1 Description

This reference design demonstrates EMI mitigation techniques required for a high-frequency, reinforced 5-kV_{RMS} isolated, 5-V bias DC/DC converter module to pass the automotive, CISPR 25, class 5, EMC test standard. The design features a 500-mW, high-efficiency, bias supply with integrated transformer, control and power stage in a 2.65 mm height, SOIC 16 package solution. Typical bias examples include: digital isolators, voltage and current sensing, CAN transceivers and signal communication used in the design of traction inverters, onboard chargers, battery management systems, infotainment, charging cables and PTC heaters.

Figure 1-1. Top of Board
Figure 1-2. Bottom of Board

Figure 1-3. EMI Filter Schematic

Figure 1-3 shows the input EMI filter schematic as built.
2 Test Prerequisites

2.1 Voltage and Current Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>12 V–14 V</td>
</tr>
<tr>
<td>Maximum Current Draw</td>
<td>150 mA</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>5 V</td>
</tr>
<tr>
<td>Output Current</td>
<td>100 mA (onboard resistor)</td>
</tr>
</tbody>
</table>

2.2 Required Equipment

• Battery cable with length per CISPR 25
• CISPR 25 Conduction Emissions Setup
• CISPR 25 Radiated Emissions Setup & Chamber
• EMI Receiver

2.3 Dimensions

The board is approximately 95 mm x 45 mm.
2.4 Test Setup

The following images show the various test setups used along with a more in-depth look at the board and its setup.

Conducted testing introduction and initial testing:

CISPR 25 conducted test calls for a battery cable length of 200 mm–400 mm (about 8–16 inches), including the LISN connector. A 9-inch cable is used for the tests (see the following images).

![Figure 2-1. Conducted Test Setup](image)

Passing cases with bottom side surface mount Y capacitor (Y cap).

The image shows two, size 1812 caps in series used to bridge the 8-mm primary to secondary gap. (581-1812HA101JAT1A Mouser / AVX MLCC - SMD/SMT 3KV 100 pF C0G 1812 5% HV) for 50 pF effective Y cap.

Also used higher value 220 pF surface mount Y caps for the effective 110-pF cap between primary and sec. 581-1825JA221KAT1A AVX / Mouser MLCC - SMD/SMT 4 KV 220 pF C0G 1825 10% Tol HV
Figure 2-2. Bottom Side, Capacitor Bridge

Passing case with 220-pF top side through-hole Y cap added:

220-pF through-hole cap used TDK CC45SL3DD221JYNNA 2-kV rating, ceramic disc.

Figure 2-3. Top Side, Through Hole Y Cap Added
The following images show the EMI testing chamber and the different antenna configurations used.

Figure 2-4. 150 kHz–30 MHz Setup, Vertical Monopole Antenna
Figure 2-5. 200 MHz –1000 MHz Setup, Horizontal Log Periodic Antenna
Figure 2-6. 30 MHz –300 MHz Setup, With Biconical Antenna Horizontal
Figure 2-7. Unit Under Test: Top Side, Version With Stitch Cap
3 Testing and Results

Two different configurations of this design were tested, with the difference between them being the effective Y capacitance. Testing was also done with and without output beads but it was found that they had no noticeable impact on testing results. The following table highlights the differences in the two configurations.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Y-Cap Values (2 in Series)</th>
<th>Effective Capacitance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100 pF</td>
<td>50 pF</td>
</tr>
<tr>
<td>B</td>
<td>220 pF</td>
<td>110 pF</td>
</tr>
</tbody>
</table>

3.1 EMI

Conducted summary: This is for an application where a system-level common-mode inductor impedance of 700 Ω at 100 MHz already exists and the primary- to secondary-stitch capacitance in the PCB inner layers of 11 pF is allowed under the isolated 5-V to 5-V converter. Both the stitch capacitor of 11 pF plus the added Y capacitor of approximately 50 pF, as in the case of configuration A, allows the passing of conducted through 108 MHz, but barely, by only one dB. Roughly doubling the Y cap value gives good passing margin of > 4 dB. Using a 220 pF through-hole Y cap as in configuration B on the top side gives even more margin, approximately 8 dB. Most runs were done in the 30 MHz–108 MHz range where noise came close to the limits. The first and last configurations were also done in the 150 kHz–30 MHz range to show passing by a wide margin in that range. The conductive scans that are summarized above are shown in the following images.

EMI conducted scans from RED LISN: December 9, 2020

PMP22845 Configuration A: Again this configuration utilizes two 100 pF “1812” size capacitors in series for effective 50 pF.
30–108 MHz:
- Peak detect: Passes with greater than 8-dB margin. Worst case 49 MHz.
- Quasi-Peak (QP) detect: 5-dB margin, worst case 82 MHz.
- CISPR average (CA) detect: 0.9-dB margin, worst case 82 MHz.

Figure 3-1. Conducted Board Configuration A, 30 MHz–108 MHz Range

150 kHz–30 MHz range shown here: Average at 24.7 MHz is 10 dB below 26–28 MHz average limit.
Figure 3-2. Conducted Configuration A, 150 kHz–30 MHz Range
PMP22845 Configuration A: Again this configuration utilizes two 220 pF through-hole capacitors in series for effective 110 pF.

30-108 MHz:
- Peak detect: Passes with greater than 11-dB margin. Worst case 49 MHz.
- Quasi-Peak (QP) detect: Passes with 7.5-dB margin. Worst case 82 MHz.
- CISPR average (CA) detect: Passes with 4.5-dB margin. Worst case 82 MHz.

**Figure 3-3. Conducted Board Configuration B, 30 M–108 MHz Range**
### 30–108 MHz:

- Peak detect: Passes with greater than 12-dB margin.
- Quasi-Peak (QP) detect: Passes with greater than 8-dB margin.
- CISPR average (CA) detect: Passes with 8-dB margin. Worst case at 49 MHz.

**Figure 3-4. Conducted Board Configuration B, 30 M–108 MHz Range**
Same as previous, but full conducted spectrum down to 150 kHz: No large peaks below 30 MHz.

![Receiver](image)

### Figure 3-5. Conducted Board Configuration B, 150 kHz–108 MHz Range

### Results Summary

Radiated testing at NTS December 2020 – Summary

PMP22845 (with stitching 11-pF cap primary ground to secondary ground at UCC12051-Q1) models were used.

Input filter off battery had 700 Ω (at 100 MHz) common mode filter plus differential mode Pi filter.

Added Y cap from primary ground to secondary ground under UCC12051-Q1 was 2 × 100 pF size 1812 caps in series to gap the 8-mm spacing between primary ground and secondary ground for an effective cap of 50 pF on configuration A of PMP22845. This previously passed conducted emissions with only one dB margin.

In general, conducted testing proved to be more severe than radiated for CISPR 25 Class 5.

Low frequency range 150 kHz–30 MHz with monopole never got within 6dB of the limits, even with the 3\textsuperscript{rd} harmonic of the 8 MHz UCC12051-Q1 switching with maximum average being 1.5 dBuV versus the specification of 20 dBuV maximum in the 26–28 MHz range. See next page.

Mid-band of 30–300 MHz with biconical antenna is considered the range of greatest risk and had the greatest test focus. Configuration A passed by at least 10 dB. Antenna horizontal and vertical orientations gave similar results. See following two pages.
High band 200–1000 MHz range: Worst cases around 240 MHz and 800–900 MHz, but still passing with 7 dB at 240 MHz and > 10 dB in the 800–900 MHz range. The 7-dB margin at 240 MHz may be due to the noise floor, as passing at this frequency with biconical antenna was with > 10 dB. CISPR 25 allows either biconical or log periodic antenna in the 200–300 MHz range. See following figures.

Radiated low frequency 150 kHz–30 MHz range with vertical monopole: Worst of the runs with PMP22845 Configuration A: 24.7 MHz average still 18.5 dB below CB band average limit of 20 dBuV/m.

Figure 3-6. 150 kHz–30 MHz Range With Vertical Monopole
Radiated mid-band 30–300 MHz range with horizontal biconical: Worst of runs with PMP22845 Configuration A:
Other runs very similar.

**Figure 3-7. 30 MHz – 300 MHz Range With Horizontal Biconical**

Operator: J. Vu

Company: TI/PR129669

Contact: Josh Mandelcorn

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>AVE Limit</th>
<th>AVE Data</th>
<th>Margin</th>
<th>QP Limit</th>
<th>QP Data</th>
<th>Margin</th>
<th>PR Limit</th>
<th>PR Data</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>49.20</td>
<td>18.00</td>
<td>5.73</td>
<td>-12.267</td>
<td>100.00</td>
<td>8.804</td>
<td>-91.196</td>
<td>28.00</td>
<td>15.379</td>
<td>-12.621</td>
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<tr>
<td>65.50</td>
<td>18.00</td>
<td>-1.40</td>
<td>-21.400</td>
<td>100.00</td>
<td>2.970</td>
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<td>81.80</td>
<td>18.00</td>
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<td>180.00</td>
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<tr>
<td>240.00</td>
<td>16.00</td>
<td>5.058</td>
<td>-10.941</td>
<td>28.00</td>
<td>12.077</td>
<td>26.00</td>
<td>18.296</td>
<td>-7.704</td>
<td></td>
</tr>
</tbody>
</table>

CTSRC25 RE 30MHz - 300MHz(Polarity H)
Broadcast(Class 5 Limit)
ModulePF Ycap50pF noFB

**Figure 3-8. 30 MHz – 300 MHz Range With Horizontal Biconical Data**
Radiated mid-band 30 MHz – 300 MHz range with vertical biconical: Worst of the runs with PMP22845
Configuration A: Other runs very similar within about 1 dB.

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Figure 3-9. 30 MHz – 300 MHz Range With Vertical Biconical

Operator: J.Vu
Company: TI/PR129669
Contact: Josh Mandelcorn

10:08:20 AM, Thursday, December 10, 2020

Figure 3-10. 30 MHz – 300 MHz Range With Vertical Biconical Data
Radiated high band 200 MHz – 1000 MHz range with horizontal log periodic antenna: Configuration A stitch cap and Y cap of 50 pF

In this frequency range horizontal was several dB worse than vertical. Worst case 240 MHz with 7-dB margin.

Figure 3-11. 200 MHz – 1000 MHz Range With Horizontal Log Periodic Antenna

Figure 3-12. 200 MHz – 1000 MHz Range With Horizontal Log Periodic Antenna Data