Design Considerations of Highly-Efficient Active Clamp Flyback Converter Using GaNFast™ Power ICs

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How to Improve Power Adapter Density?

• Added power in USB PD and Quick Charge requires dramatically higher power density (>20 W/in³)
• Higher efficiency and lower power loss are required in high density adapters
• How to dramatically improve the power density?
ACF Enables ZVS and High Frequency Switching

- No snubber losses, all leakage energy is recovered
- ZVS soft switching over entire operation range
- ZCS soft turn-off for output rectifier
- Clean waveforms reduce EMI
- Enable small adapter design with high-frequency switching
Towards Highly Efficient ACF

- Soft-switching is achieved, conduction loss dominates
- Circulating energy to the input source and clamping capacitor Cr, increasing current RMS
- Reduce both parts of circulating energy for highly efficient ACF

![Diagram showing energy flow and waveforms](image-url)
Minimizing Energy Circulated Back to Source

- Minimize negative $i_{Lm}$ for ZVS
  - $\rightarrow$ Depending on $C_0$(tr)
  - GaN has only $\frac{1}{2} C_0$(tr) even with $\frac{1}{2} R_{DS(ON)}$
  - GaN needs less circulating energy

<table>
<thead>
<tr>
<th></th>
<th>IPA60R299CP</th>
<th>IPA60R385CP</th>
<th>NV6115</th>
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</thead>
<tbody>
<tr>
<td>Voltage Rating (V)</td>
<td>650</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>$R_{DS(ON)}$</td>
<td>270</td>
<td>350</td>
<td>160</td>
</tr>
<tr>
<td>$C_0$(tr) (pF)</td>
<td>120</td>
<td>96</td>
<td>50</td>
</tr>
<tr>
<td>$Q_g$ (nC)</td>
<td>22</td>
<td>17</td>
<td>2.5</td>
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<td>$Q_{rr}$ (nC)</td>
<td>3900</td>
<td>3100</td>
<td>0</td>
</tr>
</tbody>
</table>

Energy circulated to source

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GaN ACF Minimized Negative $i_{Lm}$

- GaN ACF needs only 0.2A negative current for ZVS vs. Si’s 0.5A
- GaN ACF RMS is only 0.9A vs. Si’s 1.1A
- Besides,
  - GaN has **no** body diode loss
  - Low high-frequency gate-charge loss
Minimizing Energy Circulated in Cr

- Minimizing the shaded area
- Two methods identified
  - Creating deeper current dip
  - Using secondary resonant scheme
Method 1
GaN Increases Current Dip

- **Current dip ↑**
  - RMS value \( i_{Lr(RMS)} \) ↓
  - Less SR double turn-on ↓

- **Circulating Energy**
  - \( C_j \) ↑
  - \( C_j/C_{oss} = 0.5 \)
  - \( C_j/C_{oss} = 1 \)
  - \( C_j/C_{oss} = 2 \)

- **Use better device: GaN**
  - \( C_{oss} \) ↓

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Method 2
Secondary Resonance Scheme*

- Output capacitor to resonate with transformer leakage
- Clamping capacitor Cr has low voltage ripple
- More current pushed to the secondary side

*Navitas Patent Pending
Method 2

Secondary Resonance Reduces Circulating Energy

![Graph showing TX Primary Current $i_{Lr}(\text{rms})^*$ and TX Secondary Current $i_D(\text{rms})^*$ with marked reductions in primary and secondary resonant currents.]

*Measured results of 45W ACF
65W USB-PD ACF Using GaNFast™ Power ICs

**Input**
Universal AC (85-265V<sub>AC</sub>, 47-63Hz)

**Output**
Type C, USB-PD 2.0 (5-20V)

**Frequency**
250-350 kHz

**Power Density**
2.4 W/cc (39 W/in<sup>3</sup>) uncased
1.5 W/cc (24 W/in<sup>3</sup>) cased

**Construction**
4-layer, 2-oz Cu PCB,
“No heatsink” design
Efficiency Meets CoC Tier 2 and DOE LV VI

**Efficiency: 4-Points Average**

- 115 V\(_{AC}\)
- 230 V\(_{AC}\)
- CoC Tier 2

**Efficiency: 10% Load**

- 115 V\(_{AC}\)
- 230 V\(_{AC}\)
- CoC Tier 2
Integration Eases ACF Design

- Saved PCB space
- Avoided powertrain layout mistakes -> Noise confined
- Reduces standby loss
GaNFast™ Half-Bridge Power IC

- Asymmetric Half-Bridge for ACF
  - 2x GaN FETs (High-side 600 mΩ + Low-side 300 mΩ)
  - 2x GaN drivers
  - GaN Logic (level-shift, bootstrap, UVLO, shoot-through, ESD)

600V 2 MHz
27W USB-PD 3.0 Using GaNFast™ HB Power IC

Input
Universal AC (85-265V\text{AC}, 47-63Hz)

Output
Type C, USB-PD 3.0 (27W)

Frequency
200-400 kHz

Power Density
1.2 W/cc (19 W/in^3) uncased
0.7 W/cc (11 W/in^3) cased

Construction
4-layer, 2-oz Cu PCB,
“No heatsink” design
Efficiency:
Meets CoC Tier 2 and DOE LV VI

Efficiency: 4-Points Average

Efficiency: 10% Load
High Frequency 65W ACF with GaN ICs

Full Load $F_{SW}$: 500-600 kHz
Power Density: 47 W/ in$^3$ (Uncased)
→ 26 W/ in$^3$ (2.5mm case)

Average Efficiency = 93.4% @ 115 V$_{AC}$, 92% @ 230 V$_{AC}$
Conclusion

• Highly-efficient ACF should minimize the circulating energy
• GaN is uniquely suitable for high frequency ACF operation
• Half-Bridge GaNFast Power IC simplifies ACF design and improves density
• Examples of 27W and 65W PD designs are given showing high efficiency/density