>0.682</td>
<td>66.94</td>
<td>0.981</td>
<td>9.02</td>
<td>23.92</td>
<td>2.497</td>
<td>59.73</td>
<td>89.23%</td>
</tr>
<tr>
<td>100.18</td>
<td>0.806</td>
<td>79.59</td>
<td>0.985</td>
<td>8.04</td>
<td>23.92</td>
<td>2.998</td>
<td>71.71</td>
<td>90.10%</td>
</tr>
<tr>
<td>100.14</td>
<td>1.059</td>
<td>104.86</td>
<td>0.989</td>
<td>7.47</td>
<td>23.92</td>
<td>3.997</td>
<td>95.61</td>
<td>91.18%</td>
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<tr>
<td>100.10</td>
<td>1.315</td>
<td>130.57</td>
<td>0.992</td>
<td>6.26</td>
<td>23.92</td>
<td>5.003</td>
<td>119.67</td>
<td>91.65%</td>
</tr>
<tr>
<td>100.07</td>
<td>1.581</td>
<td>156.13</td>
<td>0.987</td>
<td>14.73</td>
<td>23.92</td>
<td>6.002</td>
<td>143.57</td>
<td>91.95%</td>
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<td>100.02</td>
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<td>182.08</td>
<td>0.990</td>
<td>13.39</td>
<td>23.92</td>
<td>7.000</td>
<td>167.44</td>
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<tr>
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<td>23.92</td>
<td>7.500</td>
<td>179.40</td>
<td>91.90%</td>
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<td>191.36</td>
<td>91.82%</td>
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<tr>
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<td>0.992</td>
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<td>23.92</td>
<td>9.000</td>
<td>215.28</td>
<td>91.61%</td>
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<td>261.70</td>
<td>0.993</td>
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<td>23.92</td>
<td>10.000</td>
<td>239.20</td>
<td>91.40%</td>
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</table>
### 2.2.2 115VAC/60Hz Efficiency Measurement

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<th>Vin (V)</th>
<th>Iin (A)</th>
<th>Pin (W)</th>
<th>P.F.</th>
<th>THD (%)</th>
<th>Vout (V)</th>
<th>Iout (A)</th>
<th>Pout (W)</th>
<th>Efficiency (%)</th>
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<td>0.550</td>
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<td>0.640</td>
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<td>79.73%</td>
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<td>1.497</td>
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<td>84.85%</td>
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<td>1.989</td>
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<td>86.47%</td>
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<td>67.12</td>
<td>0.973</td>
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<td>2.490</td>
<td>59.56</td>
<td>88.74%</td>
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<td>23.92</td>
<td>4.001</td>
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<td>23.92</td>
<td>6.002</td>
<td>143.57</td>
<td>92.27%</td>
</tr>
<tr>
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<td>1.595</td>
<td>181.14</td>
<td>0.987</td>
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<td>23.92</td>
<td>7.000</td>
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<td>23.92</td>
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<td>239.20</td>
<td>92.07%</td>
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</table>

### 2.2.3 230VAC/50Hz Efficiency Measurement

<table>
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<th>Vin (V)</th>
<th>Iin (A)</th>
<th>Pin (W)</th>
<th>P.F.</th>
<th>THD (%)</th>
<th>Vout (V)</th>
<th>Iout (A)</th>
<th>Pout (W)</th>
<th>Efficiency (%)</th>
</tr>
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<td>1.004</td>
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<td>86.74%</td>
</tr>
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<td>1.500</td>
<td>35.90</td>
<td>88.50%</td>
</tr>
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<td>0.329</td>
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<td>0.705</td>
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<td>23.93</td>
<td>1.995</td>
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<td>23.92</td>
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<td>23.92</td>
<td>4.997</td>
<td>119.53</td>
<td>93.74%</td>
</tr>
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<td>230.40</td>
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<td>0.957</td>
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<td>23.92</td>
<td>5.998</td>
<td>143.47</td>
<td>93.98%</td>
</tr>
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<td>0.967</td>
<td>6.57</td>
<td>23.92</td>
<td>7.000</td>
<td>167.44</td>
<td>94.10%</td>
</tr>
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<td>23.92</td>
<td>7.510</td>
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</tr>
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<td>23.92</td>
<td>9.010</td>
<td>215.52</td>
<td>94.15%</td>
</tr>
<tr>
<td>230.30</td>
<td>1.127</td>
<td>254.40</td>
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<td>7.07</td>
<td>23.92</td>
<td>10.000</td>
<td>239.20</td>
<td>94.03%</td>
</tr>
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</table>
2.3 **No Load Power Consumption**
No load power consumption was measured with Voltech PM1000+ power meter using 5-minute-average and Chroma 61605 AC source.

2.3.1 No Part Change (Test as is):

115VAC/60Hz: $P_{in}=113\text{mW}$.

230VAC/50Hz: $P_{in}=157\text{mW}$.

2.3.2 Test With Following Parts Change: Disconnect Vout to SR controllers (U200, U201), short RT100 and remove C117 and R121.

115VAC/60Hz: $P_{in}=80\text{mW}$.

230VAC/50Hz: $P_{in}=121\text{mW}$.
2.4 Thermal Images
The thermal images below show a top view and bottom view of the board. The board is placed vertically during the test. The ambient temperature was 25°C with no air flow. The output was loaded with 24V/10A.

2.4.1 100V_{AC}/60Hz, Top Side

![Thermal Image]

<table>
<thead>
<tr>
<th>Component</th>
<th>Max</th>
<th>Min</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bx1</td>
<td>101.2°C</td>
<td>25.5°C</td>
<td>62.4°C</td>
</tr>
<tr>
<td>Bx2</td>
<td>89.1°C</td>
<td>58.1°C</td>
<td>79.9°C</td>
</tr>
<tr>
<td>Bx3</td>
<td>91.3°C</td>
<td>29.1°C</td>
<td>69.6°C</td>
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<tr>
<td>Bx4</td>
<td>66.7°C</td>
<td>50.4°C</td>
<td>56.6°C</td>
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<td>Sp2</td>
<td>30.2°C</td>
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2.4.2 100V<sub>AC</sub>/60Hz, Bottom Side

<table>
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<tr>
<th></th>
<th>Max</th>
<th>Min</th>
<th>Average</th>
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</thead>
<tbody>
<tr>
<td>Bx1</td>
<td>90.2 °C</td>
<td>33.7 °C</td>
<td>75.7 °C</td>
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<tr>
<td>Bx2</td>
<td>89.7 °C</td>
<td>32.7 °C</td>
<td>72.2 °C</td>
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<td>Bx3</td>
<td>62.2 °C</td>
<td>37.8 °C</td>
<td>57.1 °C</td>
</tr>
<tr>
<td>Bx4</td>
<td>61.5 °C</td>
<td>34.0 °C</td>
<td>55.9 °C</td>
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<td>Bx5</td>
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<td>Bx7</td>
<td>59.3 °C</td>
<td>33.9 °C</td>
<td>51.2 °C</td>
</tr>
<tr>
<td>Sp1</td>
<td>61.0 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sp2</td>
<td>24.0 °C</td>
<td></td>
<td></td>
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</table>
### 2.4.3  115V<sub>AC</sub>/60Hz, Top Side

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Bx1</td>
<td>Max</td>
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</tr>
<tr>
<td></td>
<td>Min</td>
<td>23.1 °C</td>
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<td>Average</td>
<td>57.2 °C</td>
</tr>
<tr>
<td>Bx2</td>
<td>Max</td>
<td>78.5 °C</td>
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<td></td>
<td>Min</td>
<td>54.6 °C</td>
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<td></td>
<td>Average</td>
<td>70.8 °C</td>
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<td>Max</td>
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<td></td>
<td>Min</td>
<td>29.9 °C</td>
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<td>57.3 °C</td>
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<tr>
<td>Sp1</td>
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<td>32.4 °C</td>
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[Image: FLIR2761.jpg, FLIR E75, 78503305]
2.4.4 115V<sub>AC</sub>/60Hz, Bottom Side

<p>| | | | | |</p>
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<td></td>
<td></td>
</tr>
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<td></td>
<td>Min</td>
<td>28.2 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>65.1 °C</td>
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<td></td>
</tr>
<tr>
<td>Bx2</td>
<td>Max</td>
<td>58.1 °C</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>39.9 °C</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>54.6 °C</td>
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<tr>
<td>Bx4</td>
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<td>60.7 °C</td>
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<td></td>
<td>Min</td>
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<td></td>
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<td>53.1 °C</td>
<td></td>
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<tr>
<td>Bx5</td>
<td>Max</td>
<td>59.5 °C</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Min</td>
<td>37.3 °C</td>
<td></td>
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<td></td>
<td>Average</td>
<td>55.0 °C</td>
<td></td>
<td></td>
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<tr>
<td>Bx6</td>
<td>Max</td>
<td>58.6 °C</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>32.0 °C</td>
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<td></td>
<td>Average</td>
<td>50.4 °C</td>
<td></td>
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</tr>
<tr>
<td>Sp1</td>
<td></td>
<td>22.5 °C</td>
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</table>

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FLIR2760.jpg  FLIR E75  78503305
### 2.4.5 230V<sub>AC</sub>/50Hz, Top Side

#### Thermography Image

![Flir Image](FLIR2763.jpg)

<table>
<thead>
<tr>
<th>Location</th>
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<th>Min</th>
<th>Average</th>
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<tbody>
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<td>24.9 °C</td>
<td>49.4 °C</td>
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<td>Bx2</td>
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<td>27.7 °C</td>
<td>60.3 °C</td>
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<td>Bx3</td>
<td>67.3 °C</td>
<td>50.0 °C</td>
<td>57.1 °C</td>
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<tr>
<td>Sp1</td>
<td>29.3 °C</td>
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</table>
2.4.6 230V<sub>AC</sub>/50Hz, Bottom Side

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<td>Bx2</td>
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<tr>
<td>Bx4</td>
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<td>60.0 °C</td>
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<td>34.3 °C</td>
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<td>Bx7</td>
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<td>58.8 °C</td>
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<tr>
<td></td>
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<td>33.1 °C</td>
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<tr>
<td></td>
<td>Average</td>
<td>50.6 °C</td>
</tr>
</tbody>
</table>

Sp1 | 22.5 °C
2.5 **Startup**
The voltages at startup are shown in the images below, where Channel 1 is output voltage, Channel 3 is HV to GND, and Channel 4 is T200 Primary winding current (200mV/A).

2.5.1 100V\textsubscript{AC}/60Hz – No Load

![Graph 1](image1)

2.5.2 100V\textsubscript{AC}/60Hz – 24V/10A

![Graph 2](image2)
2.5.3 115V<sub>AC</sub>/60Hz – No Load

2.5.4 115V<sub>AC</sub>/60Hz – 24V/10A
2.5.5 230V<sub>AC</sub>/50Hz – No Load

2.5.6 230V<sub>AC</sub>/50Hz – 24V/10A
2.6 Ripple Voltages

Ripple voltages are shown in the images below, where Channel 1 is $V_{out}$ to GND voltage in AC level and Channel 3 is HV to GND voltage in AC level.

### 2.6.1 $100\text{V}_{\text{AC}}/60\text{Hz}$ – $24\text{V}/0\text{A}$

![Image of ripple voltage for 100V AC/60Hz - 24V/0A](image)

### 2.6.2 $100\text{V}_{\text{AC}}/60\text{Hz}$ – $24\text{V}/10\text{A}$

![Image of ripple voltage for 100V AC/60Hz - 24V/10A](image)
2.6.3  115V<sub>AC</sub>/60Hz – 24V/0A

2.6.4  115V<sub>AC</sub>/60Hz – 24V/10A
2.6.5 230V<sub>AC</sub>/50Hz – 24V/0A

2.6.6 230V<sub>AC</sub>/50Hz – 24V/10A
2.7 **Load Response**
Load response is tested at 230V\textsubscript{AC}/50Hz input, where Channel 3 is the output voltage in AC level and Channel 4 is output current.

**2.7.1 Load step from 0.1A to 7A:**

![Load step from 0.1A to 7A](image1)

**2.7.2 Load step from 7A to 14A:**

![Load step from 7A to 14A](image2)
2.8 Frequency Response

Frequency response of the LLC-SRC stage is tested with 230V<sub>AC</sub>/50Hz input at 10A load. Signal was injected on R215.
2.9 Key Waveforms

2.9.1 SR FET conduction at 100VAC/60Hz input, 24V/0A output: C1: Q203 \( V_{DS} \), C2: Q201 \( V_{GS} \), C3: Q203 \( V_{GS} \), C4: \( I_{PRI} \).

2.9.2 SR FET conduction at 100VAC/60Hz input, 24V/0.1A output: C1: Q203 \( V_{DS} \), C2: Q201 \( V_{GS} \), C3: Q203 \( V_{GS} \), C4: \( I_{PRI} \).
2.9.3 SR FET conduction at 100VAC/60Hz input, 24V/0.5A output: C1: Q203 $V_{DS}$, C2: Q201 $V_{GS}$, C3: Q203 $V_{GS}$, C4: $I_{PRI}$.

2.9.4 SR FET conduction at 100VAC/60Hz input, 24V/5A output: C1: Q203 $V_{DS}$, C2: Q201 $V_{GS}$, C3: Q203 $V_{GS}$, C4: $I_{PRI}$. 

![Waveform Diagrams](image-url)
2.9.5 SR FET conduction at 100VAC/60Hz input, 24V/10A output: C1: Q203 $V_{DS}$, C2: Q201 $V_{GS}$, C3: Q203 $V_{GS}$, C4: $I_{PRI}$. 

![Diagram showing SR FET conduction](image.png)
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