Navitas

GaN Power ICs Enable Breakthroughs in Adapter Performance

APEC 2018 PSMA sponsored Industry session:
Latest advancements in device and package technology for high-power, high-frequency switching devices

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A New Class of High-Density Adapters

- **Power Density (W/in³)** (AC-DC converters ~300 W)
  - **Linear Regulators**: 50 Hz
  - **Switching Regulators**: 30 kHz
  - **Switching Regulators**: 65 kHz
  - **HF Switching Regulators**: 1 MHz

- **Efficiency** improvements:
  - 40% efficiency in 1977
  - 80% in 1987
  - 90% in 2017
  - 96-98% in 2027

- **Loss and Cost Savings**:
  - 3x Lower Loss
  - 3x Lower $/W

- **Technological Advancements**:
  - New GaN Power ICs
  - New Magnetics
  - New Controllers
  - New Topologies

- **Growth Timeline**:
  - 5x Increase (18%/yr) in 10 years
  - <6%/yr improvement over 30 years
USB-PD Type C: Massive Upgrade Cycle

Type C replaces 5 different connectors in one (power, data, video, audio)

USB-PD creates universal smart charging (any device can charge any other device)

Creating a massive upgrade cycle with >2B new USB-PD Type C chargers to be shipped in the next two years
Critical Elements
Market Demands

- Legislative
  - US DoE VI, Euro CoC Tier 2

- Features
  - Type C, USB PD 3.0 / PPS / QC 4.0

- Performance
  - Fast charging, size, weight, low profile

- Cost
  - Premium vs old, slow designs?
New Switch: GaN Replaces Silicon

- WBG GaN material allows high electric fields so high carrier density can be achieved
- Two-dimensional electron gas with AlGaN/GaN heteroepitaxy structure gives very high mobility in the channel and drain drift region
- Lateral device structure achieves extremely low $Q_g$ and $Q_{OSS}$ and allows integration
- Integration on silicon substrates means mature low cost wafer fabrication is available
GaN vs. Si in CrCM:
No Spikes, Clean ZVS, Low Reverse Conduction Loss

CrCM PFC at 200 kHz
Control = ST L6562A; IPL65R199CP vs. NV6105
New Topologies: High-Speed, High-Efficiency

- High-frequency, soft-switching topologies, e.g. Active clamp ZVS flyback (ACF)
- Replaces QRF RCD snubber with clamping capacitor \( (C_r) \) and active switch (S2)
- \( V_{SW} \) is stable, no overshoot, improving the device voltage margin
- When S1 is turned off, energy stored in the leakage inductance \( (L_r) \) is transferred to \( C_r \) and delivered to the load
- S2 efficiently charges \( C_r \), allows magnetizing inductance to conduct reverse current \( (i_{Lm} < 0) \), achieve nearly loss-less ZVS for S1
- Energy stored in \( C_{OSS} \) of S1, S2 and transformer winding capacitance almost fully recovered
GaN vs. Si in ACF:

2%-3% Higher Efficiency with Low $C_{OSS}$, $Q_G$, $Q_{rr}$

GaN’s low device capacitance cuts circulating current by 20%, even with much lower $R_{DS(ON)}$.
Available Magnetics Push Power Density

- Loss-limited power stage magnetics such as inductors & transformers shrink 2x or more
- EMI filters can shrink inversely proportional to frequency or disappear altogether as filter stages are reduced or eliminated
- New and better core materials are on the way


New Integration: **GaNFast™ GaN Power IC**

Monolithic integration at 650V

- GaN FET (*range 110-560 mΩ*)
- GaN Driver
- GaN Regulator
- dV/dt control
- Logic

![Diagram of GaNFast™ GaN Power IC](image)

5 x 6 mm QFN
Clean, Controlled FET Gate

• **Discrete driver**
  - Gate loop inductance creates overshoot (even with good layout)
  - Reliability concern

• **GaNFast Power IC**
  - No gate loop parasitic
  - Clean and fast gate signal
  - No CdV/dt turn-on
  - No IV crossover turn-off switching losses
Half-Bridge GaN Power IC

- Monolithic integration at 650V
  - 2x 650V eMode GaN FETs (a/symmetrical range 110-560 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...)

2MHz soft switching operation

2A pk-pk

500V

6 x 8 mm QFN
Robust Protection with GaNFast Half-Bridge

Non-Overlapping Logic Input (Typical Operation)

Overlapping Logic Input (GaNFast Power IC Protection)

5 V digital input, 6.2 V gate output, 80 ns/div
Smooth, Stable Start-up at 1 MHz

1. Chip is enabled (red)
2. UVLO (low side) is disabled (green)
3. Low side accepts gate signals (purple)
4. Bootstrap capacitor charges (purple)
5. UVLO (high side) is disabled (blue)
6. High side accepts gate signals (purple)
7. Low side (green) and high side (yellow) inputs

0 us

16 us
The New World of Fast Charging, Shrinking 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
27W USB-PD3.0 using 300 kHz ACF

Tiny 27W USB-PD3.0 Adapter

- Size: 23 cc uncased (39 cc with 2.5 mm thick case)
- Density: 1.2 W/cc (19 W/in\(^3\)) uncased, 0.7 W/cc (11 W/in\(^3\)) cased
Waveforms for Low and High Line Operation

- **115Vac 9V/3A**
  - Frequency: 250kHz
  - Mode: Soft Switching

- **230Vac 9V/3A**
  - Frequency: 300kHz

- **115Vac 9V/1.5A**
  - Mode: Half Load
  - Mode: Burst Mode

- **230Vac 9V/1.5A**
  - Mode: Burst Mode
45W USB-PD using 600 kHz ACF

Mu One 45W

World’s Thinnest Universal Travel Adapter

- UK, US and Euro plugs
- Size: 29 cc uncased
  (41 cc with ~2 mm thick case)
- Density: 1.6 W/cc (25 W/in³) uncased,
  1.1 W/cc (18 W/in³) cased

EMI Compliant with Margin
65W USB-PD using 300 kHz ACF

- **Powertrain:** NV6115 (170mΩ) + NV6117 (120mΩ) GaNFast Power ICs
- **Control:** ACF UCC28780, SR UCC24612, PD TPS25740
- **Frequency:** ~300 kHz
- **Size:** 27 cc (45 cc with 2.5 mm case)
- **Power Density:** 2.4 W/cc (39 W/in³) or 1.5 W/cc (24 W/in³) cased

High Line (20V/3.25A)

- QP Limit
- AVG Limit
- QP
- AVG

90 VAC, 65 W, 25 °C, uncased, no airflow
Adding PFC to USB-PD for >70W Applications

Light Load Operation (20V, 500mA)

- $V_{ACF_{sw}}$
- $V_{PFC_{sw}}$

Heavy Load Operation (20V, 4.8A)

- $V_{ACF_{sw}}$
- $V_{PFC_{sw}}$

Light Load Operation (zoomed)

- $V_{ACF_{sw}}$
- $i_{ACF_{Lp}}$
- $V_{SR}$

Half Load Operation (20V, 2.5A)

- $V_{ACF_{sw}}$
- $V_{SR}$
- 5us/div
150W, 19V PFC+LLC at 200/500 kHz

- Topology: CrCM PFC, LLC
- Powertrain: NV6115 GaNFast Power ICs
- Control: PFC NCP1615, LLC NCP1399, SR NCP4305
- Frequency: PFC = \text{min} \ 200 \ kHz \ (90 \ V_{AC}, \text{peak line, full load})
\hspace{1cm} \text{LLC} = \ 500 \ kHz
- Size: 63 cc (101 cc with 2.5 mm case)
- Power Density: >2.4 W/cc (39 W/in$^3$) or >1.5 W/cc (24 W/in$^3$) cased
Now Charger Designs Can Be \textit{GaNFast}™

One & Done!

One pocket-sized, powerful charger to fast charge ALL your devices in MINUTES.

That’s \textit{GaNFast}™