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Self-Reverse-Blocking (SRB) Control of Dual-Gate Monolithic Bidirectional GaN Switch with Quasi-Ohmic On-State Characteristic

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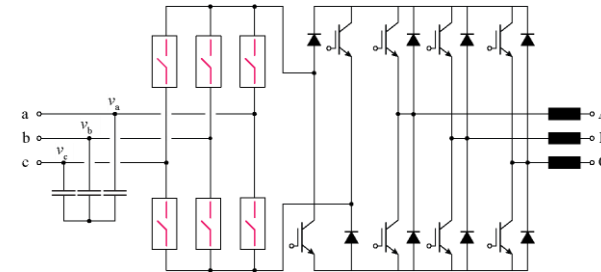
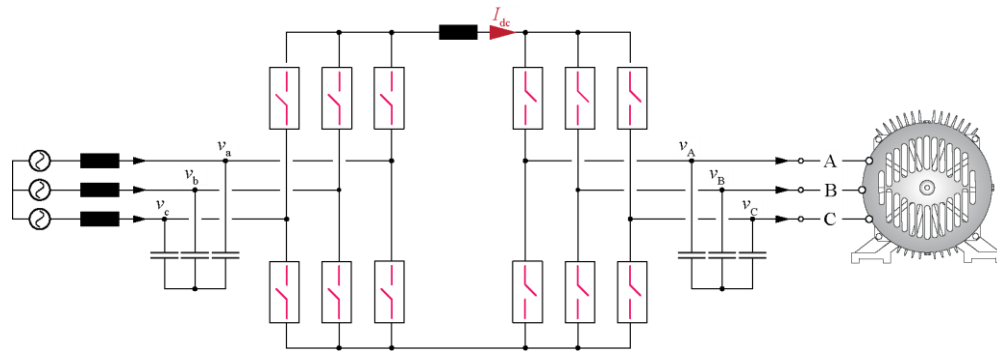
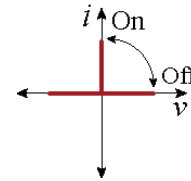
² Infineon Technologies, Austria

CURRENT DC-LINK CONVERTER SWITCH REQUIREMENT

► CSR/CSI, Inverting Link Matrix Converters, Resonant Converters, Current-Fed Converters...

Need Switch Capable of:

- Bipolar Voltage Blocking
- Unidirectional Current Conduction



- Reversible Power Flow → Inversion of DC-Link Voltage Polarity (!)



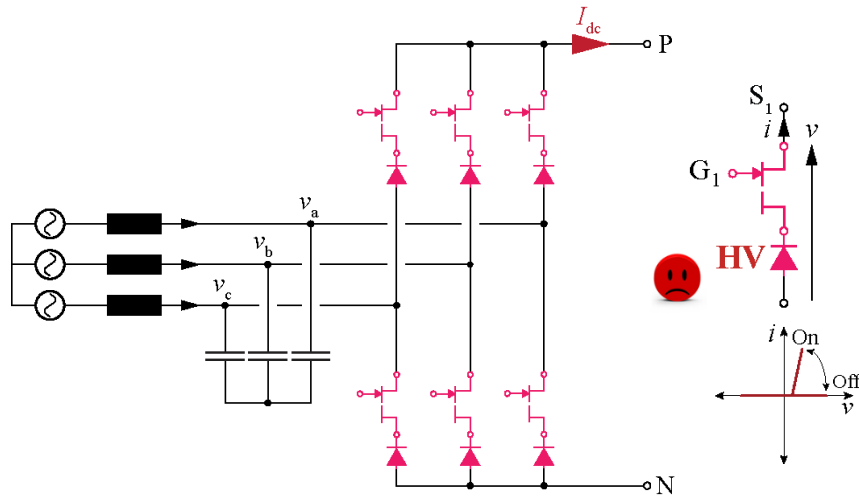
Outline

- ▶ *Existing Switch Concepts*
- ▶ *Proposed RB-MBDS Concept*
- ▶ *Experimental Proof-Of-Concept*
- ▶ *Outlook*

EXISTING SWITCH DEVICE CONCEPTS

► HV Switch + HV Diode

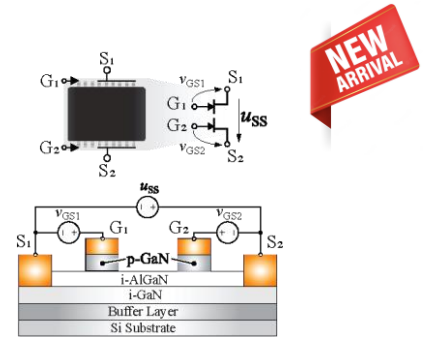
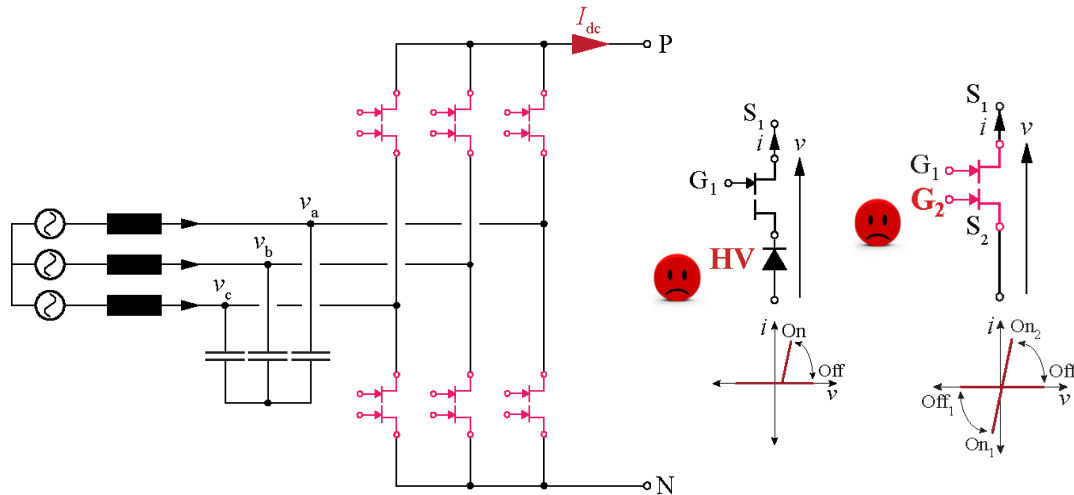
HV Diode Characteristic, $2 \times v_{\text{Blocking}}$ → High Cond. Losses



EXISTING SWITCH DEVICE CONCEPTS

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- ▶ M-BDS

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 Ohmic Cond. Char. BUT $2x$ Gate Signals/ $2x$ Gate Drives

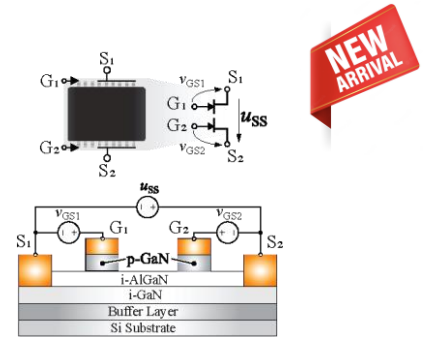
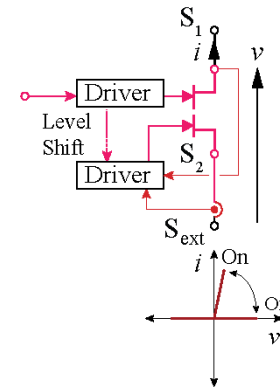
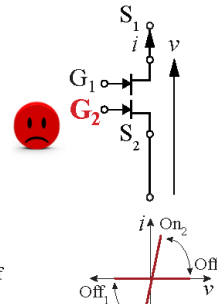
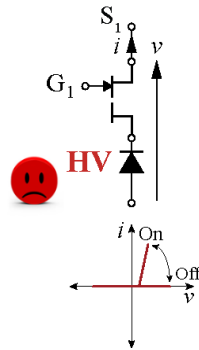
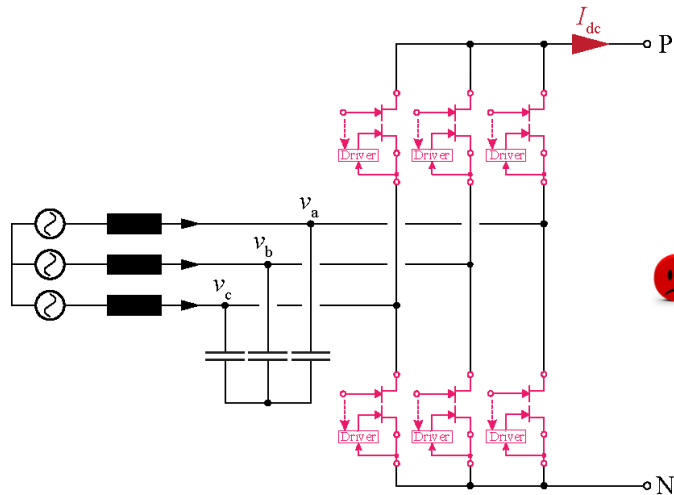


Monolithic Bidirectional GaN Device (M-BDS)

EXISTING SWITCH DEVICE CONCEPTS

- ▶ HV Switch + HV Diode
- ▶ M-BDS
- ▶ Active “Self-Switching”

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 Ohmic Cond. Char. BUT 2x Gate Signals/2x Gate Drives
 Ohmic Cond. Char. BUT High Complexity (V&I Sensing)



Monolithic Bidirectional GaN Device (M-BDS)

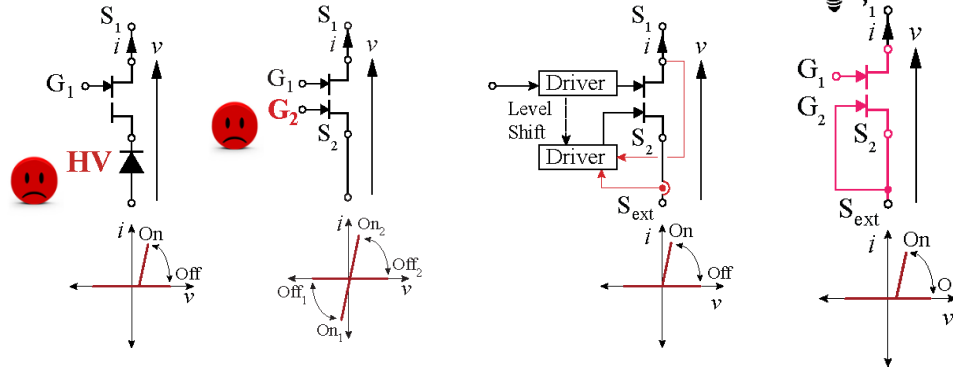
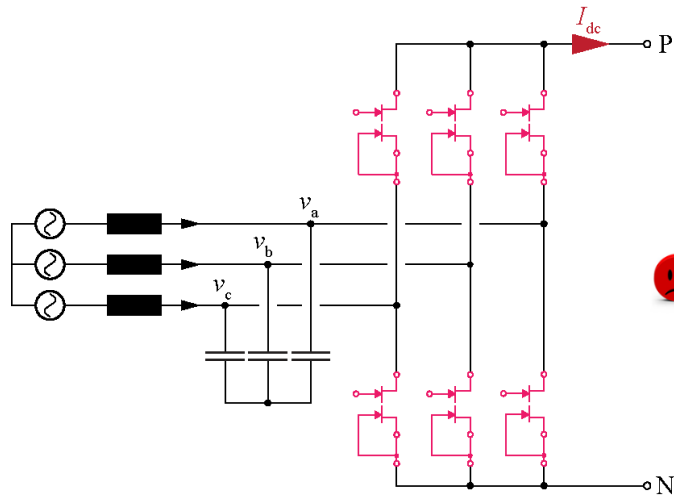
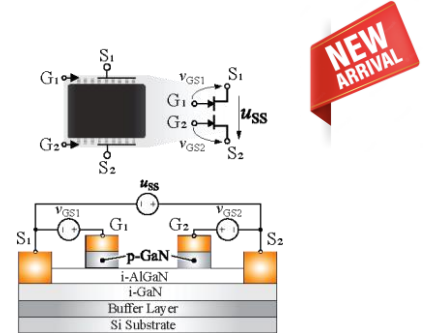
PROPOSED CONCEPT



SELF REVERSE BLOCKING M-BDS (SRB-MBDS)

- ▶ HV Switch + HV Diode
- ▶ M-BDS
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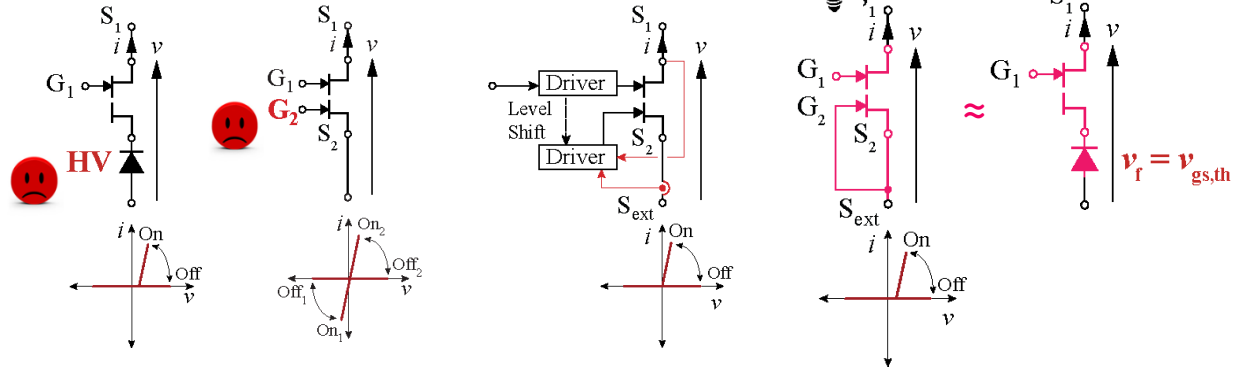
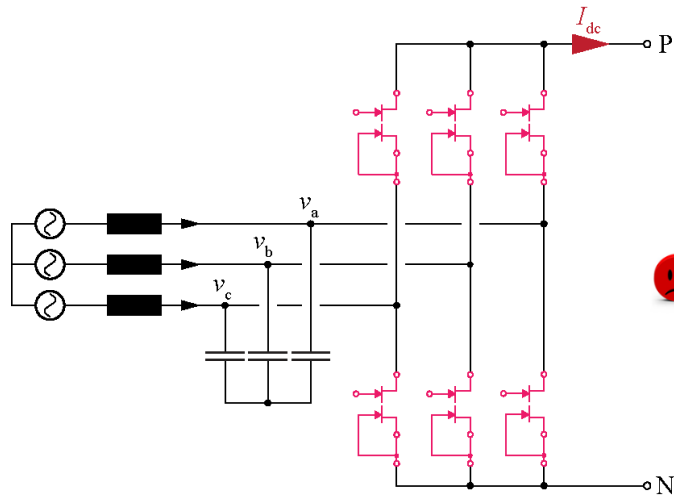
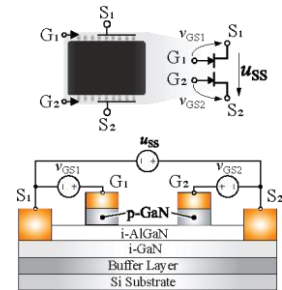
- SRB-MBDS with Norm. Off Gate 1x Gate Signals, Low Complexity

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NEW ARRIVAL

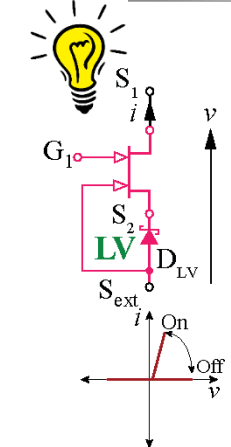
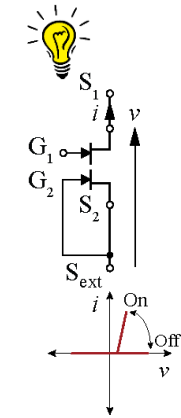
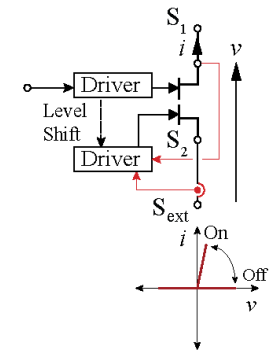
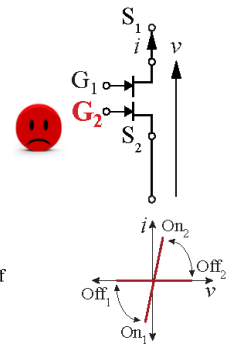
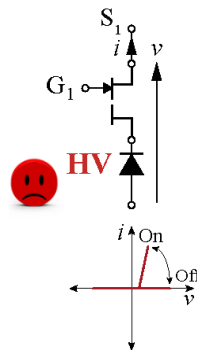
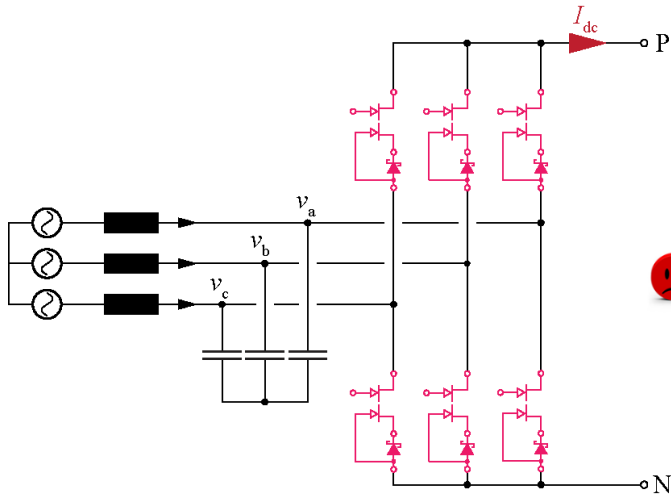
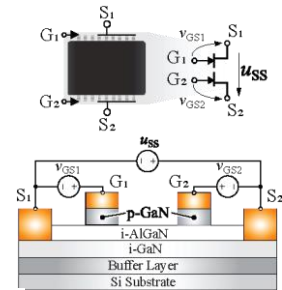


- SRB-MBDS with Norm. Off Gate 1x Gate Signals, Low Complexity BUT High $v_f = v_{gs,th}$

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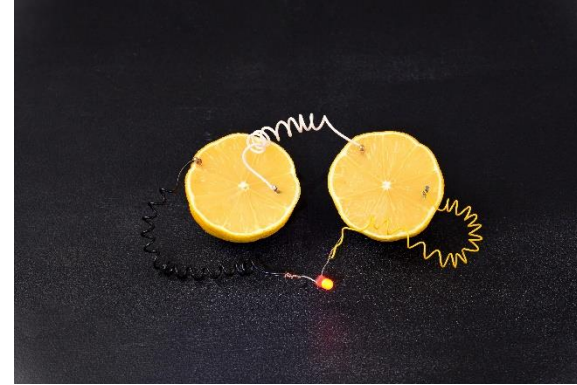
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- ★ SRB-MBDS with Norm. On Gate

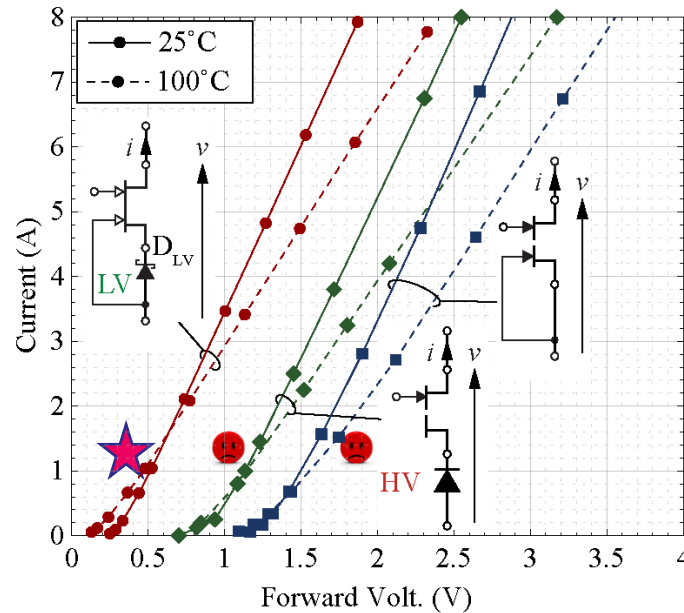
1x Gate Signals, Low Complexity BUT High $v_f = v_{gs,th}$
 Cascode with LV Si Schottky Diode
 Quasi-Ohmic Cond. Char., Low Complexity & 1x External Gate

EXPERIMENTAL VERIFICATION



MEASUREMENT RESULTS – STATIC CHARACTERISTICS (1)

► Forward Characteristics



- Proposed SRB-MBDS Concept**
 - Normally-On 600V, 190 mΩ GaN MBDS
 - -●- - 40V, 10A Si Schottky Diode (Diodes Inc., PDS1040)
- Conventional Approach**
 - ◆— Unidirectional GaN FET with Equal Chip Area as M-BDS
 - -◆- - 650V, 10A SiC Schottky Diode (ST STPSC10065)
- Alternate SRB-MBDS Concept**
 - Normally-Off 600V, 190 mΩ GaN MBDS
 - -■- -

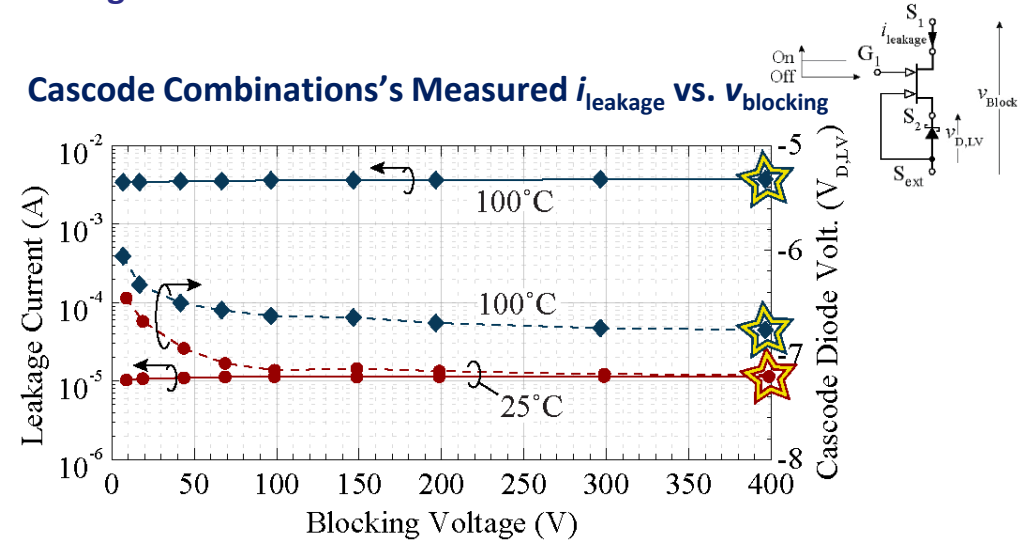
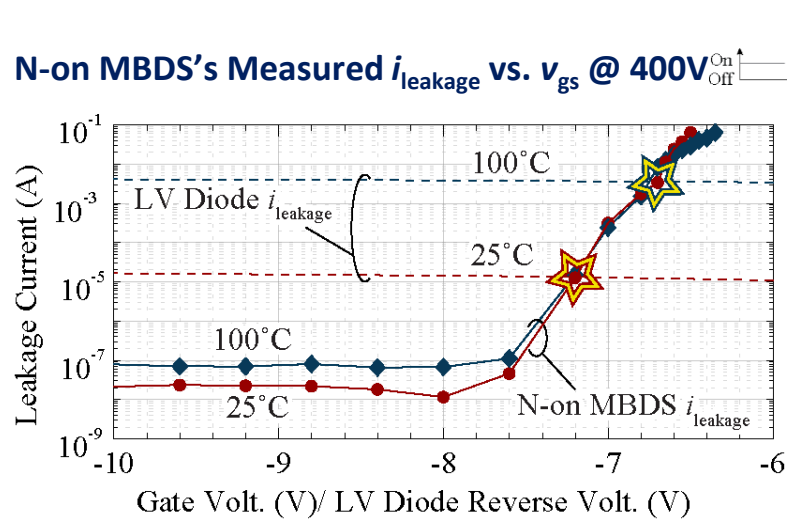
- Proposed SRB-MBDS - Quasi Ohmic Conduction Characteristics

★ Significantly Lower Voltage Drop!

- D_{LV} 's $v_{f,LV}$ Dominates at Low Current
- M-BDS $r_{ds,on}$ Dominates at High Current

MEASUREMENT RESULTS – STATIC CHARACTERISTICS (2)

► Reverse Characteristics – Proposed Cascode Combination **Blocks Voltage!**



- LV Diode $i_{leakage}$ from Datasheet
- Intersection Decides Steady State Operating Point

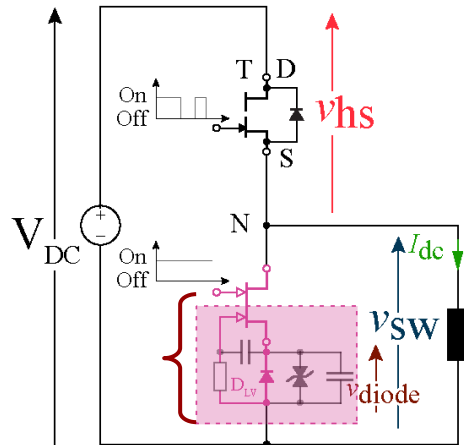
- ↓ MBDS's $i_{leakage}$ with ↓ $v_{blocking}$ Compensated by ↑ $v_{LV Diode}$
- $i_{leakage}$ Defined by LV Diode

- LV Diode Selection → Subject to Tradeoff Between Low $i_{leakage}$ and Low $v_{f,LV}$

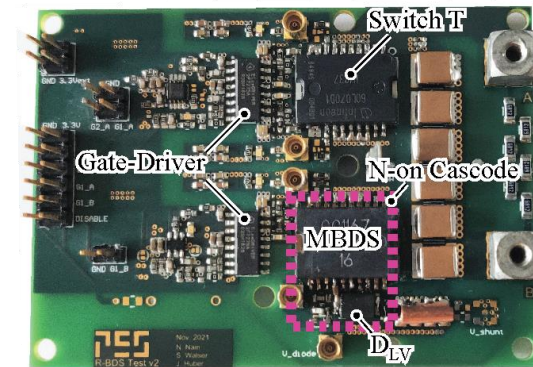
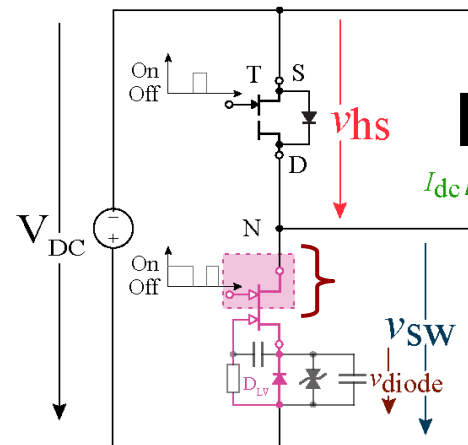
MEASUREMENT RESULTS – SWITCHING CHARACTERISTICS

► Double-Pulse Setup – Realized for Both *Blocking* Polarities

Self-Switching Cascode SRB-MBDS Blocks



Externally Accessible Gate Blocking



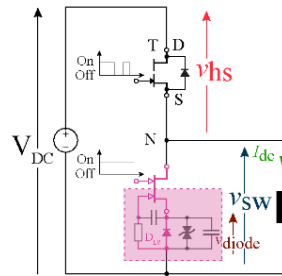
NOTE – Snubber Elements to Prevent Self-Sustained Turn-Off Oscillations

- Scope for Improvement with Co-Packaging!

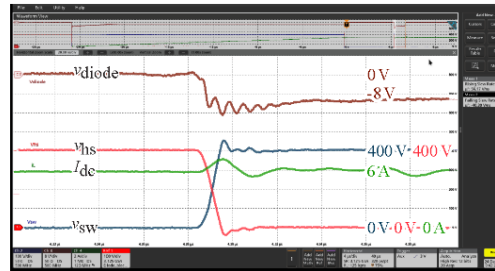
MEASUREMENT RESULTS – SWITCHING CHARACTERISTICS

► Experimental Results at $\pm 400\text{V}$, 6A and 100°C

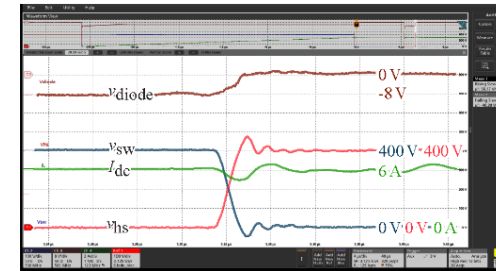
• Self-Switching Cascode SRB-MBDS



SRB-MBDS Turn-Off

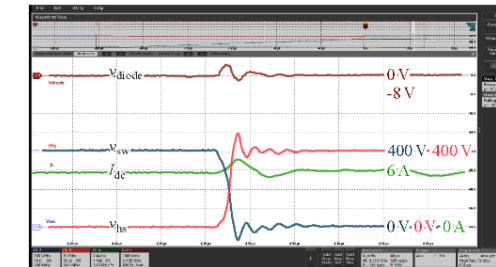
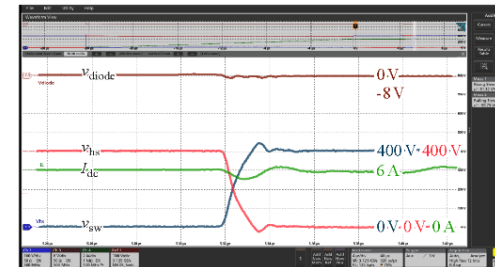
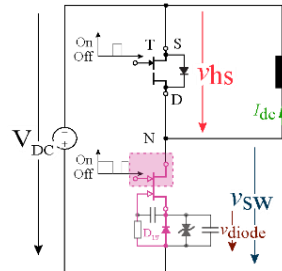


SRB-MBDS Turn-On



v_{diode} : 8 V/div
 v_{sw} : 100 V/div
 v_{gs} : 100 V/div
 I_{dc} : 2 A/div

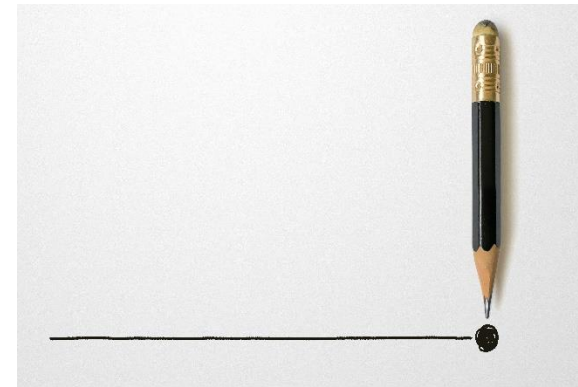
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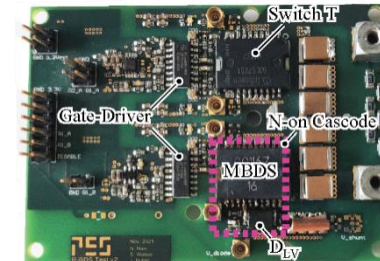
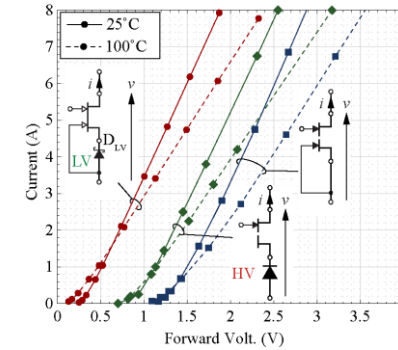
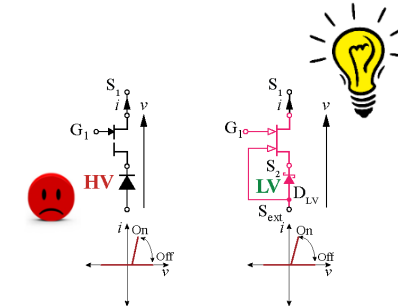
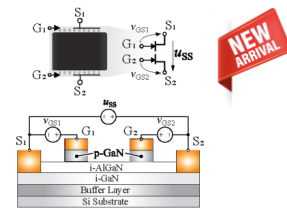
• Proposed SRB-MBDS Concept Feasible Even with Discrete Components!

CONCLUSION



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- **Bipolar Voltage Blocking & Unidirectional Current Switch Concepts Explored!**
- **Conventionally with Transistor and HV Diode**
 - ▶ **High On-State Losses**
- **New Concept Proposed → N-on GaN M-BDS and LV Si Schottky Diode Cascade**
 - ▶ **Considerably Lower On-State Losses**
 - ▶ **Only One External Gate Control**
 - ▶ **No Additional Active Sensing**
- **Proof-of-Concept Demonstrated with Discrete Components**
 - ▶ **Static and Switching Characteristics**
 - ▶ **Integration in Same Package – Possibility of Improved Performance**



THANK YOU!

