PHOTO OF THE PROTOTYPE

(The reference design PMP10215 Rev_D has been built on PMP10215 Rev_B PCB)
1 Startup behavior on PFC output voltage (TP15) and Vout

The behavior of the converter at startup is shown in the images below. The input voltage was set to 230Vac, 50Hz and all outputs unloaded (first image) and fully loaded (second image, 36Vout @ 4A). The AC voltage has been applied while switch S1 was ON. The converter goes into short circuit protection if at startup the load is > 4A, therefore first switch the converter ON, then apply full load.

Ch1: PFC output voltage, TP15 (100V/div, 50ms/div), 20MHz BWL for all waveforms.
Ch2: Vout voltage, TP3 (10V/div)
Ch4: Input AC current (2A/div)

Vin = 230Vac, No load.

Vin = 230Vac, I36v = 4A, I12v = 300mA, I3v3 = 200mA
Restart after applying 230Vac with the sequence ON→OFF→ON (CH4 @ 5A/div)

The images below show how 12V and 3.3V outputs behave at startup; in top picture both outputs are unloaded and in the bottom one are fully loaded. The input voltage was set to 230Vac, 50Hz. Ch2: 12Vout, TP20 (5V/div, 5ms/div), 20MHz BWL, Ch3: 3.3Vout, TP24 (1V/div)
2 Output voltage switch between 19V and 36V

The main output voltage 36Vout can be switched between 19V and 36V by means of applying 3.3V on pin 1 of J4 (0V → 19Vout, 3.3V → 36Vout); in case of over-temperature protection (managed by U12, set to 80C, which measures H2 temperature), the voltage is reduced automatically.

Ch3: 36Vout, TP3 (5V/div, 20ms/div), **19V → 36V transition**

![Graph 1](image1)

Ch3: 36Vout, TP3 (5V/div, 20ms/div), **36V → 19V transition**

![Graph 2](image2)
3 Efficiency

The efficiency data are shown in the tables and graphs below. The data show the PFC + AUX PSU efficiency, the DC/DC power stage (only) efficiency and the total plug-to-plug. The Auxiliary power supply was feeding only the housekeeping for this measurement.
### PFC Stage + AUX Supply, Vin = 85Vac, 60Hz

<table>
<thead>
<tr>
<th>Iout (mA)</th>
<th>Vout (V)</th>
<th>Pout (W)</th>
<th>Vin (V)</th>
<th>Pin (W)</th>
<th>PF</th>
<th>Eff_PFC (%)</th>
<th>Eff_DC (%)</th>
<th>Eff_Tot (%)</th>
<th>Pout_DC (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>393.7</td>
<td>0.00</td>
<td>85</td>
<td>2.78</td>
<td>0</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0</td>
</tr>
<tr>
<td>16.5</td>
<td>393.7</td>
<td>6.50</td>
<td>85</td>
<td>10.21</td>
<td>94.7</td>
<td>63.6%</td>
<td>60.1%</td>
<td>38.2%</td>
<td>3.9</td>
</tr>
<tr>
<td>31.3</td>
<td>393.7</td>
<td>12.32</td>
<td>85</td>
<td>17.04</td>
<td>97.9</td>
<td>72.3%</td>
<td>63.3%</td>
<td>45.8%</td>
<td>7.8</td>
</tr>
<tr>
<td>51.6</td>
<td>393.7</td>
<td>20.31</td>
<td>85</td>
<td>25.75</td>
<td>98.4</td>
<td>78.9%</td>
<td>73.5%</td>
<td>58.0%</td>
<td>14.9</td>
</tr>
<tr>
<td>90.0</td>
<td>393.8</td>
<td>35.44</td>
<td>85</td>
<td>42.47</td>
<td>99.2</td>
<td>83.5%</td>
<td>82.8%</td>
<td>69.1%</td>
<td>29.3</td>
</tr>
<tr>
<td>130.4</td>
<td>393.8</td>
<td>51.35</td>
<td>85</td>
<td>60.49</td>
<td>99.7</td>
<td>84.9%</td>
<td>85.7%</td>
<td>72.8%</td>
<td>44.0</td>
</tr>
<tr>
<td>256.6</td>
<td>394.0</td>
<td>101.10</td>
<td>85</td>
<td>113.48</td>
<td>99.8</td>
<td>89.1%</td>
<td>90.2%</td>
<td>80.4%</td>
<td>91.2</td>
</tr>
<tr>
<td>407.2</td>
<td>394.2</td>
<td>160.52</td>
<td>85</td>
<td>176.7</td>
<td>99.9</td>
<td>90.8%</td>
<td>91.4%</td>
<td>83.0%</td>
<td>146.7</td>
</tr>
<tr>
<td>567.4</td>
<td>394.4</td>
<td>223.78</td>
<td>85</td>
<td>245.6</td>
<td>99.9</td>
<td>91.1%</td>
<td>90.8%</td>
<td>82.7%</td>
<td>203.2</td>
</tr>
</tbody>
</table>

### PFC Stage + AUX Supply, Vin = 115Vac, 60Hz

<table>
<thead>
<tr>
<th>Iout (mA)</th>
<th>Vout (V)</th>
<th>Pout (W)</th>
<th>Vin (V)</th>
<th>Pin (W)</th>
<th>PF</th>
<th>Eff_PFC (%)</th>
<th>Eff_DC (%)</th>
<th>Eff_Tot (%)</th>
<th>Pout_DC (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>393.2</td>
<td>0.00</td>
<td>115</td>
<td>2.92</td>
<td>0</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0</td>
</tr>
<tr>
<td>16.6</td>
<td>393.2</td>
<td>6.53</td>
<td>115</td>
<td>10.07</td>
<td>87.9</td>
<td>64.8%</td>
<td>60.1%</td>
<td>39.0%</td>
<td>3.9</td>
</tr>
<tr>
<td>30.7</td>
<td>393.2</td>
<td>12.07</td>
<td>115</td>
<td>16.33</td>
<td>94.4</td>
<td>73.9%</td>
<td>63.3%</td>
<td>46.8%</td>
<td>7.6</td>
</tr>
<tr>
<td>51.4</td>
<td>393.3</td>
<td>20.22</td>
<td>115</td>
<td>25.31</td>
<td>96.5</td>
<td>79.9%</td>
<td>73.5%</td>
<td>58.7%</td>
<td>14.9</td>
</tr>
<tr>
<td>90.3</td>
<td>393.3</td>
<td>35.51</td>
<td>115</td>
<td>42.29</td>
<td>97.9</td>
<td>84.0%</td>
<td>82.8%</td>
<td>69.5%</td>
<td>29.4</td>
</tr>
<tr>
<td>129.8</td>
<td>393.3</td>
<td>51.05</td>
<td>115</td>
<td>59.25</td>
<td>98.5</td>
<td>86.2%</td>
<td>85.7%</td>
<td>73.8%</td>
<td>43.8</td>
</tr>
<tr>
<td>257.2</td>
<td>393.4</td>
<td>101.18</td>
<td>115</td>
<td>113.22</td>
<td>99.7</td>
<td>89.4%</td>
<td>90.2%</td>
<td>80.6%</td>
<td>91.3</td>
</tr>
<tr>
<td>404.7</td>
<td>393.6</td>
<td>159.29</td>
<td>115</td>
<td>174.0</td>
<td>99.8</td>
<td>91.5%</td>
<td>91.4%</td>
<td>83.7%</td>
<td>145.6</td>
</tr>
<tr>
<td>566.2</td>
<td>393.8</td>
<td>222.97</td>
<td>115</td>
<td>241.1</td>
<td>99.9</td>
<td>92.5%</td>
<td>90.8%</td>
<td>84.0%</td>
<td>202.5</td>
</tr>
</tbody>
</table>
The converter has been switched OFF by S1 and the stand-by losses measured (3.3Vout and 12Vout are always ON, but unloaded). Four input AC voltages have been selected.
4  Output voltage regulation (PFC and 36Vout) vs. load

The graphs below show the static variation of output voltage versus load regarding PFC output (top picture, taken at different input AC voltages) and 36V output (taken at 400Vdc, which is the DC/DC input voltage).

PFC output voltage vs. load and Vin_AC:

![PFC Output Voltage vs. Load and Vin_AC](image)

Main output voltage (TP3) vs. load:

![Main Output Voltage vs. Load](image)
5 Power factor

The Power Factor graph versus Vin and main output current is shown below (same loads condition of the efficiency tables):

![Power Factor Graph](image-url)
6 Output ripple voltage

The output ripple voltages for all outputs are shown in the plot below. The input was set to 230Vac, 50Hz and all outputs fully loaded (Iout(36Vout) = 5.5A).

Ch1: 3.3Vout, TP24 (50mV/div), Ch2: 12Vout, TP20 (20mV/div)
Ch3: 36Vout, TP3 (50mV/div), Ch4: PFC output voltage, TP15 (10V/div)
All waveforms: 2ms/div, AC coupled, 20MHz BWL

Single outputs ripple voltages (@ full load, Vin = 230Vac):

Ch3: 3.3Vout, TP24 (20mV/div, 2us/div, AC coupled, 20MHz BWL)
Ch3: 12Vout, TP20 (20mV/div, 2us/div, AC coupled, 20MHz BWL)

Ch3: 36Vout, TP3 (20mV/div, 2us/div, AC coupled, 20MHz BWL)

Ch4: PFC output voltage, TP15 (1V/div, 2ms/div, AC coupled, 20MHz BWL)
Ch4: PFC output voltage, TP15 (1V/div, 2ms/div, AC coupled, 20MHz BWL) @ 85Vac, 60Hz

7 Switching Node Waveforms
The image below shows the PFC Boost switch node (Drain of Q6) at full load (225W) and Vin = 230Vac, 50Hz.

Ch4: Q6 Drain voltage, TP14 (100V/div, 2us/div, 200MHz BWL)
Two-switch forward waveforms, \( V_{in} = 230\text{Vac}, I_{36v} = 5.5\text{A} \):
Ch3: D6 Cathode voltage (50V/div, 1us/div, 200MHz BWL)
Ch4: Q1 Source voltage (100V/div, 200MHz BWL)

Auxiliary PSU switch-node, \( V_{in} = 230\text{Vac} \), both outputs fully loaded:
Ch4: Q8 Drain voltage, TP22 (100V/div, 2us/div, 200MHz BWL)

Buck switch-node, \( V_{in} = 230\text{Vac} \), fully loaded:
Ch3: “PH” pin 3 voltage, (2V/div, 500ns/div, 200MHz BWL)
8  **Input voltage and current waveforms**

The images below show the input voltage and current waveforms while the source was set respectively to 115Vac, 60Hz and 230Vac, 50Hz. The main 36V output voltage was loaded at 5.5A while 12V and 3.3V were fully loaded.

Ch1: Input Current (1A/div, 5ms/div, 20MHz BWL)
Ch4: Input AC Voltage (100V/div, 20MHz BWL)

**Vin = 115Vac, 60Hz**

![Waveform 115Vac, 60Hz](image1)

Ch1: Input Current (1A/div, 5ms/div, 20MHz BWL)
Ch4: Input AC Voltage (100V/div, 20MHz BWL)

**Vin = 230Vac, 50Hz**

![Waveform 230Vac, 50Hz](image2)
9 Transient response

The graph below shows the responses of the main output (36Vout) during output current variation between 1A and 11A, measured at 230Vac input.
Ch1: Output current (5A/div, 200us/div, DC coupling, 20MHz BWL)
Ch3: Output voltage (200mV/div, AC coupling, 20MHz BWL)

10 Tests with TPA3251D2 Class-D audio amplifier EVM

The power supply has been connected to a TPA3251D2 EVM and the voltage set to 36V. The input AC voltage has been set to 230Vac, 50Hz and a sinusoidal signal has been applied on both inputs of the audio EVM, which has been set to work in stereo mode.
The frequency of the waveform (Fin) has been set to 20 Hz, 1 KHz and 20 KHz. The signal has been applied and the amplitude increased until clipping (“CLIP” LED) turned ON. The 36Vout voltage, 400V PFC output voltage and EVM input current have been captured by scope. The pictures below show these measurements.
Ch1: Power supply output current (5A/div, 200us/div, DC coupling, 20MHz BWL)
Ch2: Power supply output voltage (500mV/div, AC coupling, 20MHz BWL)
Ch3: PFC output voltage (10V/div, DC coupling, 20MHz BWL, -412V offset), Fin = 1 KHz
Ch1: Power supply output current (5A/div, 20ms/div, DC coupling, 20MHz BWL)
Ch2: Power supply output voltage (500mV/div, AC coupling, 20MHz BWL)
Ch3: PFC output voltage (10V/div, DC coupling, 20MHz BWL, -412V offset), \(\text{Fin} = 20 \text{ Hz}\)

Ch1: Power supply output current (5A/div, 50us/div, DC coupling, 20MHz BWL)
Ch2: Power supply output voltage (500mV/div, AC coupling, 20MHz BWL)
Ch3: PFC output voltage (10V/div, DC coupling, 20MHz BWL, -412V offset), \(\text{Fin} = 20 \text{ KHz}\)
11 Loop Response

The graphs below show the bode plots of main DC/DC converter (36Vout) and auxiliary PSU (12Vout) when respectively loaded @ 5.5A and 300mA. The input voltage was always 230Vac.

36Vout loop (TP3, TP6, TP8): Fco = 5.358 KHz, PM = 90.15 deg, GM = 18.8dB.

12Vout loop (TP19, TP21, TP26): Fco = 519.8 Hz, PM = 94.92 deg, GM = 33.19dB.
12 Thermal analysis

The thermal image has been taken after half hour in steady state condition and when the board was placed horizontally on the bench without any forced convection. The ambient temperature was 23°C; the 36Vout load was 5.5A while 12V and 3.3V were fully loaded. The input voltage was 230Vac, 50Hz.

Main Image Markers

<table>
<thead>
<tr>
<th>Name</th>
<th>Temperature</th>
<th>Emissivity</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>127.3°C</td>
<td>0.95</td>
<td>23.0°C</td>
</tr>
<tr>
<td>L3</td>
<td>106.6°C</td>
<td>0.95</td>
<td>23.0°C</td>
</tr>
<tr>
<td>H2</td>
<td>79.1°C</td>
<td>0.95</td>
<td>23.0°C</td>
</tr>
<tr>
<td>L1</td>
<td>80.8°C</td>
<td>0.95</td>
<td>23.0°C</td>
</tr>
<tr>
<td>D11</td>
<td>67.1°C</td>
<td>0.95</td>
<td>23.0°C</td>
</tr>
<tr>
<td>H1</td>
<td>68.6°C</td>
<td>0.95</td>
<td>23.0°C</td>
</tr>
<tr>
<td>PCB over Snubber</td>
<td>81.4°C</td>
<td>0.95</td>
<td>23.0°C</td>
</tr>
</tbody>
</table>
IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated (“TI”) reference designs are solely intended to assist designers (“Buyers”) who are developing systems that incorporate TI semiconductor products (also referred to herein as “components”). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer's systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. **TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design. TI may make corrections, enhancements, improvements and other changes to its reference designs.**

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS ARE PROVIDED "AS IS”. TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER’S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer's safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that have specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have not been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2016, Texas Instruments Incorporated