Description
This reference design features an LLC converter controlled by the UCC25800-Q1 (open-loop LLC transformer driver for isolated bias supplies), operating with 9 V, generating three output voltages of 9.0 V with a maximum load current of 50 mA each. An air core transformer was used to avoid the core saturation in the presence of a strong external magnetic field.

Features
- Supplies three isolated outputs, each 9 V, 50 mA from single 9-V source
- Coreless transformer cannot saturate because of external static magnetic field
- Low input-output inter-winding capacitance thanks to resonant topology
- Open loop converter: no feedback compensation
- Possibility to use coreless transformer or printed windings on the PCB

Applications
- Electricity meter
1 Test Prerequisites

1.1 Voltage and Current Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$</td>
<td>9 V</td>
</tr>
<tr>
<td>$V_{OUT1}$</td>
<td>9.0 V</td>
</tr>
<tr>
<td>$V_{OUT2}$</td>
<td>9.0 V</td>
</tr>
<tr>
<td>$V_{OUT3}$</td>
<td>9.0 V</td>
</tr>
<tr>
<td>$I_{OUT1}$</td>
<td>50 mA</td>
</tr>
<tr>
<td>$I_{OUT2}$</td>
<td>50 mA</td>
</tr>
<tr>
<td>$I_{OUT3}$</td>
<td>50 mA</td>
</tr>
</tbody>
</table>

1.2 Considerations

- To simplify the measurement process, the three output rails were shorted together. This report considers a single output voltage of 9.0 V, 150 mA.
- Transformer structure: the three secondary windings were wired together to provide a high symmetrical structure.

![Transformer Structure](image)

1.3 Dimensions

The size of the board is 89 mm × 61.4 mm. The 4-layer board has 35-μm copper thickness on each layer.
2 Testing and Results

2.1 Efficiency Graphs 9 V<sub>IN</sub>

Efficiency is shown in the following figure.

![Efficiency Graph](image)

Figure 2-1. PMP31054 Efficiency Graph

2.2 Efficiency Data

Efficiency data is shown in the following table.

<table>
<thead>
<tr>
<th>Input Voltage (V)</th>
<th>Input Current (mA)</th>
<th>Power (W)</th>
<th>Output Voltage (V)</th>
<th>Output Current (mA)</th>
<th>Output Power (W)</th>
<th>Losses (W)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.0</td>
<td>18.2</td>
<td>0.16</td>
<td>16.67</td>
<td>2.0</td>
<td>0.03</td>
<td>0.13</td>
<td>20.3</td>
</tr>
<tr>
<td>9.1</td>
<td>20.9</td>
<td>0.19</td>
<td>12.93</td>
<td>4.9</td>
<td>0.06</td>
<td>0.13</td>
<td>33.5</td>
</tr>
<tr>
<td>9.0</td>
<td>31.3</td>
<td>0.28</td>
<td>10.56</td>
<td>15.0</td>
<td>0.16</td>
<td>0.12</td>
<td>56.2</td>
</tr>
<tr>
<td>9.1</td>
<td>48.4</td>
<td>0.44</td>
<td>9.98</td>
<td>30.0</td>
<td>0.30</td>
<td>0.14</td>
<td>68.4</td>
</tr>
<tr>
<td>9.0</td>
<td>79.4</td>
<td>0.71</td>
<td>8.70</td>
<td>59.5</td>
<td>0.52</td>
<td>0.19</td>
<td>72.8</td>
</tr>
<tr>
<td>9.0</td>
<td>113.2</td>
<td>1.02</td>
<td>8.23</td>
<td>90.2</td>
<td>0.74</td>
<td>0.28</td>
<td>72.6</td>
</tr>
<tr>
<td>9.0</td>
<td>148.4</td>
<td>1.34</td>
<td>7.73</td>
<td>121.5</td>
<td>0.94</td>
<td>0.40</td>
<td>70.1</td>
</tr>
<tr>
<td>9.0</td>
<td>181.0</td>
<td>1.63</td>
<td>7.20</td>
<td>150.4</td>
<td>1.08</td>
<td>0.54</td>
<td>66.6</td>
</tr>
<tr>
<td>9.1</td>
<td>210.0</td>
<td>1.90</td>
<td>6.79</td>
<td>180.9</td>
<td>1.23</td>
<td>0.67</td>
<td>64.5</td>
</tr>
<tr>
<td>9.1</td>
<td>250.0</td>
<td>2.27</td>
<td>6.32</td>
<td>210.6</td>
<td>1.33</td>
<td>0.94</td>
<td>58.7</td>
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<tr>
<td>9.1</td>
<td>280.0</td>
<td>2.54</td>
<td>5.77</td>
<td>241.5</td>
<td>1.39</td>
<td>1.15</td>
<td>54.8</td>
</tr>
<tr>
<td>9.1</td>
<td>310.0</td>
<td>2.81</td>
<td>5.24</td>
<td>269.1</td>
<td>1.41</td>
<td>1.40</td>
<td>50.1</td>
</tr>
<tr>
<td>9.1</td>
<td>350.0</td>
<td>3.18</td>
<td>4.60</td>
<td>300.3</td>
<td>1.38</td>
<td>1.80</td>
<td>43.5</td>
</tr>
</tbody>
</table>
2.3 Output Voltage Regulation ($9 \text{ V}_{\text{IN}}$)

![Graph showing output voltage regulation](image)

**Figure 2-2.** $V_{\text{OUT}}$ Regulation
2.4 Thermal Images

Figure 2-3 shows the thermal image for a 150-mA load current.

![Thermal Image at 9 V_in and 150-mA Load Current](image1)

Figure 2-3. Thermal Image at 9 V<sub>IN</sub> and 150-mA Load Current

Figure 2-4 shows the thermal image for a 150-mA load current.

![Thermal Image at 9 V_in and 200-mA Load Current](image2)

Figure 2-4. Thermal Image at 9 V<sub>IN</sub> and 200-mA Load Current
3 Waveforms

3.1 Switching

Switching behavior is shown in the following figures.

3.1.1 Primary Side

![Switching Waveforms on Primary Side](image)

- Ch1: Switching node (A1 to GND) at 9 V_{IN} and 150-mA load current [scale: 5.0 V / div, 400 ns / div]
- Ch2: A8 to GND at 9 V_{IN} and 150-mA load current [scale: 5.0 V / div, 400 ns / div]

3.1.2 Secondary Side

![Switching Waveforms on Secondary Side](image)

- Ch1: A6 to –V_{o2} at 9 V_{IN} and 150-mA load current [scale: 5.0 V / div, 400 ns / div]
- A3 to –V_{o2} at 9 V_{IN} and 150-mA load current [scale: 5.0 V / div, 400 ns / div]
3.2 Output Voltage Ripple

Output voltage ripple is shown in the following figure.

![Figure 3-3. Output Voltage Ripple](image)

- Ch2: 9 V<sub>IN</sub>, 150-mA load, 15.6-mV peak-peak-ripple [scale: 10 mV / div, 1.0 µs / div]

3.3 Start-Up Sequence

Start-up behavior is shown in the following figure.

![Figure 3-4. Start-Up Waveform](image)

- Ch1: Input voltage at 9 V<sub>IN</sub> [scale: 5 V / div, 4.0 ms / div]
- Ch2: Output voltage at 9 V<sub>IN</sub> and 150-mA load current [scale: 5 V / div, 4.0 ms / div]
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