Magnetics Study Enables New Class of High Density AC/DC Converters

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Overview

- Existing AC/DC converter teardowns
- AC/DC converter circuit architecture
- Magnetic Study DC-DC testing of PFC and LLC stages
- New 150W AC/DC converter specifications
- Build and test new high density AC/DC converter prototype
HP 150W Adapter (Delta)

Power density (cased) = 11.9 W/in^3

Power density (uncased) = 21.3 W/in^3

EFF = 92.6% @ 90VAC/100%
HP 150W Adapter (Delta)

- Copper Wrapper
- DC Bus Capacitor
- LLC Transformer
- PFC Inductor
- 2x Input Bridge w/heatsinking
HP 150W Adapter (Chicony/LiteON)

EFF = 92.7% @ 90VAC/100%

Power density (uncased) = 23.8 W/in^3

Efficiency:

- Lres
- L=115mm
- eCap
- EMI Filtering
- Output Caps
- LLC x’fmr
- PFC Inductor

Dimensions:

- H=16.3mm
- W=55mm

Notes:

5 of 25
HP 150W Adapter (Chicony/LiteON)

EFF = 92.7% @ 90VAC/100%

Power density (uncased) = 16.3 x 55 x 115 = 23.8 W/in^3
150W Adapter (Razor BLADE)

**Performance:**
- **EFF = 91.5% @ 100VAC/100%**
- **Power density (cased) = 12 W/in^3**

**Dimensions:**
- **L = 149mm**
- **H = 22.9mm**
- **W = 60**
150W Adapter (Razor BLADE)

AC Input Connector

DC Bus eCap

EMI Filtering
Diode bridge
PFC Inductor
Resonant Inductor

Power density (uncased) = 20.2 W/in^3

Underneath the heatsink:
Vishay SiHF30N60E 650V, 0.125 Ohm PFC MOSFET

19Vout
8A

Cout

LLC X'fmr

150W Adapter (Razor BLADE)

PFC DIODE
NXP BYV25D-600: 600V/5A rectifier diode, ultrafast

ST STD13NM60N:
650V, 0.36Ohm HB MOSFETs

SR FETs
IPD088N06N3: 60V/8.8mOhm

NXP TEA1791A:
SR controller

NXP TEA1716T Combo IC
## 150W Comparison

<table>
<thead>
<tr>
<th>Company</th>
<th>L x W x H (mm) (uncased)</th>
<th>Size (cc) (uncased)</th>
<th>Power Density (W/in3) (uncased)</th>
<th>L x W x H (mm) (cased)</th>
<th>Size (cc) (cased)</th>
<th>Power Density (W/in3) (cased)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta HP</td>
<td>129 x 55 x 16.3</td>
<td>115.65</td>
<td>21.3</td>
<td>138 x 66.3 x 22.5</td>
<td>205.9</td>
<td>11.9</td>
</tr>
<tr>
<td>Razor BLADE</td>
<td>141.6 x 50.2 x 17.1</td>
<td>121.8</td>
<td>20.2</td>
<td>149.2 x 60.1 x 22.9</td>
<td>205.3</td>
<td>12.0</td>
</tr>
<tr>
<td>Chicony/LiteON HP</td>
<td>115 x 55 x 16.2</td>
<td>103.1</td>
<td>23.8</td>
<td>138 x 66.3 x 22.5</td>
<td>205.9</td>
<td>11.9</td>
</tr>
</tbody>
</table>
The Need for Speed

- Existing converters limited to 100kHz range
- Limitation due to switch capacitance
- GaN technology offers 20x reduction in switch capacitance
- GaN Power ICs can operate comfortably at 2MHz

- To shrink components we need to increase frequency!
Magnetics Study → Many Knobs to Turn

- Core Loss: 0.5 W
- Winding Loss: 0.7 W
- Temperature: 75 °C
PFC Test Circuit (150W)

100 VDC Input

100 VDC Input

VCC +15V

PWM

Ground

400 VDC Output

13 of 25
PFC Test Setup
PFC Waveforms and Thermals (300kHz@100% load)

50%

DRAIN

PWM

100%

DRAIN

PWM

ER23 Core Type
# PFC Measurements

<table>
<thead>
<tr>
<th>Version</th>
<th>V0</th>
<th>VK</th>
<th>V3</th>
<th>V4</th>
<th>V5</th>
<th>V6</th>
<th>V8</th>
<th>V9</th>
<th>V10</th>
<th>V11</th>
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<tbody>
<tr>
<td>Core Type</td>
<td>ER 25</td>
<td>ER 25</td>
<td>ER 23</td>
<td>ER 23</td>
<td>ER 20</td>
<td>ER 20</td>
<td>RM 7 LP</td>
<td>RM 7 LP</td>
<td>RM 7 LP</td>
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<tr>
<td>Core Material</td>
<td>N49</td>
<td>N49</td>
<td>N49</td>
<td>N49</td>
<td>N49</td>
<td>N49</td>
<td>ML91S</td>
<td>ML95S</td>
<td>ML91S</td>
<td>ML95S</td>
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<tr>
<td>Freq [kHz]</td>
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<td>300</td>
<td>300</td>
<td>400</td>
<td>400</td>
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<td>400</td>
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<tr>
<td>EFF [%]</td>
<td>97.74</td>
<td>98.86</td>
<td>97.33</td>
<td>98.2</td>
<td>97.45</td>
<td>97.42</td>
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<td>98</td>
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<td>L [uH]</td>
<td>80</td>
<td>80</td>
<td>60</td>
<td>63</td>
<td>45</td>
<td>44</td>
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<td>4.07</td>
<td>2.96</td>
<td>2.96</td>
<td>2.05</td>
<td>2.05</td>
<td>2.03</td>
<td>2.03</td>
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<td>Temperature [degC]</td>
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<td>58.3</td>
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<td>122.1</td>
<td>95.9</td>
<td>94.8</td>
<td>102.2</td>
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<td>63.3</td>
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<td>30</td>
<td>18</td>
<td>24</td>
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<td>25</td>
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<td>Wire AWG</td>
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<tr>
<td>Strands #/AWG</td>
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<td>177/44</td>
<td>177/44</td>
<td>177/44</td>
<td>177/44</td>
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<td>175/46</td>
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<tr>
<td>Ae [mm²]</td>
<td>70.8</td>
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<td>50</td>
<td>50</td>
<td>28.66</td>
<td>28.66</td>
<td>45.3</td>
<td>45.3</td>
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**PFC Efficiency and Core Size vs. Frequency**  
(DC-DC Testing, Vin=100V, Vout=400V, 150W, CrCM)
LLC Test Setup

- 2x NV6115
- L1
- P1
- S1

- 200 VDC Output
- VCC
- PWM
- Ground
- 400 VDC Input
LLC Waveforms and Thermals (740kHz)

DRAIN
CURRENT
PWM

100%

ER23 Core Type
## LLC Measurements

<table>
<thead>
<tr>
<th>Version</th>
<th>V0</th>
<th>VK1</th>
<th>VK2</th>
<th>VK3</th>
<th>V8</th>
<th>LLC9</th>
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<th>LLC11</th>
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<tbody>
<tr>
<td>Core Type</td>
<td>ER 25</td>
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<td>ER 23</td>
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<td>RM7LP</td>
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<tr>
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<td>N49</td>
<td>ML91S</td>
<td>ML91S</td>
<td>ML91S</td>
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<td>Freq [kHz]</td>
<td>520</td>
<td>750</td>
<td>750</td>
<td>750</td>
<td>740</td>
<td>950</td>
<td>900</td>
<td>1000</td>
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<tr>
<td>EFF [%]</td>
<td>97.1</td>
<td>97.2</td>
<td>97.0</td>
<td>97.3</td>
<td>97.4</td>
<td>97.1</td>
<td>96.9</td>
<td>97.1</td>
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<tr>
<td>Lm [uH]</td>
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<td>122</td>
<td>118</td>
<td>119</td>
<td>122</td>
<td>50</td>
<td>50</td>
<td>50</td>
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<tr>
<td>Core Size [cc]</td>
<td>4.07</td>
<td>2.96</td>
<td>2.96</td>
<td>2.96</td>
<td>2.96</td>
<td>2.03</td>
<td>2.03</td>
<td>2.03</td>
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<tr>
<td>Temperature [degC]</td>
<td>74.6</td>
<td>72.0</td>
<td>72.3</td>
<td>71.6</td>
<td>83.6</td>
<td>102.3</td>
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<td>106.7</td>
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<tr>
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<td>27</td>
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<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Strands #/AWG</td>
<td>60/44</td>
<td>40/44</td>
<td>40/44</td>
<td>40/44</td>
<td>177/48</td>
<td>40/44</td>
<td>40/44</td>
<td>40/44</td>
</tr>
<tr>
<td>Ae [mm²]</td>
<td>70.8</td>
<td>50</td>
<td>50</td>
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<td>50</td>
<td>45.3</td>
<td>45.3</td>
<td>45.3</td>
</tr>
</tbody>
</table>

### LLC Efficiency and Size vs Frequency

(Vin=400V, Vout=200V, Np:Ns=1:1, 50% duty cycle, Pout=150W)
# 150W Demoboard Specifications

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$</td>
<td>Input Voltage</td>
<td>90-265 V</td>
<td>$V_{AC}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>47-63 Hz</td>
<td></td>
</tr>
<tr>
<td>$V_{OUT}$</td>
<td>Output Voltage</td>
<td>19 V</td>
<td></td>
</tr>
<tr>
<td>$I_{OUT}$</td>
<td>Output Current (100% load)</td>
<td>8 A</td>
<td></td>
</tr>
<tr>
<td>$I_{OUT_LIM}$</td>
<td>Output Current Limitation (short-circuit or over-load)</td>
<td>9.5 A</td>
<td></td>
</tr>
<tr>
<td>$P_{OUT}$</td>
<td>Output Power (max)</td>
<td>150 W</td>
<td></td>
</tr>
<tr>
<td>$F_{SW}$</td>
<td>Switching Frequency</td>
<td>PFC (120V, 100% load)</td>
<td>200 kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PFC (220V, 100% load)</td>
<td>100 kHz</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Efficiency</td>
<td>LLC</td>
<td>500 kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>230 $V_{AC}$, 150 W</td>
<td>94.5 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td>115 $V_{AC}$, 150 W</td>
<td>93.2 %</td>
</tr>
<tr>
<td>$P_{STBY}$</td>
<td>Standby Power</td>
<td>115 $V_{AC}$</td>
<td>&lt; 210 mW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>230 $V_{AC}$</td>
<td>&lt; 210 mW</td>
</tr>
<tr>
<td>$PF$</td>
<td>Power Factor</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>Board Dimensions</td>
<td>110 x 50 x 12.5 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Board Volume (uncased)</td>
<td>68.75 cc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Density (uncased)</td>
<td>35.75 W/in³</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.18 W/cc</td>
<td></td>
</tr>
</tbody>
</table>

Proposed Floorplan

![Proposed Floorplan Diagram](image-url)
150W Demoboard

Diagram showing various components:
- GaN Card
- EMI Filtering
- Res Inductor
- LLC xfrm
- X2 Cap
- PFC Inductor
- DC Bus Caps
- SR Card
- LLC Cr
- PFC RCS
- LLC IC
- PFC Diode
- PFC IC

Dimensions:
- 110mm
- 12.5mm
- 50mm
150W Demoboard Efficiency and Thermals

Vin=90VAC, 100% load, with copper wrapper
<table>
<thead>
<tr>
<th>Company</th>
<th>L x W x H (mm) (uncased)</th>
<th>Size (cc) (uncased)</th>
<th>Power Density (W/in3) (uncased)</th>
<th>L x W x H (mm) (cased)</th>
<th>Size (cc) (cased)</th>
<th>Power Density (W/in3) (cased)</th>
<th>Efficiency (%) @90VAC/100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navitas 150W</td>
<td>110 x 50 x 12.5</td>
<td>68.8</td>
<td>35.7</td>
<td>121 x 61 x 18.5</td>
<td>136.5</td>
<td>18.1</td>
<td>92.3</td>
</tr>
<tr>
<td>Delta HP</td>
<td>129 x 55 x 16.3</td>
<td>115.65 (+40.6%)</td>
<td>21.3 (-40.3%)</td>
<td>138 x 66.3 x 22.5</td>
<td>205.9 (+50.8%)</td>
<td>11.9 (-34.3%)</td>
<td>92.6</td>
</tr>
<tr>
<td>Razor BLADE</td>
<td>141.6 x 50.2 x 17.1</td>
<td>121.8 (+43.6%)</td>
<td>20.2 (-43.4%)</td>
<td>149.2 x 60.1 x 22.9</td>
<td>205.3 (+50.4%)</td>
<td>12.0 (-33.7%)</td>
<td>92.7</td>
</tr>
<tr>
<td>Chicony/LiteON HP</td>
<td>115 x 55 x 16.2</td>
<td>103.1 (+33.3%)</td>
<td>23.8 (-33.3%)</td>
<td>138 x 66.3 x 22.5</td>
<td>205.9 (+50.8%)</td>
<td>11.9 (-34.3%)</td>
<td>91.5 (@100VAC)</td>
</tr>
</tbody>
</table>
**Special Thanks To:**

- Isaac Cohen (Texas Instruments)
- Brent McDonald (Texas Instruments)
- Jack Ribarich (Navitas Semiconductor)
- Wurth Electronics