A New 650V GaNFast Half Bridge IC for AC/DC Converter Applications

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Outline

• Background
  • GaN on Silicon
  • Power ICs in GaN
  • Navitas GaNFast™ IC platform

• Navitas Half-Bridge IC
  • Why Half-Bridge IC?
  • Half Bridge Architecture
    • Key Features & Performance

• Application examples
  • Active Clamp Flyback (ACF) Topology

• Summary
GaN Material Properties compared to Si and SiC

- **High voltage operation**
- **High T° applications**
- **High Frequency switching**

**Theoretical specific $R_{DS}/V_{DS}$ curves**

- **Vertical Si Current Performance**
- **Lateral GaN Current Performance**

- **Si limit** $T = 300$ K
- **SiC limit**
- **GaN limit**
- **Lateral GaN 2-D Limit** (with 400 ohm-sq 2-DEG)
  - 2.5 MV/cm, 3.5 MV/cm

<table>
<thead>
<tr>
<th>Maximum Voltage (V)</th>
<th>$R_{DS(ON)}$ (m$\Omega$-cm$^2$)</th>
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<tr>
<td>$10^2$</td>
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<td>$10^3$</td>
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<td>$10^4$</td>
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<td>$10^5$</td>
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Advantages of Lateral GaN on Si Technology

• AlGaN/GaN heterojunction enables high 2DEG concentration and lateral electron mobility under channel and drift region → Low specific Rdson
• 10x higher breakdown field → High breakdown voltage
• Absence of junctions → low $Q_G/Q_{OSS}/Q_{rr}$
• Lateral device structure → Easy to integrate different flavors of active components (eMode/dMode/Schottky) and passives with different voltage handling capabilities & good isolation
• Integration on Silicon substrate means , low cost Silicon fabs can be used
eMode vs dMode GaN

**dMode GaN Technology**

- Depletion mode GaN with Silicon FET Cascode
- Silicon FET gate easy to drive
- Complicated multi chip package
- Prone to oscillations and instability
- No dV/dt control

**eMode GaN Technology**

- Low Q_G
- Easy to package and low package inductance
- Good dv/dt control with gate access
- No reverse recovery loss
- Requires careful gate voltage control

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eMode GaN FET gates can be easily damaged by voltage or current spikes

→ Integrated Gate Control offers the most promise in terms of realizing the full potential of eMode GaN
Navitas GaN IC Platform

Navitas GaN IC PDK
• Sets up physical and electrical constraints for IC design in GaN
• Offers great deal of design flexibility
• Fast design/tape out cycle time
• Enables seamless integration of new devices and features
• Scalable models, streamlined for voltage, process corners and temperature

First & Fastest Integrated GaN Gate Drivers

Navitas Proprietary GaN devices and circuit elements
• eMode and dMode transistors
• Integrated capacitors
• Integrated resistors
• Inverters
• Buffers
• Logic gates
• Pulse generators
• ESD I/O circuits

• Hysteretic Digital input
• Wide operating power supply range (10V – 30V)
• Regulated internal power supply
• Integrated Bootstrap
• Integrated level shifters
• Protection
  • UVLO
  • ESD
  • Shoot-through
• Monolithic GaN integration
Navitas Integrated Drive Solution

Driver challenges addressed by Navitas power ICs:

- Eliminates gate voltage oscillations
- Excellent Miller immunity (>150V/ns)
- Well regulated gate drive voltage
- Extremely low turn off losses
- Gate ESD protection
- Externally programmable dv/dt control for EMI/noise reduction
- Extremely fast turn on and turn off speeds (<5ns)
- Clean HV switching characteristics
- Fast chip startup capability
- Low standby power losses
- Safe power up and power down
- Low cost/low PCB real estate and PCB layout insensitive
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Half-Bridge Level-Shifter Options

**Conventional Si JI based level shifters**
- High junction capacitances
- Very Lossy
- Unsuitable for high frequency switching applications

**High Frequency Isolators**
- Capacitive and Inductive coupled isolators
- Multiple die structures using capacitor plates or magnetic coils
- Use disparate materials
- Low power consumption but very costly fabrication and assembly process

**Logical Extension**

**Fully Integrated Half Bridge Drivers**
- Leverages low $R_{DS}/Q_G/C_{oss}$ & high $V_{DS}$ GaN for HV level shifting
  - Level shifters can be made extremely small and fast
  - Very low current resulting in low power loss
  - High common mode noise immunity
  - Pulsed level shifting
Combination of extremely fast low-power consumptive level shifters, Zero Q\textsubscript{RR}/low R\textsubscript{DS} bootstrap FET, integrated gate drive + power stage enables multi MHz operation with short propagation delays and low system losses!!!

- Integrating drivers, level-shifters, bootstrap FET and power FETs in a monolithic package reduces PCB footprint
Half-Bridge GaN Power IC

- 2x GaN FETs (High side and Low side) & 2x GaN drivers
- Gate voltage regulation
- Hysteretic digital inputs
- Compatible with a wide range of analog and digital controllers
- Integrated high voltage bootstrap FET for fast bootstrap capacitor charging capable of high frequency operation
- Level-shift circuit; low loss/fast and >200V/ns CM noise immunity
- UVLO for safe startup and shut down
- ESD protection
- Shoot-through protection (non overlapping logic)
- Chip enable function for low loss standby mode operation
Half-Bridge Startup

**Chip Startup Sequence**

1. ENB = 0V chip kept in “Standby”
   - This shuts off the internal regulator
   - <190μA current draw from Vcc @ 15V
2. ENB = HI; Internal regulator will turn on and start charging VDDL
3. Low side chip comes out UVLO
4. Low side gate switches in response to INL signal

**Measured Standby Current**

- Very low standby $P_{LOSS}$ (<10mW)
- Fast startup coming out of standby mode
Half-Bridge Performance

High-side Startup Characteristics

- Integrated bootstrap FET charges the high side power supply when $IN_L = HI$
  - Chip capable of fast charging high side bootstrapped power supply even for INL pulses as small as 100ns
- Bootstrap FET immune to dv/dt induced noise – clean high side power supply charging profile
- Ideal for high frequency operation
Half-Bridge Performance

Hard Switching Characteristics

500V low side hard switching (BOOST mode)

400V high side hard switching (BUCK mode)

Excellent common mode noise immunity – chip can handle very stressful hard switching environments
Half-Bridge Performance

Boost-mode Switching $dV/dt$ Control

- Ability to modulate hard switched edge $dv/dt$ important to reduce system noise and reduce EMI
- Low side FET $dv/dt$ can be modulated by adding external components

With combination of external resistor and capacitance

Measured $dV/dt$
Half-Bridge Performance

- Typical propagation delays
  - Low side: $T_{ON} = 20$ns, $T_{OFF} = 15$ns
  - High side: $T_{ON} = 40$ns, $T_{OFF} = 40$ns
- Chip capable of transmitting 100ns high side pulses even under hard switching conditions
Half-Bridge Performance

Non–overlapping logic to ensure full shoot through protection
What makes the half bridge IC ideal for high frequency ZVS applications?

- Low $C_{OSS}$ of power FETs
- Low $T_{ON}$ and $T_{OFF}$
- Ability to transmit ON pulses during $dv/dt$
- High $dv/dt$ immunity (no false ON or OFF pulses due to $dv/dt$ induced noise)
Half-Bridge Performance

- Level shifter capable of transmitting ON pulses over a wide range of $V_{SW} \text{ dv/dt}$’s without any degradation of turn on prop delay
- Critical attribute of the half bridge IC – specially under light load or startup conditions which demand some partial hard switching capability
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Active Clamp Flyback (ACF) Topology

- ACF is an advancement over the standard hard switching Quasi-Resonant (QR) Flyback Converter
- Adding an extra switch (high side of the Half Bridge IC) enables ZVS
- Reduces switching loss and enables frequency increase -> minimize transformer/EMI filters size and cost
- Increase power density and efficiency!!!
Half Bridge IC in ACF

Half Bridge operating in an Active Clamp Flyback topology

Clean high side startup (as evidenced by the negative current excursions)
High side startup after just one low side pulse

Excellent immunity to high frequency ringing
NO FALSE SIGNALS !!!

High side power supply charging and discharging sequence during and after a burst of PWM signals respectively

Primary side current
Vsw
INL
INH
VB - VSW

Hard switched transition at the 2nd INL pulse

Negative current valleys indicate high side turn on resulting in full ZVS
Half Bridge IC in ACF

Half Bridge operating in various ACF modes

- **Current**
- **Vsw**

1 us/div  
5 us/div  
500 us/div

- **Full power**
- **Light load**
- **Burst mode**
27W USB PD Charger

27W ACF board → 75% increase in power density

Four point efficiency, 25°C, no case, no air flow, no heat sink

Efficiency @ 10% load, 25°C, no case, no air flow, no heat sink
Fast USB-A & USB-C chargers from Aukey using Navitas GaNFast™ Half Bridge IC
Summary

• Innovative Half-Bridge GaN power IC developed using Navitas proprietary GaN-on-Si technology and PDK
• Sets a new paradigm in efficiency and power density for AC/DC power conversion
• Ideally suited for ACF topology that is commonly employed in consumer adapter solutions over a wide range of power from 10W – 100W