Navitas

Let's go GaNFast™

GaNFast™ Power IC Modeling

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CPSSC, Nov 2019

Agenda

- Introduction
- Spectre models for IC Design
- SPICE models for detailed system simulation
- SIMPLIS models for high level system simulation
- System simulation example: Active Clamp Flyback
- Conclusions

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Navitas eMode Power FET Technology

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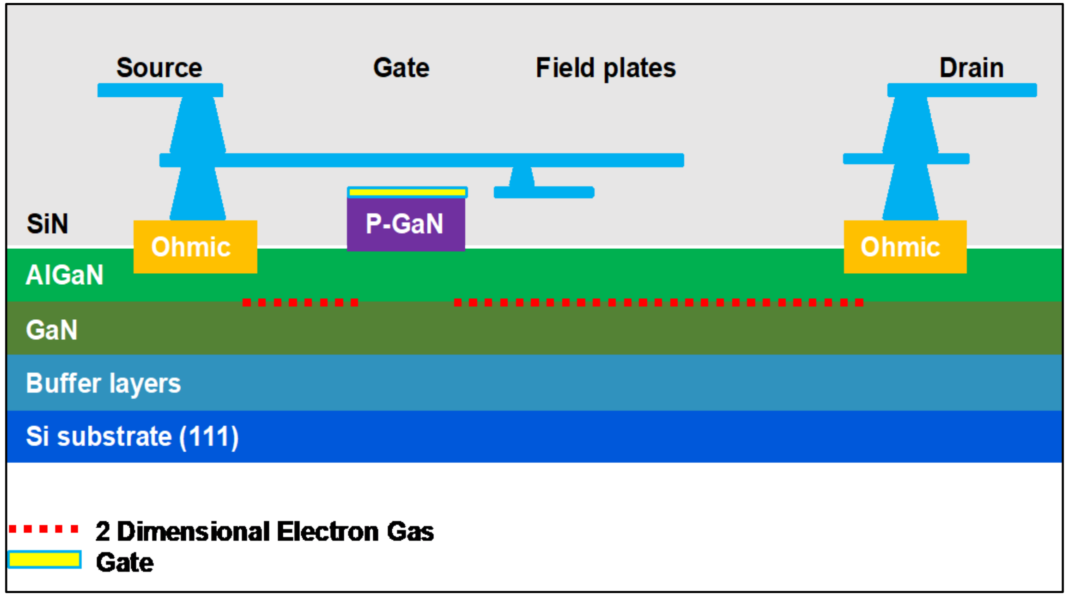
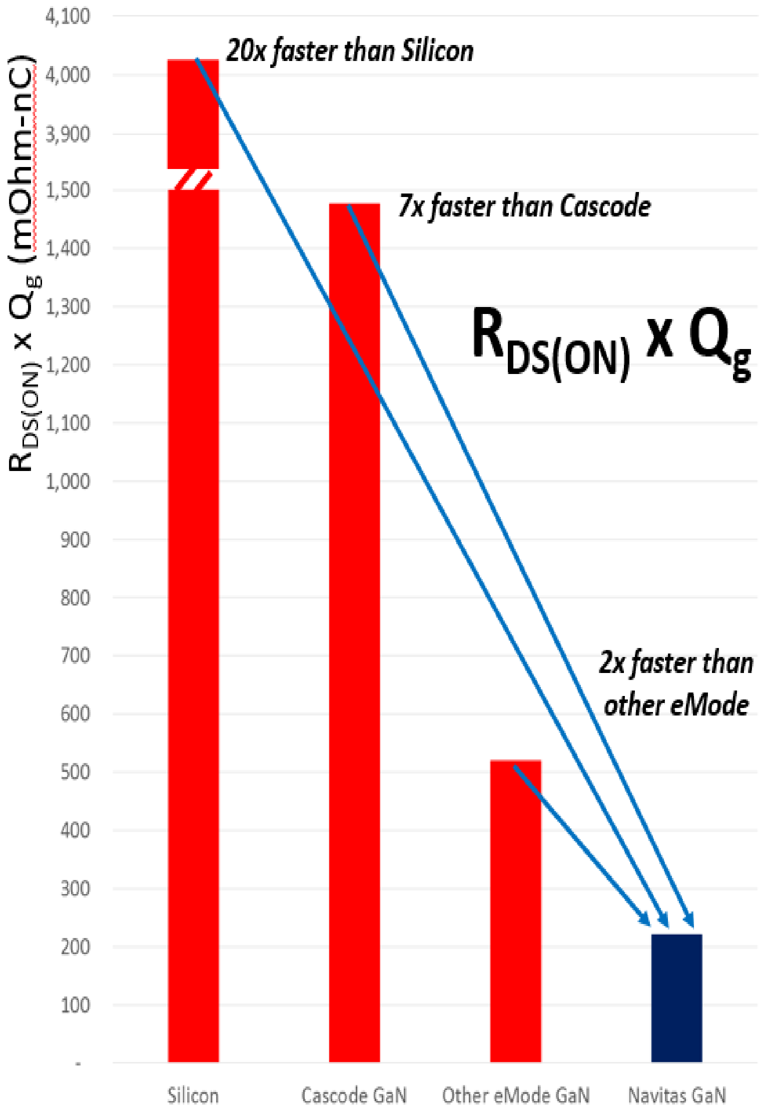
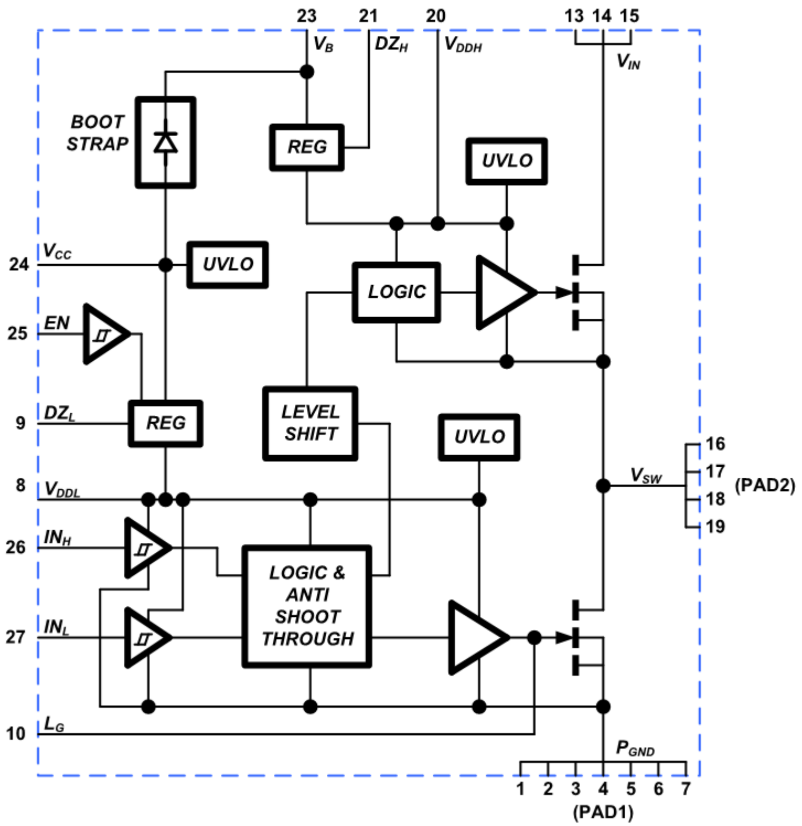




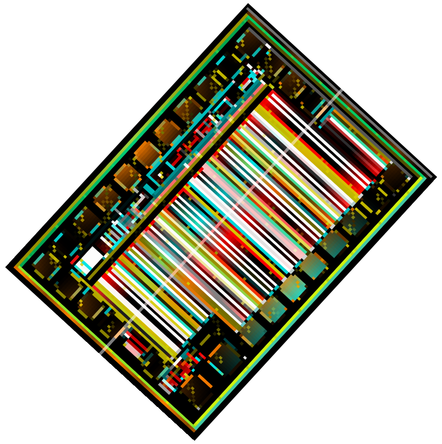
- Large RQ FOM advantage
  - High frequency, high power density
- Lateral
  - Convenient voltage isolation
  - Multi device and IC integration
- Standard CMOS production
  - High yield, high capacity, multilevel metallization
  - Ideal for power IC development

650 V Monolithic GaN Integration



World's First

GaN Power ICs



- Complicated power IC development requires capable process and IC design environment
  - PDK (Process Design Kit) is essential to reliability and manufacturability of IC products
  - Process corners, mismatch, temperature effect, layout parasitic, and design verification
- Accurate device modeling is essential part of PDK
  - Multi tiered models are developed for accurate and fast system simulation

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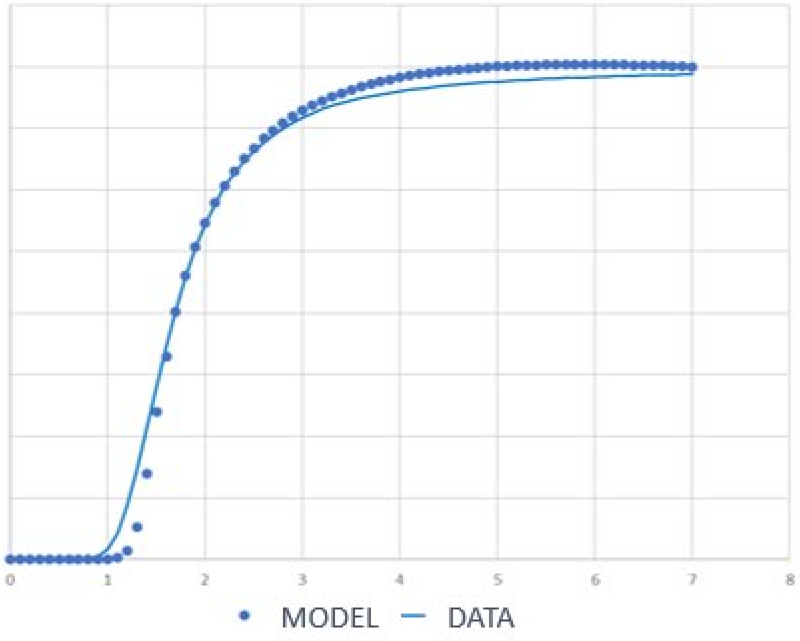
Power IC Spectre Models: IC Development

- Excellent process design kit:
  - Device symbols
  - Pcells for automated device construction
  - Scalable, accurate
  - Verified for schematic and layout rules
  - Layout parasitic extraction
- Angelov, ASM and silicon models are <u>not</u> suitable
  - Lack of dMode, scalability, flexibility, speed
- Navitas GaN eMode FET scalable VerilogA model
  - Flexible: customized features/equations
  - High correlation between simulation and product
  - High-speed simulations

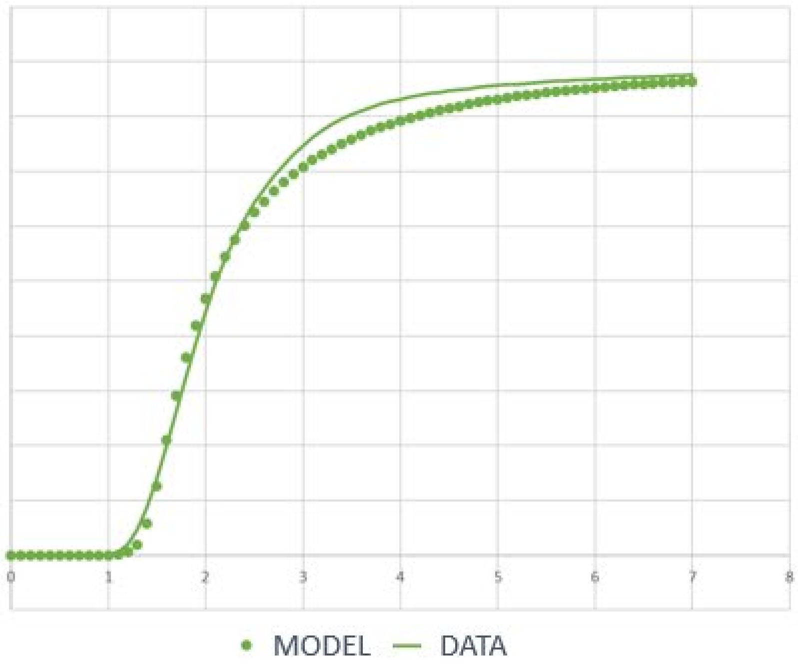
Accurate over Temperature

- GaN FET $I_D V_G$ Model with Temperature Effects
  - Solid lines = measured, dotted lines = Cadence simulation

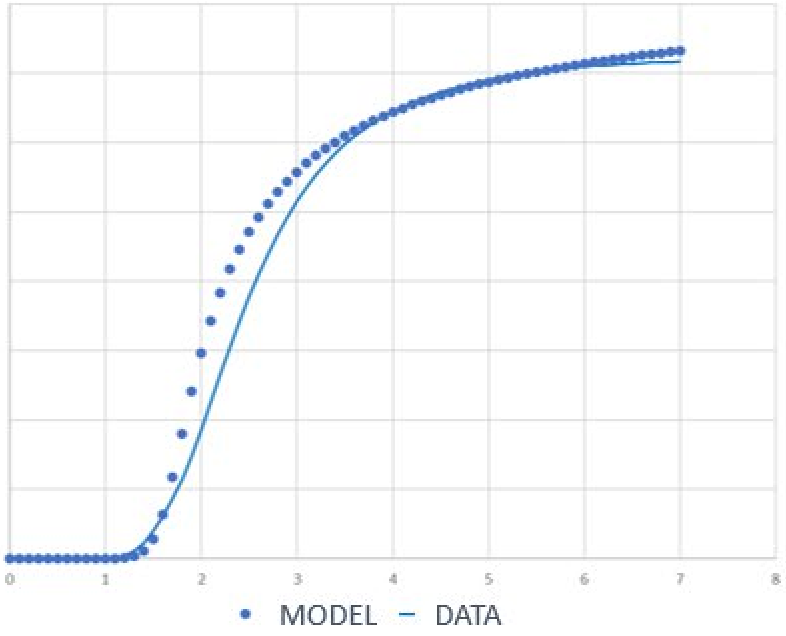
IDLIN/VG -40C



IDLIN/VG 25C



IDLIN/VG 125C



Accurate over Drain Voltage

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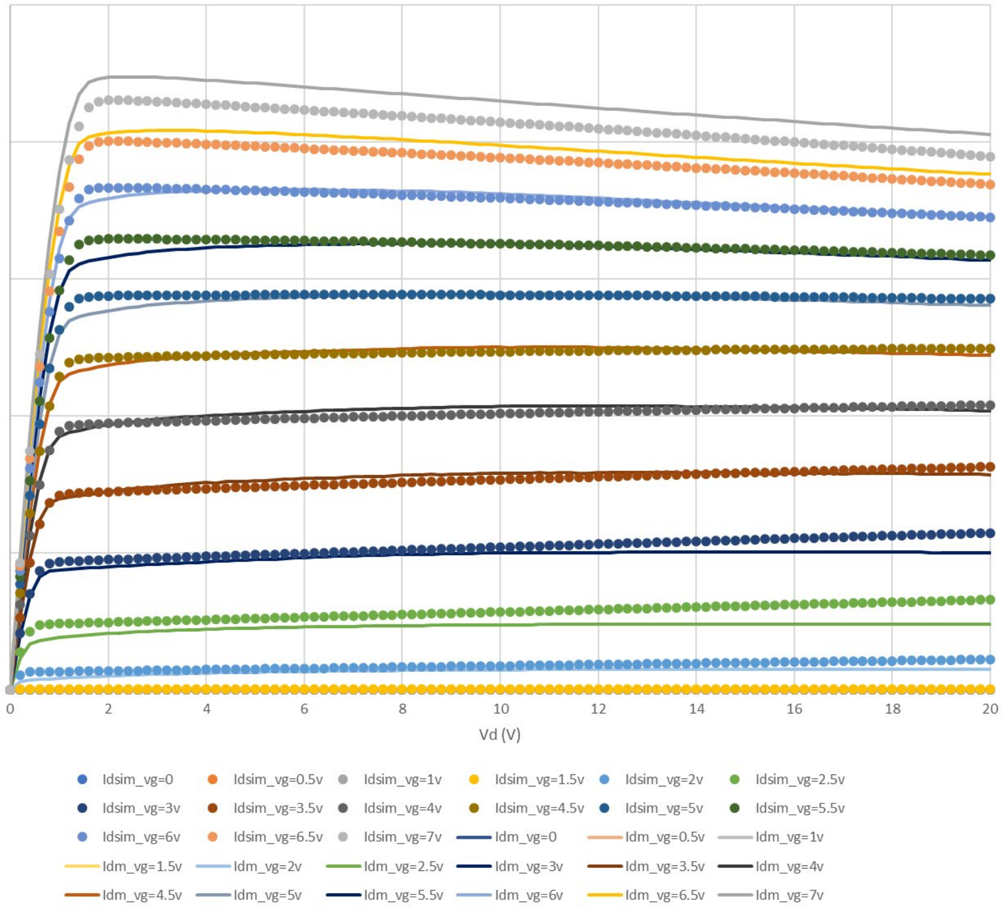
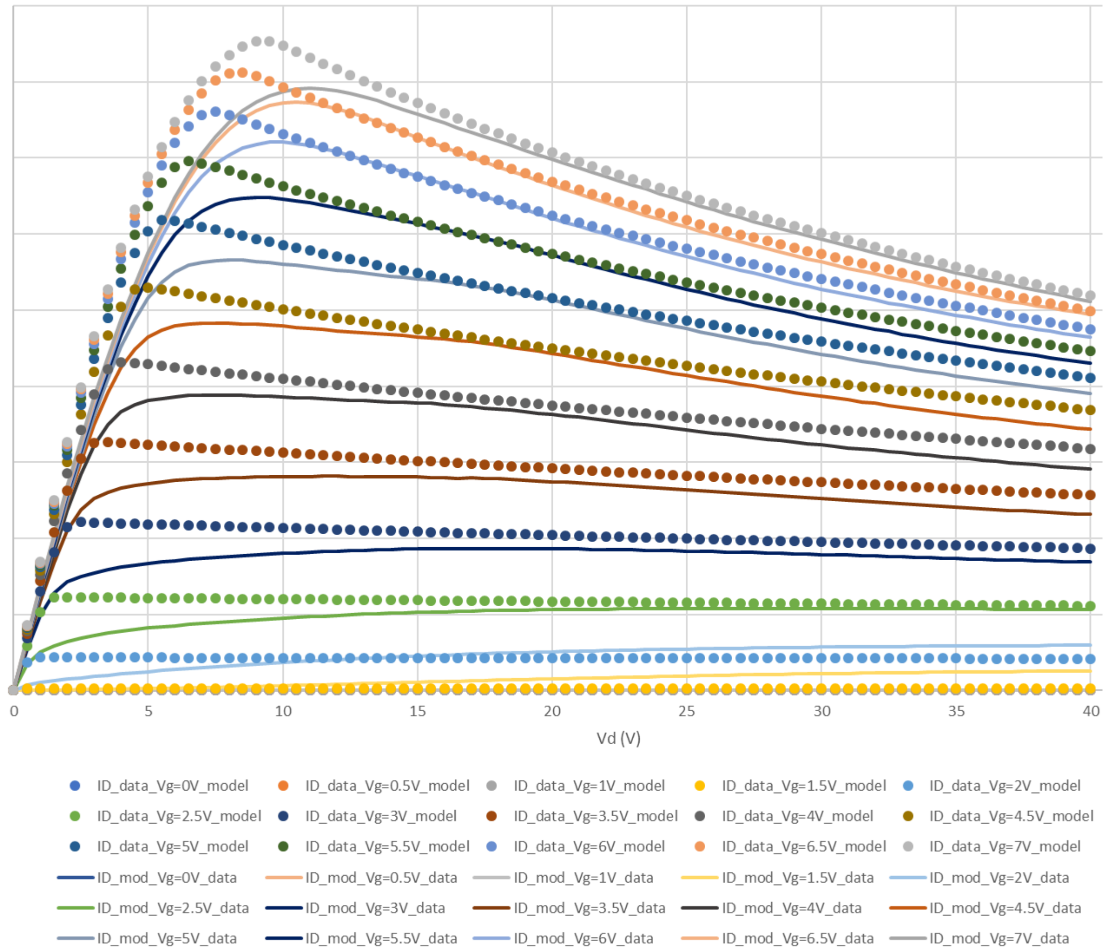
- Solid lines = measured, dotted lines = Cadence Spectre

- 20V rated eMode FET

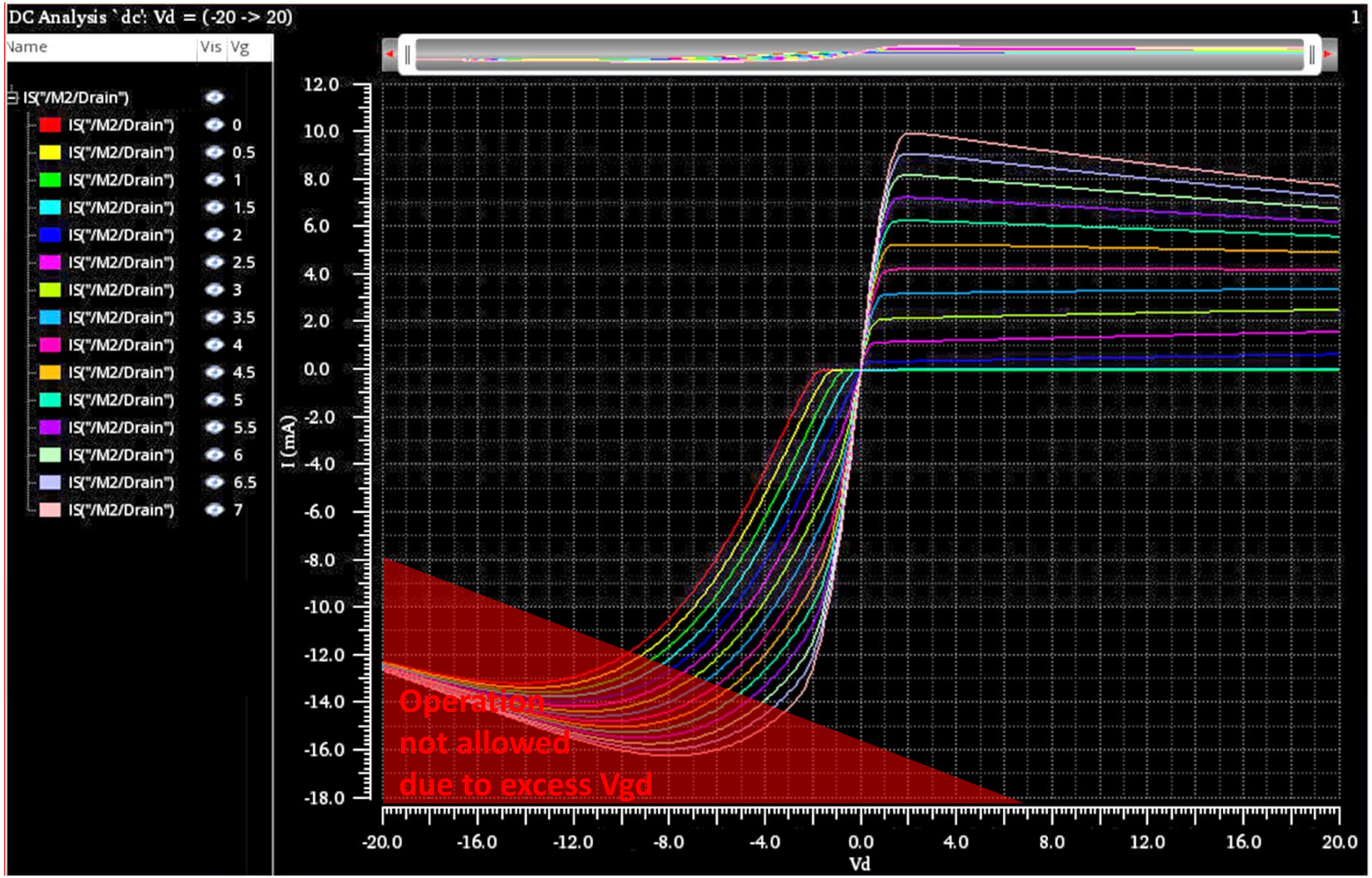
650V rated eMode FET





Bi-directional Drain Current vs. V_D , V_G

650V device model simulation with self-heating effects in Spectre



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Spice Models: Application Simulation

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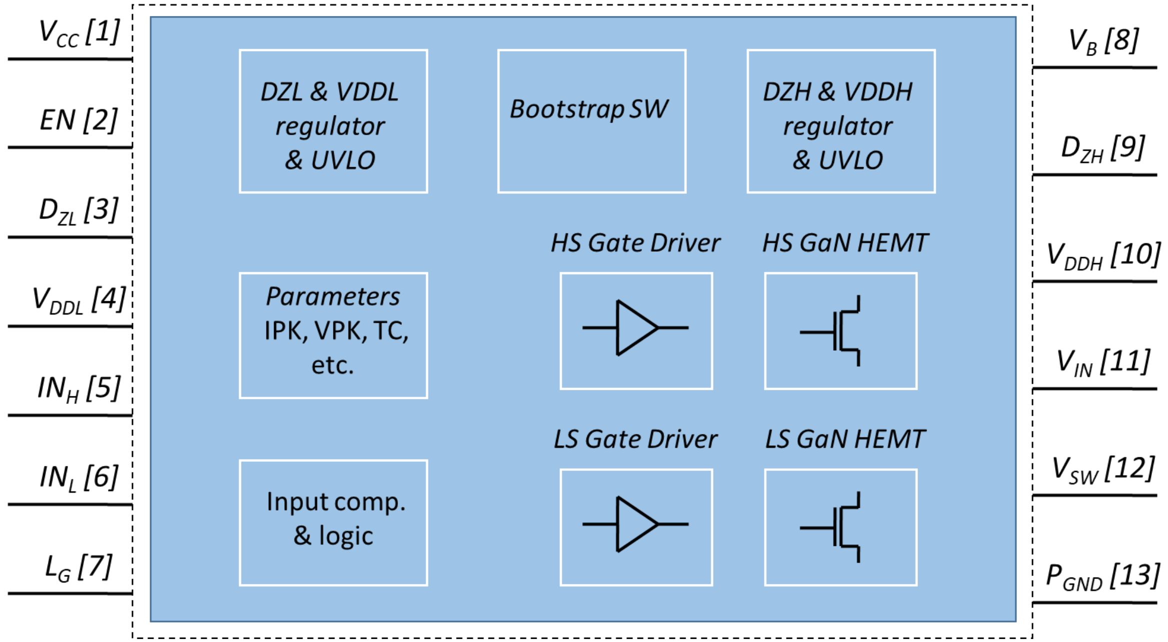
Half Bridge Functional Blocks



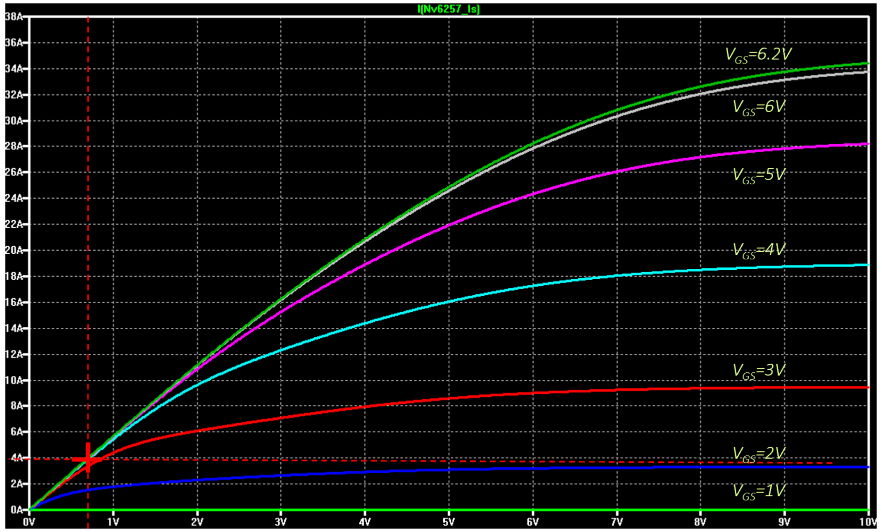
Top-Level Model Parameters

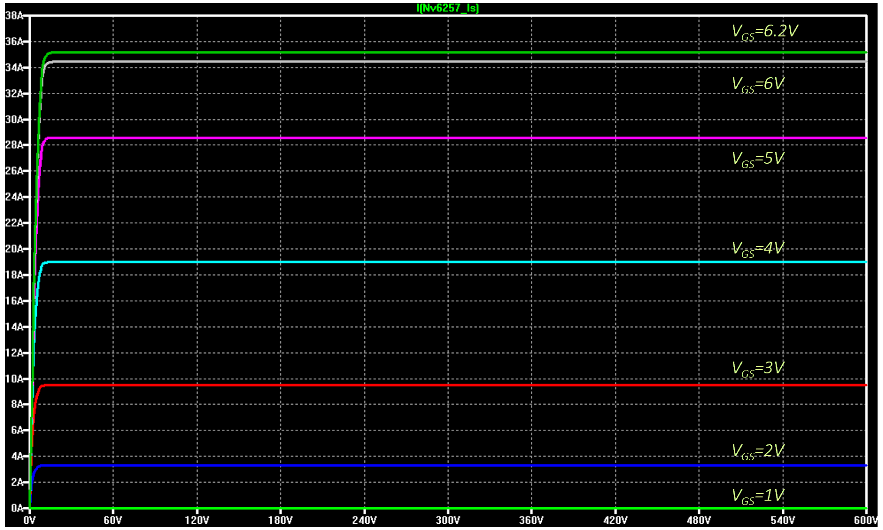
#	Parameter Name	Description	Value	Unit
1	V_{CCTH}	V_{CC} Undervoltage Lockout Threshold	9.0	V
2	V_{CCHYS}	V_{CC} Undervoltage Lockout Hysteresis	0.5	V
3	V_{LTH}	V_L Input Logic Threshold	2.5	V
4	V_{LHYS}	V_L Input Logic Hysteresis	0.5	V
5	V_{BTH}	V_B Undervoltage Lockout Threshold	9.0	V
6	V_{BHYS}	V_B Undervoltage Lockout Hysteresis	0.5	V

- Each Navitas power IC product will be released to public with a Spice model
  - It captures all functionalities and behaviors
- Spice models combines Angelov and behavioral techniques
  - Fast and accurate
  - Ideal for detailed in-circuit waveform and power loss study

650V GaN eMode FET Output Curves

I_D 38A





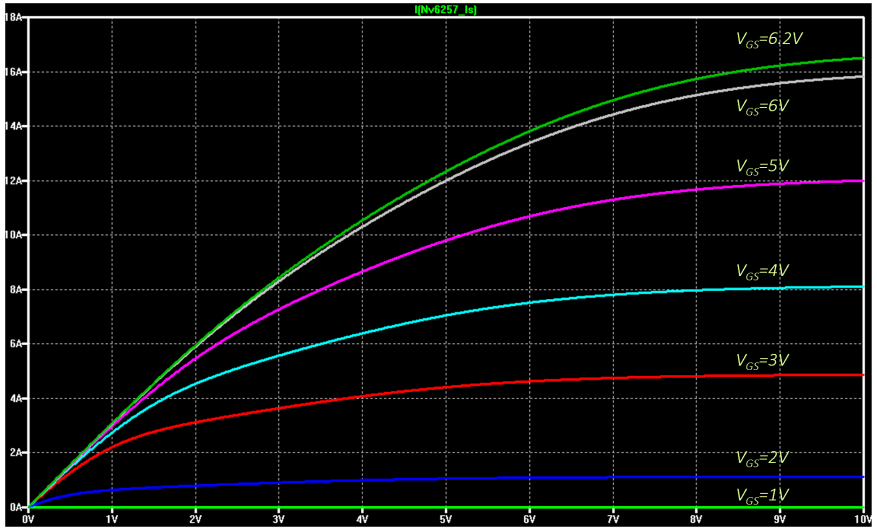
25C

Datasheet: I_D=4A@ V_{DS}=720mV

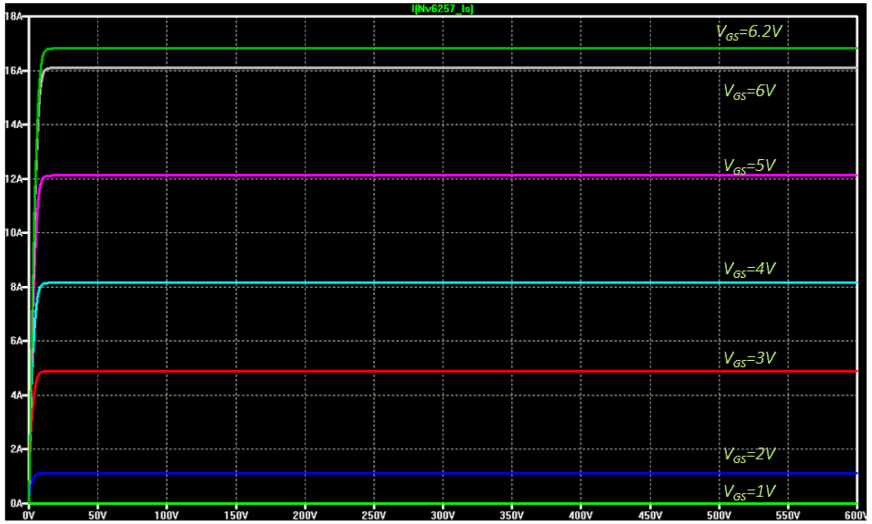
V_{DS} 10V

V_{DS} 600V

I_D 18A



150C



Reverse Conduction Characteristics

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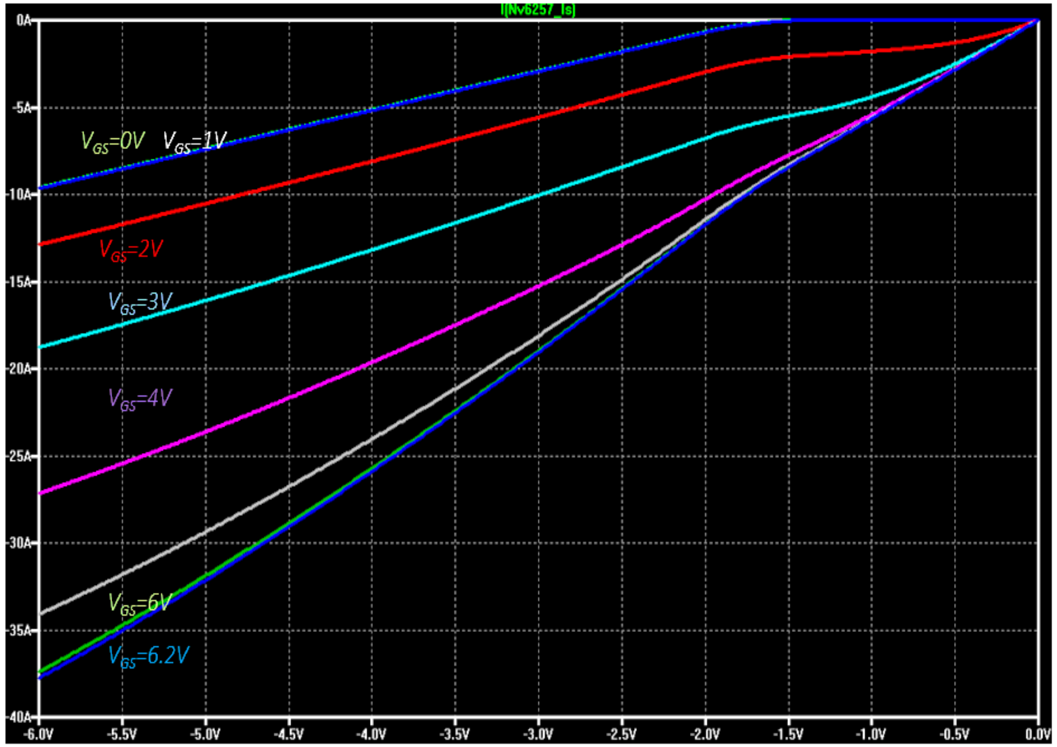
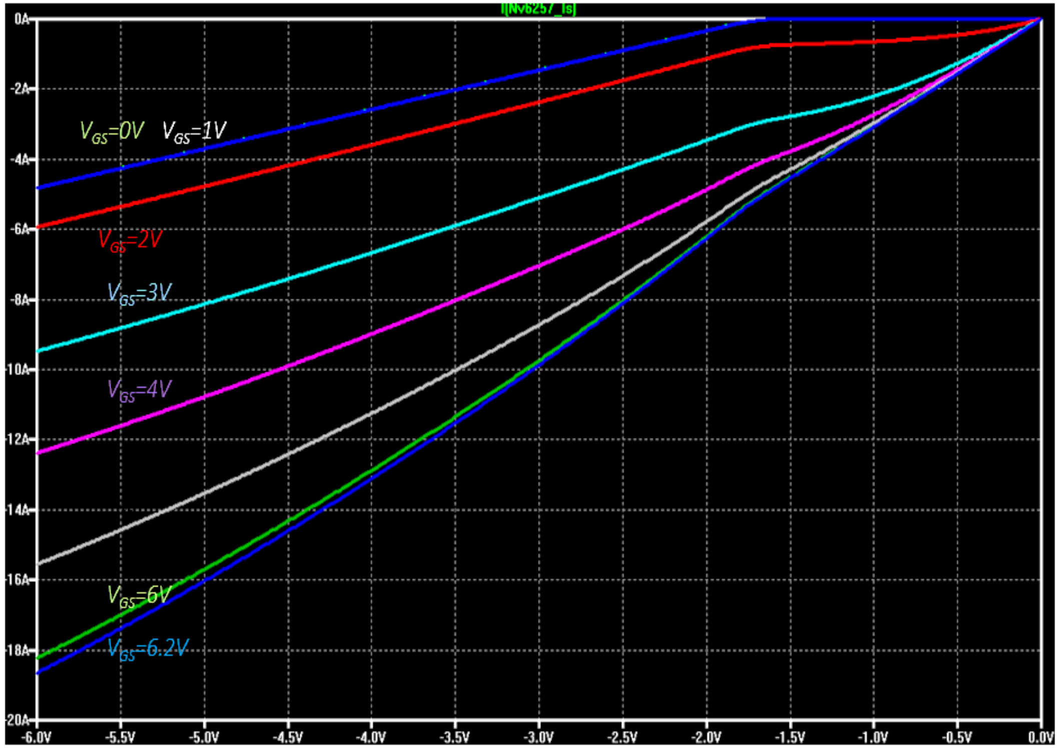
25C



I_D -40A

V_{DS} -6V

150C



I_D -20A

V_{DS} -6V

- Third quadrant I-V curves at 25C and 150C under gate bias
- Synchronous drive reduces reverse conduction loss

Output Capacitance and Charge Simulation

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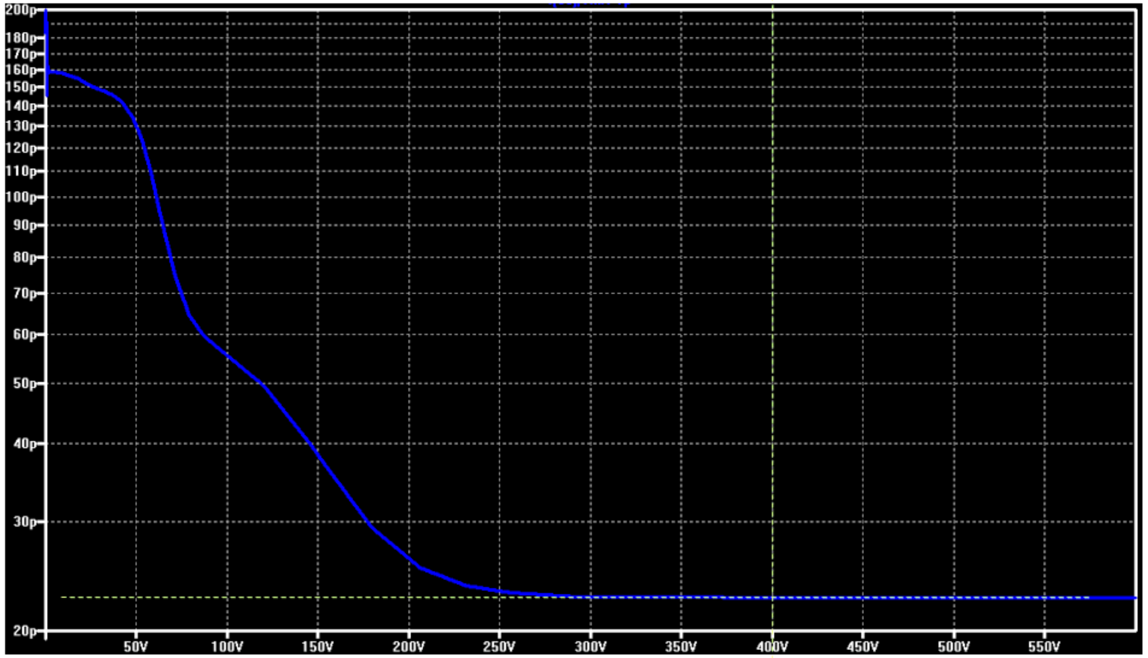
Capacitance

Coss 200pF full scale



VDS 600V

Model:

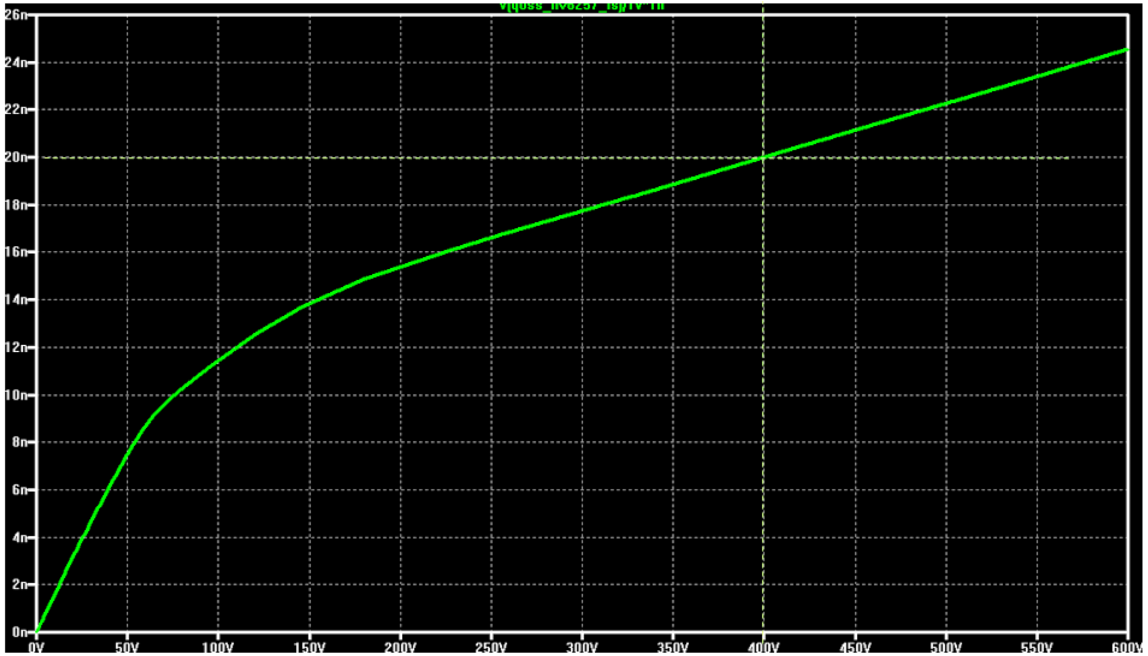
22pF @ 400V

Datasheet:

22pF @ 400V

Output Charge

Qoss 26nC full scale



VDS 600V

Model:

20.0nC @ 400V

Datasheet:

20nC @ 400V

- Model matches the measurement in datasheet

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Simplis Models: Ultra Fast System Sim

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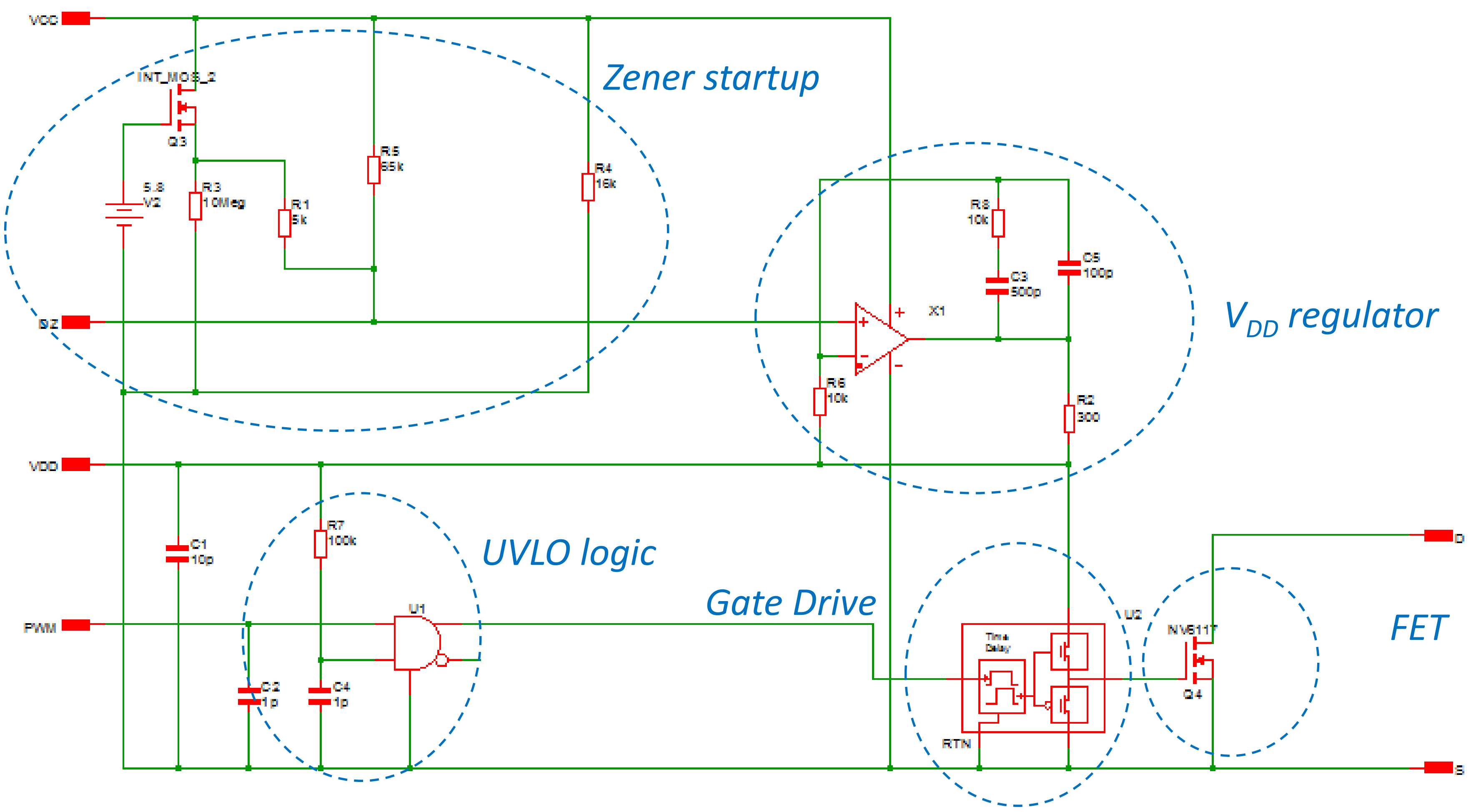
Optimized for system simulation run time

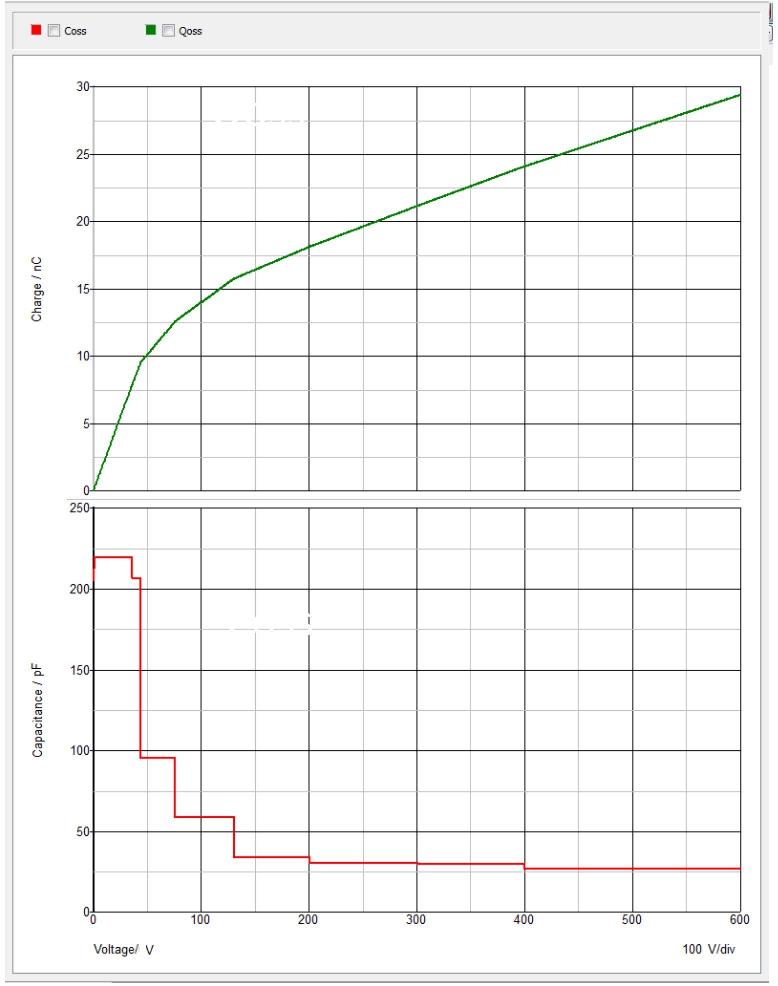


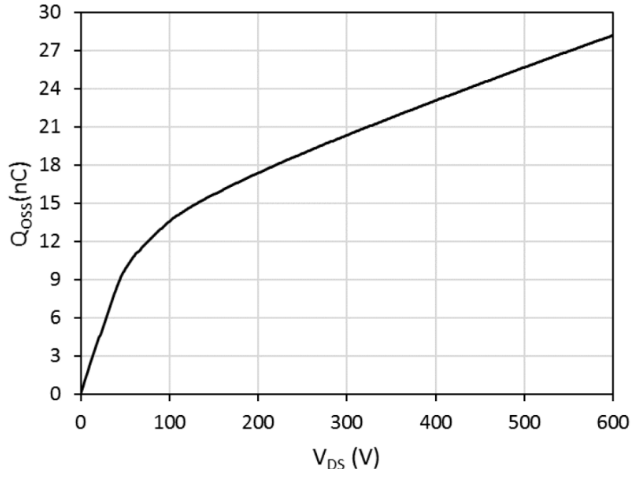
Piece-wise Linear Model

Simulation

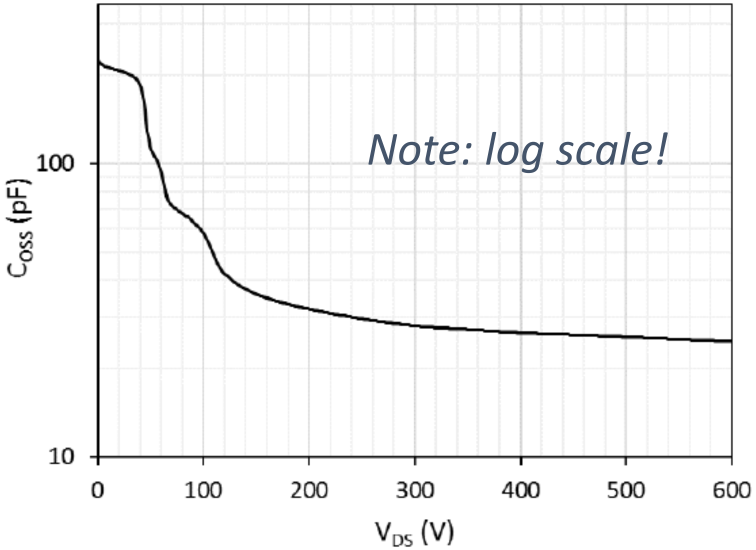
Measured

QOSS





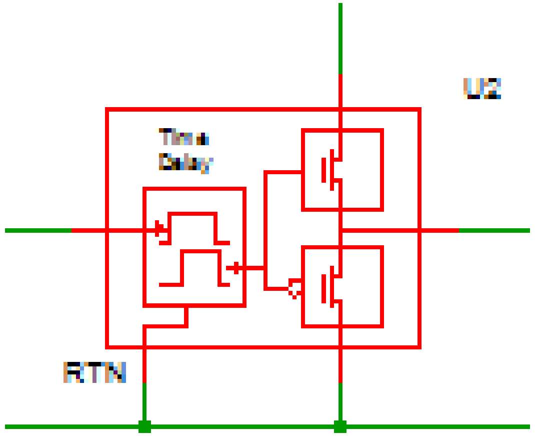
COSS

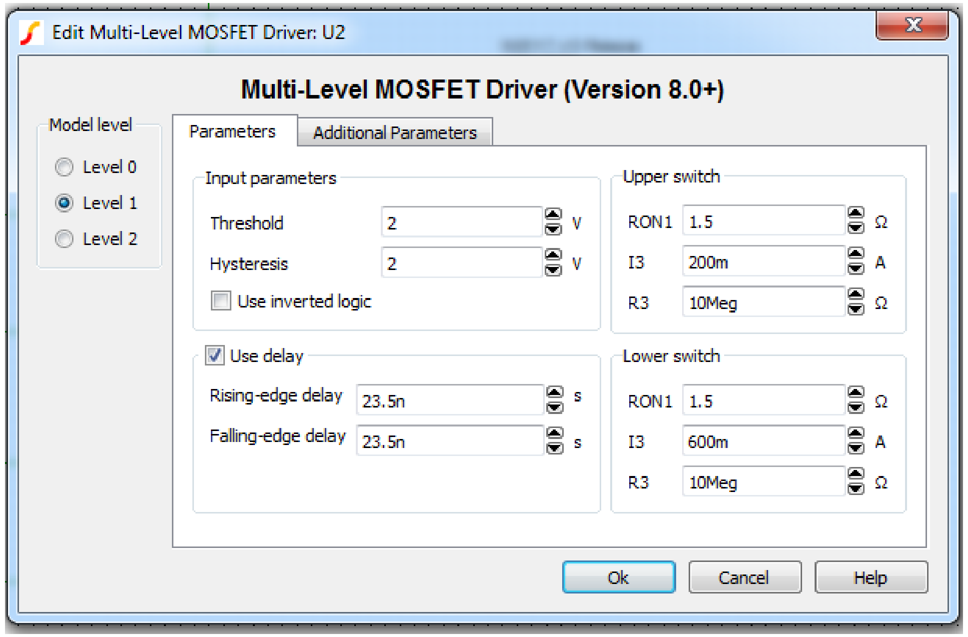


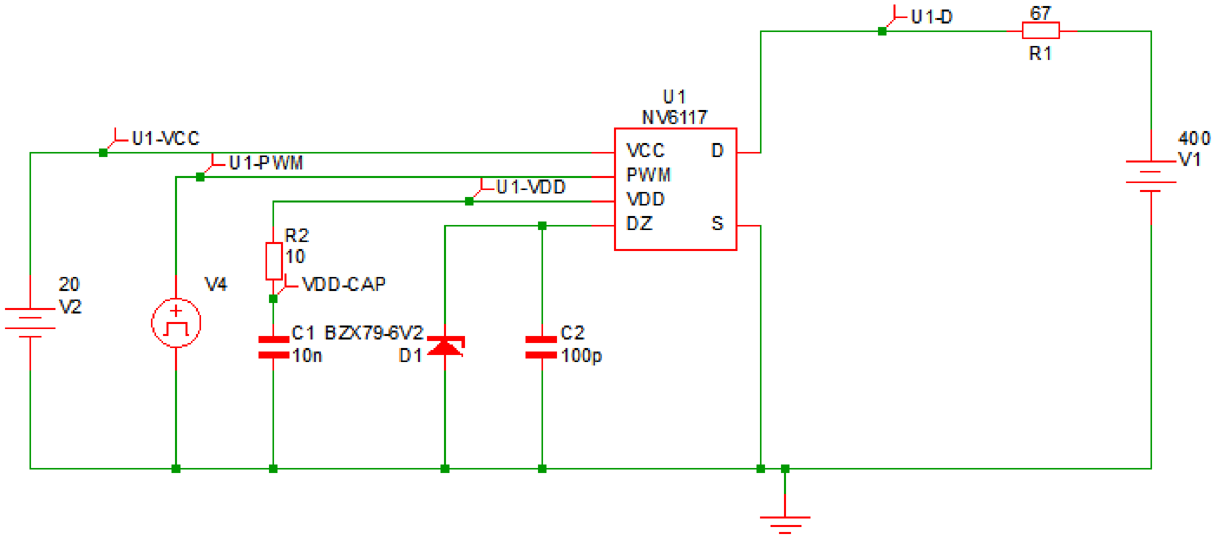
- Nonlinear parameters are largely preserved: speed without loss of accuracy

Simplified Gate Driver

- Gate driver replaced by “Level 1” SIMPLIS native high-level gate driver block
- Driver parameters adjusted to meet timing of T_r, T_f







Low-side test circuit

Simulated Switching Waveforms

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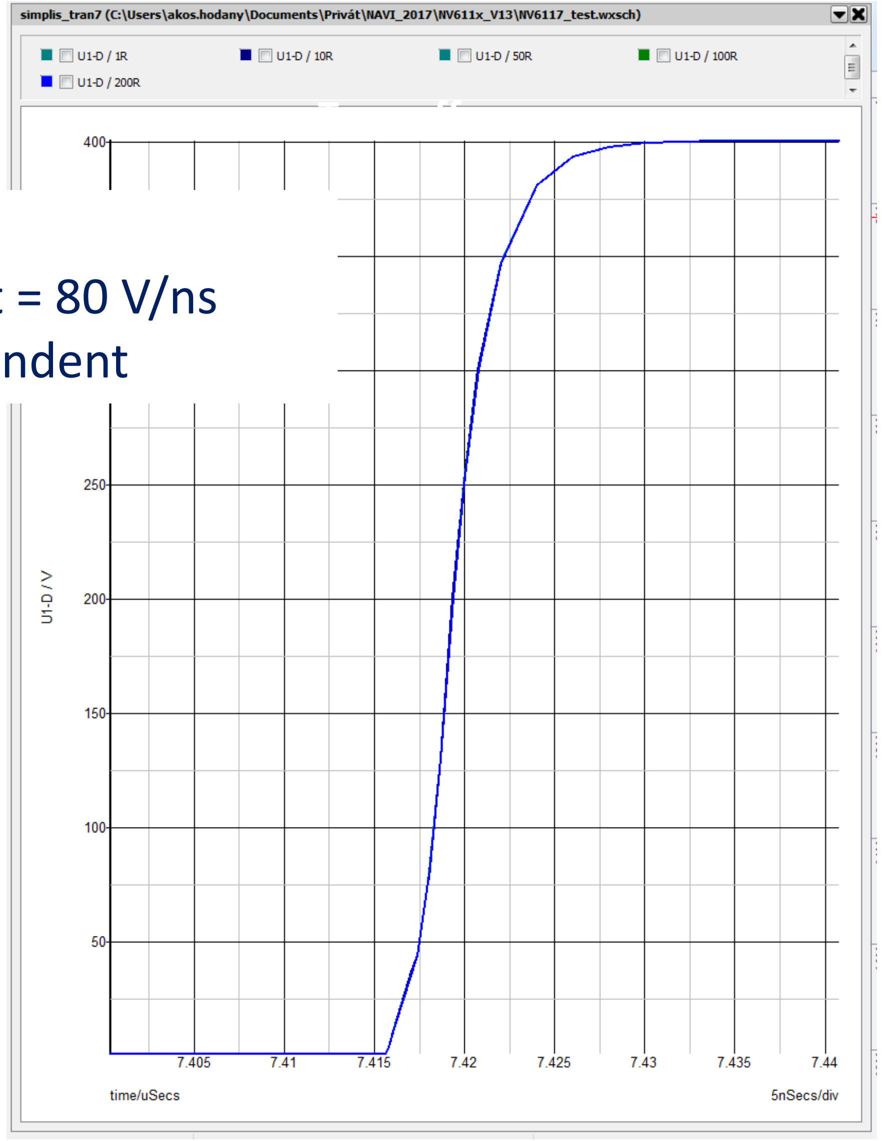
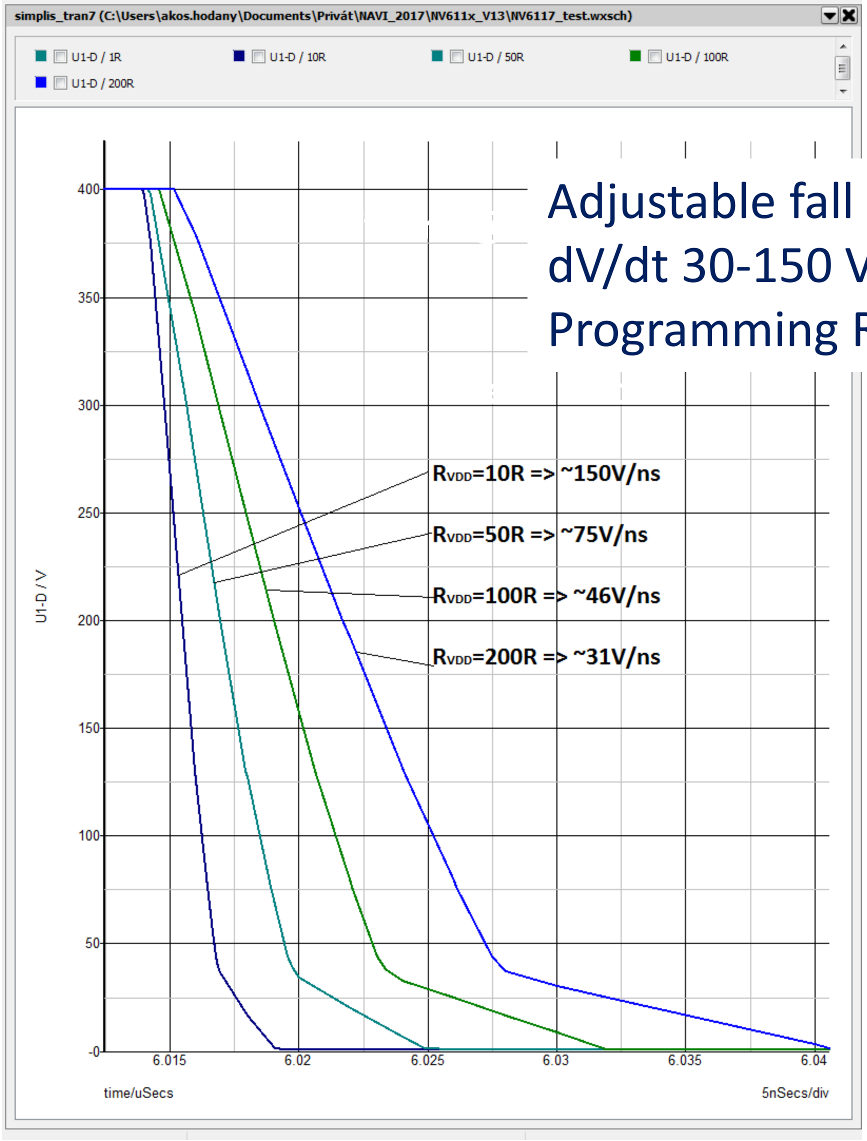
6ns V_{DS} t_r
Max dV/dt = 80 V/ns
Load dependent





Adjustable fall time
dV/dt 30-150 V/ns
Programming R dependent

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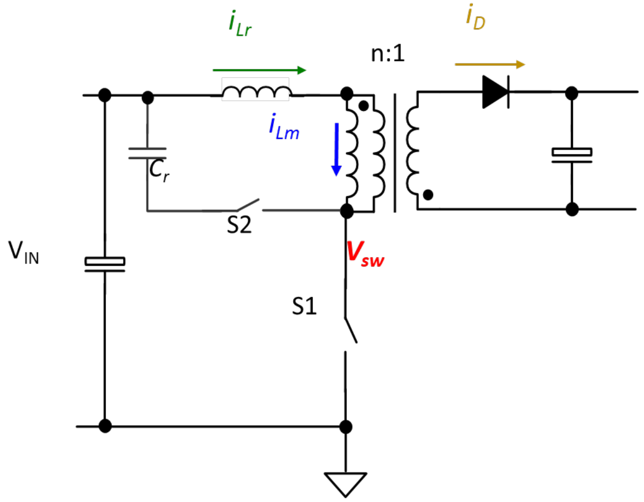
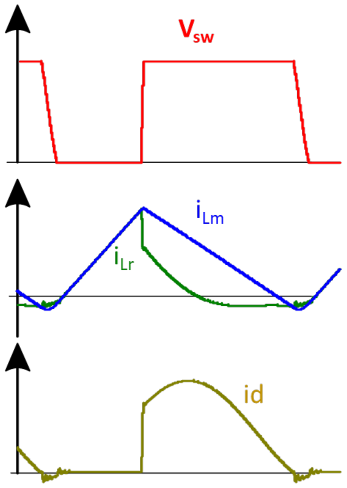
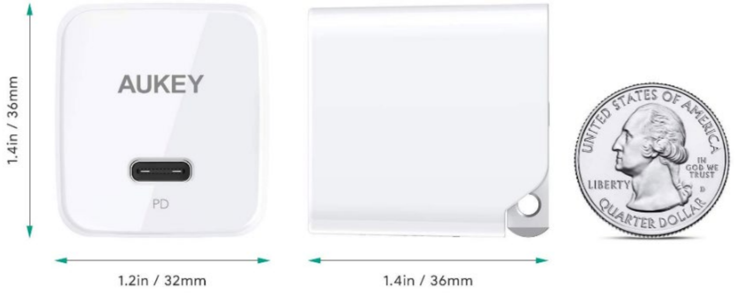
Active Clamp Flyback & GaN IC: High Density ZVS





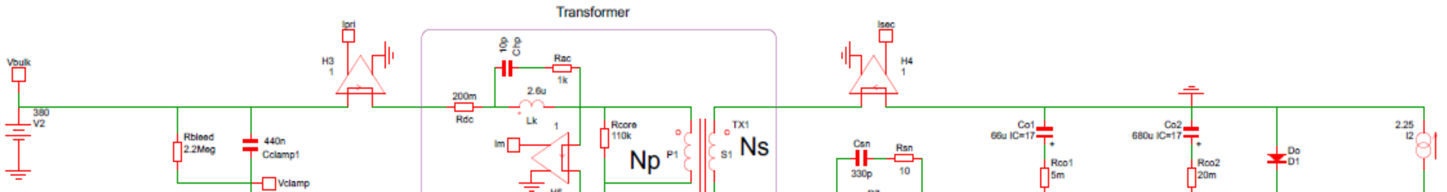


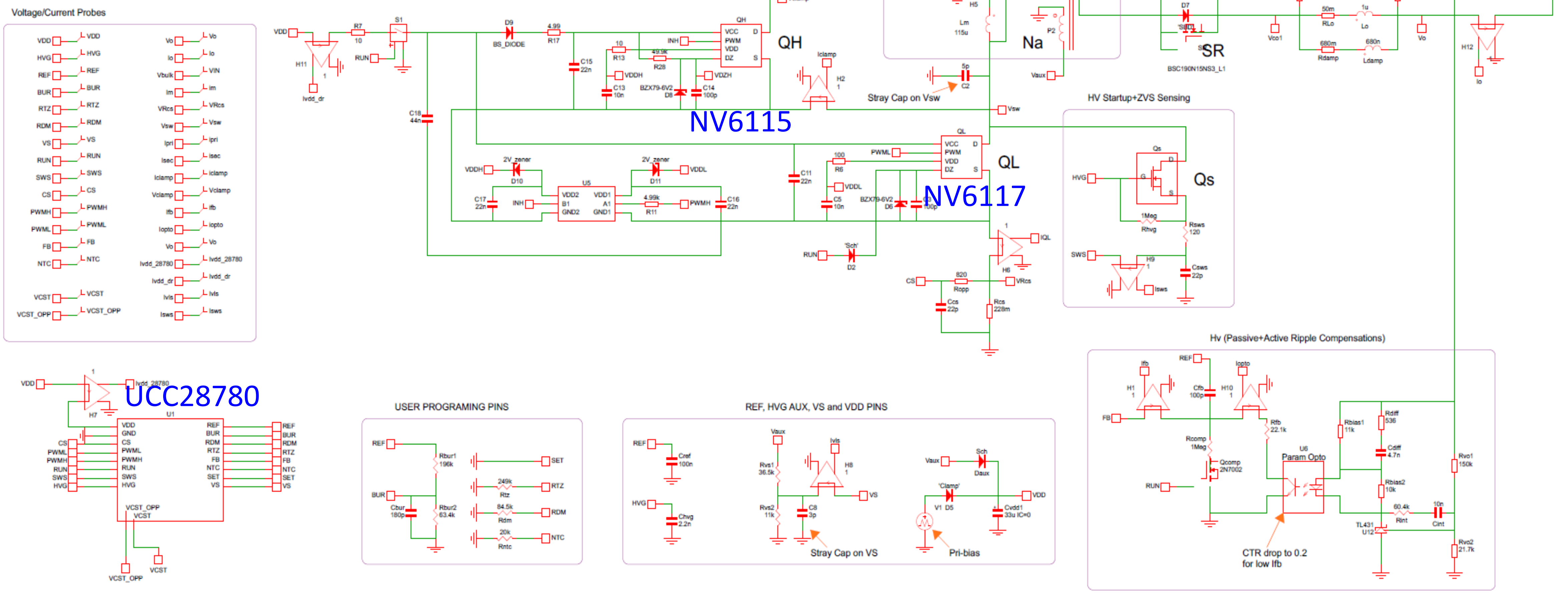
- *World's smallest 27W USB-C*
- Available now from amazon.com

- *World's smallest Charger 42W (30W-C + 18W-A) + Battery Pack (5,000 mAhr)*
- Available now from Apple Store

ACF Simplis Models: Controller & GaN ICs

Very fast and accurate for startup, transient, line cycle ripple, etc.

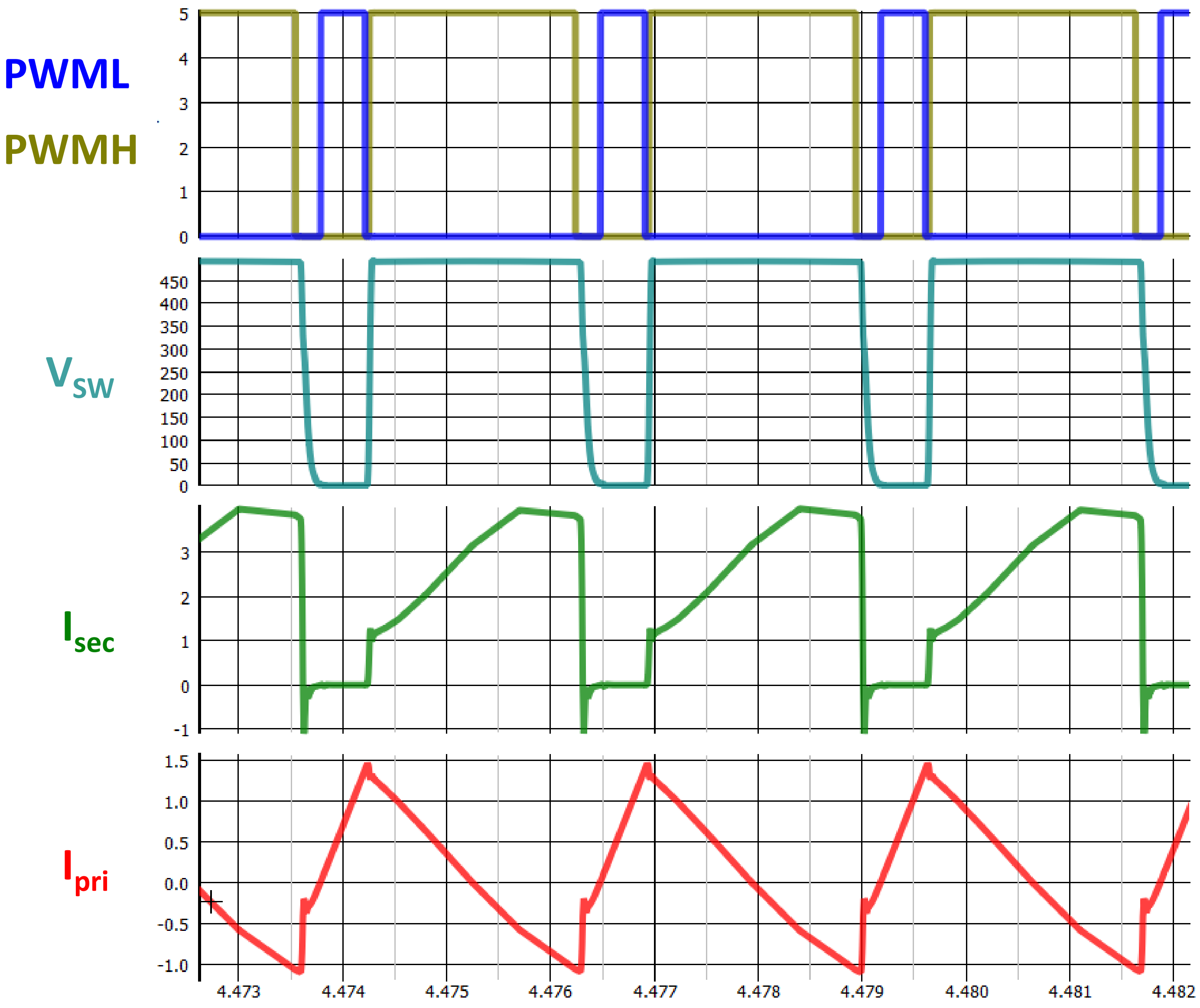




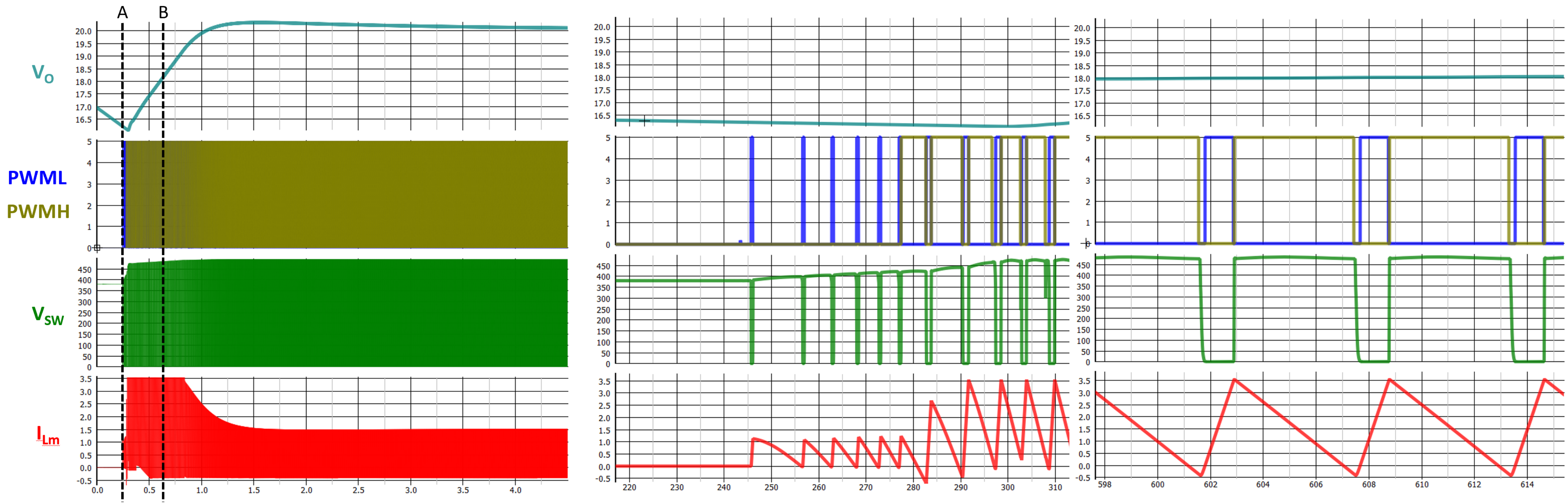
Schematic from Texas Instruments. System jointly developed with Navitas

Simplis Sim Example: ACF Steady State

- Detailed and accurate enough for system optimization
- V_{SW} is half-bridge midpoint
  - Detailed soft switching waveforms
- I_{SEC} SR current
  - Rms current analysis and reduction
- I_{PRI} transformer current
  - Minimize negative current to achieve ZVS and reduce rms



Simplis Sim Example: Start-up



- Various modes of operation can be observed and analyzed during startup
  - Current limit mode, burst mode, ACF mode, Vout transient

Simplis Sim Example: Load Transient

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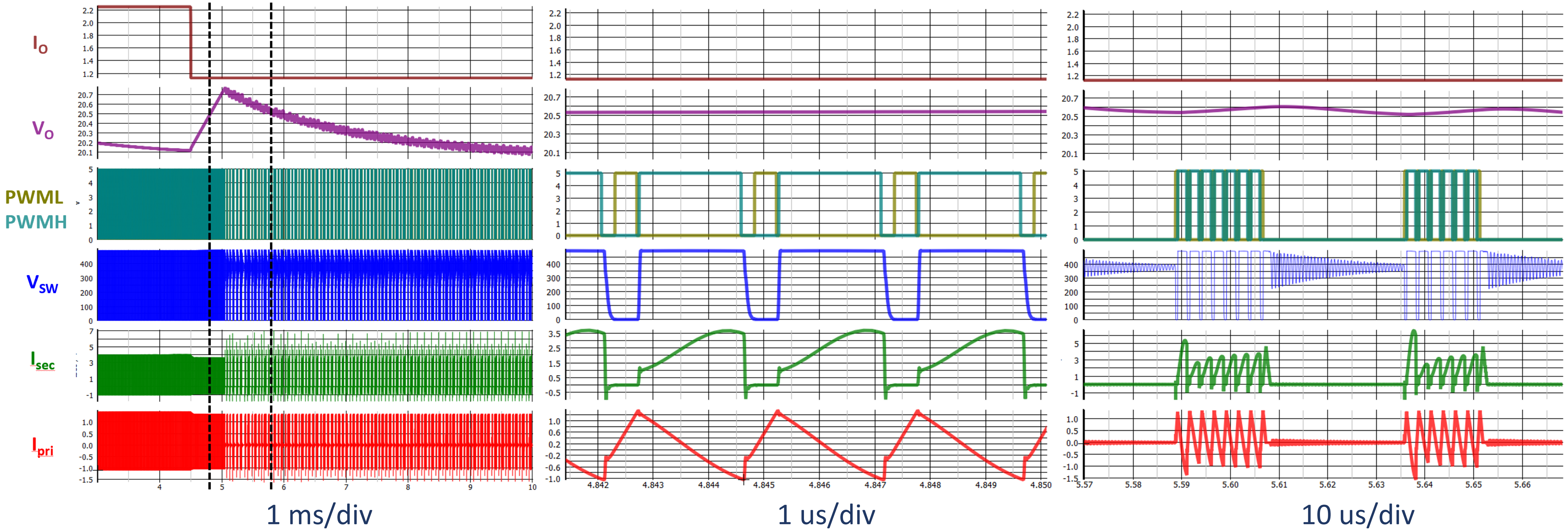
- I_O steps from full load to half load
- V_{OUT} rises due to response delay
- Settles down by entering into burst mode



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Conclusions

- eMode GaN is suitable for power IC integration
- Proprietary PDK for robust GaN Power IC design and manufacture
- Accurate multi-tier models are developed
- Advanced, highly-accurate, 4-terminal symmetric, scalable GaN FET Verilog model for IC design
- Accurate SPICE model for each product is essential for optimal accuracy
- SIMplis models also available for released products for ultra fast top level system design
- GaNFast™ Power ICs are successfully developed and in mass production

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