Monolithically Integrated Protection Circuits in 650V Power GaN

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Integration in WBG Semiconductors: Increased Power Density and Advanced Functionalities at Application Level

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Presenters Bio

Manish Shah is a co-founder and VP of Engineering at Tagore Technology; The company involved in developing RF and Power Management products based on GaN Technology. He leads an engineering team who is responsible for developing GaN Power IC, High Power GaN RF switch, Power Amplifier and Low Noise Amplifier products. He has more than 25 years of experience in the semiconductor industry including GaN technology, design and development of integrated GaN Power IC, HV driver, level shifter, protection circuits, High Power RF frontend, Cellular RF transceivers, CMOS RFIC and PMIC. He has 12 issued patents and more pending.

He holds a Master's Degree in Electrical Engineering from National Technological University and Bachelors Degree in Electrical Engineering from University of Illinois at Chicago.

Outline

- GaN HEMT as a power device
  - Technology options & Tradeoff
  - Challenges
- Integration Options
- Monolithically integrated protection circuit:
  - Gate voltage control circuit for gate protection
  - Slew rate control circuit
  - Unbiased dv/dt immunity circuit for dv/dt induced false turn-on
  - UVLO to prevent high supply ramp rate induced false turn-on and turn PFET on at right gate voltage
- Summary

GaN Power HEMT for Chargers and Power Supplies

❑ Mobile/PC Chargers

❑ Server/Networking Supplies

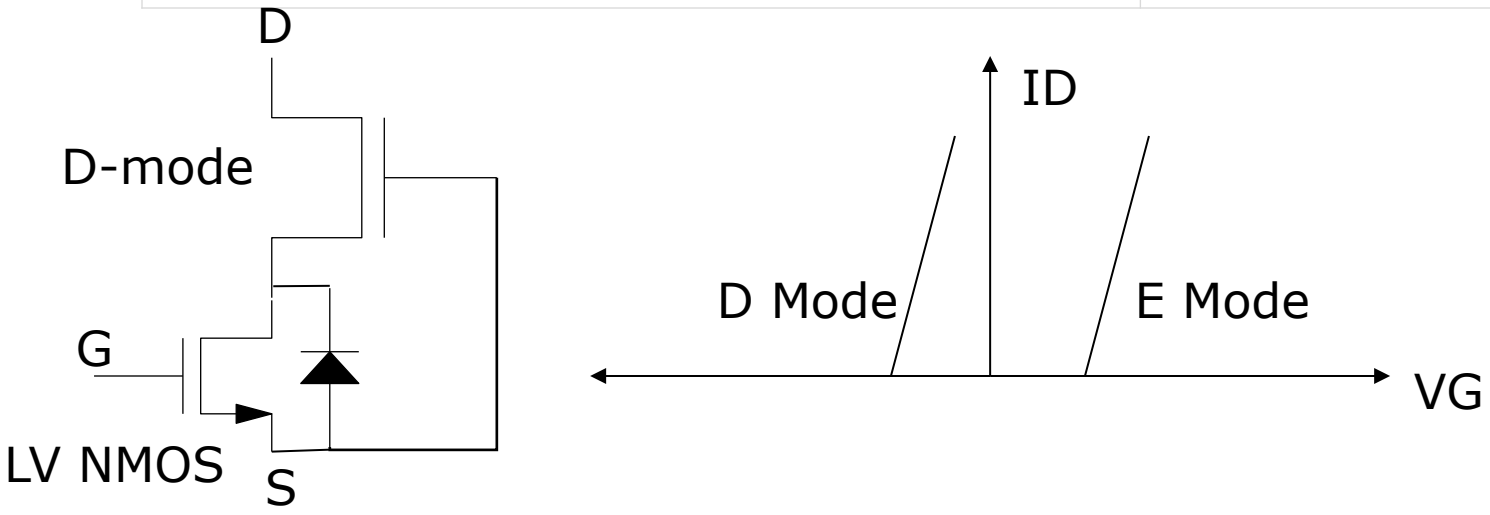
❑ EV Chargers

Better Device: GaN ➢ **Energy Efficiency** ➢ **Size/Cost↓** ➢ **Greener Planet**

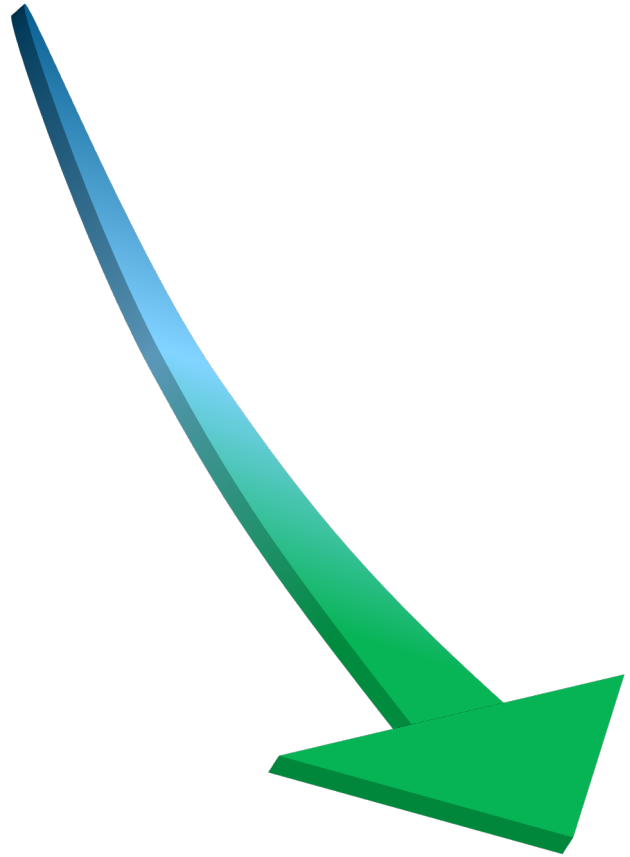
Better Driver: Integration ➢ **Performance** ➢ **Protection** ➢ **Reliability** ➢ **Easier Adoption**

Two Broad Choices of GaN HEMT: E-mode vs. D-mode

Metric	E-Mode	D-Mode
❑ Threshold voltage V_t	Positive	Negative
❑ Need for Cascode /Negative driver-supply	No	Yes
❑ Monolithic integration	Possible	Very difficult



GaN power HEMT offers excellent performance leading to



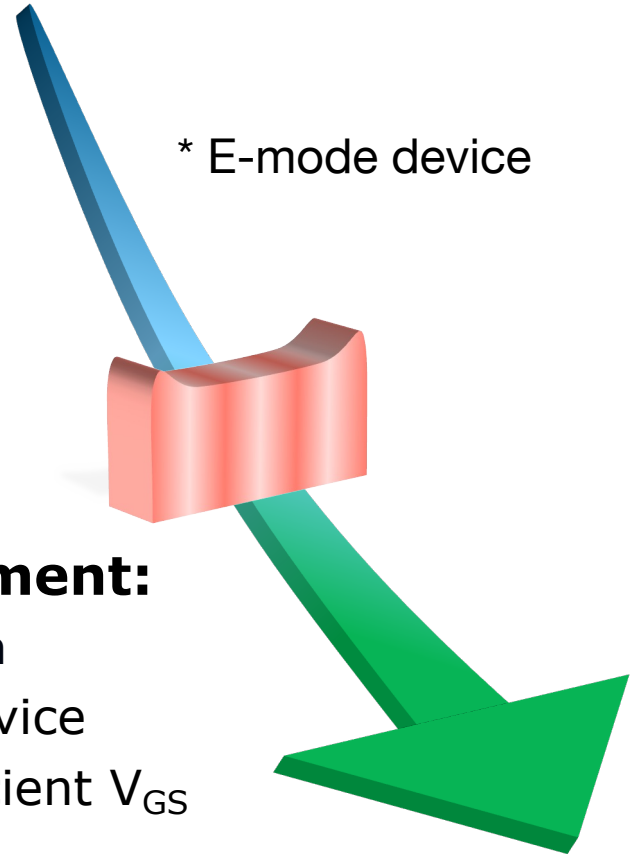
✓ **Energy savings**

✓ **Size/BOM savings**

GaN power HEMT offers excellent performance leading to

However, gate of GaN HEMT* is sensitive:

- 1.5 V typical V_t, easily goes ±0.7 V
- >1 Miller-ratio at high voltage ($\equiv Q_{GD}/Q_{GS}$)
- Max V_{GS} is SOA limited; typical ~6.5 V



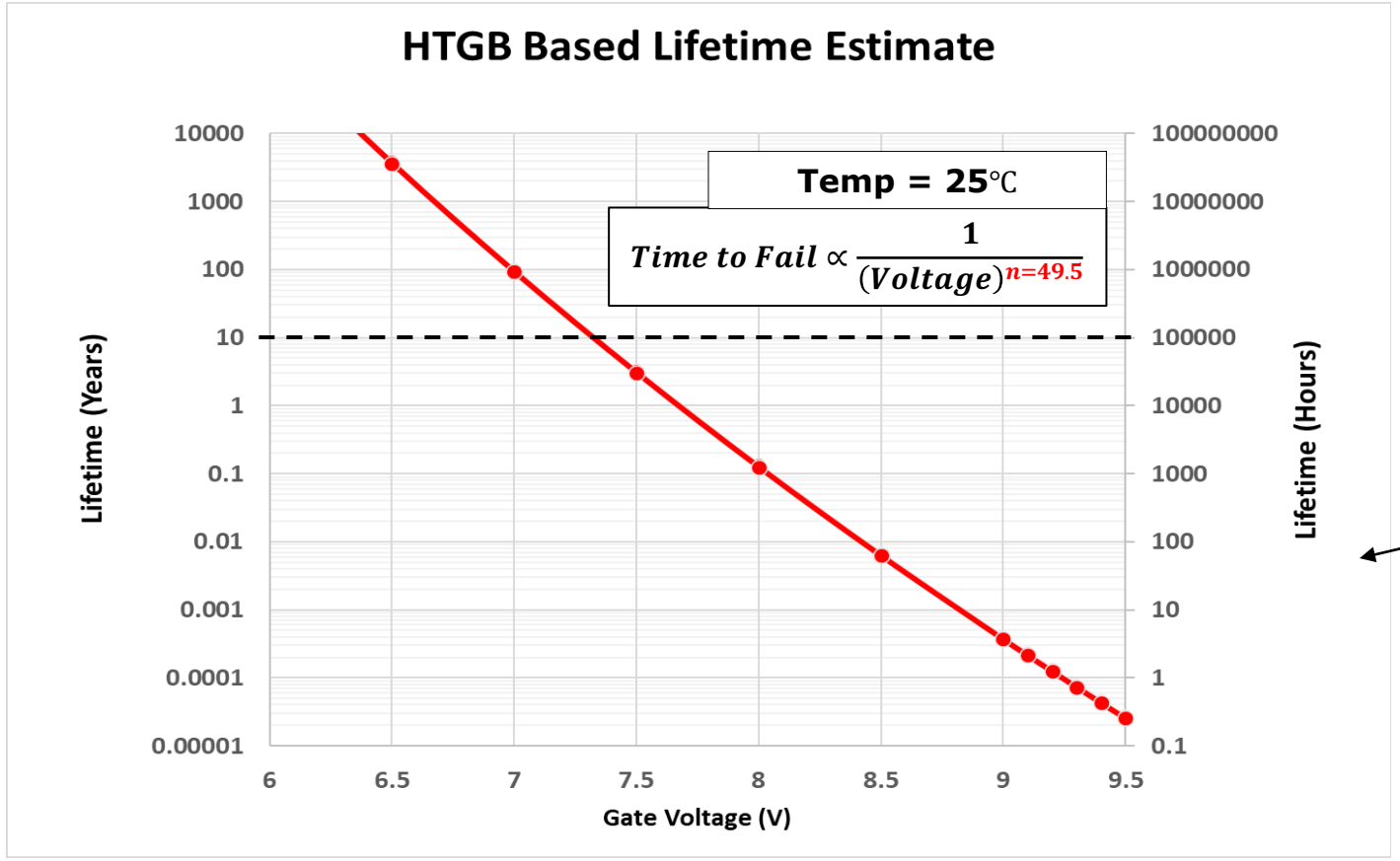
Leading to roadblocks in successful deployment:

- Higher Susceptibility to drain dv/dt induced turn-on
- Slight noise-coupling to gate can turn-on the device
- Performance (R_{dson} and I_{dsat}) suffers with insufficient V_{GS}
- Unregulated V_{GS} is a reliability hazard

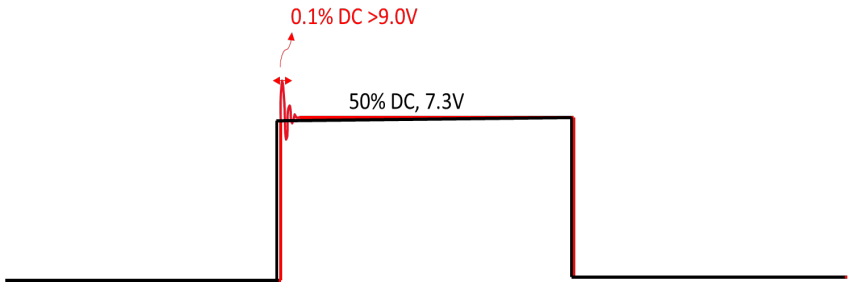
✓ **Energy savings**

✓ **Size/BOM savings**

A Typical HTGB Chart for a GaN Power Device



Voltage/Temp	25℃	55℃	75℃
9.5V	✓		
10V	✓	✓	✓
10.5V	✓		

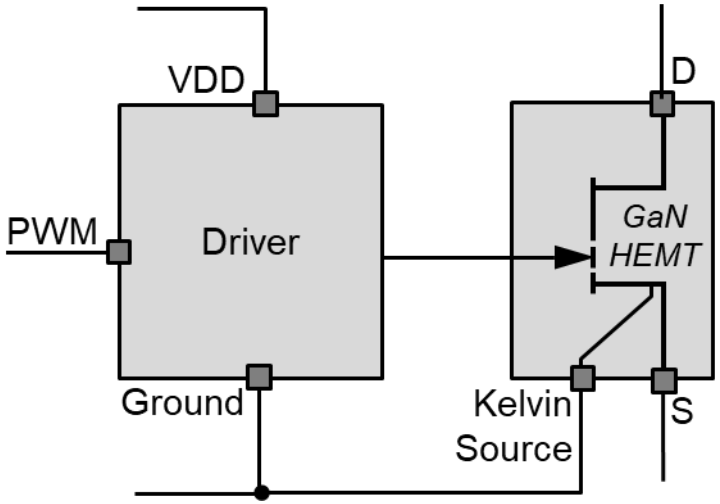


Implication of higher gate-to-source voltage

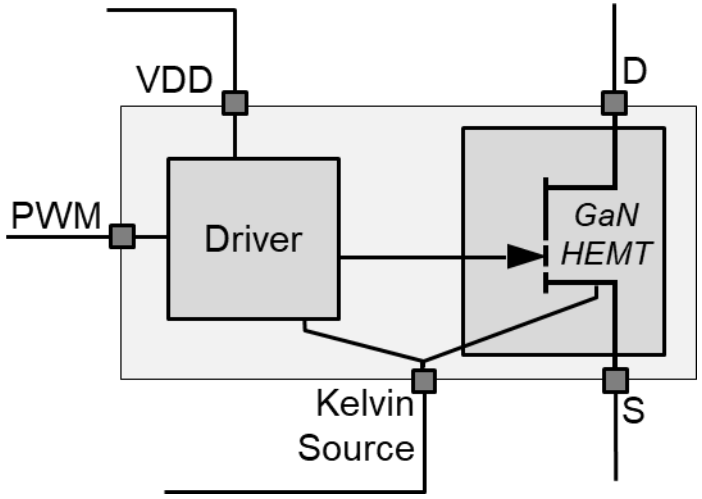
- n = 49.5 → Very large AF
- Gate voltage of 7.3V with 50% duty cycle will have >15yrs lifetime
- Ringing of gate voltage > 9V for 0.1% of total period, will reduce lifetime <0.5yrs*

* First order approximation

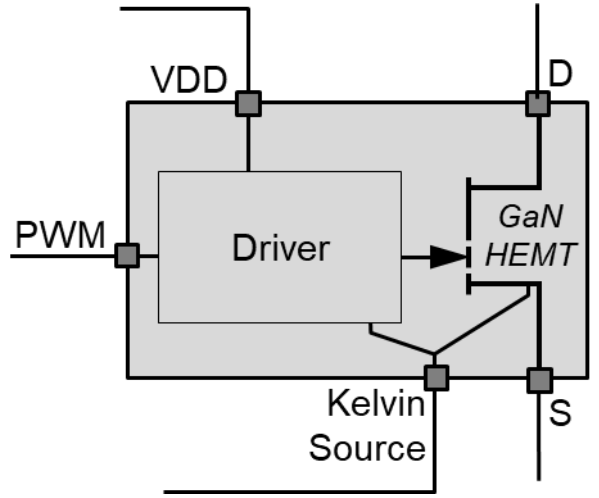
Integration Options



Driver and HEMT
Two-ICs, Two-Packages



Driver and HEMT
Two-ICs, Co-packaged

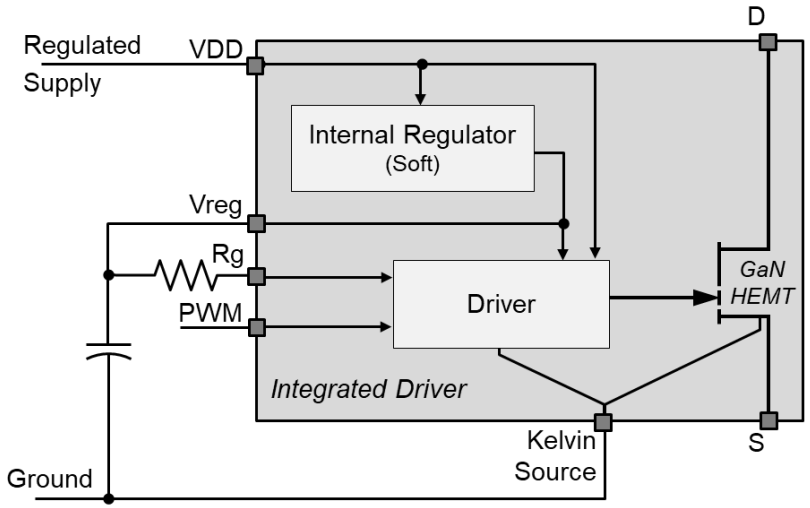


Driver and HEMT
Single-Die

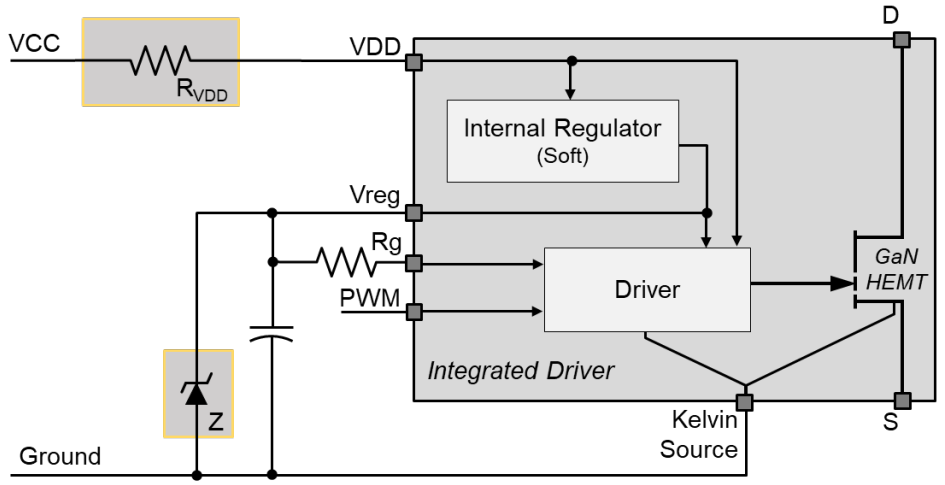
Present Topic:

- Smaller Gate-Loop
- On-Die Protection Circuits
- Challenges: Driver Circuit Design

Configurable Driver-Supply Architecture

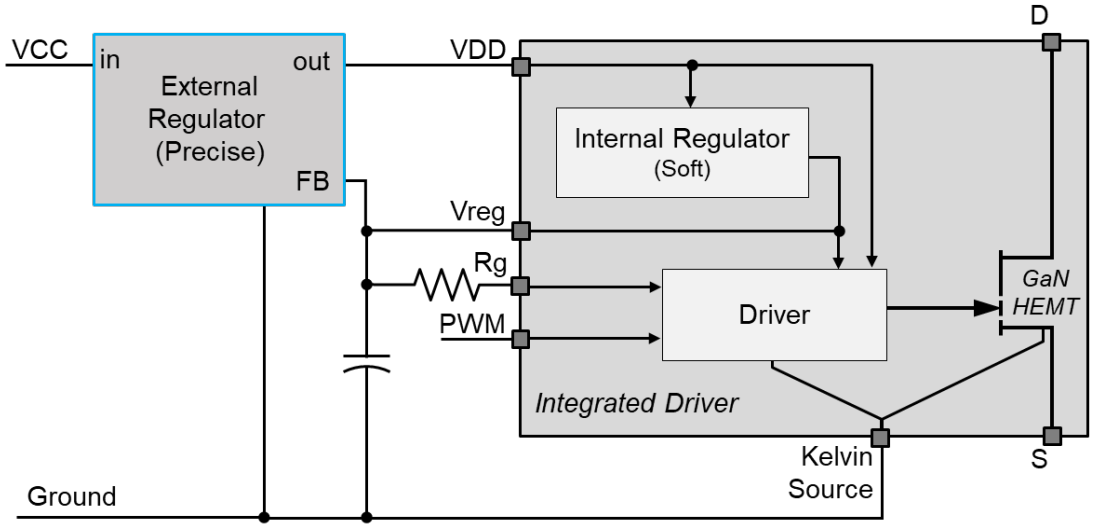


V_{GS} is (imprecisely) regulated.



V_{GS} is regulated by Zener.

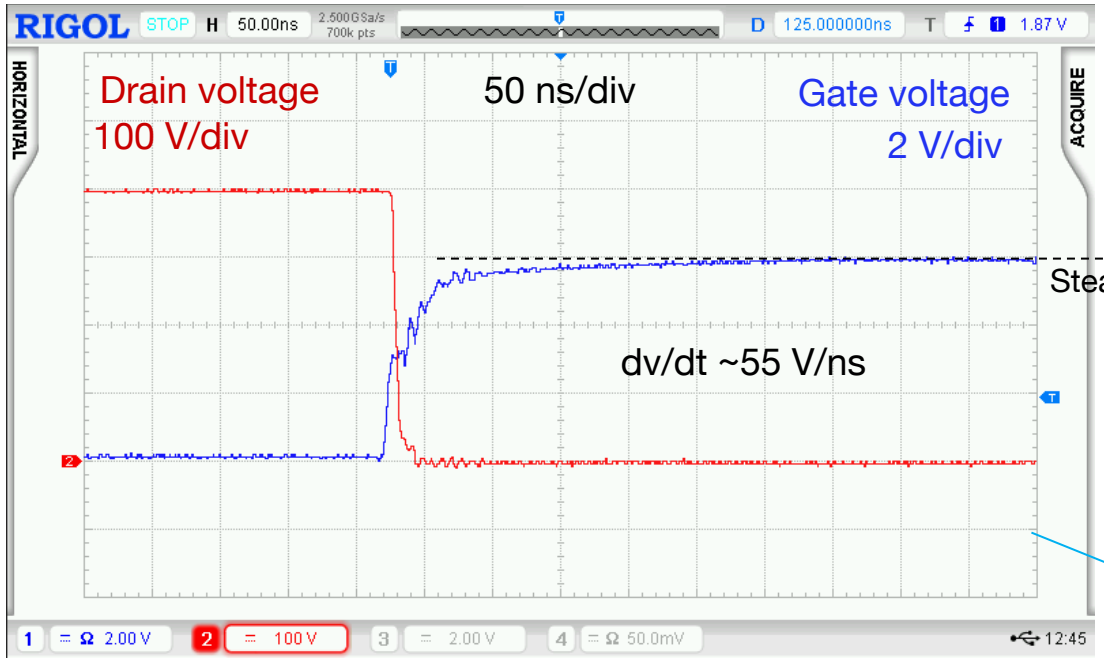
- A flexible architecture allows various user-selectable levels of V_{GS} regulation.

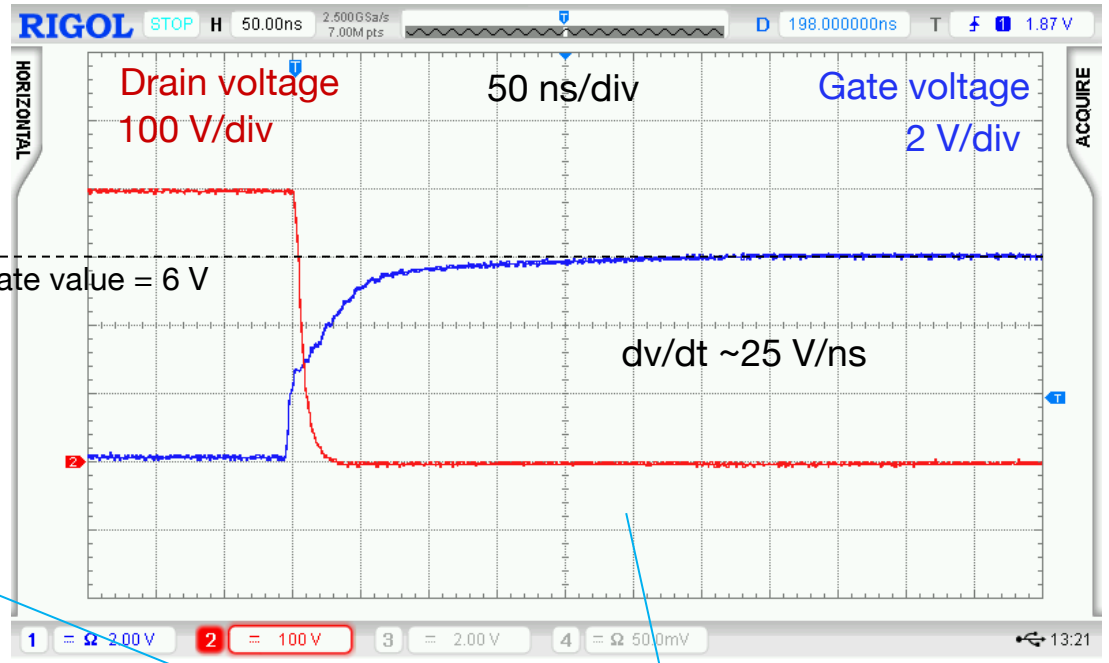


V_{GS} is precisely regulated.*

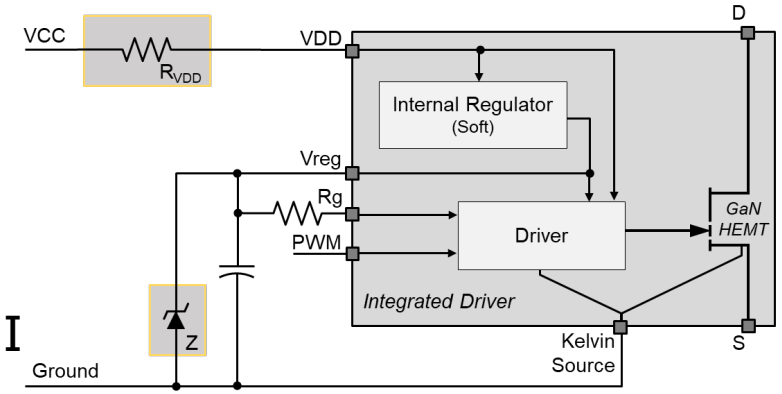
* Patent pending.

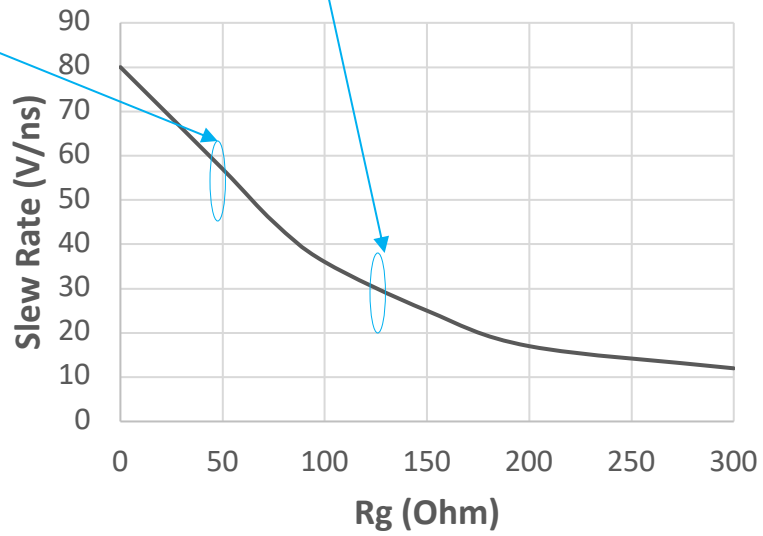
Gate Voltage Regulation and Slew rate performance





- Gate voltage control to desired level
- Ringing free clean gate voltage
- Slew rate control through external Rg resistor for EMI mitigation

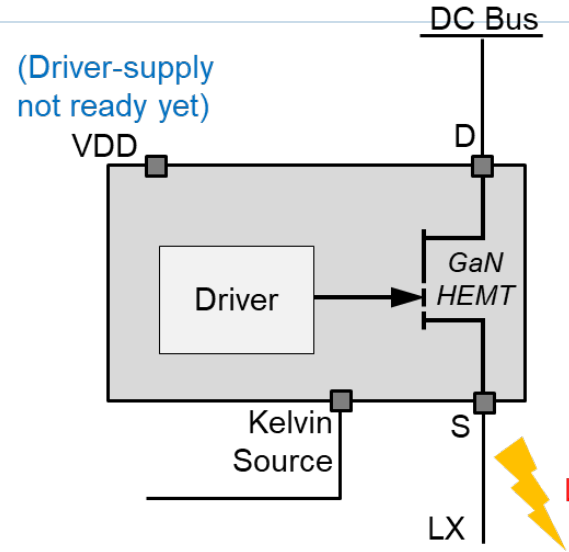




Bias-less dv/dt Protection Requirement

High-Side:

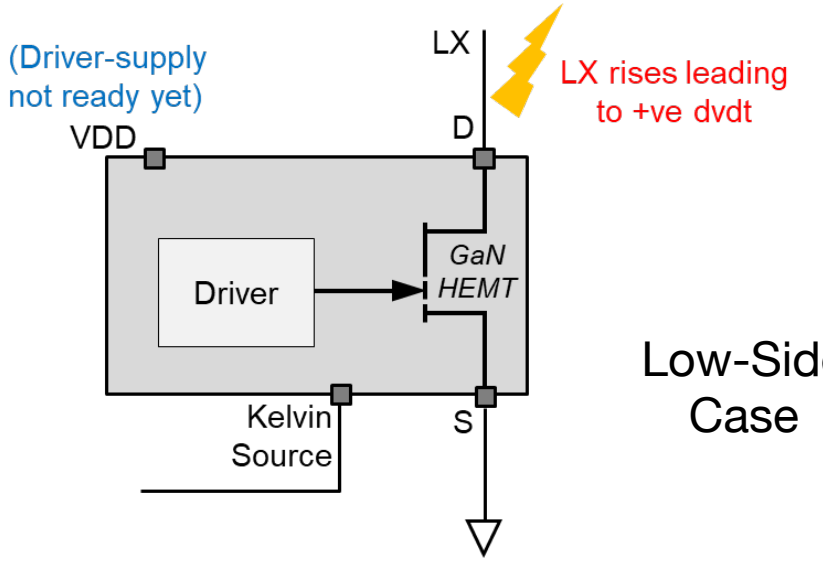
- HS driver-supply (bootstrap) builds up when LS switch turns on.
- At this point, HS experiences +ve dv/dt.
- A (usual) driver cannot help as bias-supply is not ready yet.



High-Side Case

Low-Side:

- If driver-supply is sequenced to rise after DC bus is already up, then LS might experience substantial dv/dt while the corresponding driver is bias-less.



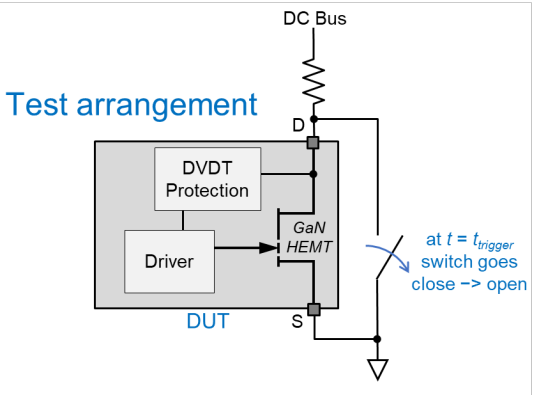
Low-Side Case

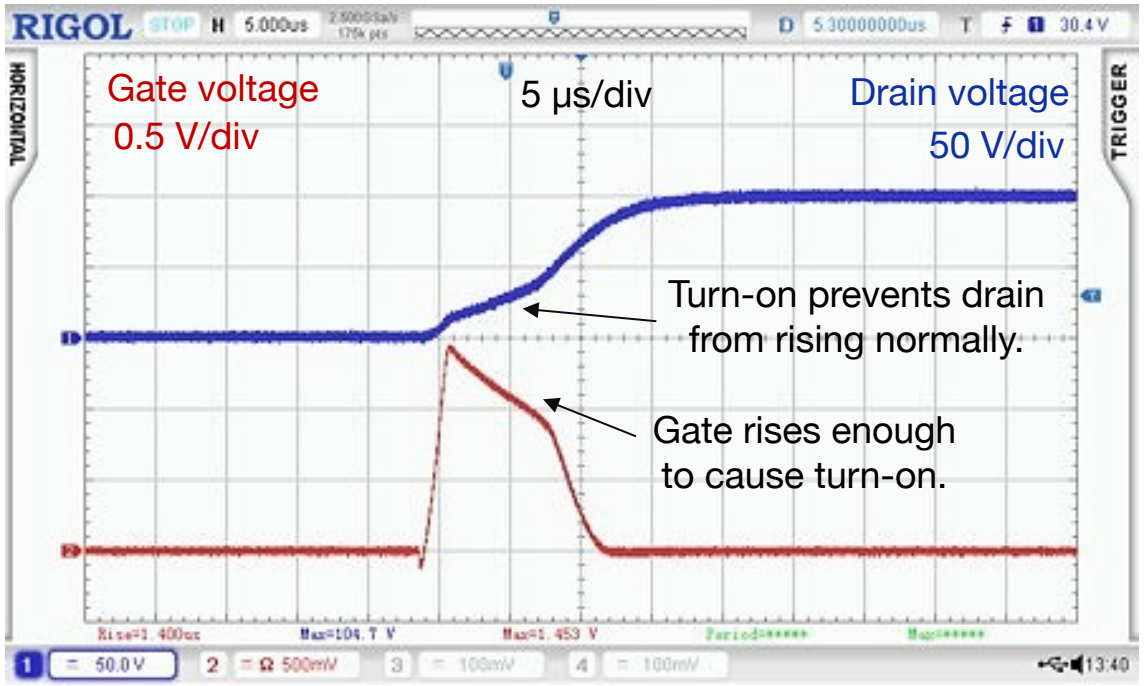
In both cases,

A low V_t of GaN HEMT combined with its high Miller-ratio means a high propensity for false turn-on while driver is not there to help.

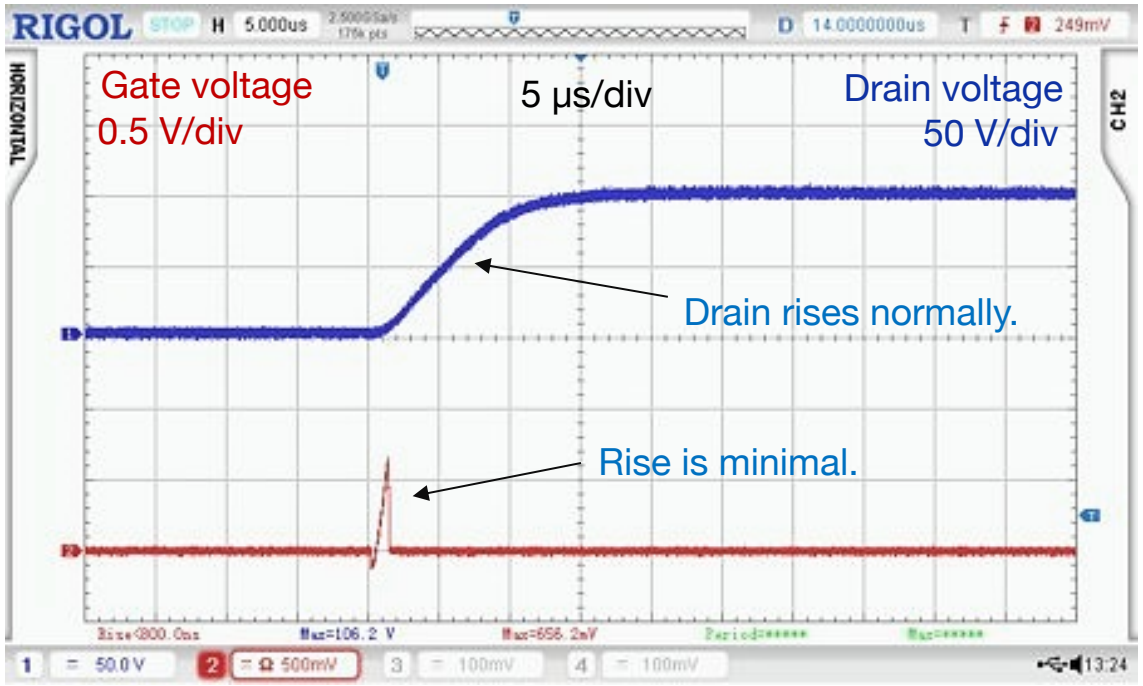
Bias-less DVDT Protection in Operation

Bias-less DVDT-protection-circuit* prevents false turn-on.





Without Bias-less DVDT-Protection-Circuit

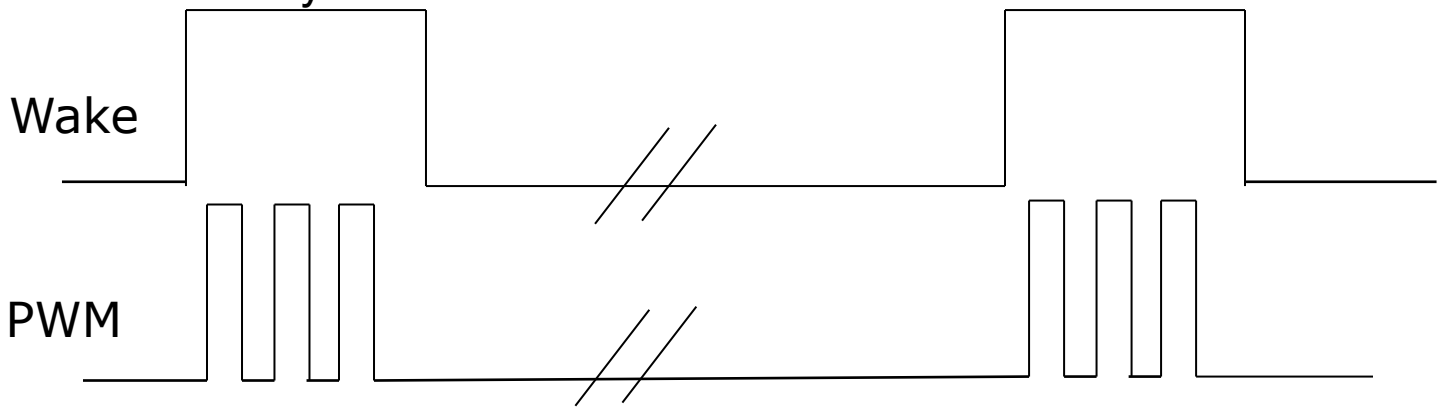


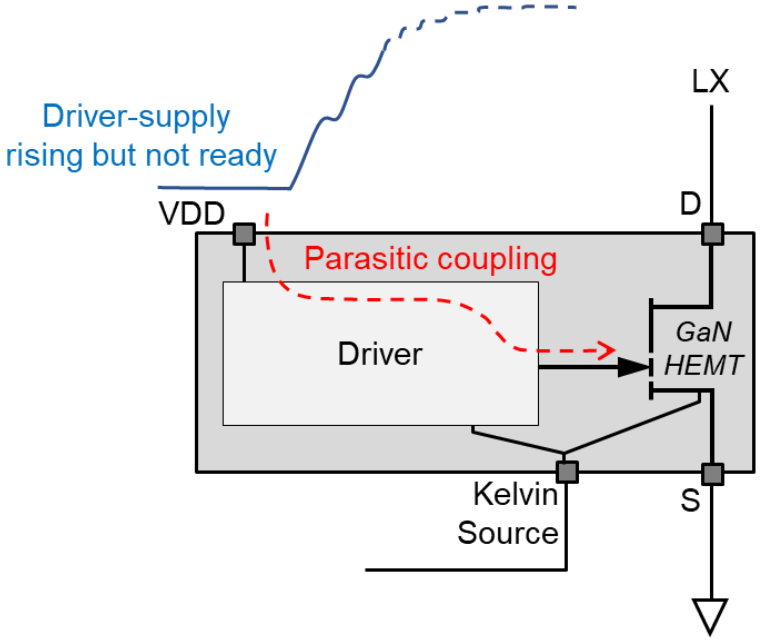
With Bias-less DVDT-Protection-Circuit*

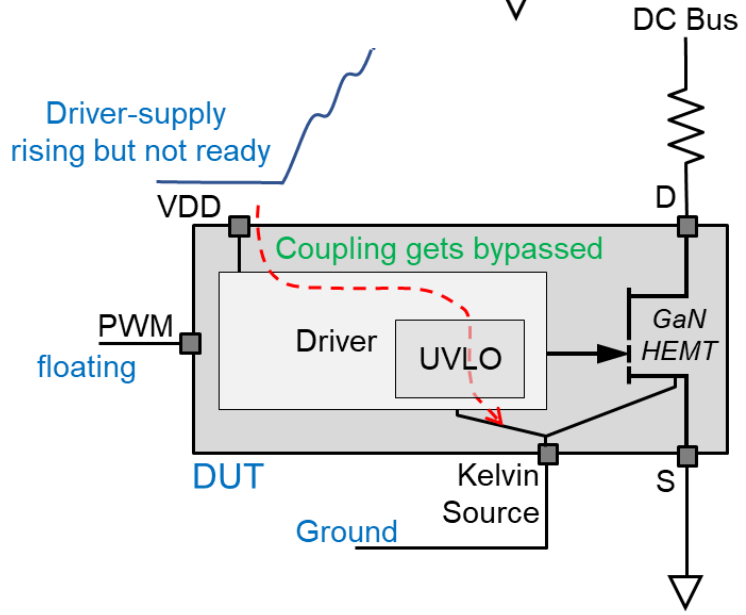
* Patent pending

UVLO function

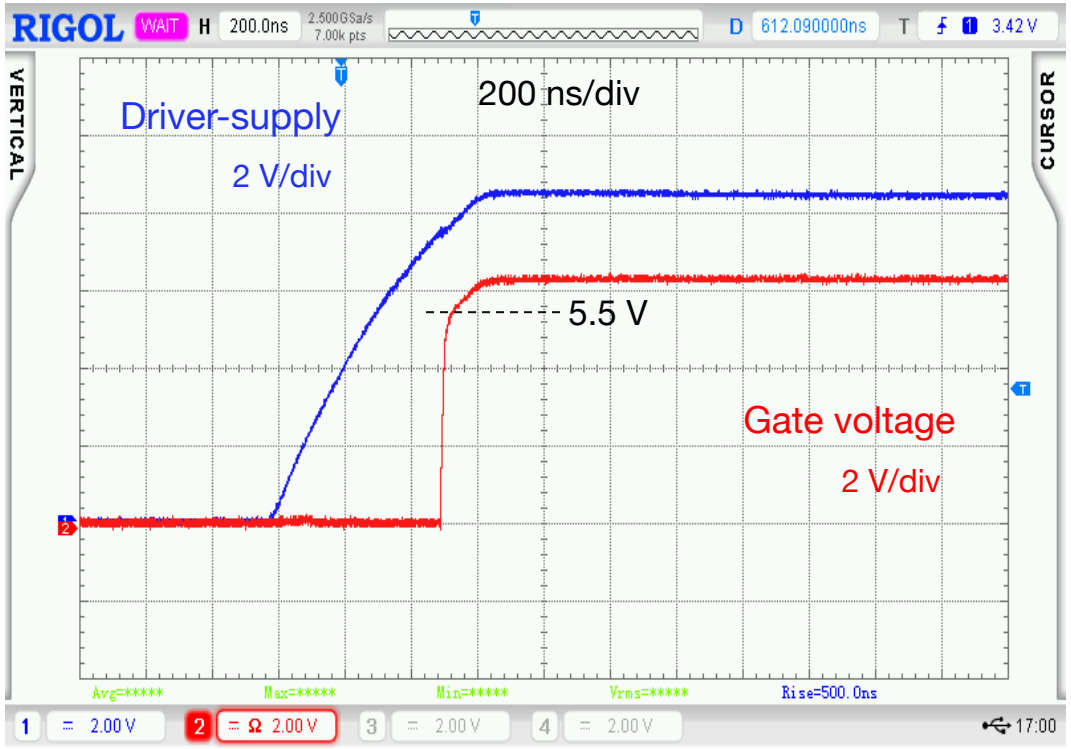
- High-frequency converters present many new challenges
- Push to improve no load efficiency present additional challenges
- High supply-ramp-rate
  - HS bootstrap charging in ACF
  - LS in ACF where driver supply is power cycled
- Require UVLO with fast response time
  - With UVLO, a driver becomes operational, offering reliable control of HEMT's gate, only when driver's supply is ready.





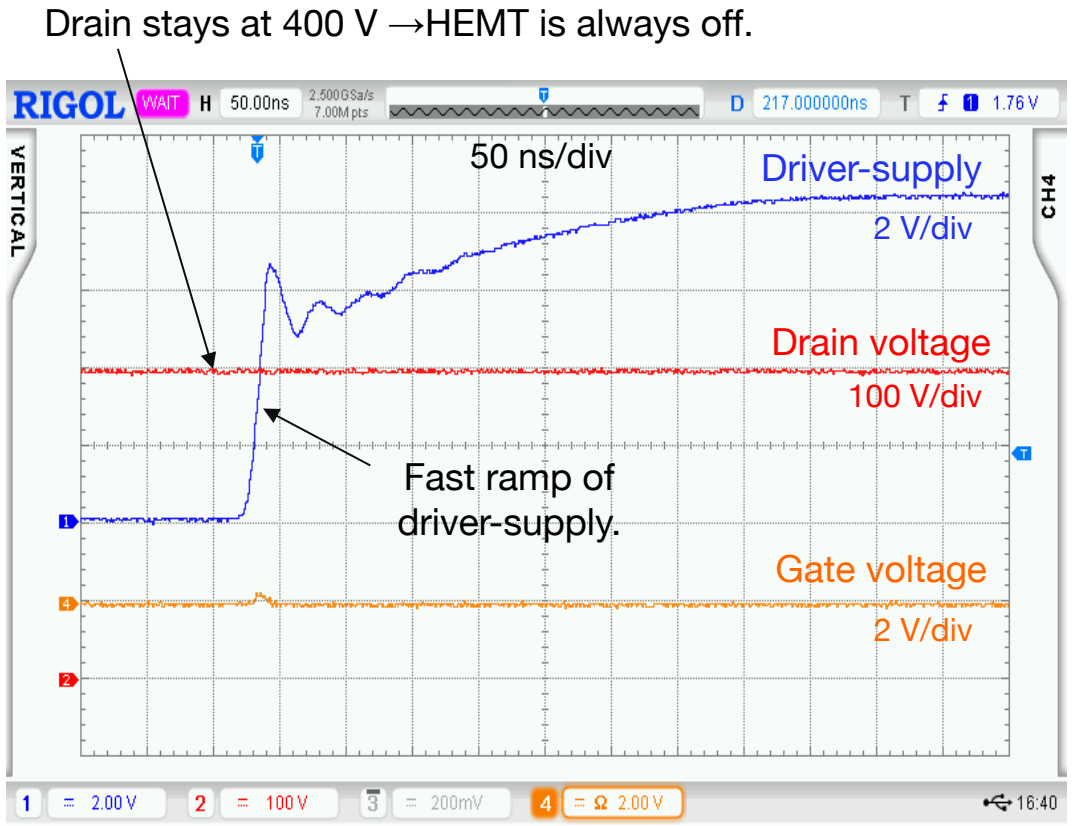


UVLO circuit performance



UVLO allowing operation only when driver-supply becomes sufficient.

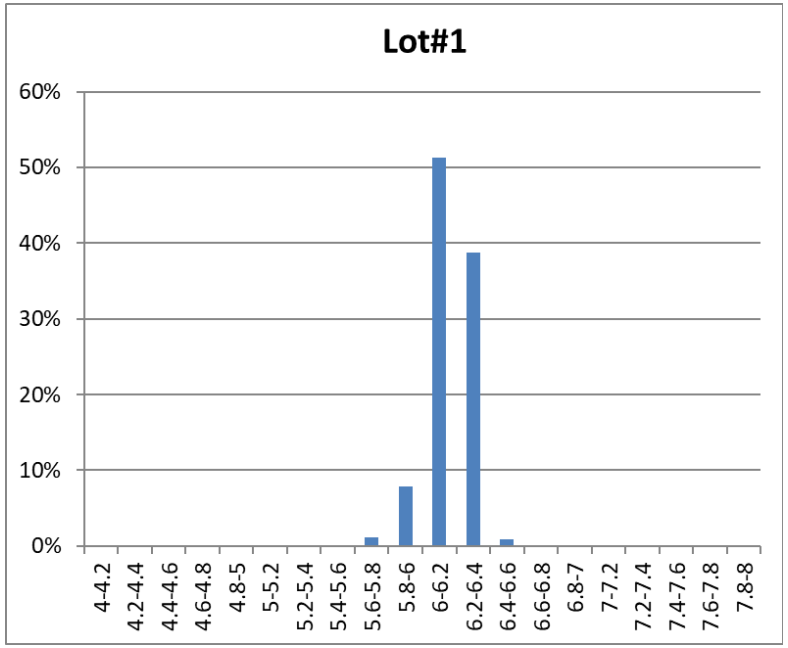
PWM is always high.

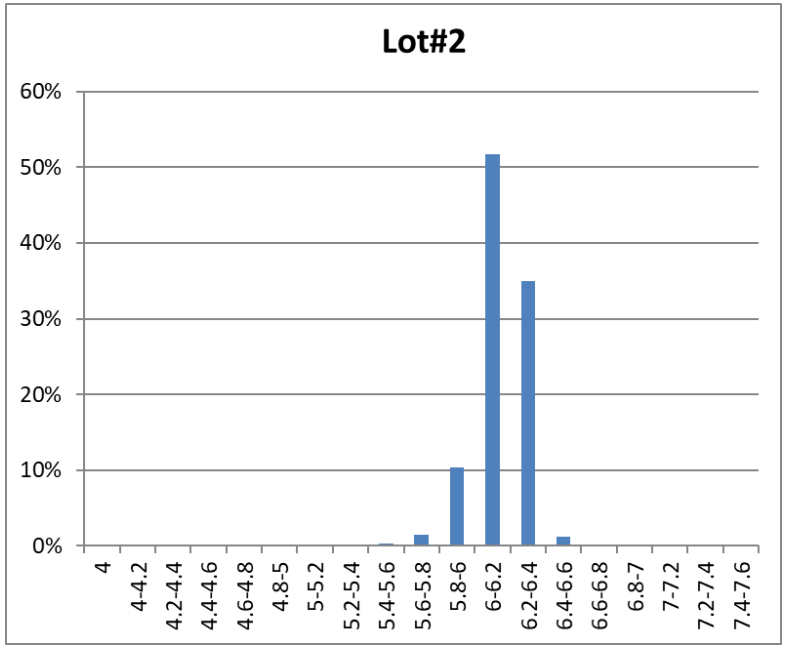


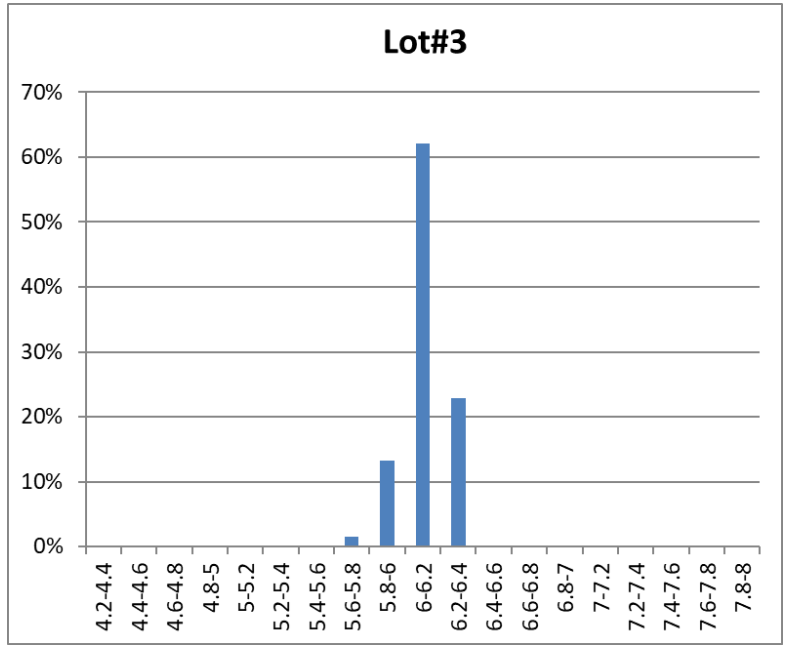
UVLO providing the protection at driver-supply ramping.

PWM is floating.

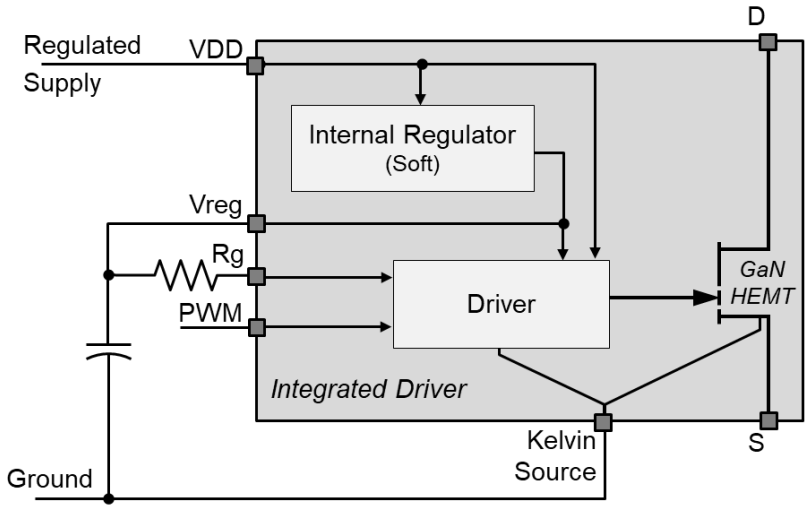
Production data - Vreg Voltage







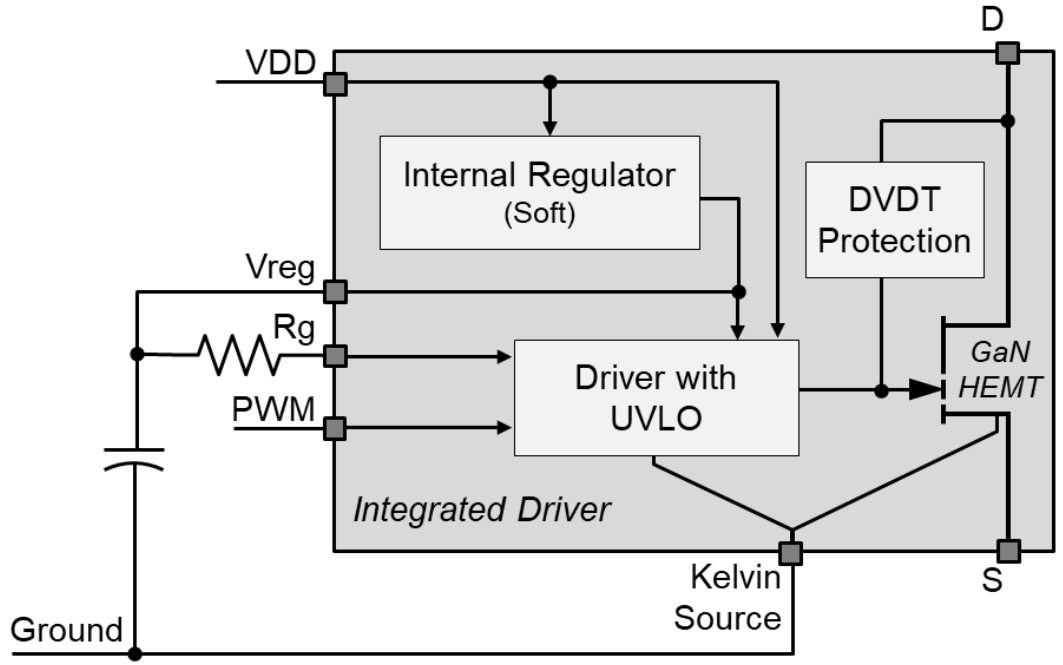
- Good tight distribution of Vreg voltage
- Data illustrate feasibility of monolithic integration of essential protection circuits



Summary

Monolithically-integrated IC demonstrated with

- Configurable driver-supply as per controller type
- Better control of gate voltage while maintaining on-state gate voltage within SOA limit
- Protection against dv/dt induced turn-on even under no driver-supply
- UVLO ensures that FET turns on only when supply is sufficiently high



Easy GaN adoption for efficient and reliable operation leading to ever higher power density!

Thank you for your interest!

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Tagore Technology Inc.

Integration in WBG Semiconductors: Increased Power Density and Advanced Functionalities at Application Level (Session IS07)