Test Report: PMP30524
Isolated 24-W Flyback Reference Design for Industrial and Automotive Applications

Description
This reference design provides functional isolation 500 Vrms by simply using a dual inductor from stock. Overall, the design is driven by minimum cost using TPS40210 and adding discrete UVLO. Also, the input range of 1:6 exceeds industrial standard by 7 V to 42 V, which makes this reference design ideal for several applications.
1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1. Voltage and Current Requirements

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>7 V to 42 V</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>24V</td>
</tr>
<tr>
<td>Output Current (max)</td>
<td>1A</td>
</tr>
<tr>
<td>Isolation</td>
<td>here: 500Vrms functional*</td>
</tr>
</tbody>
</table>

* limited by dual inductor; Xcap allows up to 2kV, opto isolator up to 3.75kV

1.2 Considerations

Unless otherwise indicated, resistor was used as load. The output current was adjusted to 1A. The circuit switches on at 6.7 V and off at 6.3 V. This individual circuit switches around 205 kHz.

The converter itself works in boundary mode, means CCM at low input voltage and respectively DCM at high input voltage. Reducing magnetizing inductance results in smaller transformer geometry and increased loop bandwidth due to bigger RHPZ – but accepting slightly increased peak currents.

The transfer region DCM to CCM could be seen around:

7Vin 150mAout
12Vin 350mAout
24Vin 800mAout
>32Vin 1000mAout
2 Testing and Results

2.1 Efficiency Graphs

![Efficiency vs Output Current](image1)

*Figure 1 Efficiency vs Output Current*

![Loss vs Output Current](image2)

*Figure 2 Loss vs Output Current*
2.2 Load Regulation

Figure 3 Load Regulation

2.3 Line Regulation
The output current was adjusted to 1A.

Figure 4 Line Regulation
With the same setup efficiency and loss were calculated.

![Figure 5 Efficiency and Loss vs Input Voltage](image)

**Figure 5 Efficiency and Loss vs Input Voltage**
2.4 Thermal Images

2.4.1 12 V Input Voltage - full load 1A

![Figure 6 IR Photo for 12 V Input Voltage](image1)

<table>
<thead>
<tr>
<th>Name</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>75.1°C</td>
</tr>
<tr>
<td>L1</td>
<td>75.6°C</td>
</tr>
<tr>
<td>Q1</td>
<td>72.1°C</td>
</tr>
<tr>
<td>R1</td>
<td>70.6°C</td>
</tr>
<tr>
<td>R11</td>
<td>75.5°C</td>
</tr>
</tbody>
</table>

2.4.2 24 V Input Voltage - full load 1A

![Figure 7 IR Photo for 24 V Input Voltage](image2)

<table>
<thead>
<tr>
<th>Name</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>73.1°C</td>
</tr>
<tr>
<td>D3</td>
<td>70.1°C</td>
</tr>
<tr>
<td>L1</td>
<td>82.8°C</td>
</tr>
<tr>
<td>Q1</td>
<td>72.9°C</td>
</tr>
</tbody>
</table>
2.4.3  24V Input Voltage and 700mA Output Current

![Figure 8 IR Photo for 24 V Input Voltage and 0.7 A Output Current](image)

<table>
<thead>
<tr>
<th>Name</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>58.7°C</td>
</tr>
<tr>
<td>L1</td>
<td>69.5°C</td>
</tr>
<tr>
<td>Q1</td>
<td>52.3°C</td>
</tr>
<tr>
<td>R1</td>
<td>54.6°C</td>
</tr>
</tbody>
</table>
3 Waveforms

3.1 Switching

3.1.1 Transistor Q1, 100V FET (Drain-Source)

3.1.1.1 12 V Input Voltage

Figure 9 Switchnode Q1 at 12 V Input Voltage
3.1.1.2 24 V Input Voltage

**Figure 10 Switchnode Q1 at 24 V Input Voltage**

(at maximum input 42V Vds is clamped to less than 90Vpk)
3.1.2 Transistor Q1 Gate (Gate to Source)

3.1.2.1 12 V Input Voltage

Figure 11 Q1 Gate at 12 V Input Voltage

Ch1 => 2 V/div
full bandwidth
1 µs/div

Ch1 => 2 V/div
full bandwidth
50 ns/div
### 3.1.2.2 24 V Input Voltage

![Graph showing Q1 Gate at 12 V Input Voltage](image)

**Figure 12** Q1 Gate at 12 V Input Voltage
3.1.3 Diode D1
These waveforms were measured with reference to output voltage.

3.1.3.1 12 V Input Voltage

Figure 13 Diode D1 at 12 V Input Voltage
3.1.3.2 24 V Input Voltage

Figure 14 Diode D1 at 24 V Input Voltage
3.2 Output Voltage Ripple

Figure 15 Output Ripple Voltage

<table>
<thead>
<tr>
<th>Channel</th>
<th>Description</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch1</td>
<td>output voltage @ 12 V input</td>
<td>50 mV/div</td>
</tr>
<tr>
<td></td>
<td>voltage</td>
<td>20MHz bandwidth</td>
</tr>
<tr>
<td>Ch2</td>
<td>output voltage @ 24V input</td>
<td>1 μs/div</td>
</tr>
<tr>
<td></td>
<td>voltage</td>
<td></td>
</tr>
</tbody>
</table>
3.3 Input Ripple Voltage

3.3.1 12 V Input Voltage

Ch1 => input voltage 12 V
50 mV/div
20MHz bandwidth
1 µs/div

Figure 16 Input Ripple Voltage (12V Input Voltage)

3.3.2 24 V Input Voltage

Ch1 => input voltage 24 V
50 mV/div
20MHz bandwidth
1 µs/div

Figure 17 Input Ripple Voltage (24 V Input Voltage)
3.4 **Bode Plot**

Table 1 summarizes the results from Figure 18, Figure 19 and Figure 20. Bode box good for 100Hz to 10kHz were used.

<table>
<thead>
<tr>
<th></th>
<th>7 V</th>
<th>12 V</th>
<th>24 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth (Hz)</td>
<td>907</td>
<td>1300</td>
<td>1795</td>
</tr>
<tr>
<td>Phasemargin</td>
<td>83°</td>
<td>93°</td>
<td>98°</td>
</tr>
<tr>
<td>slope (20dB/decade)</td>
<td>-1.0</td>
<td>-0.87</td>
<td>-0.75</td>
</tr>
<tr>
<td>gain margin (dB)</td>
<td>18</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>slope (20dB/decade)</td>
<td>-0.7</td>
<td>-1.2</td>
<td>-1.6</td>
</tr>
<tr>
<td>freq (kHz)</td>
<td>10.9</td>
<td>16.2</td>
<td>17.3</td>
</tr>
</tbody>
</table>

**Table 1 Summery of the Bodeplots**

3.4.1 **7 V Input Voltage**

![Figure 18 Bode Plot for 7 V Input Voltage](image)
3.4.2 12 V Input Voltage

Figure 19 Bode Plot for 12 V Input Voltage

3.4.3 24 V Input Voltage

Figure 20 Bode Plot for 24 V Input Voltage
3.5 Load Transients
Electronic load has been used to create the load steps of 0.5 A to 1 A (100 Hz); The deviation is only around 1% Vout!

3.5.1 12V Input Voltage

Figure 21 Load Transient with 12V Input Voltage

3.5.2 24V Input Voltage

Figure 22
3.6 Start-up Sequence
Oscilloscope with isolated channels was used. The power supply was plugged in.

3.6.1 12 V Input Voltage

![Figure 23 Start-Up with 12 V Input Voltage]

Ch1 => input voltage
5 V/div

Ch2 => output voltage
5 V/div

20 MHz bandwidth
10 ms/div

3.6.2 24 V Input Voltage

![Figure 24 Start-Up with 24 V Input Voltage]

Ch1 => input voltage
10 V/div

Ch2 => output voltage
5 V/div

20 MHz bandwidth
10 ms/div
3.7 **Shutdown Sequence**
Oscilloscope with isolated channels was used. The power supply was disconnected.

3.7.1 **12 V Input Voltage**

![Figure 25 Shutdown with 12 V Input Voltage](image)

Ch1=> input voltage
5 V/div

Ch2=> output voltage
5 V/div

20MHz bandwidth
4 ms/div

3.7.2 **24 V Input Voltage**

![Figure 26 Shutdown with 24 V Input Voltage](image)

Ch1=> input voltage
10 V/div

Ch2=> output voltage
5 V/div

20MHz bandwidth
4 ms/div
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