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A Power Supply Revolution Once Again!

**Power Density (W/in³)**

- Linear Regulators
- Switching Regulators
- Switching Regulators
- HF Switching Regulators

- 50 Hz
- 30 kHz
- 65 kHz
- 1 MHz

**Efficiency**

- 40% efficiency
- 80%
- 90%
- 96-98%

**Improvement**

- 5x Increase (18%/yr) in 10 years
- <6%/yr improvement over 30 years

**New Technologies**

- 3x Lower Loss
- 3x Lower $/W

- New GaN Power ICs
- New Magnetics
- New Controllers
- New Topologies

**Timeline**

- 1977
- 1987
- 2017
- 2027
The Power of GaN Power ICs
... Unequaled Integration, Speed & Efficiency

- **Driver Circuits**
- **Power Devices**
- **Passive Components**
- **Switching Frequency**
- **Energy Efficiency**

**Silicon**
- <100kHz
- 85-90%

**Discrete GaN**
- 300kHz
- 88-92%

**GaN Power ICs**
- >500kHz
- 90-95%
The New World of GaNFast™ Adapters

Power Density (uncased, W/in³)

600kHz ACF low profile planar xfrmr

500kHz ACF low profile planar xfrmr USB-PD

300kHz ACF Wound xfrmr USB-PD

300kHz ACF wound xfrmr USB-PD Convention

2-stage 200/300kHz CrCM PFC/ACF wound xfrmr USB-PD

2-stage 200/500kHz CrCM PFC, plus LLC wound xfrmr

Conventional Silicon-based Designs

27W 45W 65W 100W 150W
Key Elements For High-Density Adaptor

- New Topologies
- Higher Integration
- GaN Device
- Hi-Frequency Magnetic
- Hi-Frequency Controllers

>500Khz Controllers are ready!
Modified Performance factor

\[ F_{3/4} = B f^{3/4} (T \cdot Hz^{3/4}) \]

- **ML91S** (Hitachi Metal) ~2010s
- **3C90** (Ferroxcube) ~1990s
- **67** (Fair-Rite) ~2015s
- **3F35** (Ferroxcube) ~2000s

Future

High frequency, high VA capability (limited by power loss density)


Speed Reduces Size: Magnetics

150W PFC Boost Inductor (Lm)

CrM Mode, Design Frequency (kHz)

Vol (mm³)

3x smaller

EER3019
RM10
ER25
RM8-LP
Speed Reduces Size: Capacitors

Resonant tank

Vin

T1

D1

D2

C₀

Lᵣ

Lₘ

V₀

+ -

100kHz

500kHz
High Frequency Topologies

Active Clamp Flyback

Bridge CrM Boost PFC

LLC

Bridgeless CrM Totem Pole PFC

>1MHz(GaN) Soft-switching

>200kHz Quasi-Resonant

>1MHz(GaN) Soft-switching

>1MHz(GaN) with Soft-switching
Monolithic integration at 650V

- GaN FET (range 120-600 mΩ)
- GaN Driver
- GaN Regulator
- dV/dt control
- Logic

5 x 6 mm QFN
Voltage Slew-Rate Control... Easy EMI Tuning

- dV/dt controllable from 100 V/ns to 10 V/ns
External drivers
• Just 1-2 nH of gate loop inductance can cause unintended turn-on
• Gate resistors reduce spikes but create additional losses

Integrated GaN drivers (iDrive™)
• Eliminate the problem
• Negligible turn-off losses
• Removes unintended turn-on due to high dV/dt

Discrete FET and drive, no $R_G = $ out of control
Discrete FET and drive, with $R_G = $ slow, lossy
Integrated FET and drive, no $R_G = $ fast, efficient
Monolithic integration at 650V
- 2x 650V eMode GaN FETs (a/symmetrical range 120-600 mΩ)
- 2x 6V GaN gate drivers
- 2x 30V to 6V GaN regulators and UVLO circuits
- 650V GaN level-shifters and bootstrap drivers
- GaN Logic (shoot-through protection, fault mgmt, ESD, etc…)

2 MHz soft-switching operation
150W, 19V: PFC min 200 kHz, LLC 500 kHz

Power ICs

PFC

LLC

PFC Inductor, ER25

LLC Transformer, ER25

LLC Resonant Inductor (LLC IC NCP13992 on bottom side)

SR IC NCP4305, FETs

Bulk Caps

PFC Inductor, ER25

AC Bridges

EMI
<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</td>
<td>$V_{AC}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>47-63</td>
<td>Hz</td>
</tr>
<tr>
<td>$V_{OUT}$</td>
<td>Output Voltage</td>
<td>19</td>
<td>V</td>
</tr>
<tr>
<td>$I_{OUT}$</td>
<td>Output Current (100% load)</td>
<td>8</td>
<td>A</td>
</tr>
<tr>
<td>$I_{OUT_UM}$</td>
<td>Output Current Limitation (short-circuit or over-load)</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>$P_{OUT}$</td>
<td>Output Power (max)</td>
<td>150</td>
<td>W</td>
</tr>
<tr>
<td>$F_{SW}$</td>
<td>Switching Frequency</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PFC (120V, 100% load)</td>
<td>200</td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>PFC (220V, 100% load)</td>
<td>100</td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>LLC</td>
<td>500</td>
<td>kHz</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>230 $V_{AC}$, 150 W</td>
<td>94.9</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>115 $V_{AC}$, 150 W</td>
<td>93.8</td>
<td>%</td>
</tr>
<tr>
<td>$P_{STBY}$</td>
<td>Standby Power Consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>115 $V_{AC}$</td>
<td>&lt; in progress</td>
<td>mW</td>
</tr>
<tr>
<td></td>
<td>230 $V_{AC}$</td>
<td>&lt; in progress</td>
<td>mW</td>
</tr>
<tr>
<td>PF</td>
<td>Power Factor</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Board Dimensions</td>
<td>100 x 50 x 12.5</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Board Volume (uncased)</td>
<td>62.5</td>
<td>cc</td>
</tr>
<tr>
<td></td>
<td>Power Density (uncased)</td>
<td>39.3</td>
<td>W/in^3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.4</td>
<td>W/cc</td>
</tr>
</tbody>
</table>
Switching Waveforms: CrCM PFC Boost Stage

Fig. 8a: CrCM PFC Boost 90 V\text{IN}, 400 V\text{OUT}, 150 W, 182 kHz (peak of AC line)
Switching Waveforms: DC-DC (LLC) Stage

Fig. 9a: LLC $V_{SW}$, $I_L$, 19 $V_{OUT}$, 8 A
Reduced Magnetics Size @ 500kHz

\[ L = \frac{V_{\text{rms}}^2 \cdot (V_O - \sqrt{2} \cdot V_{\text{rms}})}{2 \cdot f_{\text{sw}}(\text{min}) \cdot P_i \cdot V_O} \]

- Fsw ↑ → Lm ↓ → Size ↓
- Fsw ↑ → Lr, Cr ↓ → Lm ↓ → Size ↓
- GaN → Coss ↓
**TDK N49 Core Material (500kHz)**

### Material properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preferred application</strong></td>
<td>Power transformers</td>
</tr>
<tr>
<td><strong>Material</strong></td>
<td>N49</td>
</tr>
<tr>
<td><strong>Base material</strong></td>
<td>MnZn</td>
</tr>
<tr>
<td><strong>Initial permeability</strong> (T = 25 °C)</td>
<td>( B_i )</td>
</tr>
<tr>
<td><strong>Unit</strong></td>
<td>1500 mT</td>
</tr>
<tr>
<td><strong>Flux density</strong> (H = 1200 A/m, f = 10 kHz)</td>
<td>( B_f )</td>
</tr>
<tr>
<td><strong>Unit</strong></td>
<td>490 mT</td>
</tr>
<tr>
<td><strong>Coercive field strength</strong> (f = 10 kHz)</td>
<td>( H_c )</td>
</tr>
<tr>
<td><strong>Unit</strong></td>
<td>38 A/m</td>
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<tr>
<td><strong>Optimum frequency range</strong></td>
<td>kHz</td>
</tr>
<tr>
<td><strong>Unit</strong></td>
<td>3000...10000</td>
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<tr>
<td><strong>Hysteresis material constant</strong></td>
<td>( \eta_m )</td>
</tr>
<tr>
<td><strong>Unit</strong></td>
<td>10⁻⁵ mT⁻¹</td>
</tr>
<tr>
<td><strong>Curie temperature</strong></td>
<td>( T_C )</td>
</tr>
<tr>
<td><strong>Unit</strong></td>
<td>10³ K</td>
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<tr>
<td><strong>Mean value of ( c_p )</strong></td>
<td>&gt; 240</td>
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<tr>
<td><strong>Density (typical values)</strong></td>
<td>kg/m³</td>
</tr>
<tr>
<td><strong>Relative core losses</strong></td>
<td>kW/m³</td>
</tr>
<tr>
<td><strong>25 kHz, 200 mT, 100 °C</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>100 kHz, 200 mT, 100 °C</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>300 kHz, 100 mT, 100 °C</strong></td>
<td>330</td>
</tr>
<tr>
<td><strong>500 kHz, 50 mT, 100 °C</strong></td>
<td>80</td>
</tr>
<tr>
<td><strong>1 MHz, 50 mT, 100 °C</strong></td>
<td>475</td>
</tr>
<tr>
<td><strong>Resistivity</strong></td>
<td>( \rho )</td>
</tr>
<tr>
<td><strong>Unit</strong></td>
<td>( \Omega \cdot \text{m} )</td>
</tr>
<tr>
<td><strong>Core shapes</strong></td>
<td>RM, FE, EL, EL, Toroid, EQ, ER</td>
</tr>
</tbody>
</table>

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**Navitas Proprietary & Confidential**
Reduced Output Cap @ 500kHz

- Output ripple = ESR ripple ($I_o$, ESR) + Cap ripple ($C_o$, $I_o$, $f_{sw}$ dependent)
- ESR is dominant factor for output ripple at high $f_{sw}$
- Small output cap is used for high $f_{sw}$

93% Efficiency @ 90VAC, Full Load

Efficiency vs Load & AC line voltage

Power Loss Estimate by Component

<table>
<thead>
<tr>
<th>Summary</th>
<th>90V</th>
<th>90V</th>
<th>115V</th>
<th>115V</th>
<th>230V</th>
<th>230V</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Ploss</td>
<td>%</td>
<td>Ploss</td>
<td>%</td>
<td>Ploss</td>
<td>%</td>
</tr>
<tr>
<td>Diode Bridge</td>
<td>3.6</td>
<td>31.0</td>
<td>2.6</td>
<td>28.5</td>
<td>1.4</td>
<td>20.1</td>
</tr>
<tr>
<td>EMI Filter</td>
<td>0.5</td>
<td>4.3</td>
<td>0.3</td>
<td>3.1</td>
<td>0.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Boost Switch</td>
<td>0.9</td>
<td>8.3</td>
<td>0.6</td>
<td>6.0</td>
<td>0.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Boost Diode</td>
<td>1.8</td>
<td>15.5</td>
<td>1.4</td>
<td>14.3</td>
<td>0.7</td>
<td>10.0</td>
</tr>
<tr>
<td>Boost Inductor (1x)</td>
<td>0.75</td>
<td>6.5</td>
<td>0.8</td>
<td>7.7</td>
<td>0.8</td>
<td>10.8</td>
</tr>
<tr>
<td>Half Bridge FETs</td>
<td>0.2</td>
<td>1.5</td>
<td>0.2</td>
<td>1.7</td>
<td>0.2</td>
<td>2.4</td>
</tr>
<tr>
<td>LLC Transformer (1x)</td>
<td>1.2</td>
<td>10.5</td>
<td>1.2</td>
<td>12.4</td>
<td>1.2</td>
<td>17.5</td>
</tr>
<tr>
<td>Resonant Inductor</td>
<td>0.7</td>
<td>6.1</td>
<td>0.7</td>
<td>7.2</td>
<td>0.7</td>
<td>10.1</td>
</tr>
<tr>
<td>SR FETs (2x)</td>
<td>1.1</td>
<td>9.6</td>
<td>1.1</td>
<td>11.3</td>
<td>1.1</td>
<td>15.9</td>
</tr>
<tr>
<td>SR gate charge (2x)</td>
<td>0.2</td>
<td>1.7</td>
<td>0.2</td>
<td>2.1</td>
<td>0.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Output Caps</td>
<td>0.4</td>
<td>3.3</td>
<td>0.4</td>
<td>3.8</td>
<td>0.4</td>
<td>5.4</td>
</tr>
<tr>
<td>Boost Sense Resistors</td>
<td>0.2</td>
<td>1.7</td>
<td>0.2</td>
<td>2.0</td>
<td>0.2</td>
<td>2.8</td>
</tr>
</tbody>
</table>

No heatsink, no airflow, room ambient
GaN Increases Efficiency

- Si $C_{\text{OSS}}$ is 50x-100x worse than GaN at $V_{\text{DS}} < 30\text{V}$
- High loss due to large stored charge while hard-switching

**120V\text{AC, Si CP partial hard-switching (≈200kHz)}**

- Turn-off losses low due to integrated drive
- Near loss-less ZVS turn-on transition
- Minimize deadtime for low reverse conduction loss
- No voltage spikes / overshoot

**120V\text{AC, GaN clean ZVS waveforms (≈200kHz)}**
<table>
<thead>
<tr>
<th>ITEM</th>
<th>Existing Silicon 140W Design</th>
<th>GaNFast 150W Design (NEV031)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture</td>
<td><img src="image1" alt="Existing Silicon 140W Design" /></td>
<td><img src="image2" alt="GaNFast 150W Design" /></td>
</tr>
<tr>
<td>Spec</td>
<td>140W (19V / 7.37A)</td>
<td>150W(19V/7.9A)</td>
</tr>
<tr>
<td>Power Device</td>
<td>Si</td>
<td>Navitas GaNFast IC</td>
</tr>
<tr>
<td>PCB Size</td>
<td>60 x 149.5 x 31</td>
<td>50 x 100 x 12.5</td>
</tr>
<tr>
<td>Case Size</td>
<td>68 x 156 x 39 (414cc)</td>
<td>126cc (estimated)</td>
</tr>
<tr>
<td>Efficiency</td>
<td>89%</td>
<td>93%</td>
</tr>
<tr>
<td>PWM frequency</td>
<td>PFC= 40kHz, LLC= 85kHz</td>
<td>PFC= 200kHz, LLC = 500kHz</td>
</tr>
</tbody>
</table>
Next Generation 1MHz 150W NB Adaptor

Topology: Totem-Pole PFC + LLC at 1 MHz
Power Device: GaNFast power ICs
Efficiency: >95% peak efficiency at full load
Let’s go GaNFast™