GaN Power ICs: Integration Drives Performance

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Navitas Semiconductor Inc.

- World’s first & only GaN power IC company
- Founded January 2014
- HQ in El Segundo, CA, USA
- World-class team
- World-class manufacturing partners
- www.navitassemi.com
A Question on History...

• What happened in 1977?
A Question on History...

• *What else* happened in 1977?
The First Revolution in Power

Linear Regulators → Switching Regulators

- **Power Density (W/in^3)**
  - Transition from Linear to Switching Regulators
  - Efficiency improvement:
    - 1977: 40% efficiency
    - 1987: 80% efficiency
    - 2017: <10%/yr improvement over 30 years

- **Technology Evolution**
  - **Si BJT → Si FETs**
  - New Magnetics
  - New Controllers
  - New Topologies

- **Performance Improvements**
  - 2x Lower Loss
  - 3x Lower $/W

- **Frequency Evolution**
  - 50 Hz → 30 kHz → 65 kHz

- **Technical Milestones**
  - 1977: 40% efficiency
  - 1987: 80% efficiency
  - 2017: 90% efficiency
Today's Power Revolution

- Power Density (W/in³)
  - Linear Regulators: ~300W
  - AC-DC converters
  - 40% efficiency in 1977

- Switching Regulators
  - 30 kHz, 2x Lower Loss, 3x Lower $/W
  - Si BJT → Si FETs
  - New Magnetics
  - New Controllers
  - New Topologies

- Switching Regulators
  - 65 kHz, 90% efficiency in 2017

- HF Switching Regulators
  - 1 MHz, 95-98% efficiency in 2027
  - 5x Increase in 10 years

- <10%/yr improvement over 30 years

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

- 5x Increase in 10 years

World’s First AllGaN™ Power ICs

Fastest, most efficient GaN Power FETs

- >20x faster than silicon
- >5x faster than cascoded GaN
- Proprietary design

iDrive First & Fastest Integrated GaN Gate Drivers

- >3x faster than any other gate driver
- Proprietary design
- 30+ patents granted/applied

World’s First AllGaN™ Power IC

Up to 40MHz switching, 5x higher density & 20% lower system cost
AllGaN™: Monolithic GaN Power IC

- Monolithic integration at 650 V
  - GaN FET (range 110-560 mΩ)
  - GaN Driver (iDrive™)
  - GaN Logic
- “Digital In, Power Out”
Integrated Drive ➔ Simple & Robust

- Wide-range $V_{CC}$ (10-30 V)
- Regulator ensures $V_{GS}$ within SOA
- PWM hysteresis for noise immunity
- No inductance or ringing in gate loop
- Total layout flexibility & simplicity
- Gate protected from external noise
Clean, Controlled FET Gate

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

- iDrive™ GaN Power IC
  - No gate loop parasitic
  - Clean and fast gate signal
Fast & Clean Hard Switching

IC prevents noise coupling into gate

Zero gate-loop inductance
Eliminate turn-off loss

Clean HV hard switching

Prop delay 10-20 ns

PWM

Driver

HV power FET

V_IN

L_d

L_{load}

V_{IN}

V_{DRAIN}

\approx 100 \text{ V/ns } dV/dt

\frac{dV}{dt}

V_{PWM}

(100 \text{ V/div})

500 V

500 V

I_{Load} = 5 \text{ A}
Speed & Integration ➔ Eliminate Turn-off Losses

- 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 dV/dt turn-on

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
Easy EMI with dV/dt control

dV/dt controllable from 180 V/ns to 10 V/ns
Discrete GaN

Low $C_{iss} \rightarrow$ Fast switch, but...

HBM < 250 V (typical)
ESD Protected

Discrete GaN

Low $C_{iss} \rightarrow$ Fast switch, but...

HBM < 250 V (typical)

GaN Power IC

Integrated ESD Protection

HBM, CDM > 1,000 V
AllGaN™ Half-Bridge GaN Power IC

- Monolithic integration at 650V
  - 2x GaN FETs (110-560 mΩ)
  - 2x GaN drivers (iDrive™)
  - GaN Logic (level-shift, bootstrap, UVLO, shoot-through, ESD)
- “Digital In, Power Out”
Old Level-Shift: High Loss, High Cost

Disparate Technologies
Hybrid isolator, discrete driver, discrete power, bootstrap diode

**High Power Loss**

- Driver loss, $R_G$ loss
- Bootstrap diode $Q_{RR}$, $V_F$
- Pulsed high current level shifter power (?)
GaN Level-Shift: Low Loss, High-Frequency

Disparate Technologies
Hybrid isolator, discrete driver, discrete power, bootstrap diode

High Power Loss
- Driver loss, $R_G$ loss
- Bootstrap diode $Q_{RR}$, $V_F$
- Pulsed high current level shifter power (?)

Low Power Loss
- No gate driver loop parasitics, matched driver-FET capability, negligible loss vs. frequency
- Zero $Q_{RR}$, low $V_{DS}$ in synchronous charging
- Very fast, low-power loss, MHz+

Monolithic Platform
Lateral GaN-on-Si, Half-Bridge GaN Power IC
Complex Design ➔ Easy-to-Use

Half-Bridge *Discrete* GaN

- 20x smaller PCB area
- 40+ fewer components
- Lower cost
- Robust & protected
- Simple
- Easy layout

**Half-Bridge GaN Power IC**

PCB Area: 6 x 8 = 48 mm²
65W USB-PD ACF: World’s Smallest Adapter

- **Input**: Universal AC (85-265V<sub>AC</sub>, 47-63Hz)
- **Output**: USB-PD (5-20V) (65W)
- **Primary**: NV6115 (160mΩ) + NV6117 (110mΩ) GaN Power ICs
- **Frequency**: ~300 kHz
- **Size**: 38 x 46 x 15.5 mm = 27 cc uncased
  - 43 x 51 x 20.5 mm = 45 cc with 2.5 mm case
- **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, SMT powertrain
  - “No heatsink” design
Efficiency at $20 \text{ V}_{\text{OUT}}$ (25°C, no airflow)

Efficiency measured at PCB
65W USB-PD ACF

Efficiency (25°C, no airflow)

- **4-point Average Efficiency**
  - 115 V<sub>AC</sub>
  - 230 V<sub>AC</sub>
  - CoC Tier 2

- **10% Load Efficiency**
  - 115 V<sub>AC</sub>
  - 230 V<sub>AC</sub>
  - CoC Tier 2

- Standby: 25 mW at 115 V<sub>AC</sub>, 40 mW at 230 V<sub>AC</sub> (CoC Tier 2 spec is < 75mW, DoE Level VI spec <= 210 mW)

Efficiency measured at PCB
1 MHz, 25 W ACF in 5W Size

- Single-stage EMI
- Level-shifter
- 2x Navitas single GaN Power ICs
- Planar transformer
- DSP (for prototype)
1 MHz, 25 W ACF – Next Step

- Single-stage EMI
- 1x Navitas Half-Bridge GaN Power IC
- Planar transformer
- ACF IC
GaN Power ICs: Integration Drives Performance

纳微 Navitas 65W USB-PD