How GaN helps power supplies achieve extraordinary levels of efficiency

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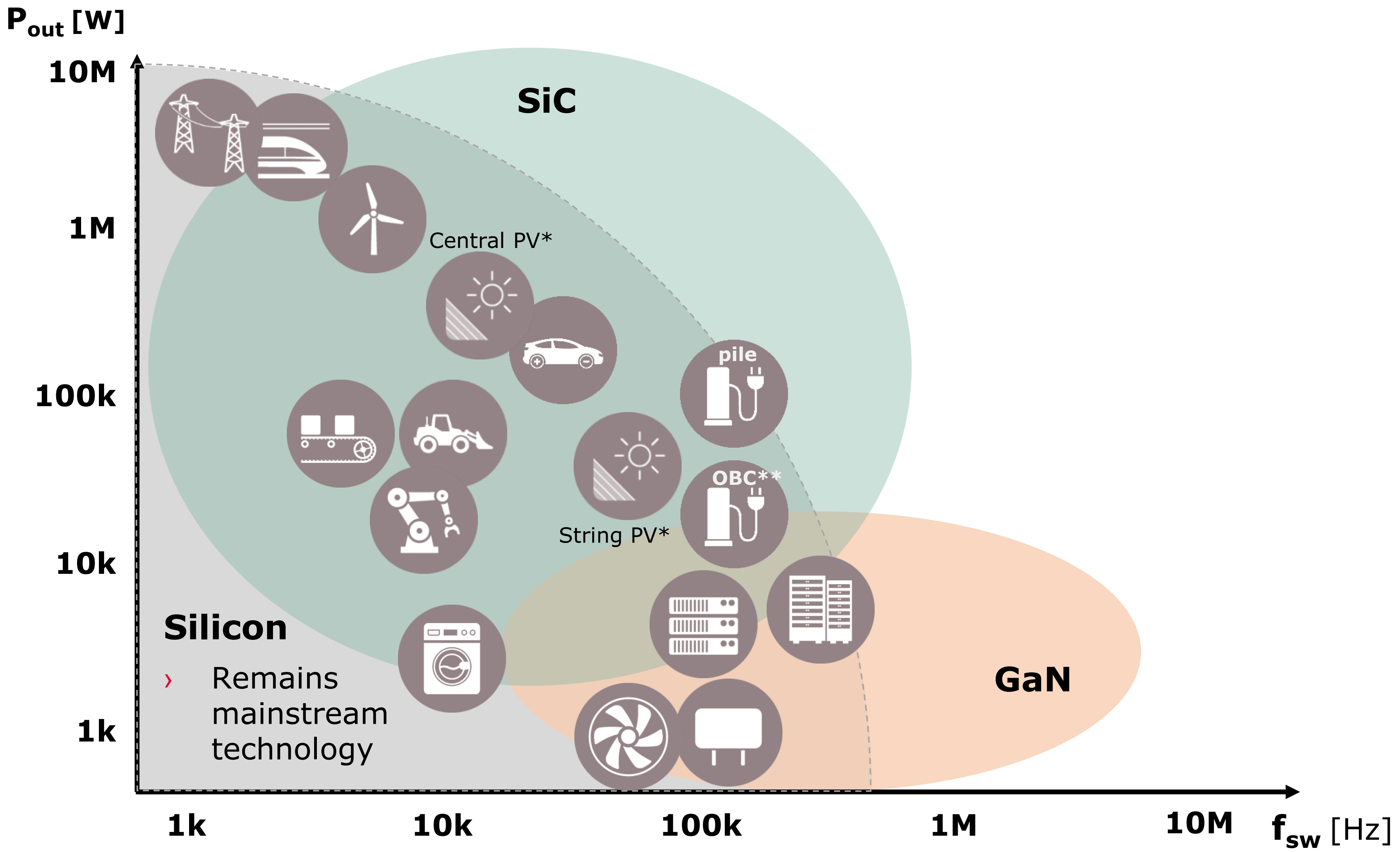
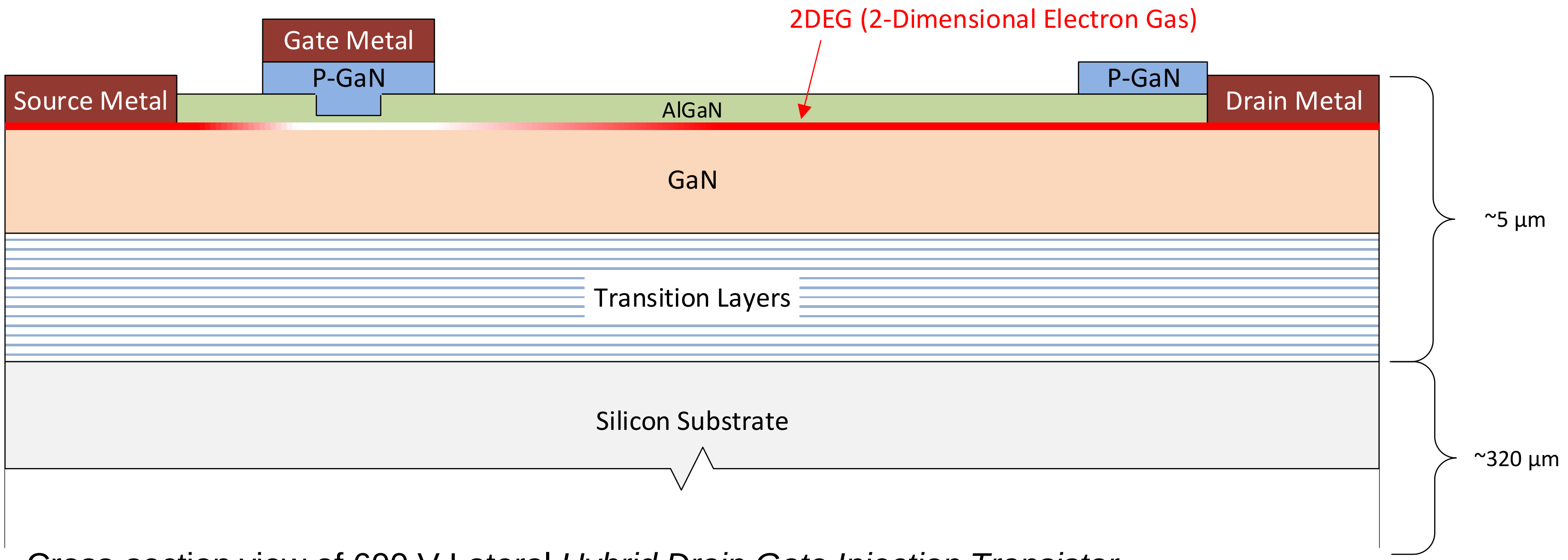
Application map for Si, SiC, GaN



* PV = photovoltaic inverter; ** OBC = onboard charger

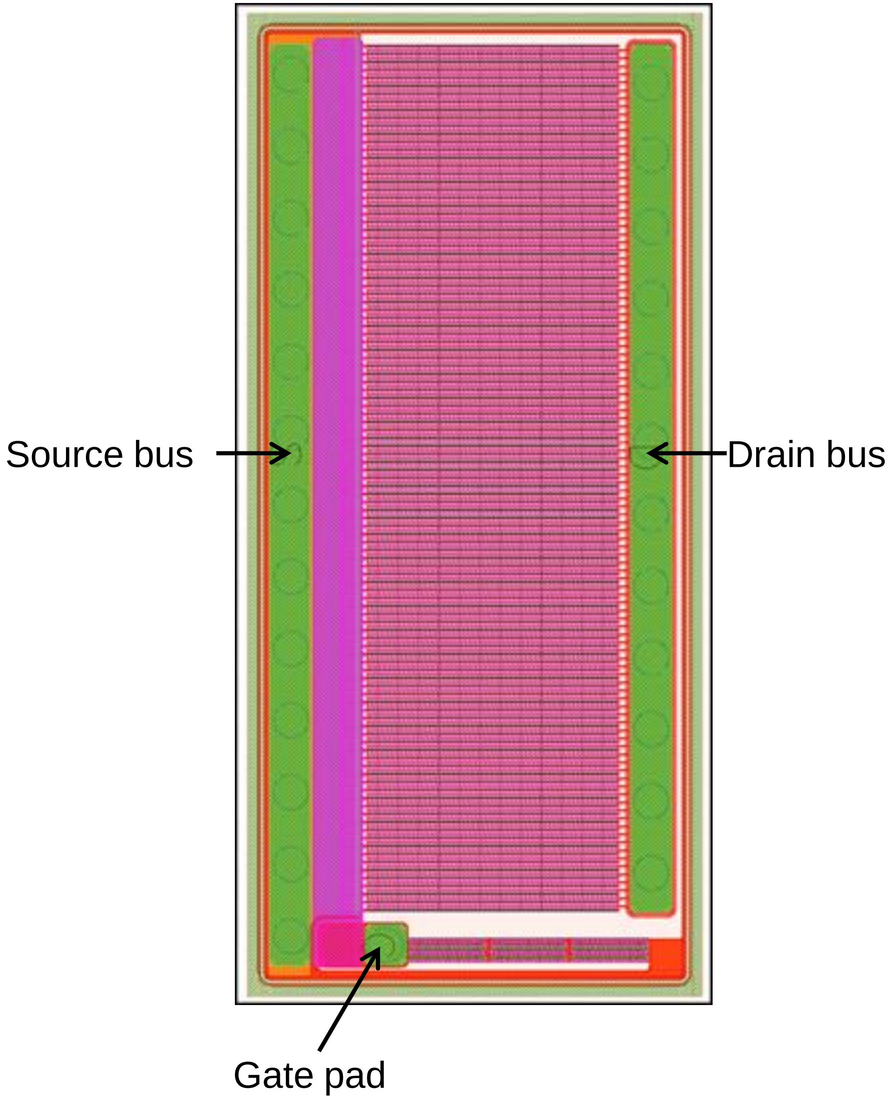
What is GaN – the technology

- GaN is a "wide-bandgap" semiconductor material that can be fabricated into high-performance power transistors
- Infineon makes devices by epitaxially growing layers of GaN (with other elements) onto Silicon substrates

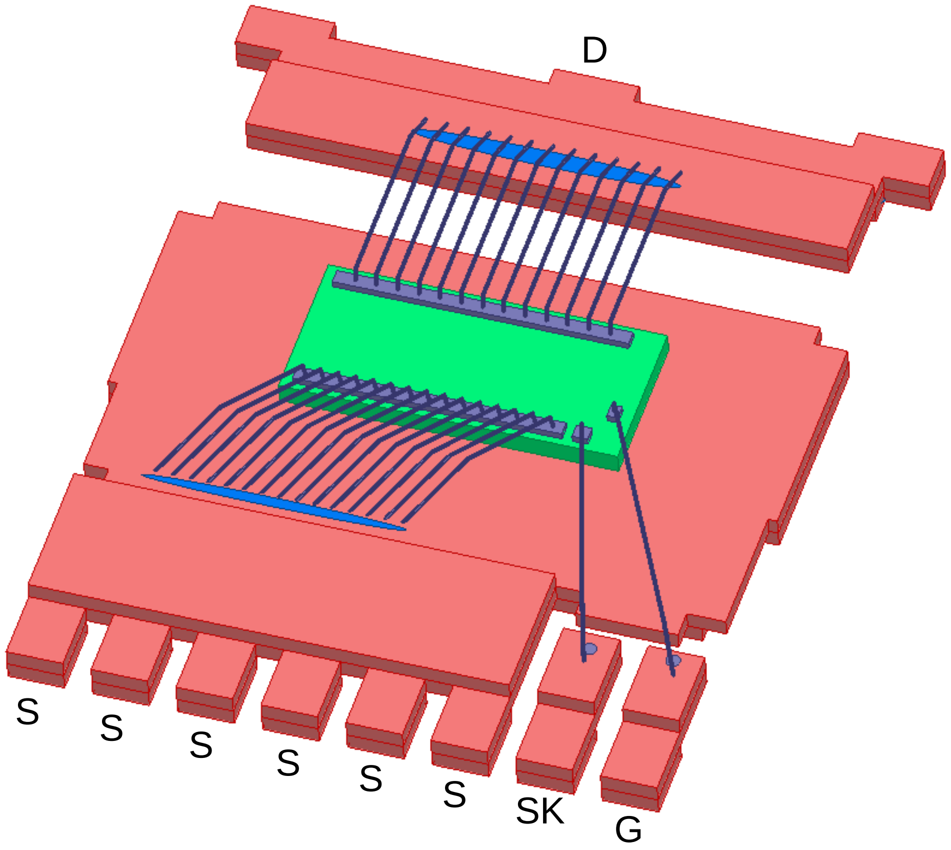


Cross-section view of 600 V Lateral *Hybrid Drain Gate Injection Transistor*.
This is an **enhancement-mode** (normally-off) device

CoolGaN™ die and package example



TO-Leadless package (TOLL) shown



Note substrate is connected to source potential:

How is CoolGaN™ better performing than Si or SiC?

The 3 key benefits of GaN transistors:

1. GaN transistors conduct in the reverse direction (third quadrant) like a diode, but there is **zero** reverse-recovery charge
   - This is a huge benefit that enables hard-switching with low-loss and low EMI
2. GaN transistor capacitance/charge is much smaller than comparable Si or SiC transistor
   - Both gate charge and output charge are lower than any competing technology – enabling fast, low-loss switching
3. Because of low charge and no minority-carriers, GaN switching speed can be <u>very</u> fast (single-digit ns range)
   - Especially at turn-off, the channel current can be cut-off in a few ns making turnoff losses extremely low

Comparing 600 V transistor key parameters

Parameter	CoolGaN (IGT60R070)	CoolMOS (CFD7)	SiC (SCT3060AL)	Comments
$R_{DS(on),typ}$ (mΩ)	55	57	60	Very close typical room-temp Rds(on) ±5%
$Q_{rr,typ}$ (nC)	0	570	55	CoolMOS max >1000
$Q_{OSS,typ}$ @ 400 V (nC)	41	400	~60	SiC estimated from chart
$E_{OSS,typ}$ @ 400 V (µJ)	6	8	9	Relatively small differences!
t_r/t_f typ (ns)	7/10	23/6	37/21	SiC has large internal R_G
$I_{D,pulse}$ (A)	60	129	97	@25°C. GaN is 35 A @ T_C = 125°C
$R_{thJC\ (MAX)}$ °C/W	1.0	0.8	0.91	Not significant differences

- Note: Rohm SiC MOSFET is rated at 650 V, GaN and Si are rated at 600 V
- CoolMOS t_f looks deceptively fast because it does not include the time spent 0-10% V_{DS} (measurement is from 10-90%)

Why are these key transistor characteristics?

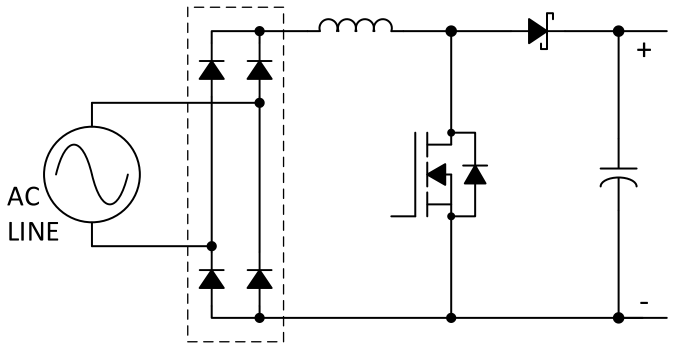
- What makes these so important?
- Consider the main loss mechanisms in power transistors:
- Conduction loss: nearly the same for these 3 examples
- Switching loss – dominated by 3 factors:

1. “crossover” loss – during the switching interval, both I_D and V_{DS} are simultaneously large creating high peak power loss
   - GaN has fastest turn-on time = lowest loss
2. E_{OSS} – the C_{OSS} energy is dissipated during hard turn-on
   - GaN is lowest, but not by much compared to CoolMOS or SiC
3. Reverse-recovery loss: in hard-switched half-bridge topology this can be a **huge** loss for superjunction
   - SiC is 10X better than CoolMOS, but GaN is far better than either

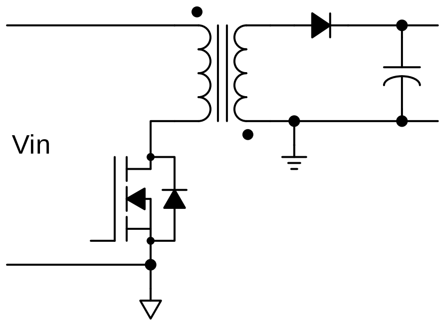
Benefit of GaN in single-ended topologies

- Body-diode performance does not matter – so benefit is limited:

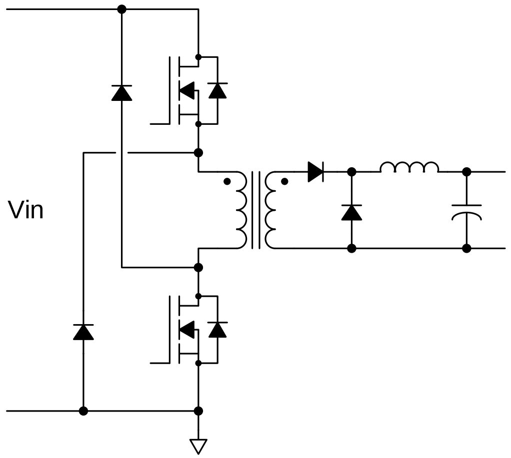
Classic Boost PFC



Flyback

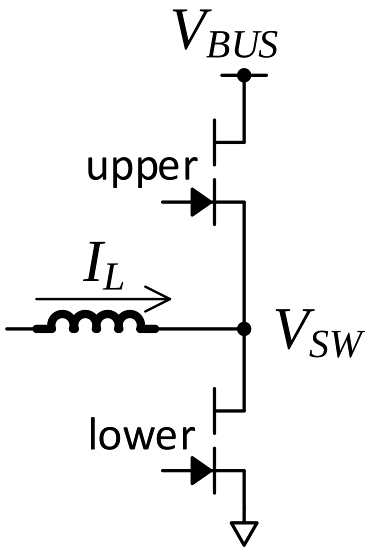


2-transistor forward



- Current flow is unipolar in each case
  - So body diode never conducts – its performance is irrelevant
- **CoolMOS is typically the best choice for these applications**
  - Any small improvement in switching loss using GaN is likely not worth the additional cost

Circuits where GaN ***does*** provide significant benefit



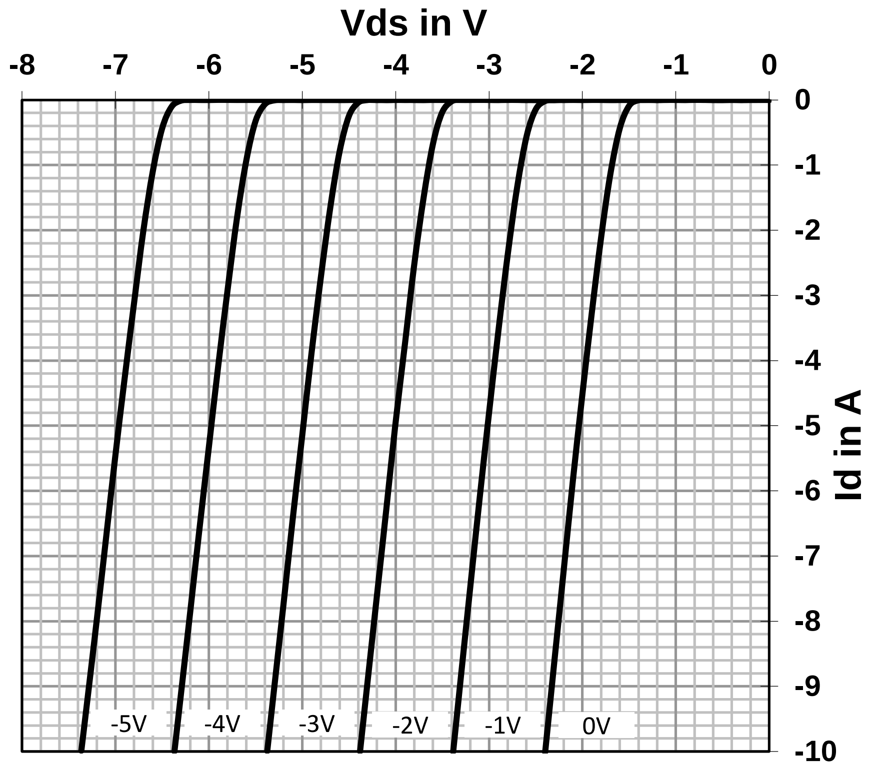
- Topologies based on the half-bridge:
  - Totem-pole PFC
  - LLC converter
  - Phase-shifted bridge converter
  - Active-clamp flyback converter
  - Inverters
- The benefit provided by GaN depends on 2 key factors:

1. Control strategy – hard or soft-switching?
   - For all hard-switching, GaN is clear choice due to zero Qrr
   - For resonant/soft switching, CoolMOS for <250 kHz, GaN >250 kHz
2. Operating frequency:
   - For Hard-switching, losses $\propto$ frequency, so lower frequency is used for maximum efficiency
   - For soft-switching, advantage of GaN is at >250 kHz

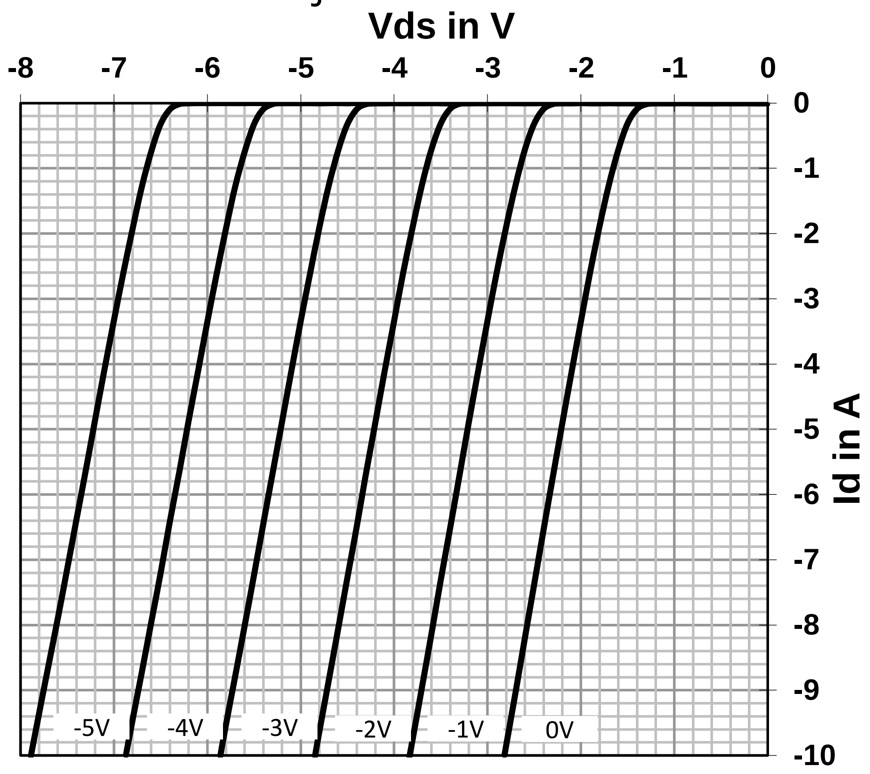
3rd quadrant conduction characteristic

- HEMT turns back ON when drain goes below G, S

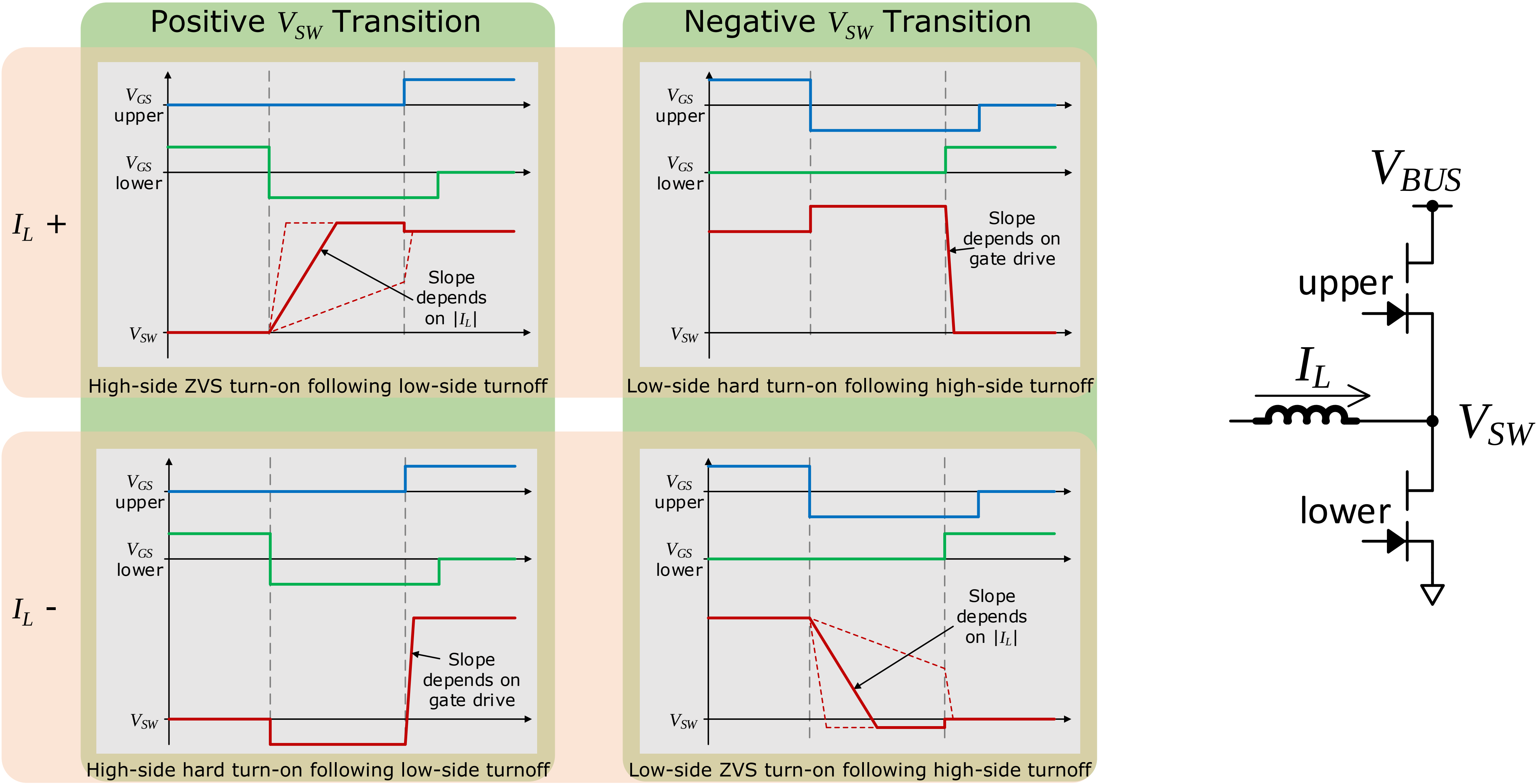
T_j = 25°C



T_j = 125°C



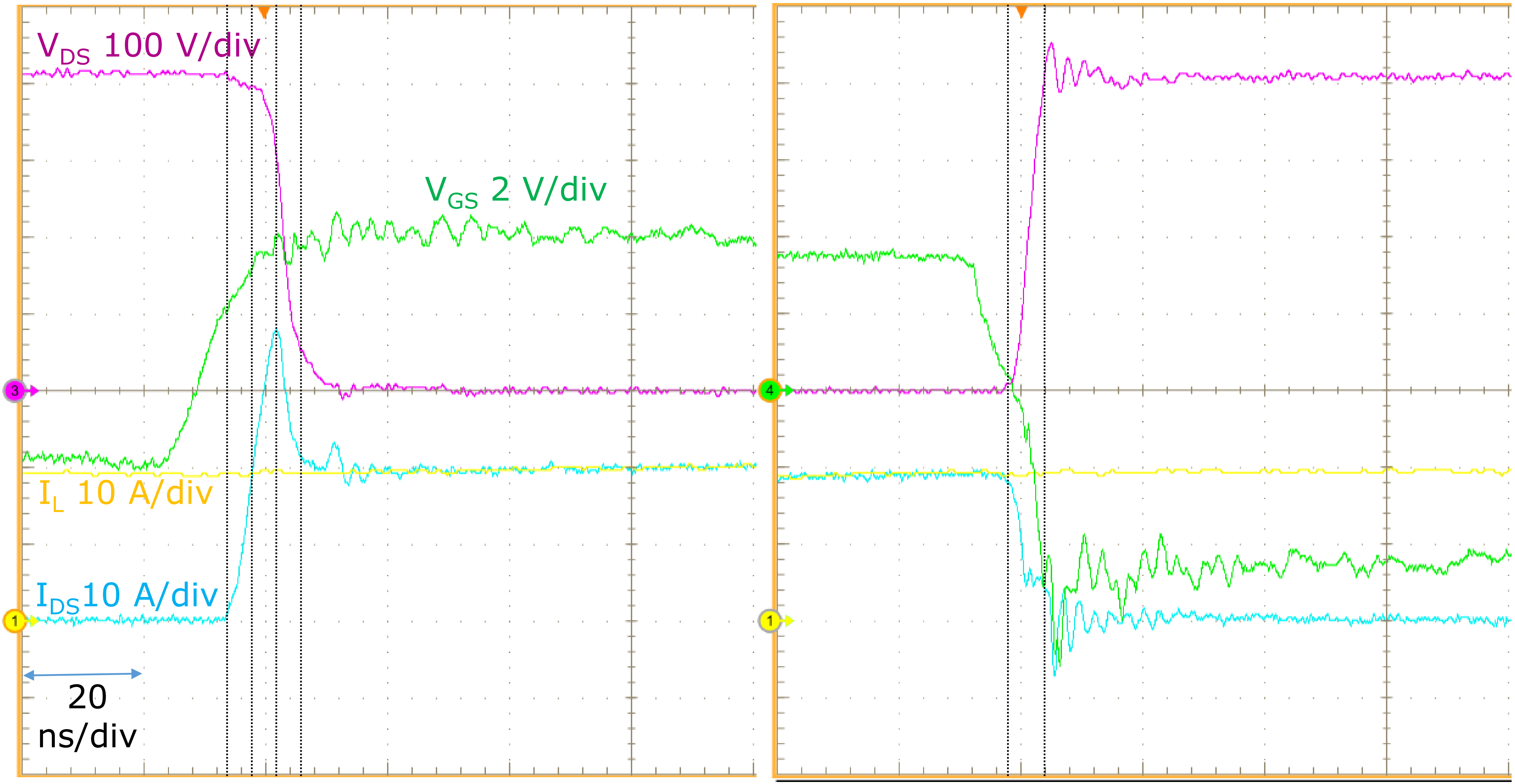
4 possible half-bridge commutation conditions



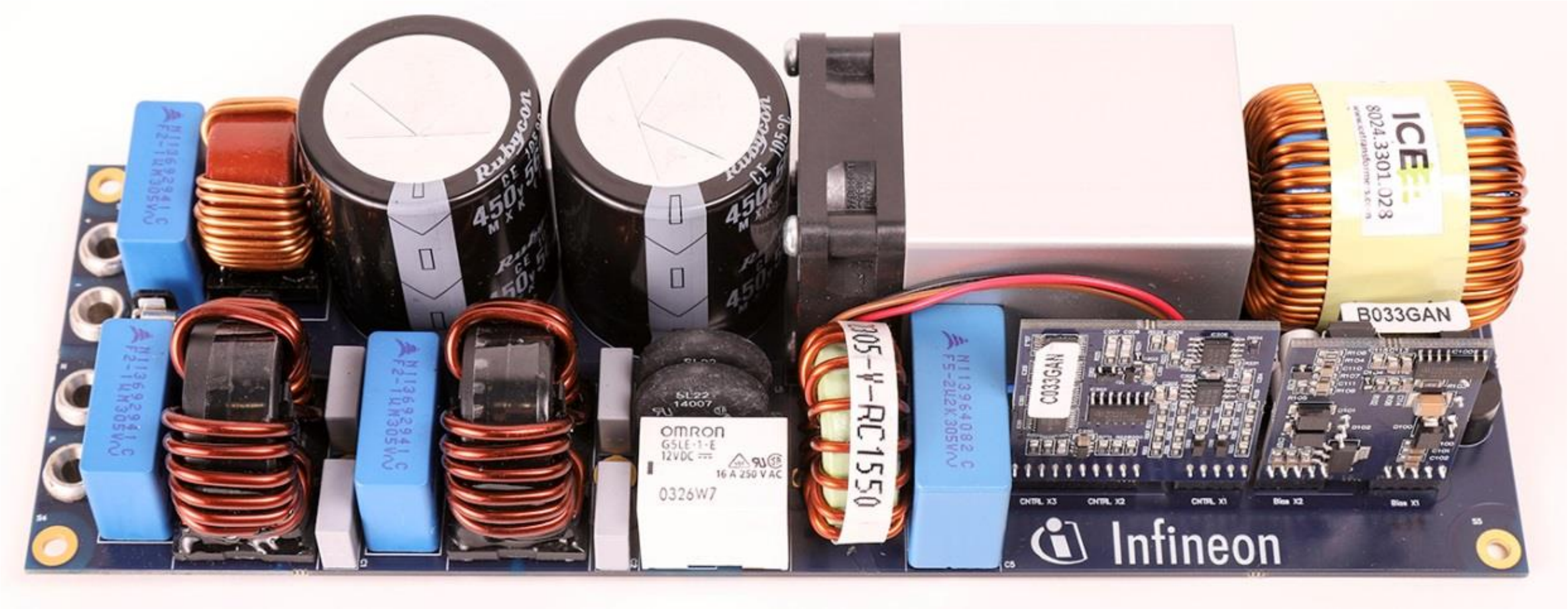
Minimizing 3rd quadrant losses

- Power dissipated in 3rd quadrant "diode mode" proportional to V_{SD} x I_{SD} x time x frequency
- Minimize V_{SD} by using only as much negative gate drive as necessary to prevent shoot-through
- Minimize time spent in diode mode:
  - Use shortest deadtime possible, or
  - Employ adaptive deadtime optimization
    - Look-up table or calculate pulse-by-pulse

Example 20 A hard-switching waveforms

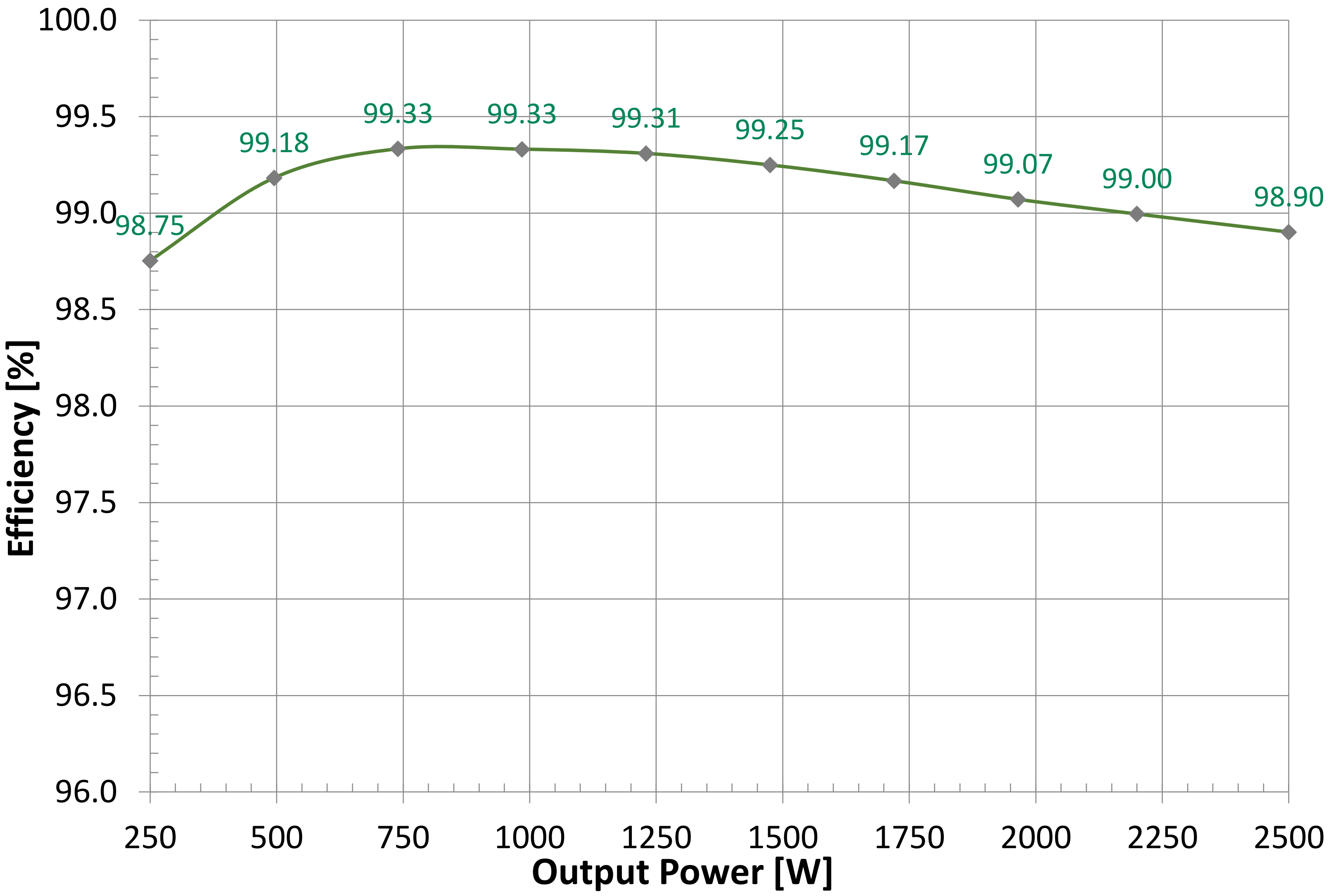


The Results:



- 2.5 kW GaN Reference Design
- CCM Full-Bridge PFC operating @ 65 kHz
- >99% efficiency over most of the load range

GaN 2.5 kW PFC measured efficiency



S/N 035 – no external power supplies – everything included. Vin = 230 V ac, Vout = 390 V dc, 25 °C Ambient

GaN 2.5 kW PFC loss breakdown

- At 1000 W output power:
  - GaN conduction loss 1.5W
  - GaN switching loss 1.1 W
  - Coolmos conduction loss 0.7 W
  - EMI filter, cap ripple loss 0.5 W
  - PFC inductor total loss 2.0 W
  - Bias supply + control circuit 1.3 W
  - (fan not running at this load)
  - Total losses ~7.1 W

Example high-density resonant application

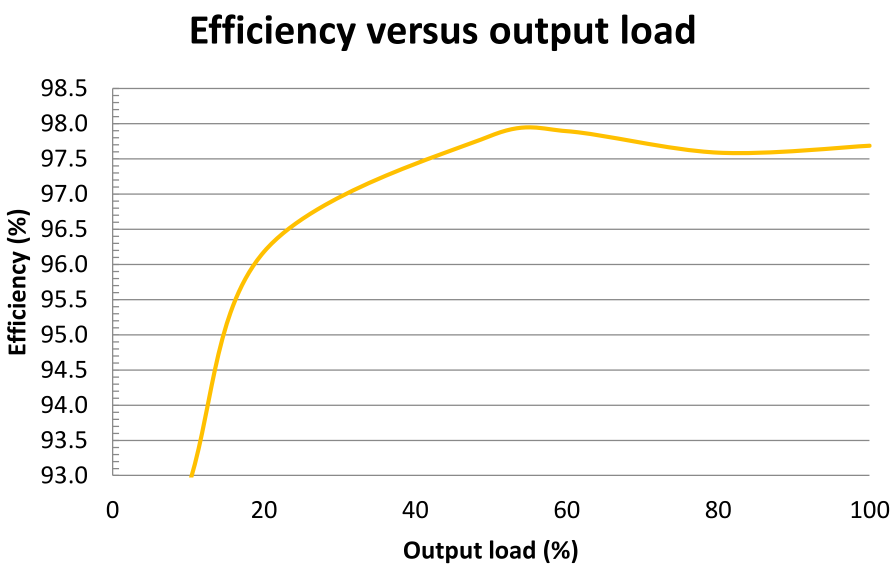
Main Specifications:

- Input: 350-400 V DC, 385 V nominal
- Output: 52 V @ 70 A, 3600 W
- Power density: 160 W/in^3
- LLC resonant frequency: 350 kHz

Components Used:

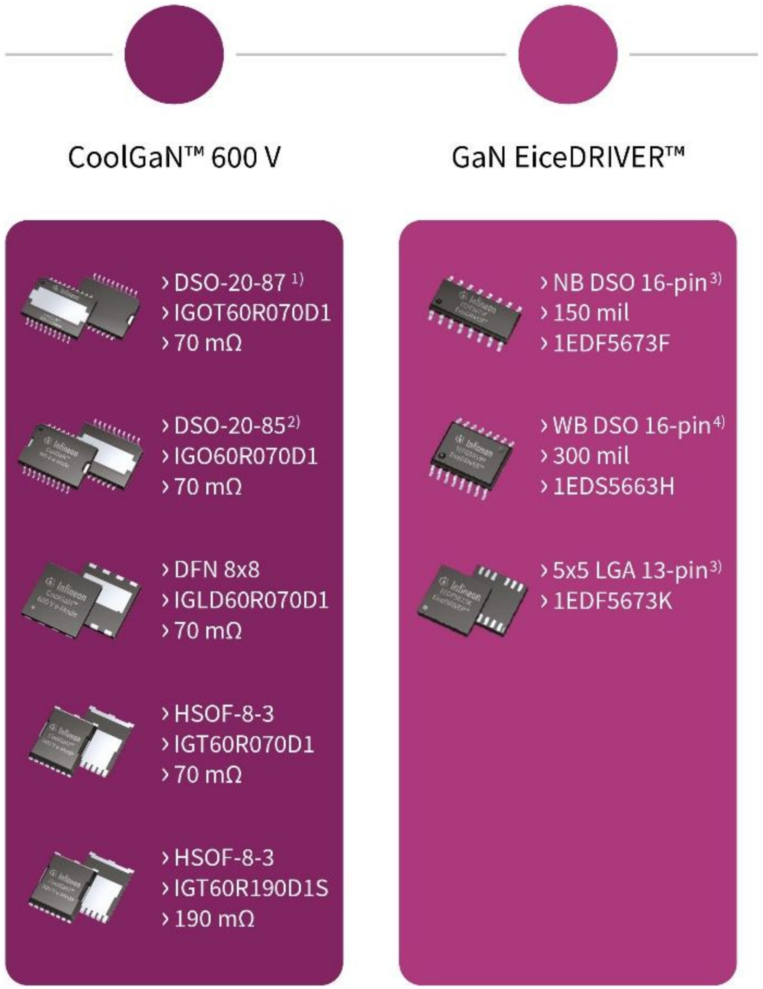
- CoolGaN: 70 mΩ IGT60R070D1
- SR: 2.6 mΩ Optimos BSC026N08NS5
- HV Driver: 1EDI20N12AF
- LV Driver: 2EDN7524R
- Controller: ICE2HS01G
- Aux Supply: ICE2QR2280Z

Performance:



Demoboard available

CoolGaN™ and EiceDRIVER™ in production now



1) Top-side cooling 2) Bottom-side cooling 3) Functional isolation
4) Reinforced (safe) isolation

CoolGaN™ **the new power paradigm:**
ultimate efficiency and reliability

- The most **reliable** GaN solution delivering **highest performance** amongst all available GaN devices
- **Manufacturing expertise** throughout the entire supply chain
- Global application design **support**
- Broad **portfolio** including drivers
- **Volume** capability
- Attractive **price** projection

Summary

- 3 key features of GaN transistors enable high performance:
  - Zero reverse-recovery charge
  - Lower charge than competing technologies
  - Capable of faster switching
- These features are of particular benefit to half-bridge topologies
  - Lowest loss in hard-switching applications
  - Lowest rms current in soft-switching and resonant applications
- CoolGaN can be driven by off-the-shelf gate drivers
- In production and available now
- (See production power supply example in session IS16.5)