An Ultra-High Efficiency High Power Density 140W PD3.1 AC-DC Adapter Using GaN Power ICs

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Outlines

• Background

• Design Considerations of PFC Converter with GaNSense IC
  – How GaNSense IC benefit the PFC converter
  – Efficiency optimization by using Follower Boost PFC

• Design Considerations of AHB Converter with GaN Half-bridge IC
  – GaN half-bridge IC benefits AHB converter
  – AHB efficiency optimization
  – A novel design of $V_{CC}$ power supply circuit for synchronous rectifier

• Experimental Results

• Summary
## >100W Adapters

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Topology Consideration for >100W PD3.1 Adapter

- **PFC + QR flyback**
  - Mature and simple
  - High voltage spike and EMI issue
  - Hard to design Tx turns ratio with PD3.1 output

- **PFC + ACF**
  - Voltage clamp and soft switching
  - Primary device voltage increases with higher output voltage
  - Hard to design Tx turns ratio with PD3.1 output

- **PFC + AHB**
  - Voltage clamp and soft switching
  - Two energy storage elements
  - Control complexity

![Diagram showing circuit configurations for PFC + QR flyback, PFC + ACF, and PFC + AHB.]
Innovation of GaN Device: Highly Integration

**GaNFast**
- **200-300 kHz**
  - Old, slow
  - High Qg
  - High \(C_{oss}\)
  - \(F_{sw} < 100\ kHz\)
  - Exposed gate
  - External gate drive
  - dV/dt sensitivity
  - Layout sensitivity
  - ESD sensitivity
  - Unknown reliability
  - Unknown robustness

- Autonomous Standby
- Autonomous Protection
- Loss-less Current Sensing
- High Precision
- High Efficiency

**GaNFast plus:**
- Internal Gate
- Integrated Gate Drive
- dV/dt Immunity
- Layout Insensitive
- 2 kV ESD rating
- Proven Reliability
- Proven Robustness

**GaNSense**
- **500 kHz**
  - Highest integration
  - Integrated HS and LS FETs
  - Integrated level-shift isolation
  - Integrated boot-strap
  - Shoot-through protection
  - Enlarged cooling pads

- Fastest switching
- Highest efficiency

**GaNSense Half-Bridge**
- **1 MHz**
  - 800 Vmax
  - 24V ESD
  - Autonomous Over-Current Protection
  - Autonomous Standby Mode
  - Over-Temperature Protection

Silicon FET

Discrete GaN

- Exposed gate
- dV/dt sensitivity
- Layout sensitivity
- ESD sensitivity
- Unknown reliability
- Unknown robustness

External gate drive

- dV/dt sensitivity
- Layout sensitivity
- ESD sensitivity
- Unknown reliability
- Unknown robustness

Old, slow

- High Qg
- High \(C_{oss}\)
- \(F_{sw} < 100\ kHz\)
Benefit of GaNSense Technology

- Greatly reduced conduction loss
- Efficiency increases up to 0.5%
- 50% reduction of $R_{DS(ON)}$ TOTAL
- Save more than 30mm$^2$ PCB space
Features of GaNSense Halfbridge

- Integrated HS and LS FETs
- Integrated lossless current sensing
- Over current protection
- Over temperature protection
- Integrated level shift
- Autonomous low-current standby mode
Comparison between Discrete and Integrated GaN Half-bridge

**Discrete GaN Half-Bridge**
- 33 components
- 250 mm² footprint
- External HB driver HVIC
- External HV bootstrap
- 2x HV bypass diodes
- 2x external gate drives
- Exposed gates

**GaNSense Half-Bridge IC**
- 13 components
- 90 mm² footprint
- Level shifters
- Bootstrap
- Gate drivers
- No exposed gates

- 61% fewer components
- 64% smaller footprint
- Complete integration

**Severe Ringing & Glitching!**

**No Ringing, No Glitching!**
How GaNSense IC Benefit the PFC Converter

- **Boost PFC with Si MOSFET**
- **with GaN device**
- **with GaNSense IC**

**Switching loss is significantly reduced with GaNFast.**

**Completely removed the current sensing loss with GaNFast and GaNSense.**
Traditional Boost PFC with Fixed Output Voltage

Traditional CRM/DCM Boost PFC

- High core loss
- High device conduction loss
- Low efficiency @ low line input w/ fixed output

Low diode conduction loss

V_{in}=90\text{Vac}, V_{BUS}=400\text{V}
Follower Boost PFC Benefits

- Output voltage varies according to the input voltage
- On-time and off-time is more balanced
- Lower resonant current and circulating energy
- Lower device conduction loss
- Higher diode conduction loss

Follower Boost PFC

E.g. $V_{in}=90\text{Vac}$, $V_{BUS}=260\text{V}$
Follower Boost PFC Benefits

- **Lower switching frequency**
- **Lower core loss**

V_{BUS} should be chosen based on the whole system performance.
GaN Half-Bridge IC Benefits AHB Converter

- Significantly reduces system complexity
- Increase system efficiency
- More compact PCB design
Both $N$ and $V_{BUS}$ impact system efficiency
Proposed $V_{CC}$ Power Supply Circuit

$V_{CC}$ is decoupled with $V_o$ compared with traditional methods

$V_{CC}$ range is narrowed and suitable for PD3.1 application

$V_{DS_{-SR}} = V_{rg1} + V_{F_{-D1}} + V_{rg2} = \frac{V_{in}}{N}$
140W PD3.1 AC-DC Adapter

- Power density is 35W/in³ (excludes the case)
Key Waveforms of PFC Converter

90Vac 140W

115Vac 140W

230Vac 140W_1

230Vac 140W_2
Key Waveforms of AHB Converter

115Vac
28V/5A

230Vac
28V/5A

230Vac
5V/3A

230Vac
5V/0A
System Efficiency

- Four-point efficiency @ 115Vac and 230Vac
- Efficiency at different input voltages

- Achieves 94.5% full load efficiency @ 90Vac
- At least 1% higher than the state of art product.
Conductive EMI Spectrum

115Vac 140W

230Vac 140W

Pass the CE standard with more than 8dB margin
Radiation EMI Spectrum

230Vac 140W

- RE margin is more than 6dB
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Summary

• The boost follower PFC improves low line efficiency by adjusting bus voltage

• The new SR $V_{CC}$ supply circuit simplifies the complexity and reduces the driving loss significantly at high output voltage condition

• the new GaNsense and GaN half-bridge power ICs reduce switching loss and circulating energy, improves system efficiency and power density significantly

• This design achieves 35W/in$^3$ power density, 94.5% full load efficiency @ 90Vac, and passes CE and RE standards with enough margin.
Thank You