

IPCEI workshop
An introduction to Gallium Nitride transistor

IPCEI Microelectronics and Communication Technologies

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public

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Introduction GaN material

III-V group semiconductor material

	III	IV	V			2 HE
	5 B	6 C	7 N	8 O	9 F	10 Ne
	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

Properties	GaN	Silicon
Band gap (eV)	3.4	1.1
Critical field (MV/cm)	2.5	0.3
Electron mobility ($cm^2/V*sec$)	1900	1350
Thermal conductivity (W/cm^2K)	1.5	1.5

GaN – Gallium Nitride

- Wide bandgap and high electron mobility
- HEMT: high electron mobility transistor

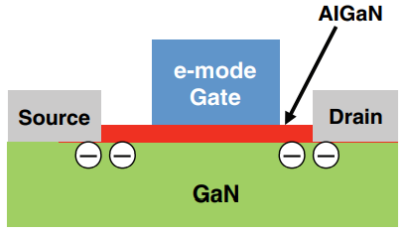
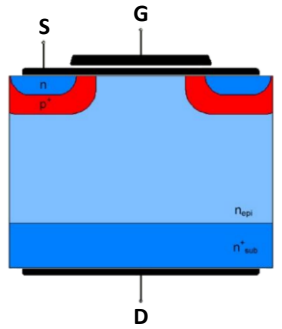
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Power Device Comparisons – Based on similar Rdson Market Available Products

Parameters		CoolGaN™ IGLD65R140D2	CoolMOS™ IPL60R185P7	GaN's values
		GaN	Si	
Blocking voltage	V_{ds}; V	650	650	
On resistance	$R_{DS(on),}$typ; mΩ	**140**	149	Almost same typical $R_{DS(on)}$
Time related effective output capacitance	$C_{o(tr)}$; pF	**40**	381	Shorter dead time with lower circulating loss in soft-switching applications.
Output charge @ 400V	Q_{oss}; nC	**16**	134	Lower switching on loss in hard-switching applications; Shorter dead time with lower circulating loss in soft-switching applications.
Gate to drain charge	Q_{gd}; nC	**0.84**	8	Lower switching loss
Total gate charge	Q_g; nC	**3.2**	25	Lower gate drive loss
Reverse Recovery charge @ 400V	Q_{rr}; nC	**0**	1300	Lower switching on loss in hard-switching applications; Lower EMI issue and shoot through/ hard communication concerns.

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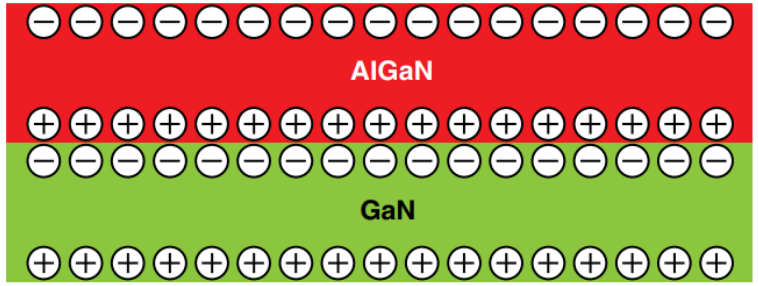
Power Device Comparisons

		GaN HEMT	Silicon MOSFET
GaN HEMT is small	Typical $R_{DS(on)}$ x A	~200 mΩ x mm²	~800 mΩ x mm²
GaN HEMT is fast	Typical switching frequency	Up to Tens of MHz	<300 kHz
GaN HEMT is enabling hard-switching	Typical switching behavior	No reverse recovery	Reverse recovery
GaN HEMT is a power lateral technology	Typical build-up	 **Ideal for integration**	

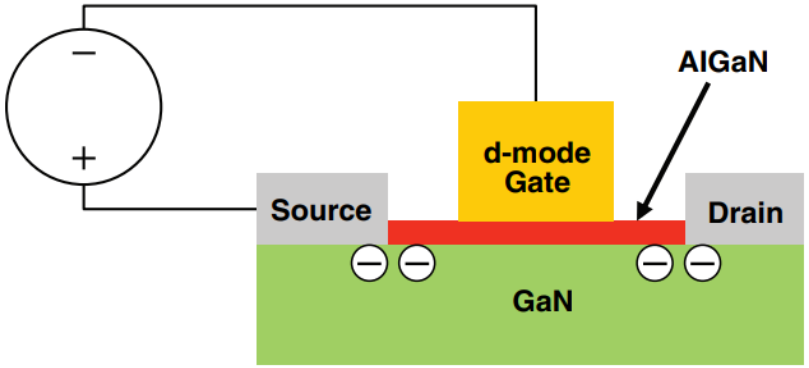
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Introduction GaN HEMT

*



Two-dimensional electron gas (2DEG) formed by GaN/AlGaN heterostructure



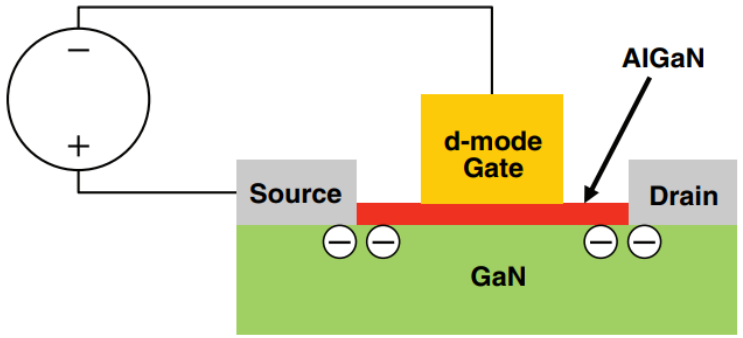
d-mode GaN HEMT

Not favored in voltage source converter applications due to normally-on characteristics

*Lidow, Alex, Michael De Rooij, Johan Strydom, David Reusch, and John Glaser. GaN transistors for efficient power conversion. John Wiley & Sons, 2019.

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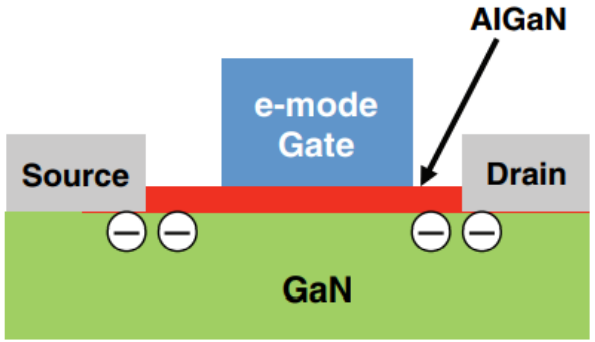
Introduction GaN HEMT



d-mode GaN HEMT

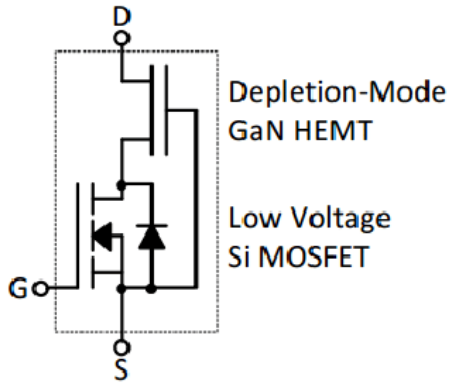
Not favored in power conversion applications due to normally-on characteristics

E-mode GaN HEMT



e-mode gate depletes the 2DEG with zero voltage on the gate

Cascode GaN HEMT



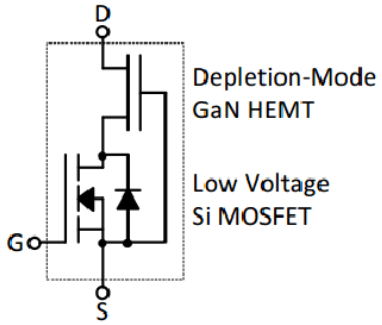
Cascode d-mode GaN in series with e-mode silicon MOSFET

*Lidow, Alex, Michael De Rooij, Johan Strydom, David Reusch, and John Glaser. GaN transistors for efficient power conversion. John Wiley & Sons, 2019.

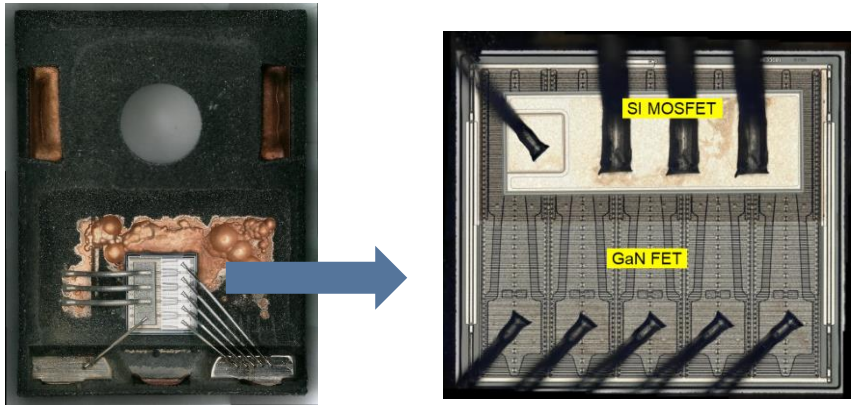
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Introduction Cascode GaN HEMT

Cascode d-mode GaN

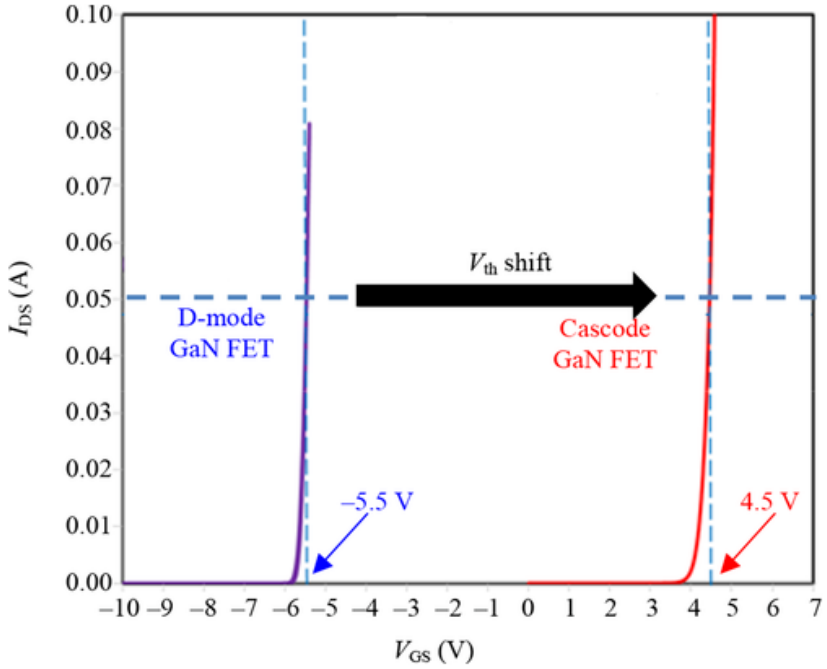


Normally-on GaN in cascode with normally-off Si MOS

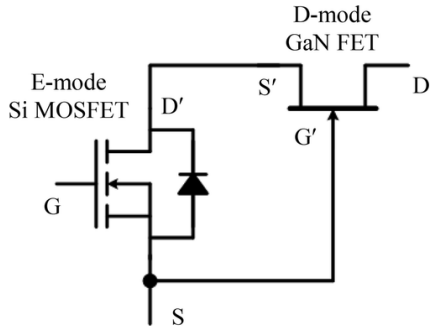


Cascode GaN HEMT

Si MOSFET Stacked on the top of GaN FET

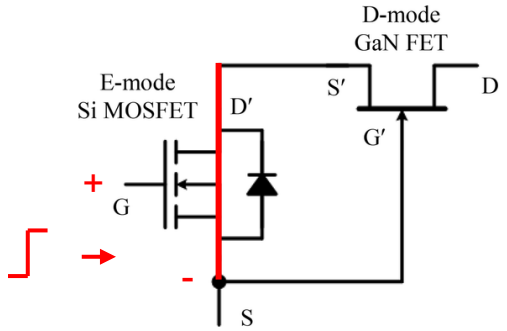


Gate characteristic of cascode GaN HEMT

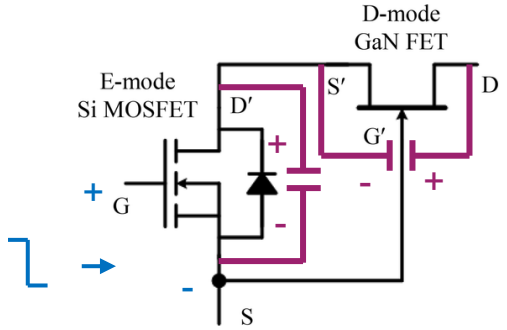


Cascode GaN structure

Turn on



Turn off



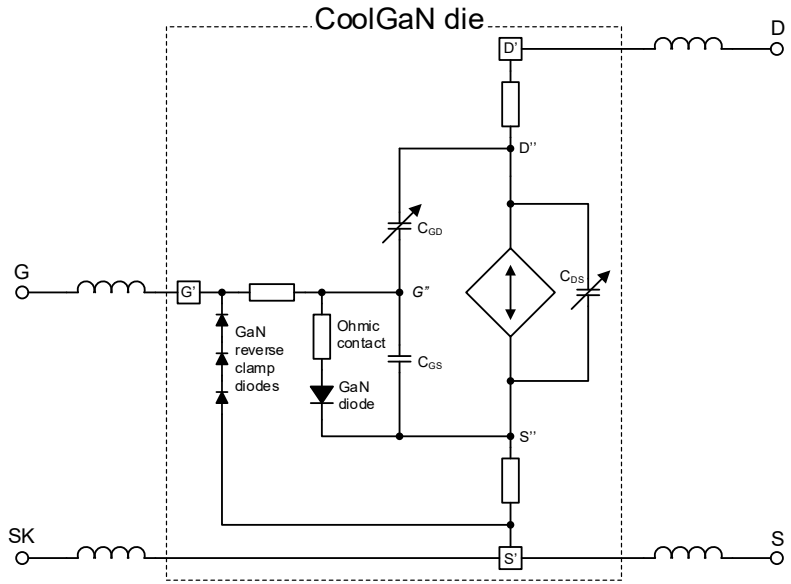
Drive it like a Silicon MOSFET

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Introduction e-mode GaN HEMT

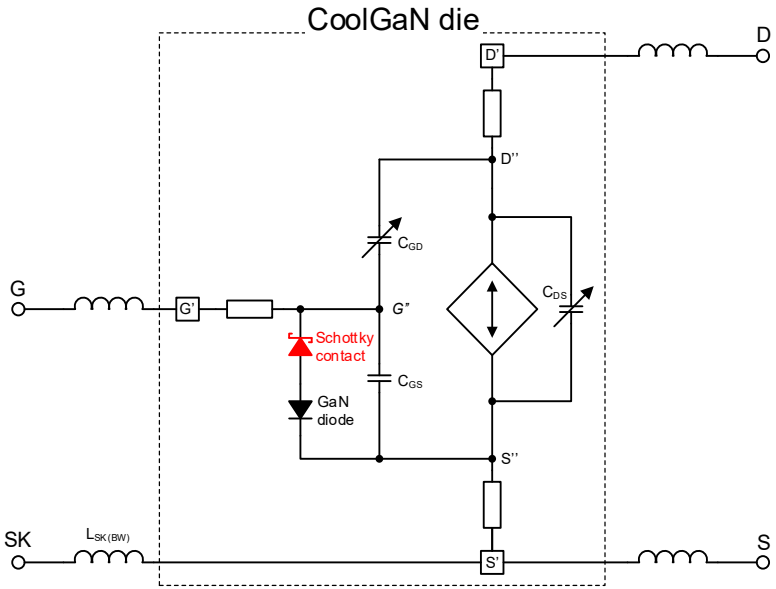
E-mode GaN

Ohmic pGaN

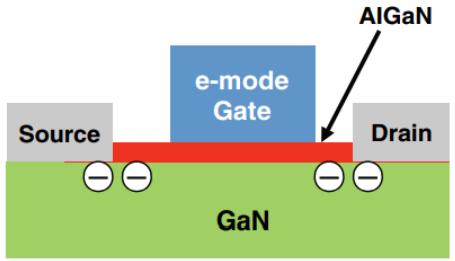


CoolGaN™
GIT (Gate Injection Transistor) HEMT

Schottky pGaN



CoolGaN™
SG (Schottky Gate) HEMT



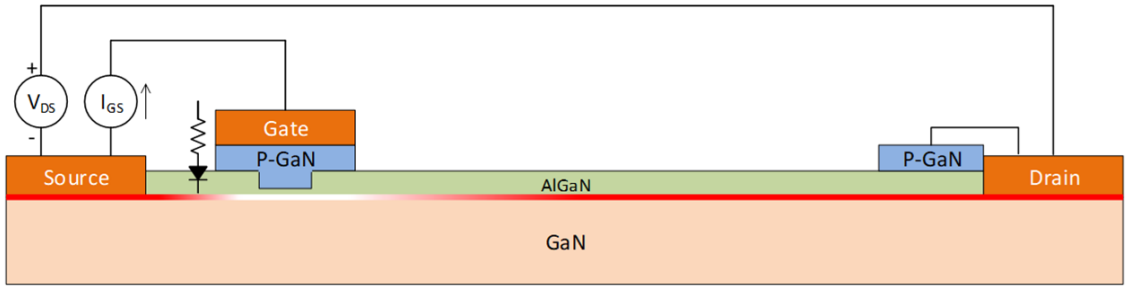
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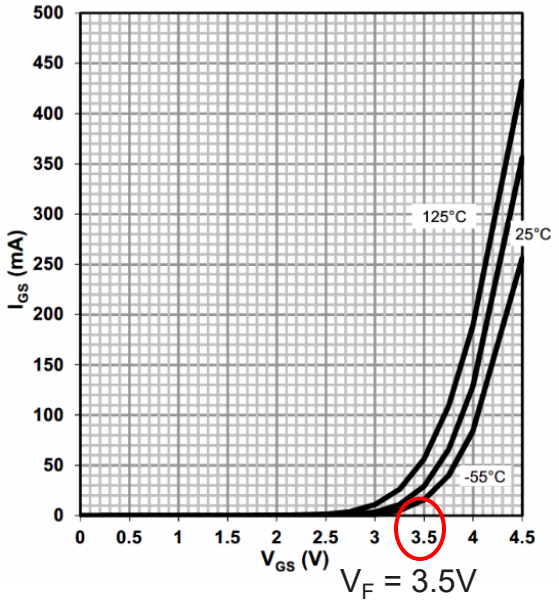
E-mode GaN: gate drive characteristic

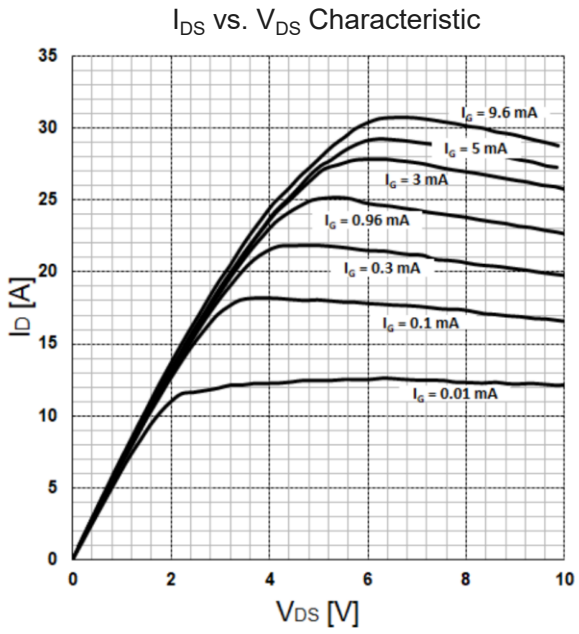
E-mode GaN

Ohmic pGaN

Current source gate drive

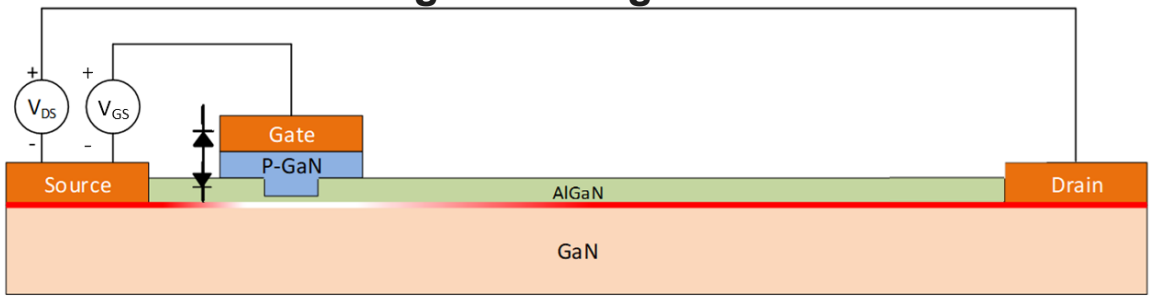


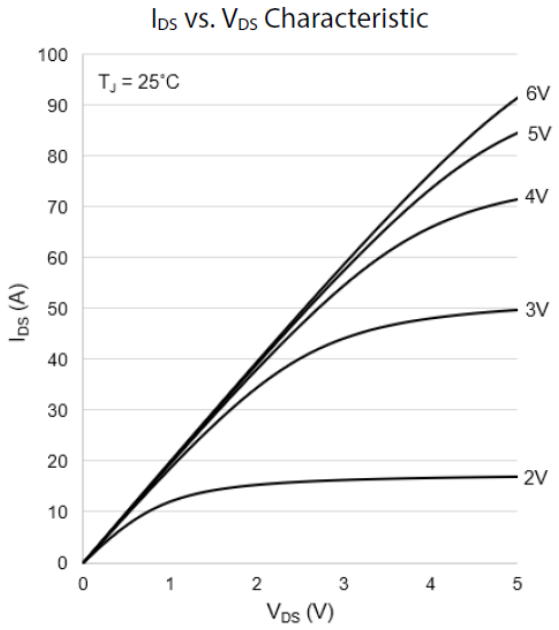




Schottky pGaN

Voltage source gate drive

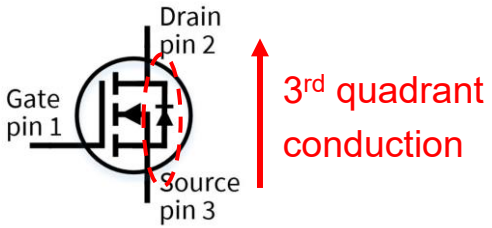




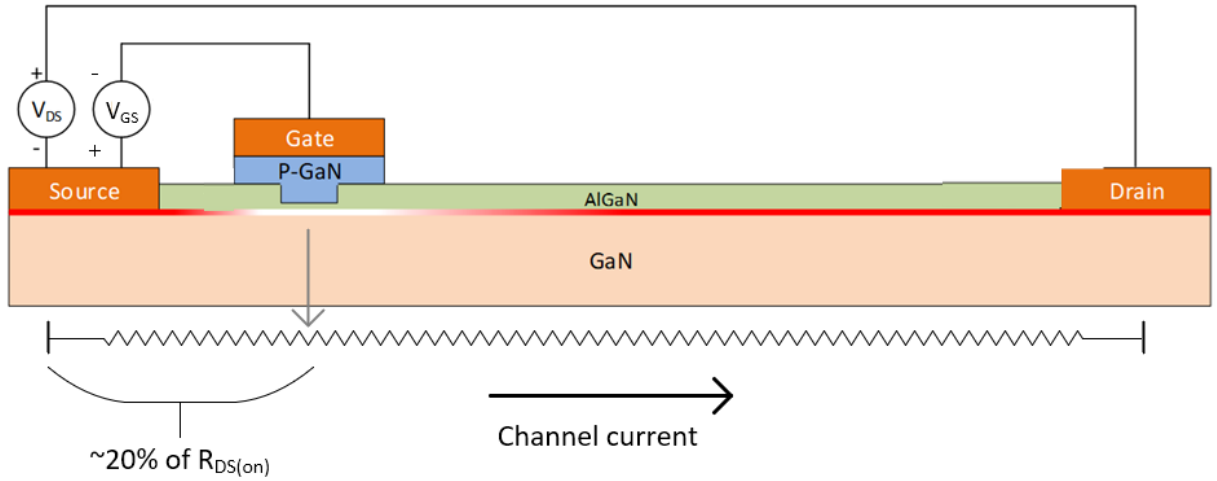
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E-mode GaN: third quadrant conduction characteristic

Body diode of Silicon MOSFET



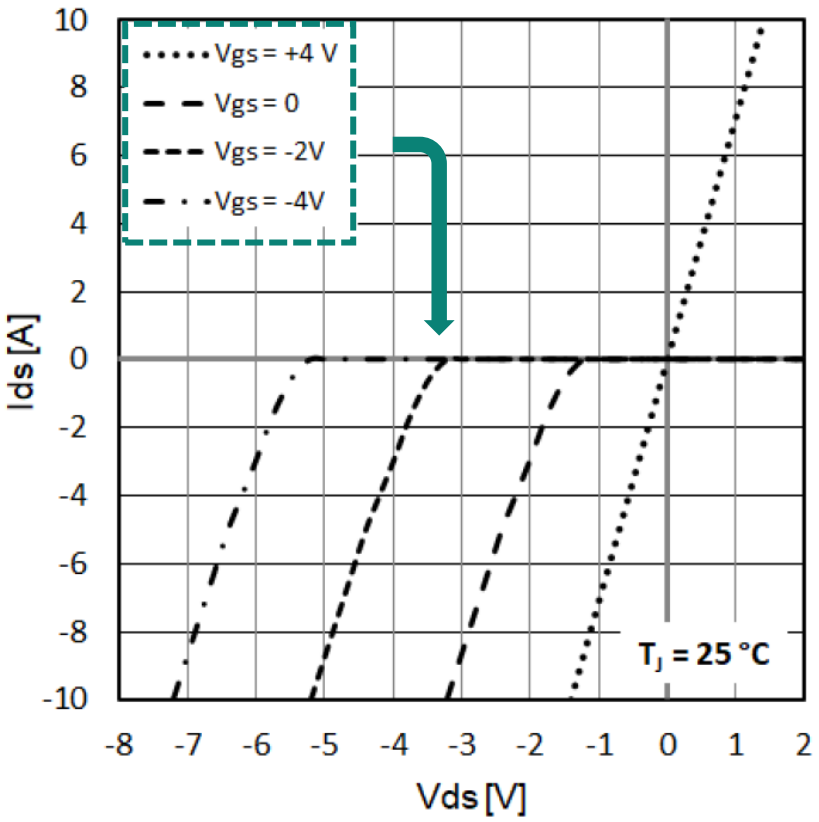
E-mode GaN: third quadrant conduction



$V_{GS} > V_{th}$ → 1st quadrant conduction

$V_{GD} > V_{th}$ → 3rd quadrant conduction

E-mode GaN: third quadrant characteristics I_{ds} - V_{ds}



When designing **negative gate bias** for GaN, it's a trade-off between **cross-conduction immunity** and **3rd quadrant loss**

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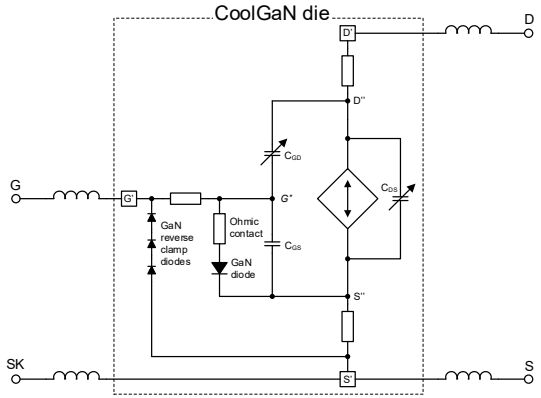
4 GaN HEMT application 33

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Driving e-mode GaN HEMT

E-mode GaN

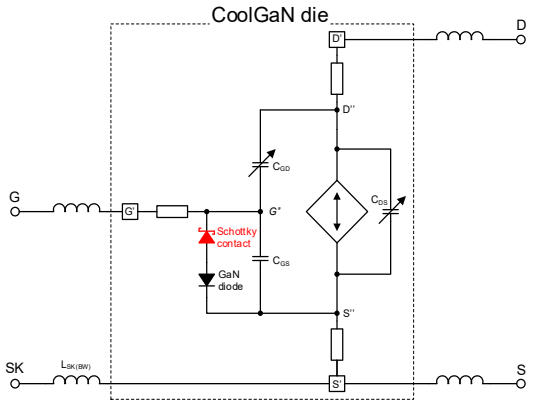
Ohmic pGaN



CoolGaN™

GIT (Gate Injection Transistor) HEMT

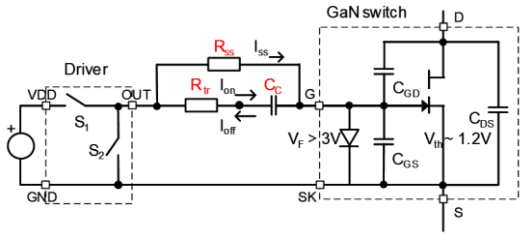
Schottky pGaN



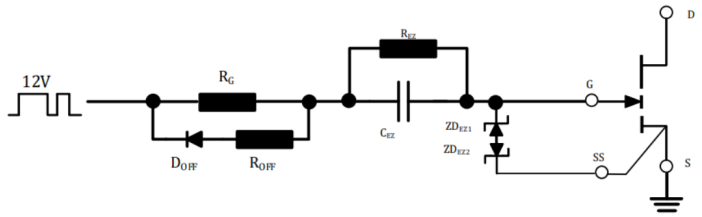
CoolGaN™

SG (Schottky Gate) HEMT

+



RC interface

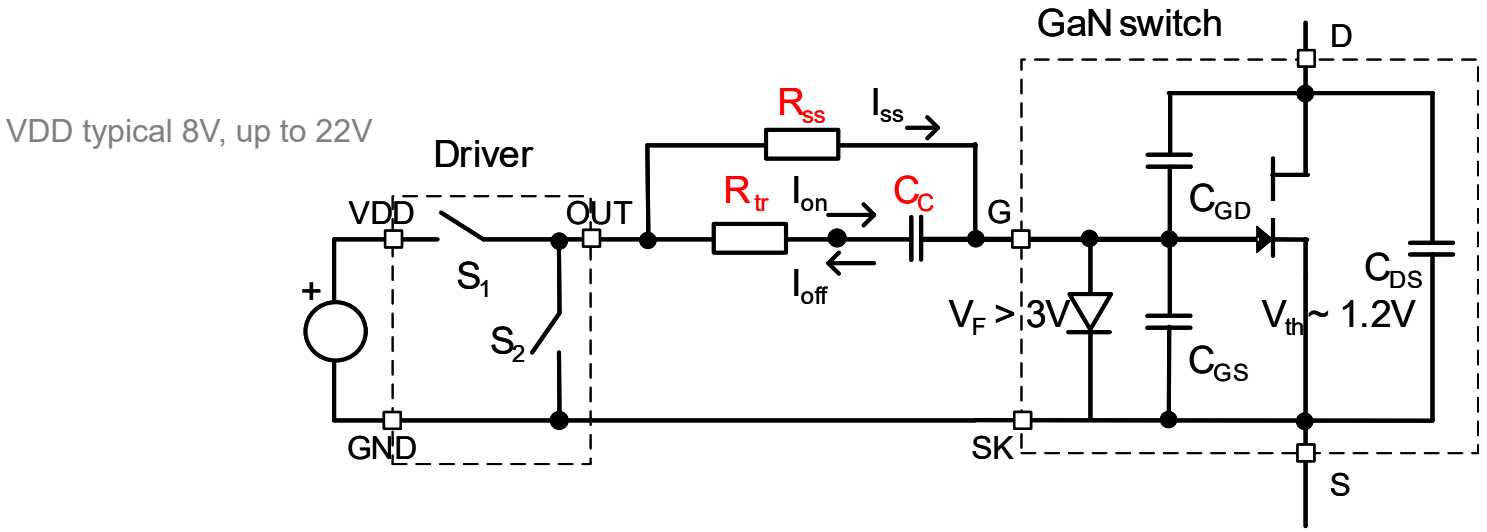


EZDrive

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Driving CoolGaN™ GIT HEMT

RC interface



Typical gate drive RC interface for Infineon CoolGaN™ GIT HEMT

R_{ss}: steady-state gate current tuning resistor

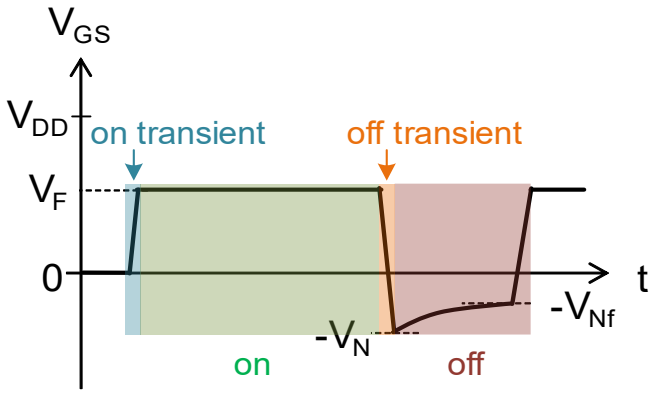
R_{tr}: transient switching speed dv/dt tuning resistor

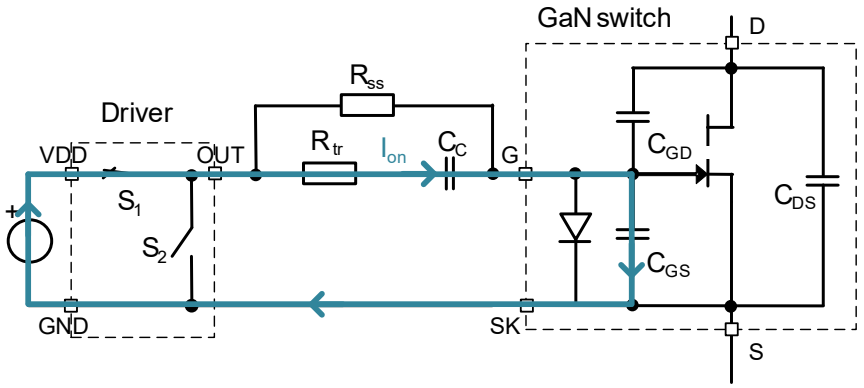
C_C: coupling capacitor as charge pump to provide fast-switching transient as well as negative gate bias

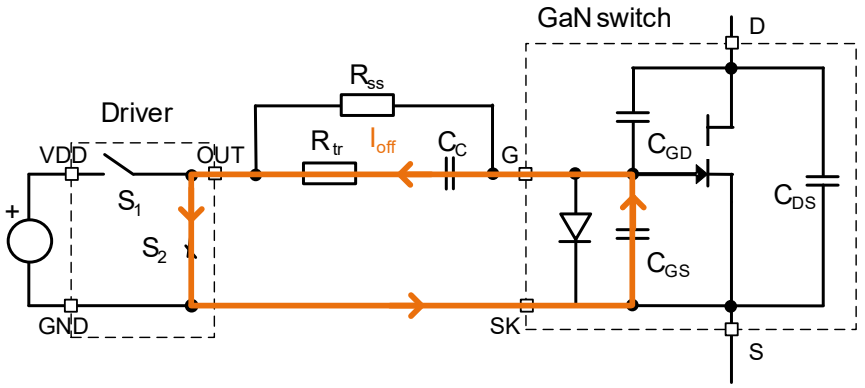
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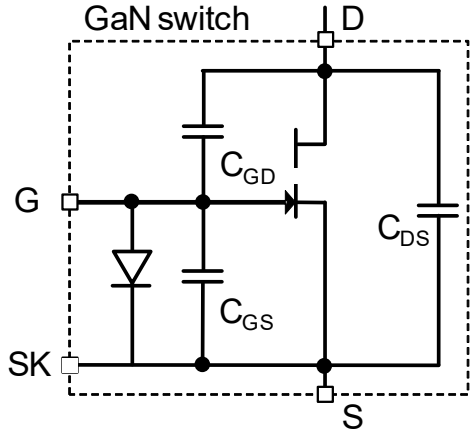
Driving CoolGaN™ GIT HEMT

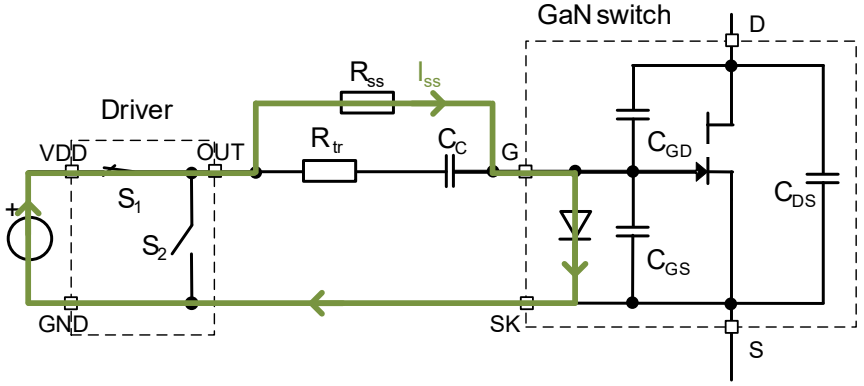
RC interface

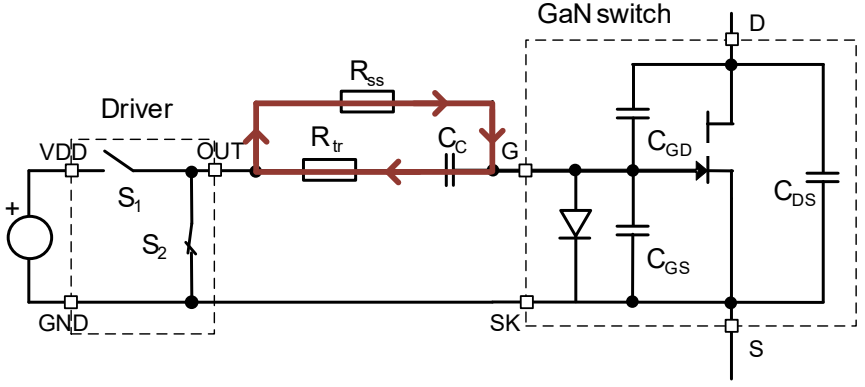












CoolGaN™ GIT HEMT equivalent circuit

Typical gating procedure of CoolGaN™ GIT HEMT

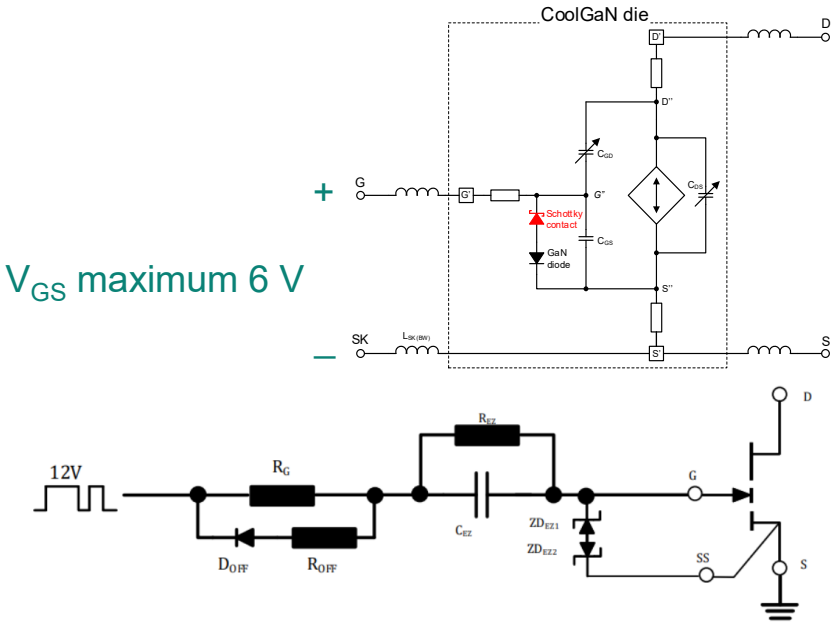
https://www.infineon.com/dgdl/Infineon-Gate_drive_configurations_for_GaN_power_transistors-Whitepaper-v01_00-EN.pdf?fileId=8ac78c8c8e7ead30018ee5fe05620899&da=t

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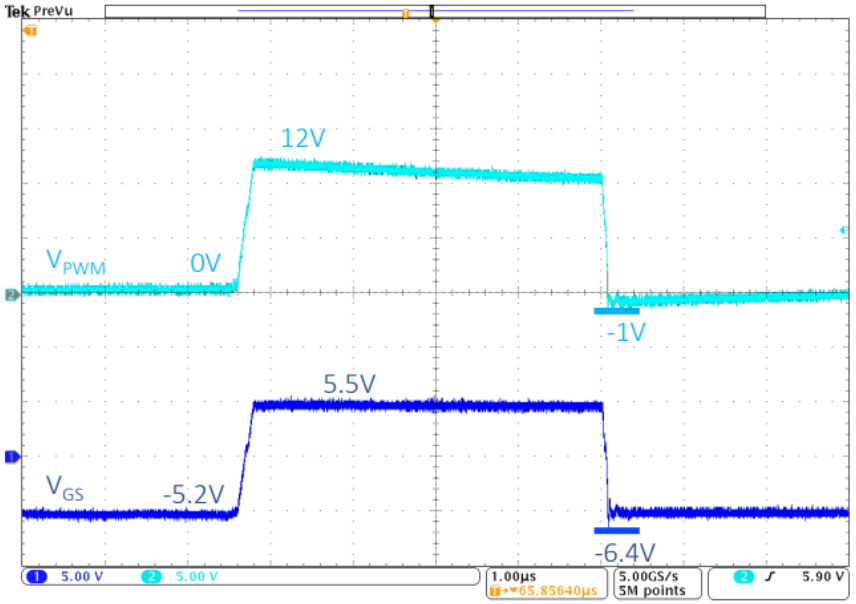
Driving CoolGaN™ SG HEMT

EZDrive

V_{GS} maximum 6 V



Typical gate drive configuration for legacy GaNSystems SG HEMT



Enables 12 V driver to drive 6 V GaN

R_{EZ}: steady-state current for Zener diode biasing

$R_{G,}$ R_{OFF}: transient switching speed dv/dt tuning resistor

C_{EZ}: coupling capacitor as charge pump to provide fast-switching transient as well as negative gate bias

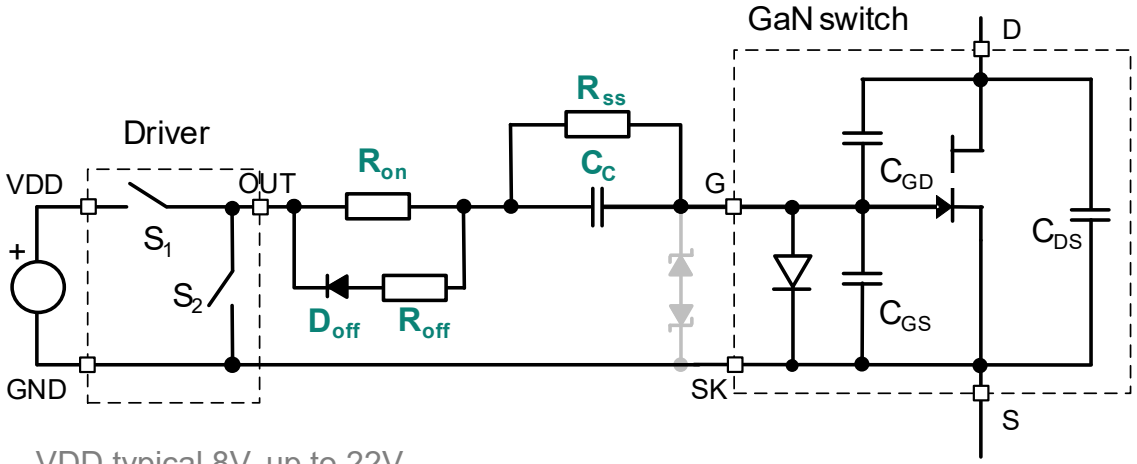
ZD_{EZ1}, ZD_{EZ2}: Zener diode to clamp the positive and negative gate voltage

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Universal gate drive design for Infineon e-mode GaN HEMT

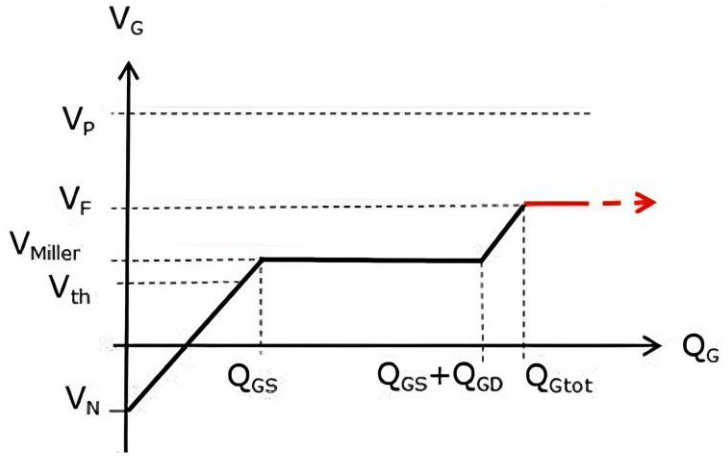
Ohmic pGaN – GIT HEMT

* **Gray component in the schematic is redundant design to accommodate both ohmic pGaN and Schottky pGaN products from Infineon**

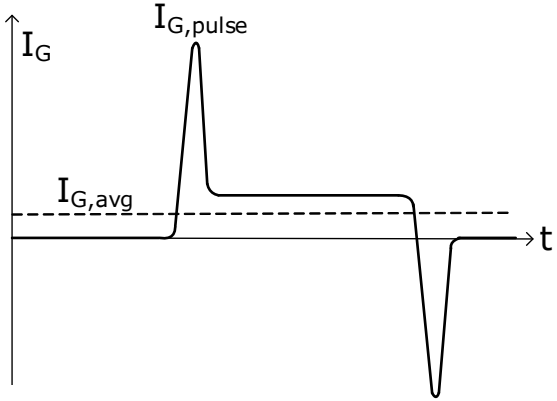


VDD typical 8V, up to 22V

Typical RC interface for Infineon CoolGaN™ GIT HEMT



Gate voltage during turn-on



Gate current waveform

R_{ss}: keep the steady-state gate current I_{ss}

R_{on}, R_{off}: transient switching speed dv/dt tuning resistor

Gate drive configurations for GaN power transistors

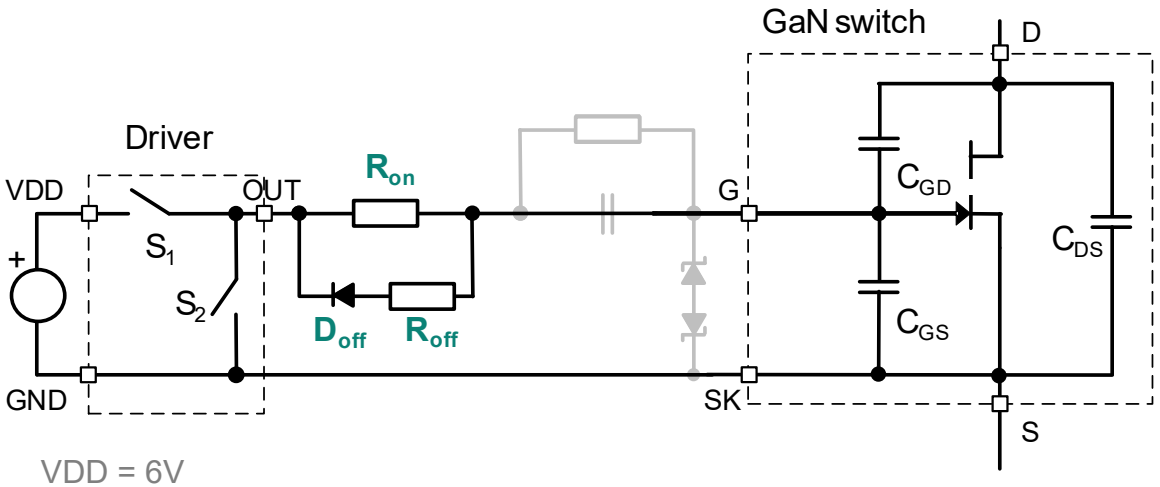
C_C: coupling capacitor as charge pump to provide fast-switching transient as well as negative gate bias

Ohmic pGaN and Schottky pGaN from Infineon are inter-replaceable, fitting on the same PCB

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Universal gate drive design for Infineon e-mode GaN HEMT

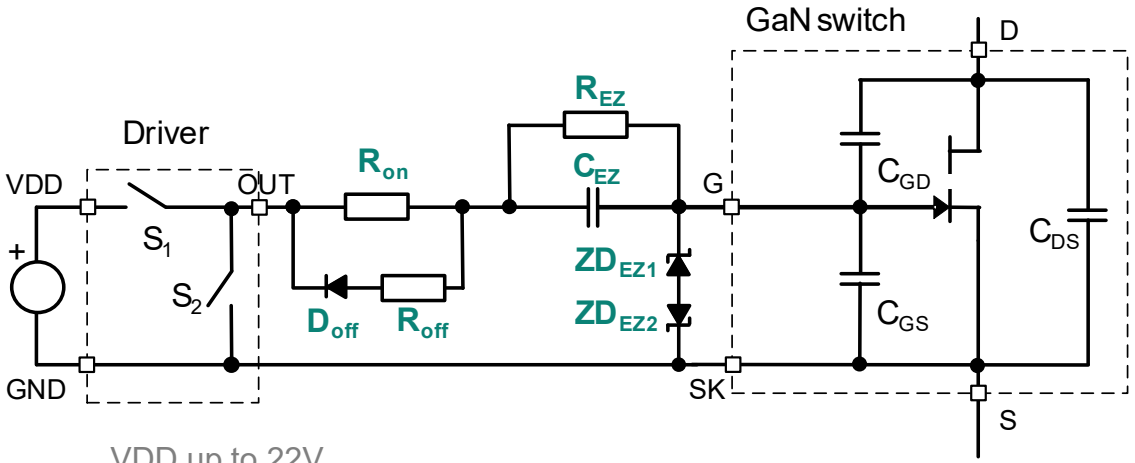
Schottky pGaN – SG HEMT



VDD = 6V
VDD = 9V, bipolar gate voltage +6V, -3V recommended

When VDD = 6V, drive with gate resistor **R_{on} & R_{off}**, just like Silicon MOSFET

* **Gray component in the schematic is redundant design to accommodate both ohmic pGaN and Schottky pGaN products from Infineon**



VDD up to 22V

When VDD > 6V, drive with EZDrive

R_{EZ}: keep the driving voltage

ZD_{EZ1}, ZD_{EZ2}: Zener diode to clamp the positive and negative gate voltage

C_{EZ}: coupling capacitor as charge pump to provide fast-switching transient as well as negative gate bias

EZDrive Power Stage Solutions for GaN Systems' GaN Transistor

Ohmic pGaN and Schottky pGaN from Infineon are inter-replaceable, fitting on the same PCB

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3 **Dynamic Rds(on) of GaN HEMT** **20**

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What is Dynamic $R_{DS(on)}$?

- Increase in effective $R_{DS(on)}$ due to **trapping** of electrons in undesired locations of the GaN device structure

- Two electron trapping mechanisms:

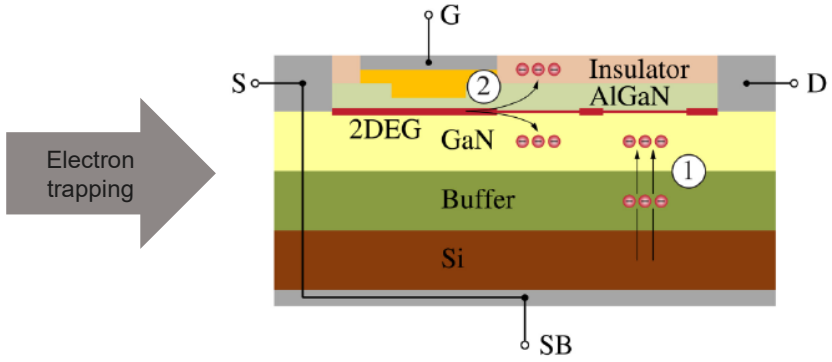
  1. **OFF-state trapping** due to large electric field between Drain and Substrate resulting in holes filled with electrons coming from the leakage current through Si Substrate

  2. **Hot-electron trapping** due to large electric field and large current at the same time (I–V overlap) in the 2DEG area during hard-switching transition resulting in high-energy electrons trapped in different layers

- Dynamic $R_{DS(on)}$ is a factor of conduction parameters

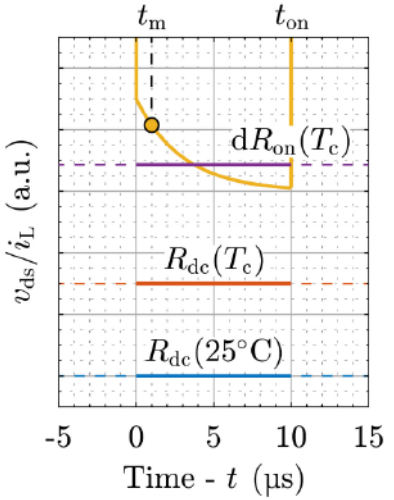
- From **application perspective**, it is important to determine:
  - the averaged $R_{DS(on)}$ during the ON-state interval

- From **technology perspective**, it is important to determine:
  - main factors impacting Dynamic $R_{DS(on)}$



$$P_{cond} = R_{DS(on),dyn} \cdot I^2$$

Averaged $R_{DS(on)}$ over t_{on}



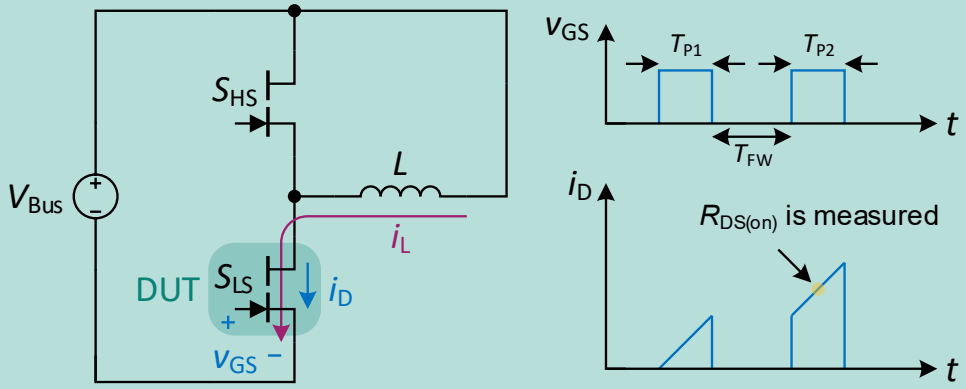
[Source: G. Zulauf, M. Guacci, and J. W. Kolar, "Dynamic On-Resistance in GaN-on-Si HEMTs: Origins, Dependencies, and Future Characterization Frameworks", IEEE TPEL, 2020]

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Methods to measure Dynamic $R_{DS(on)}$

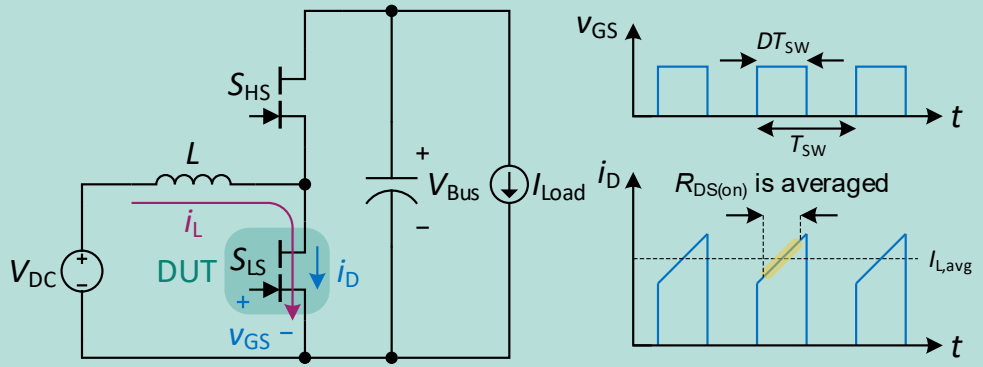
Double-pulse test (DPT)

- Faster to run
- Easier to run
- Not able to capture system-related parameters such as
  - Switching frequency
  - Duty cycle
  - Switching transition (HSW or SSW)



Continuous-run test (CRT)

- Needs more time to run
- Needs more test equipment
- Able to capture system-related parameters such as
  - Switching frequency
  - Duty cycle
  - Switching transition (HSW or SSW)



» **Due to being more similar to the real application, the CRT method is selected for measurement.**

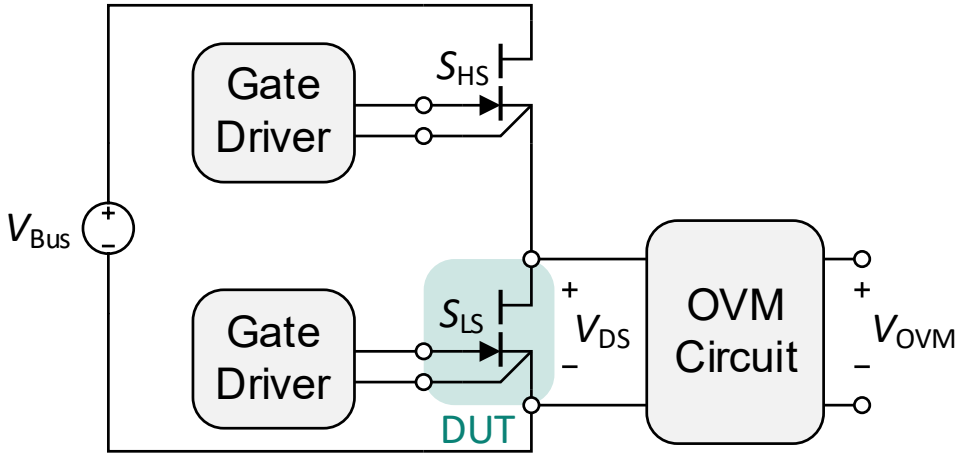
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On-state voltage measurement (OVM) circuit

- Objectives
  - Accurately measure low-voltage $V_{DS(on)}$ when DUT* is ON
  - Block high-voltage V_{BUS} when DUT is OFF

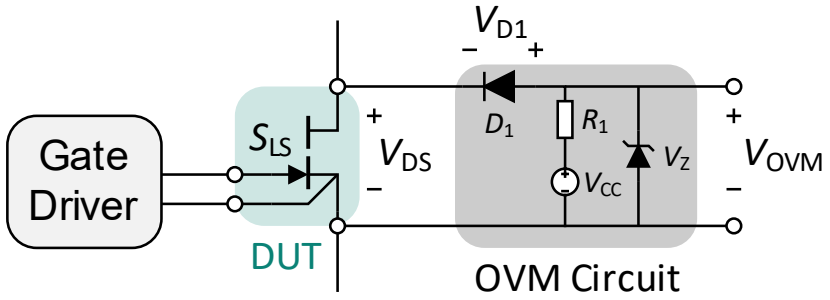
Note: Dynamic response of the OVM circuit needs to be short enough.

It determines how long after turning DUT ON, voltage measurement is valid.



* DUT: Device under test

OVM circuit concept



- DUT: ON → $V_{OVM} = V_{DS} + V_{D1}$
- DUT: OFF → $V_{OVM} = V_Z$

Varies with temp. and current

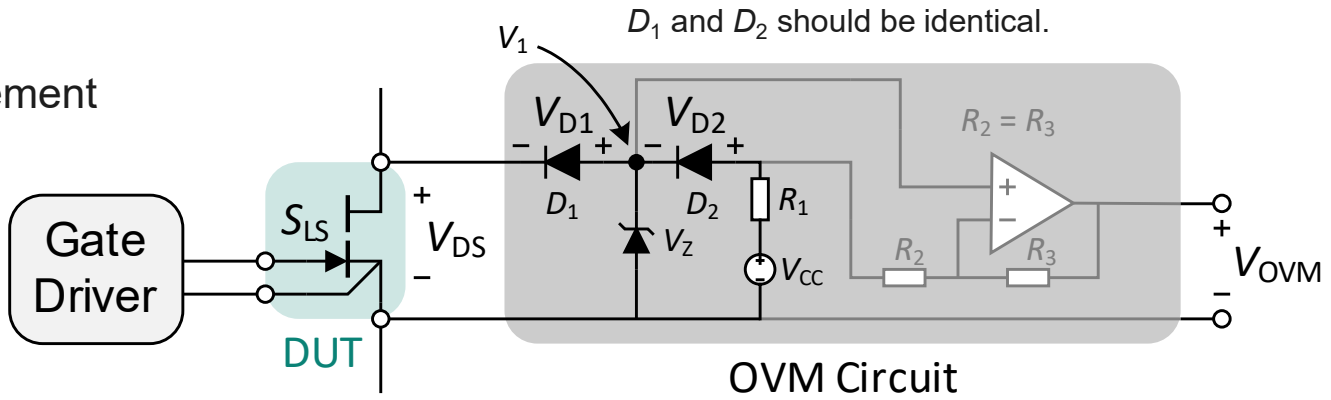
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On-state voltage measurement (OVM) circuit

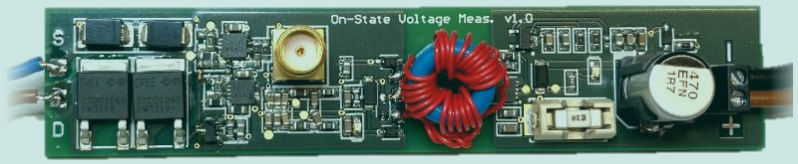
Dual-diode solution

New solution to improve ON-state voltage measurement

- Idea
  - Removing the blocking diode voltage from measurement using an analog circuit
- Features
  - Self-compensates the blocking diode voltage
  - Eliminates the impact of temp. on measurement
  - Longer response time due to additional analog circuit



OVM board



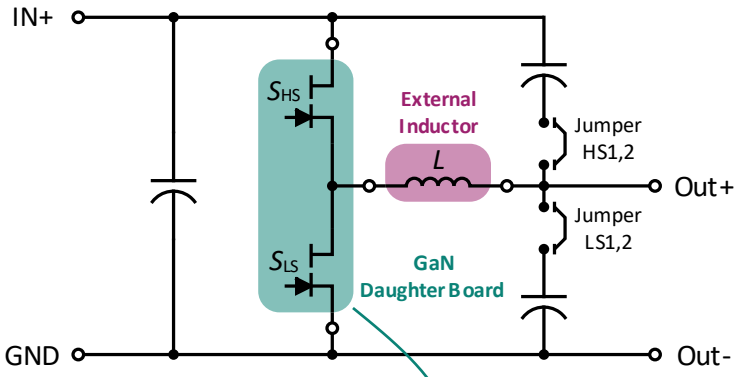
- $V_{OVM} = V_1 - V_{D2}$ — Independent of diode voltage
- DUT: ON → $V_1 = V_{DS} + V_{D1}$ → $V_{OVM} = V_{DS}$
- DUT: OFF → $V_1 = V_Z$ → $V_{OVM} = V_Z - V_{D2}$

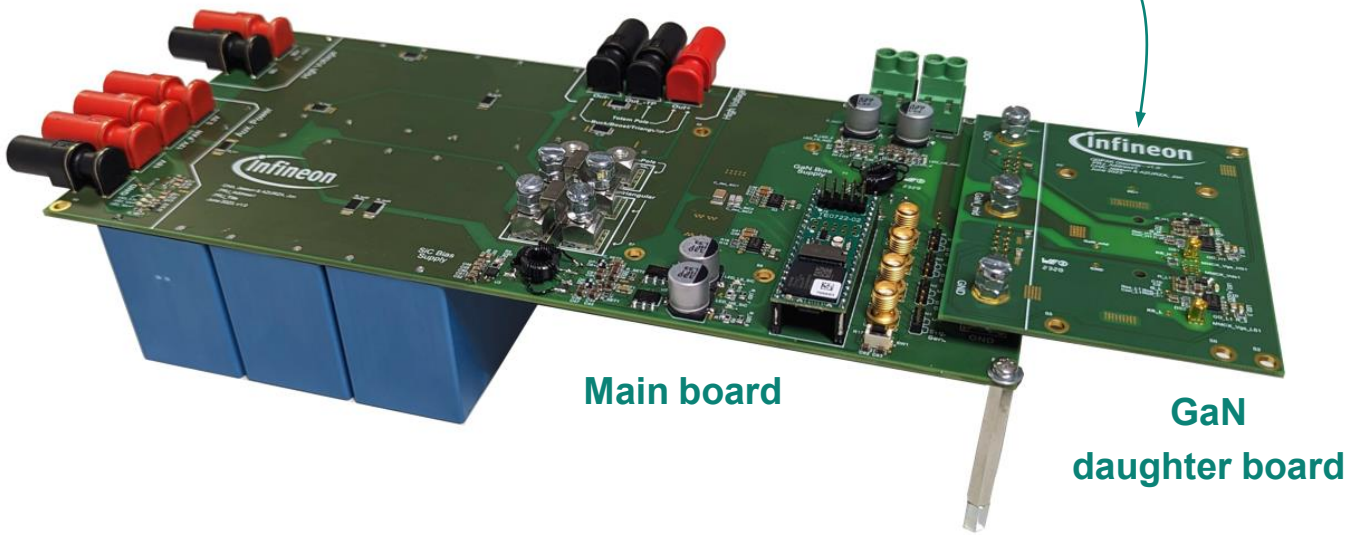
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Test platform

Main board + daughter board approach

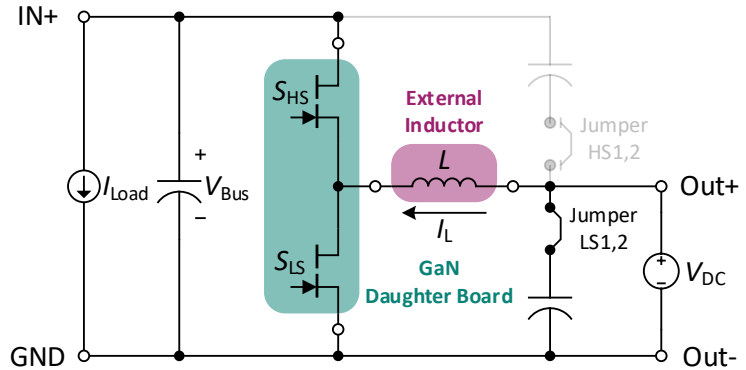
- Features
  - Configurable for different circuit topologies
  - Able to test different device packages
  - Adjustable supply voltages to be compatible with both SG and GIT technologies



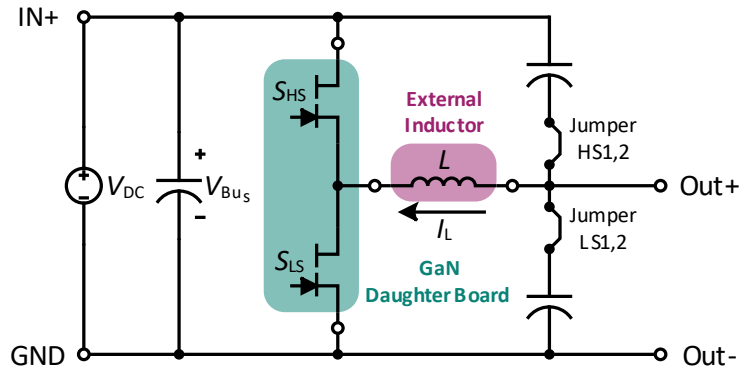


Circuit configurations

Hard-switched boost circuit

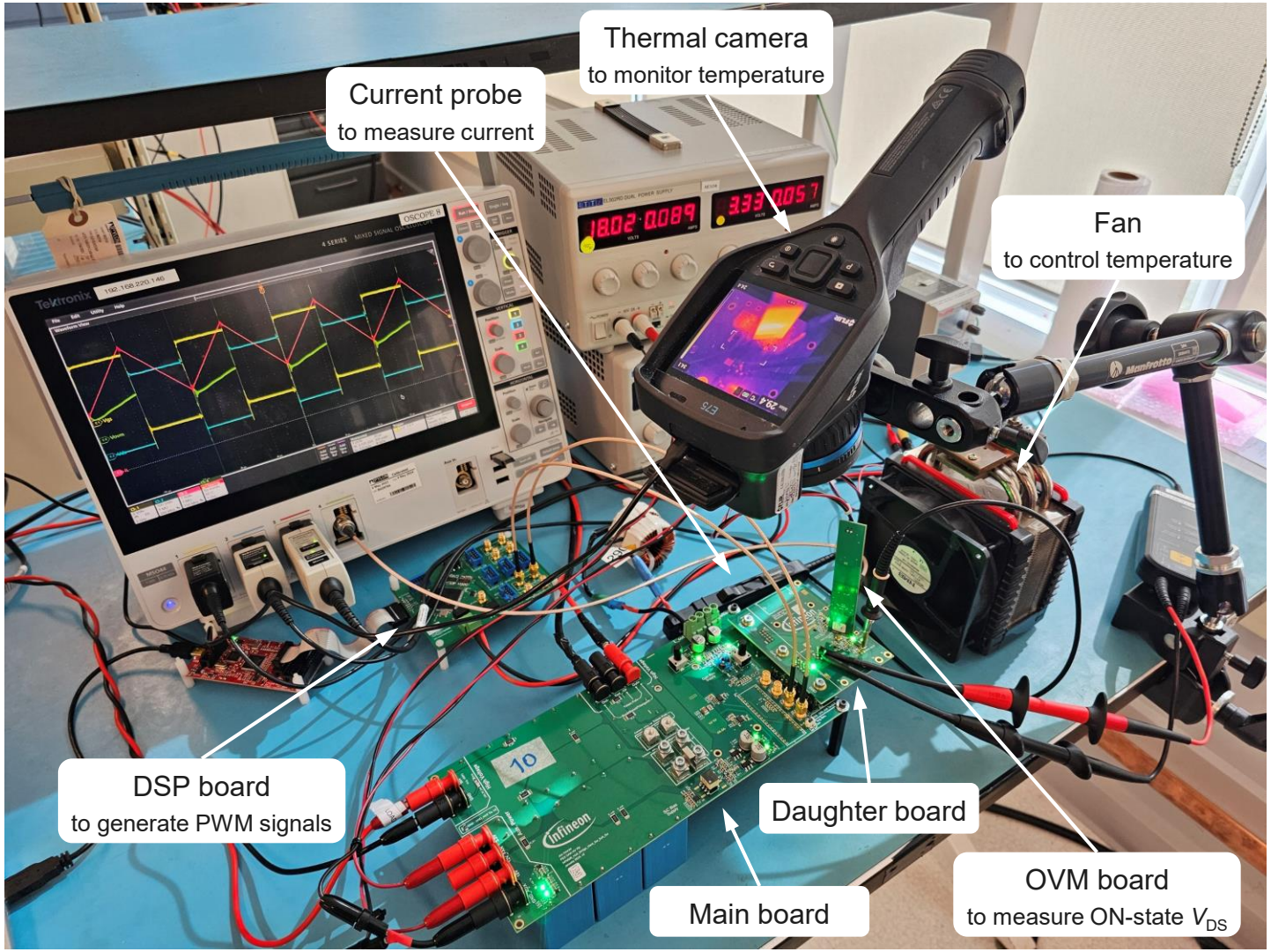


Soft-switched half-bridge circuit



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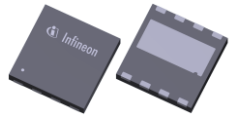
Test setup



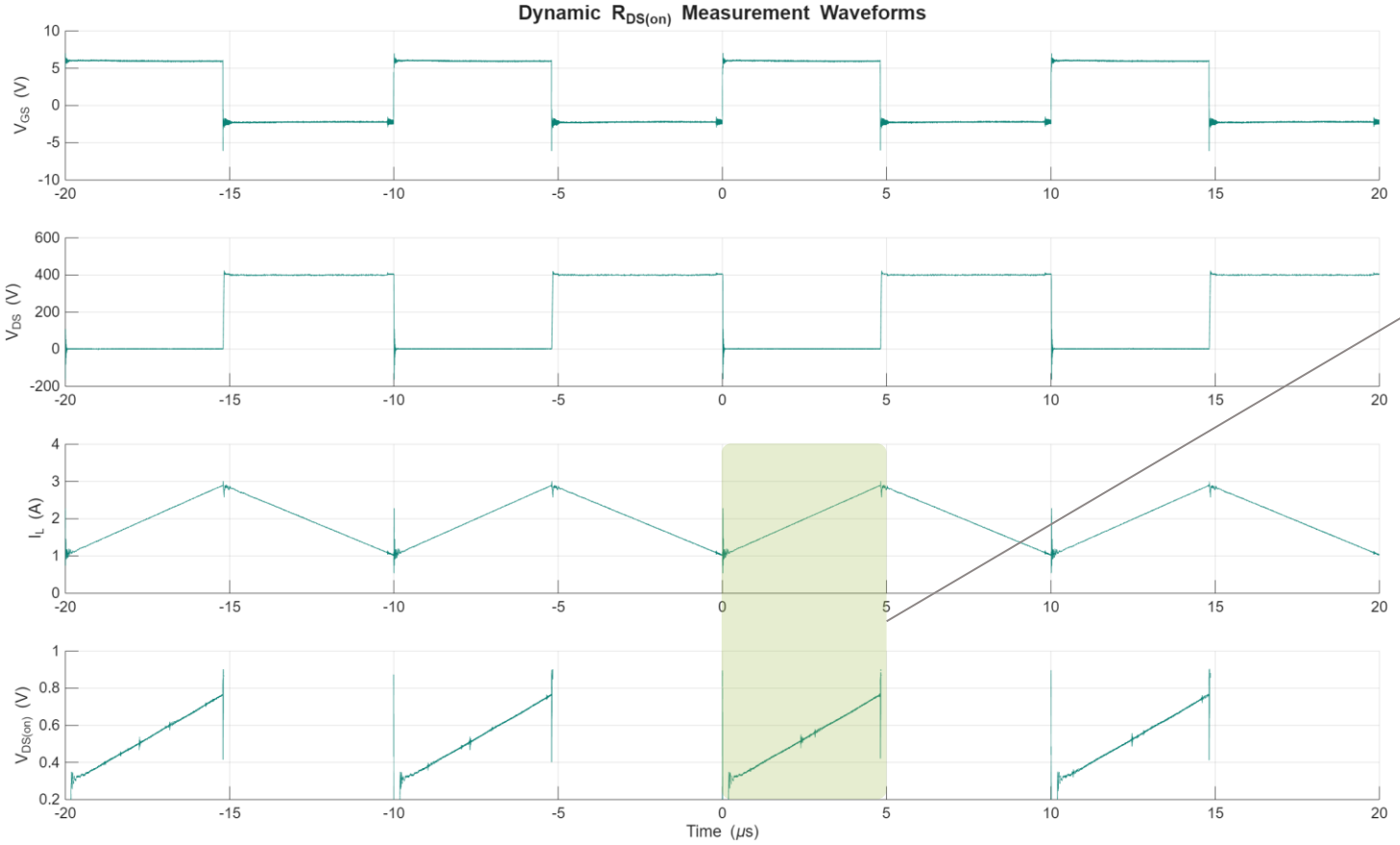
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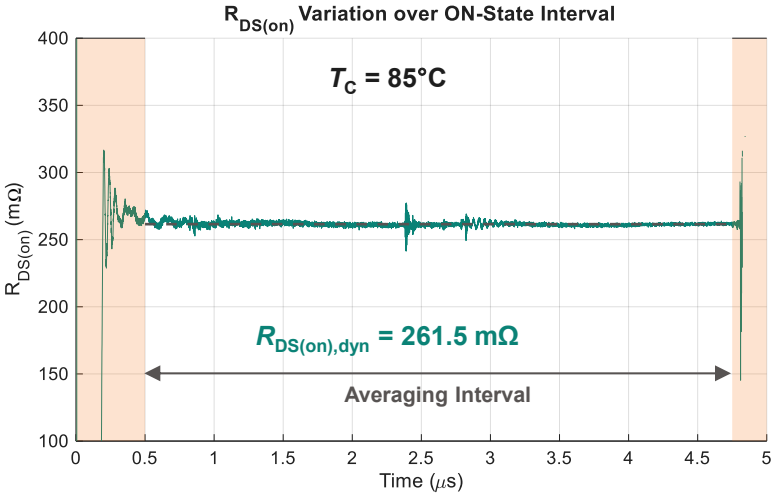
Measurement example

GS-065-011-6-LR in hard-switching operation



Waveforms





$R_{DS(on),static}$ = 199.3 mΩ @ 85°C

Dynamic $R_{DS(on)}$ ratio = 1.32

Test Conditions

System Parameters:

V_{Bus} = 400 V, $I_{L,avg}$ = 2 A, f_{sw} = 100 kHz, D = 0.5, Dead Time: 200 ns, L = 500 µH

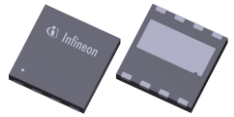
Gate Drive Parameters:

V_{Drive} = 6 V / -3 V, $R_{g,on}$ = 15 Ω, $R_{g,off}$ = 2 Ω

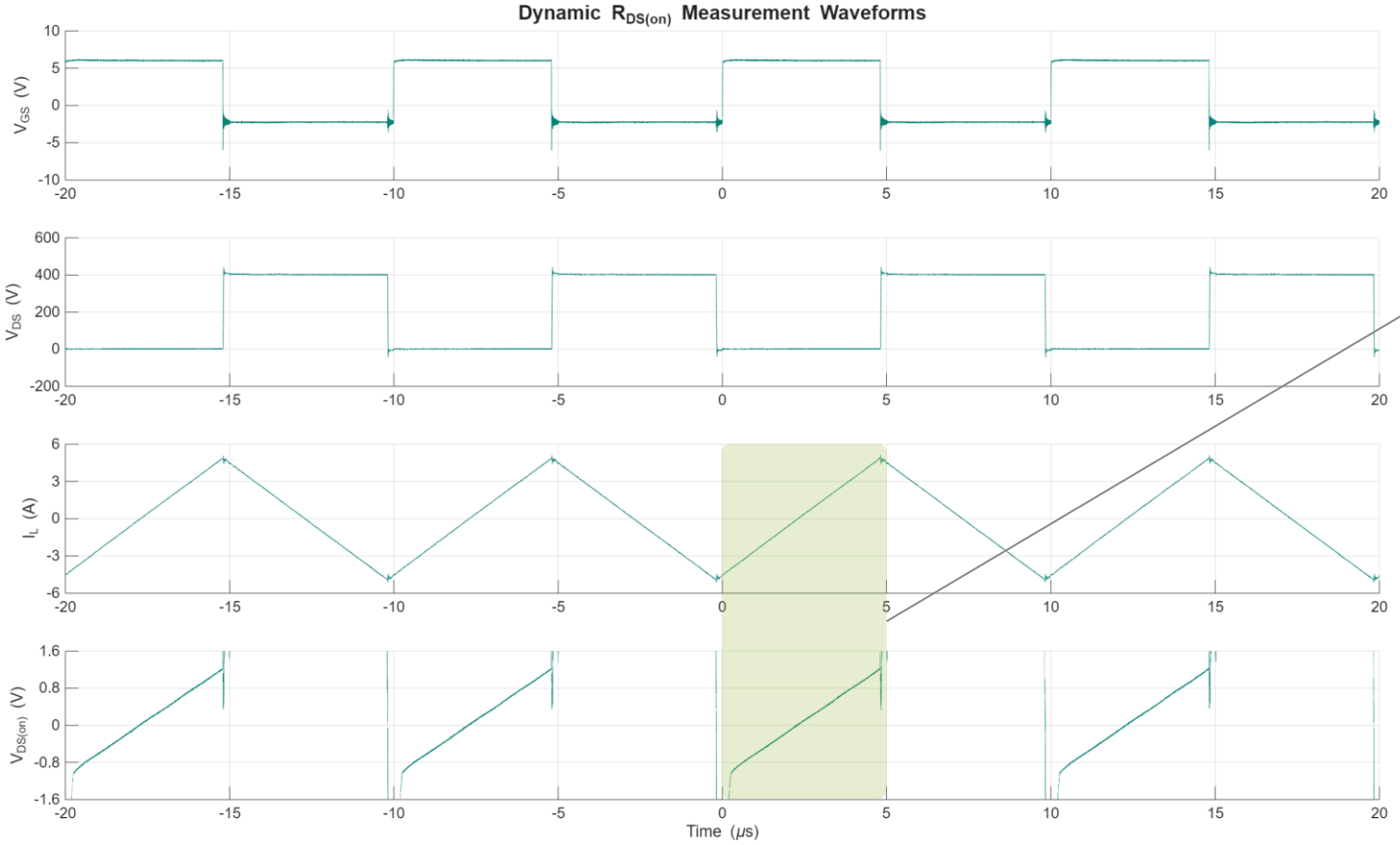
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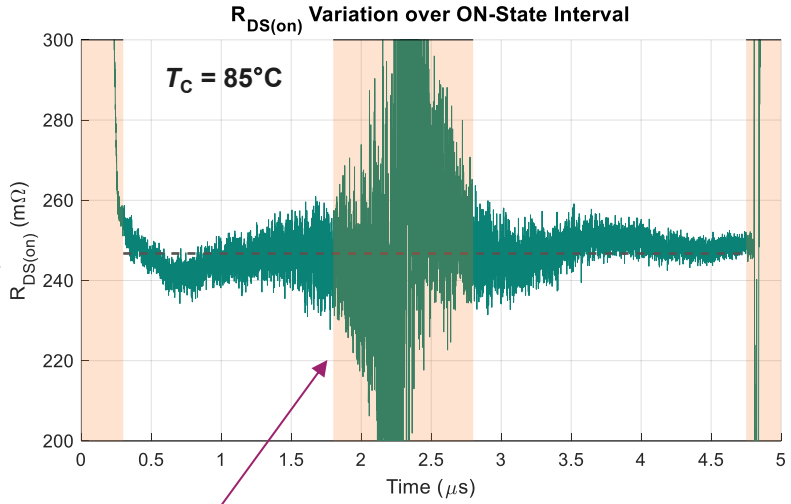
Measurement example

GS-065-011-6-LR in soft-switching operation



Waveforms





Test Conditions

System Parameters:

V_{Bus} = 400 V, $I_{L,peak}$ = 5 A, f_{sw} = 100 kHz, D = 0.5, Dead Time: 200 ns, L = 100 µH

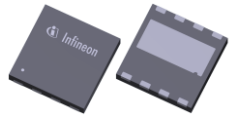
Gate Drive Parameters:

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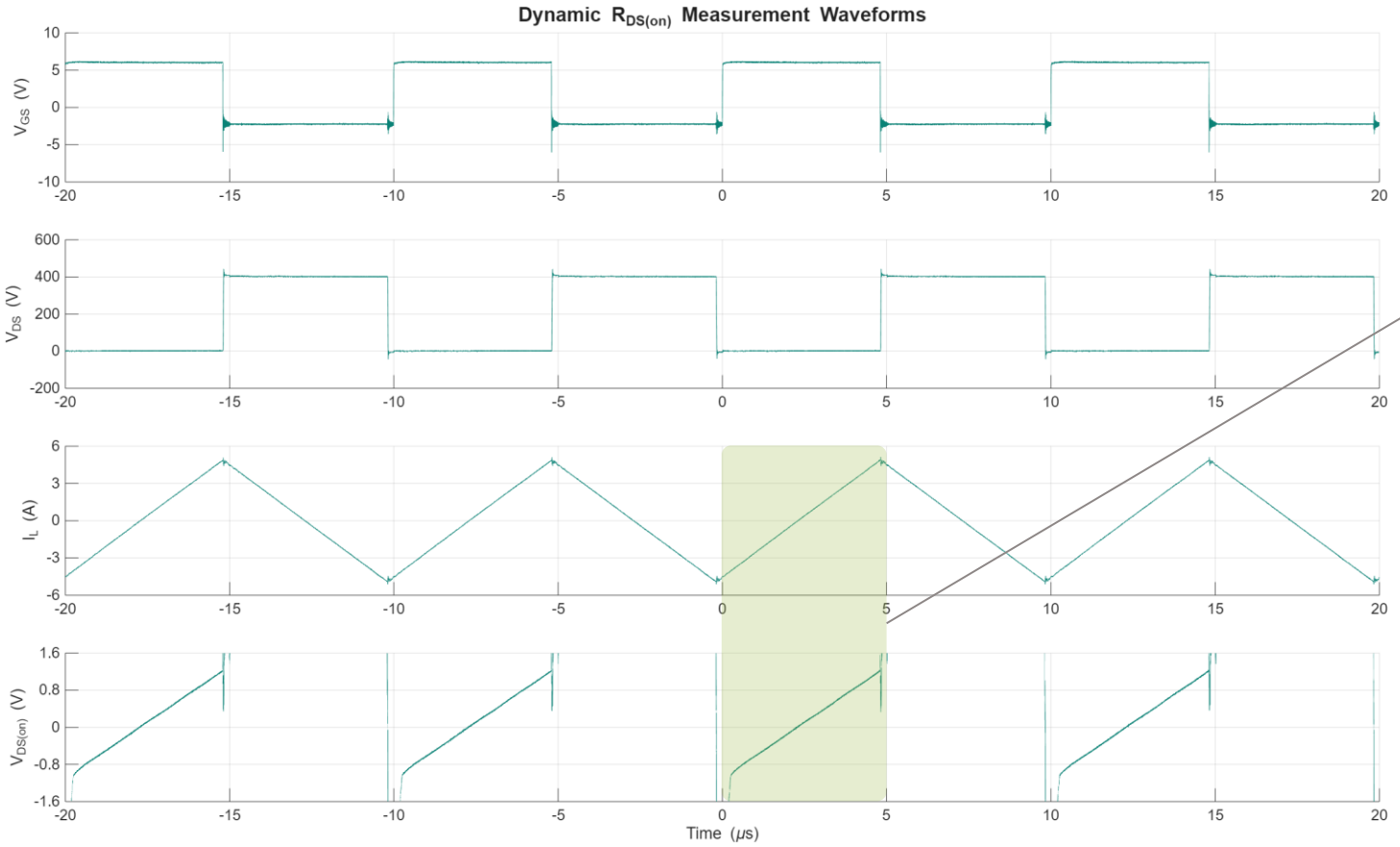
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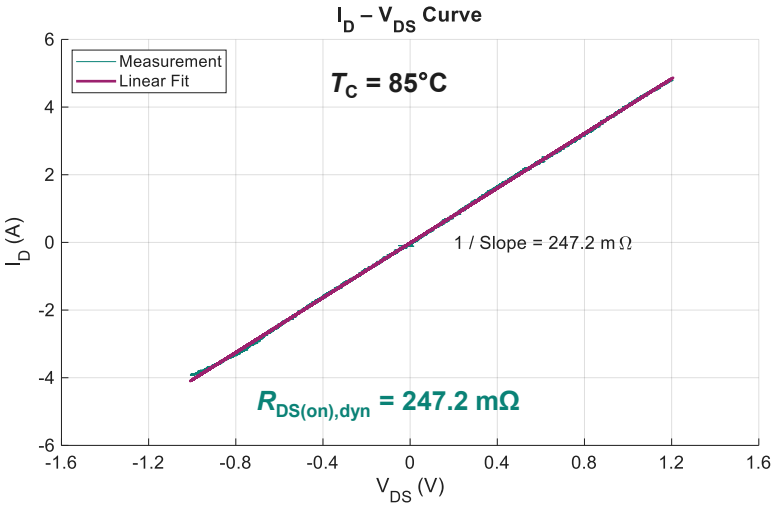
Measurement example

GS-065-011-6-LR in soft-switching operation



Waveforms





$R_{DS(on),static}$ = 199.3 mΩ @ 85°C

Dynamic $R_{DS(on)}$ ratio = 1.24

Test Conditions

System Parameters:

V_{Bus} = 400 V, $I_{L,peak}$ = 5 A, f_{sw} = 100 kHz, D = 0.5, Dead Time: 200 ns, L = 100 µH

Gate Drive Parameters:

V_{Drive} = 6 V / -3 V, $R_{g,on}$ = 15 Ω, $R_{g,off}$ = 2 Ω

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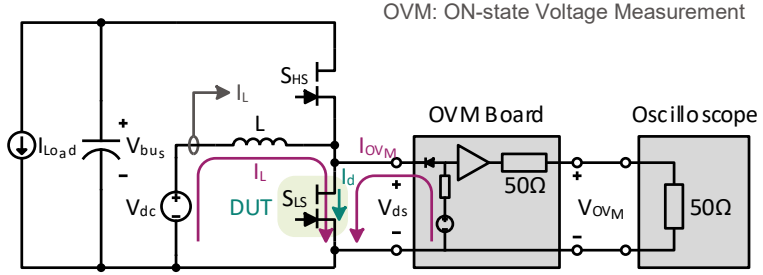
Dynamic $R_{DS(on)}$ Comparison

- The DUT is operated in a boost circuit to measure its dynamic $R_{DS(on)}$ under **hard-switching** operation
- All measurements are done **after 15 min** (long enough for thermal stability)
- The case temperature is adjusted on **85°C** by controlling **fan speed**

Test Conditions					
Part Number	$R_{g,on}$	$R_{g,off}$	R_{SS} / FB	C_C	V_{Drive}
NV6127	10 Ω	–	–	–	12 V / 0 V
IGLD65R140D2	12 Ω	12 Ω	820 Ω	1.2 nF	12 V / 0 V
INN700D140C	10 Ω	2 Ω	–	–	6 V / -3 V
TP65H150BG4JSG	50 Ω	10 Ω	330 Ω		6 V / -3 V

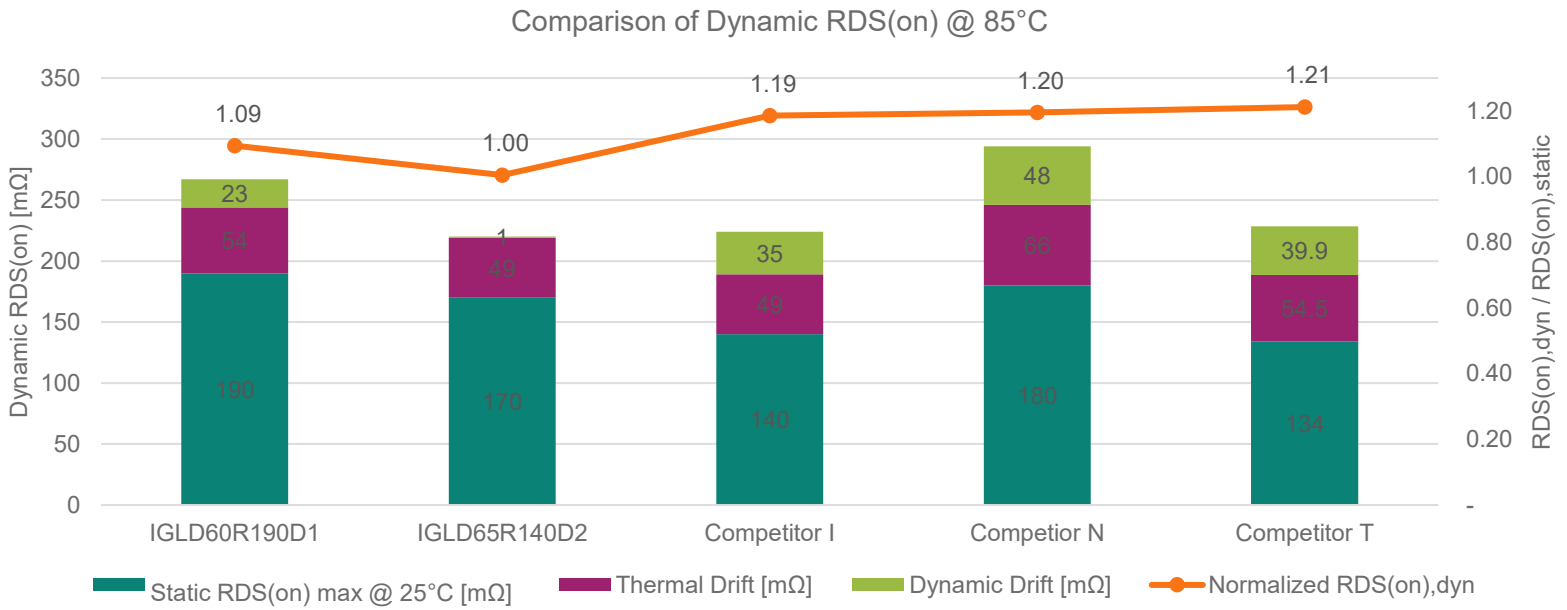
V_{Bus} = 400 V, $I_{L,avg}$ = 2 A, f_{sw} = 100 kHz, D = 0.5, Dead Time: 200 ns, L = 500 µH

OVM: ON-state Voltage Measurement



Dynamic $R_{DS(on)}$ comparison

T_c=85°C, hard switching operation and continuous runinng after 15 mins



- CoolGaN™ G5 transistors are offering **smaller dynamic & thermal drift of $R_{DS(on)}$ over competition**
- CoolGaN™ offering **~ 20 % lower dynamic $R_{DS(on)}$ drift** compared to competition
- Enabling reduced conduction losses & better thermals

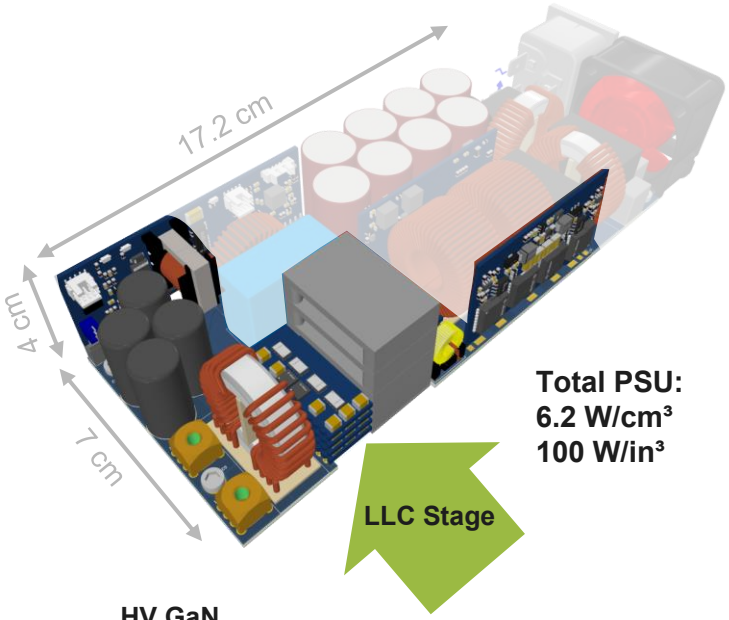
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System impact example

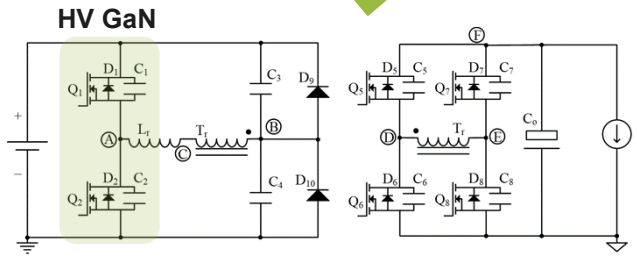
3.3 kW LLC module, 400 V $V_{dc,in}$ to 43–59 V $V_{dc,out}$, f_{res} = 400 kHz, soft-switching system

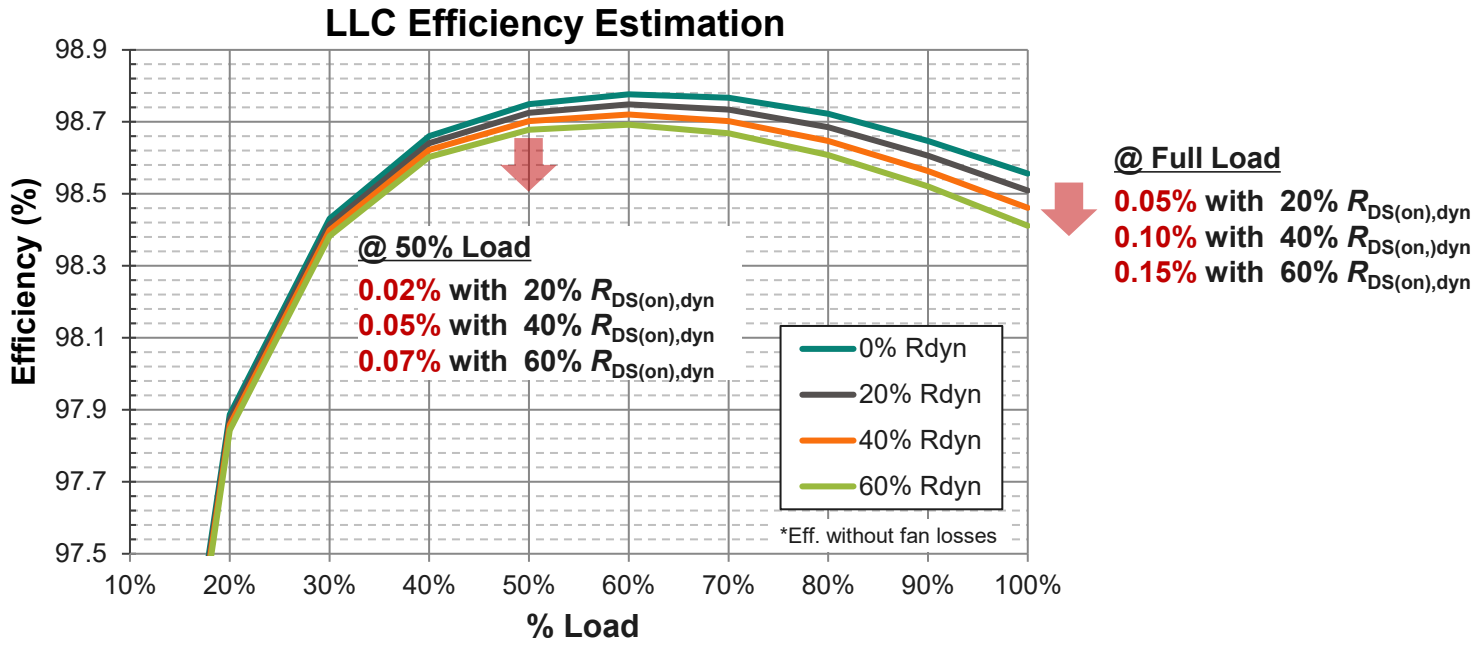
- Efficiency curves at 400 V $V_{dc,in}$ to 50 V $V_{dc,out}$, f_{sw} ≈ 380 kHz
- Calculated with 42 mΩ GaN devices, **assuming different $R_{DS(on),dyn}$**

Source:
Matteo Kutschak & Manuel Escudero
(PSS PS SYS SAA SAE ACDC)



HV GaN





@ Full Load
0.05% with 20% $R_{DS(on),dyn}$
0.10% with 40% $R_{DS(on),dyn}$
0.15% with 60% $R_{DS(on),dyn}$

@ Full Load	20% $R_{DS(on),dyn}$	40% $R_{DS(on),dyn}$	60% $R_{DS(on),dyn}$
Junction temp. increase	+5.1ºC (58.5ºC)	+10.3ºC (63.7ºC)	+15.7ºC (69.1ºC)
Loss increase (per prim-side device)	+18%	+36%	+54%

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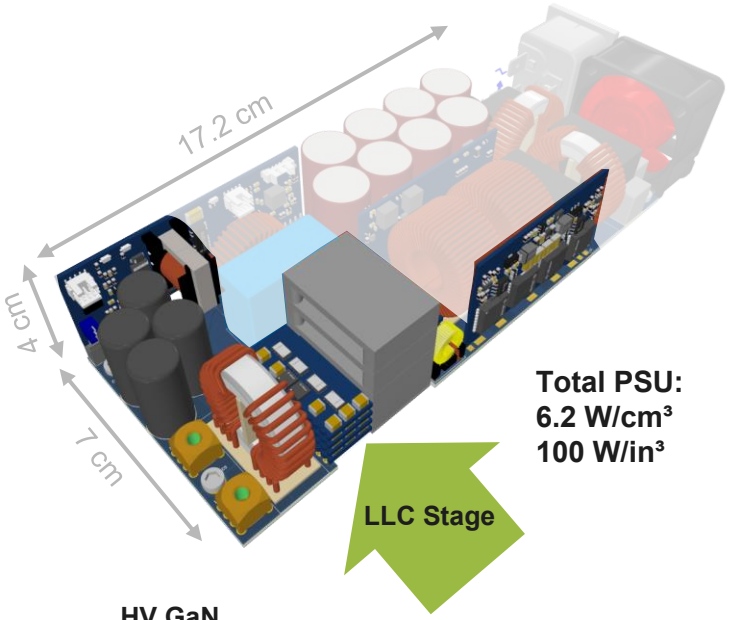
System impact example

3.3 kW LLC module, 400 V $V_{dc,in}$ to 43–59 V $V_{dc,out}$, f_{res} = 400 kHz, soft-switching system

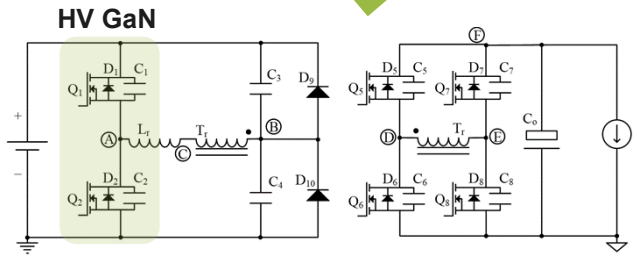
– Efficiency curves at 400 V $V_{dc,in}$ to 50 V $V_{dc,out}$, f_{sw} ≈ 380 kHz

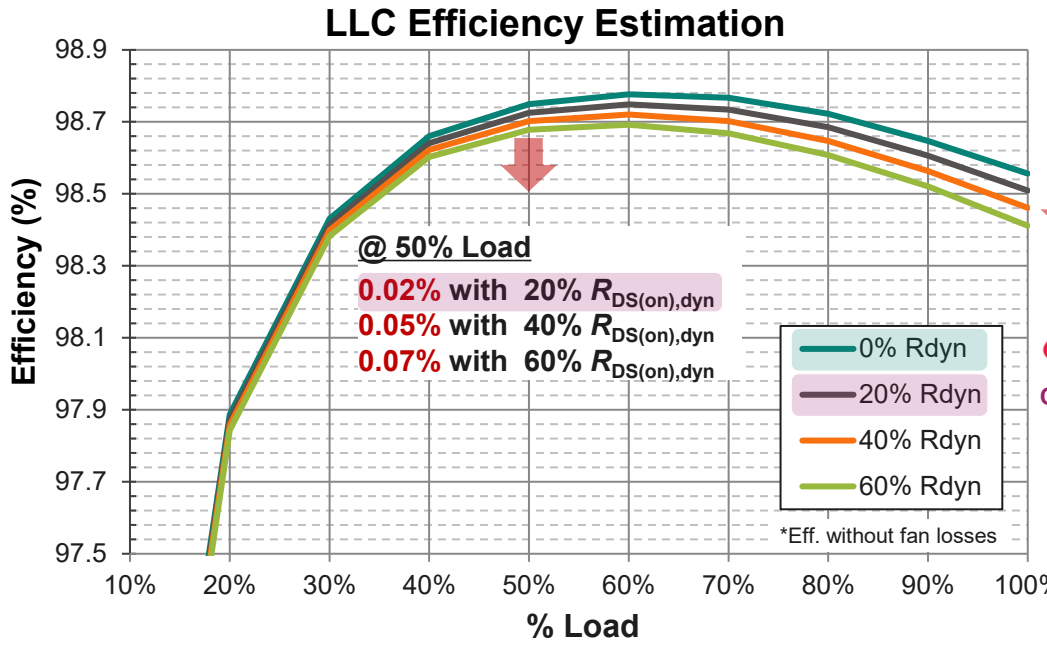
– Calculated with 42 mΩ GaN devices, **assuming different $R_{DS(on),dyn}$**

Source:
Matteo Kutschak & Manuel Escudero
(PSS PS SYS SAA SAE ACDC)



HV GaN





@ Full Load
0.05% with 20% $R_{DS(on),dyn}$
0.10% with 40% $R_{DS(on,)dyn}$
0.15% with 60% $R_{DS(on),dyn}$

Competitors

This enables using a CoolGaN™ device with 20% larger $R_{DS(on),typ}$ compared to competitors to achieve the same system efficiency.

@ Full Load	20% $R_{DS(on),dyn}$	40% $R_{DS(on),dyn}$	60% $R_{DS(on),dyn}$
Junction temp. increase	+5.1ºC (58.5ºC)	+10.3ºC (63.7ºC)	+15.7ºC (69.1ºC)
Loss increase (per prim-side device)	+18%	+36%	+54%

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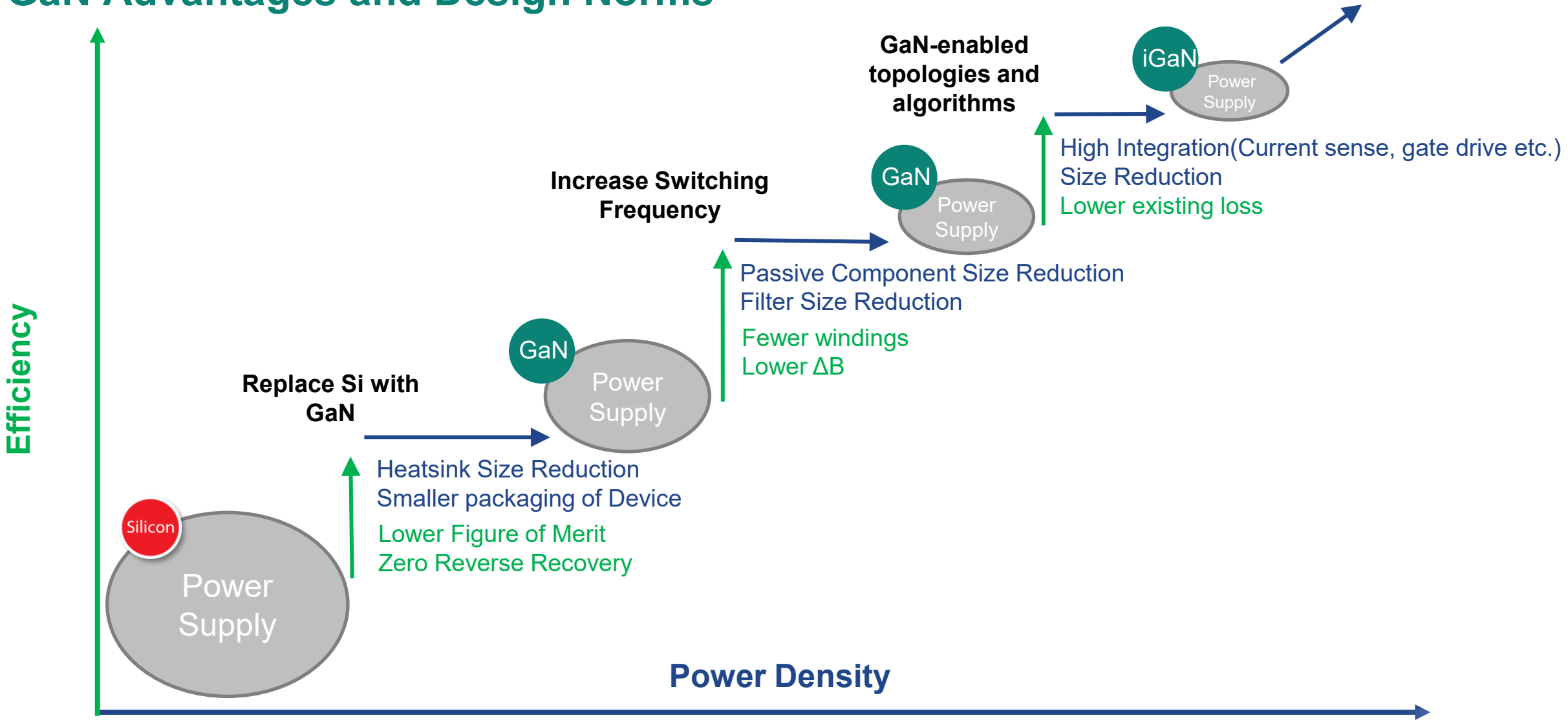
2 Driving e-mode GaN HEMT 13

3 Dynamic Rds(on) of GaN HEMT 20

4 **GaN HEMT application** **33**

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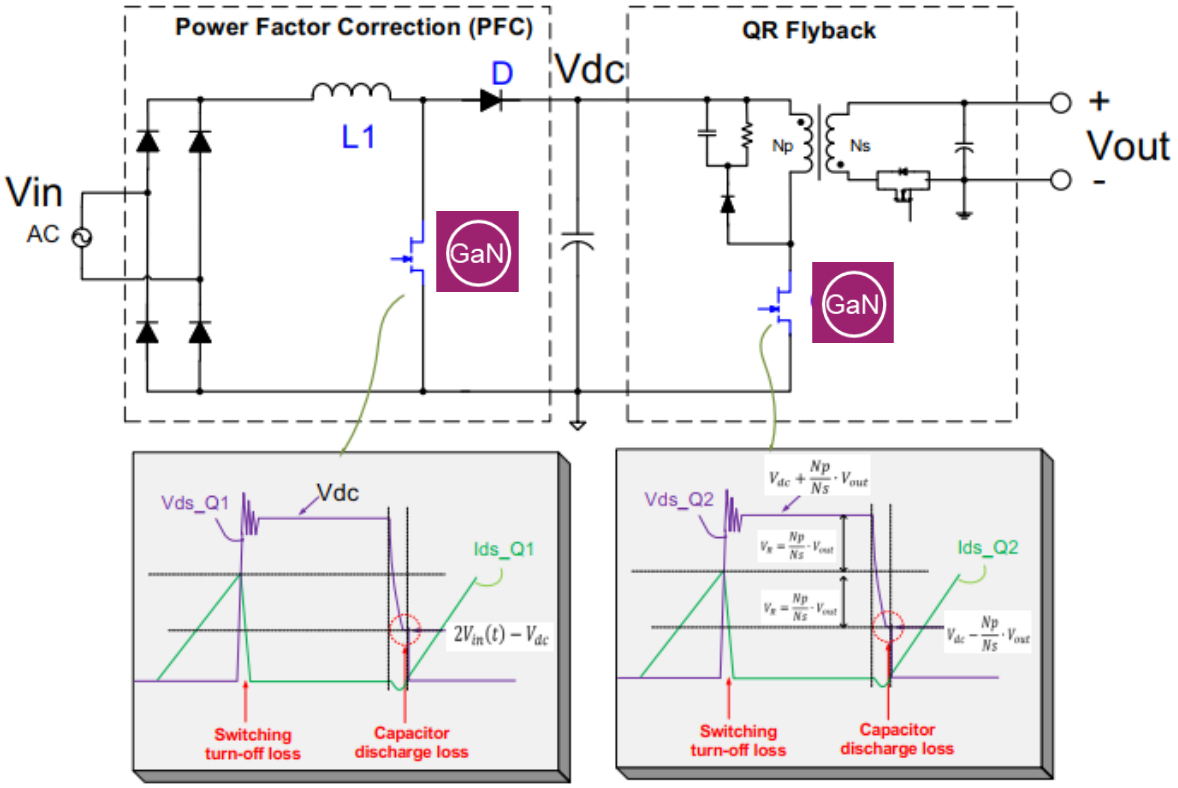
GaN Advantages and Design Norms



The **superior performance of GaN** enables higher system power density and efficiency

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Charger adapter market < 100 W
GaN value for Boost PFC, QR Flyback applications



Although both PFC and QR Flyback achieve a valley switching turn-on to minimize the switching turn-on loss, there are two types of switching frequency related losses that need to be considered.

Switching turn-off loss:
During the turn-off period, the Ids current reaches peak current, and the transistor is turned off with hard switching at this peak primary current, which will result in a switching crossover turn-off loss.
The loss depends on the turn-off energy (Eoff) of the transistor and effect parameters are gate charge, **Qg**, and **Qgd**.

Capacitor discharge loss:
During the turn-on period. In PFC stage, if the instant sinusoid AC voltage Vin(t) is larger than half of Vdc voltage (Vdc/2), mean is switching voltage is non-zero.

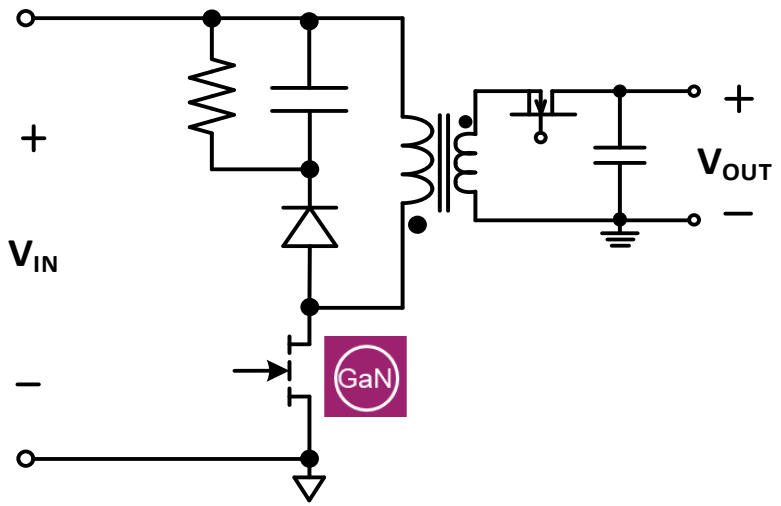
There is a capacitor discharge loss due to the parasitic capacitance of the transistor. Similarly, for QR Flyback. For this reference design at high Vdc=390V, the transformer turns ratio is 7.2 and the output voltage is 22V. The valley switching voltage is equal to $232V$. The capacitance discharging loss can be evaluated by the transistor's stored energy Eoss at around 200V and effect parameter is gate charge **Qoss** .

Ref: GS-EVM-CHG-65WQR-GS1

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QR Flyback – 150kHz and 300kHz Designs (GaN Vs Si)

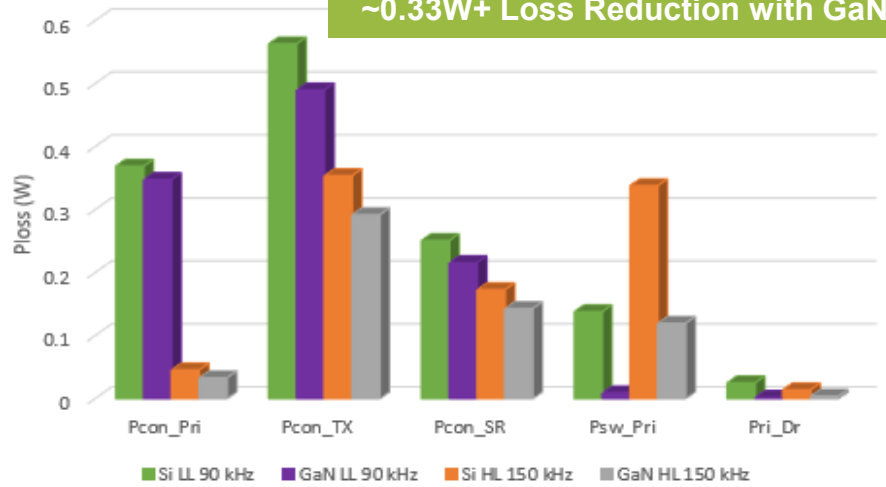
65W PD (20V/ 3.25A)

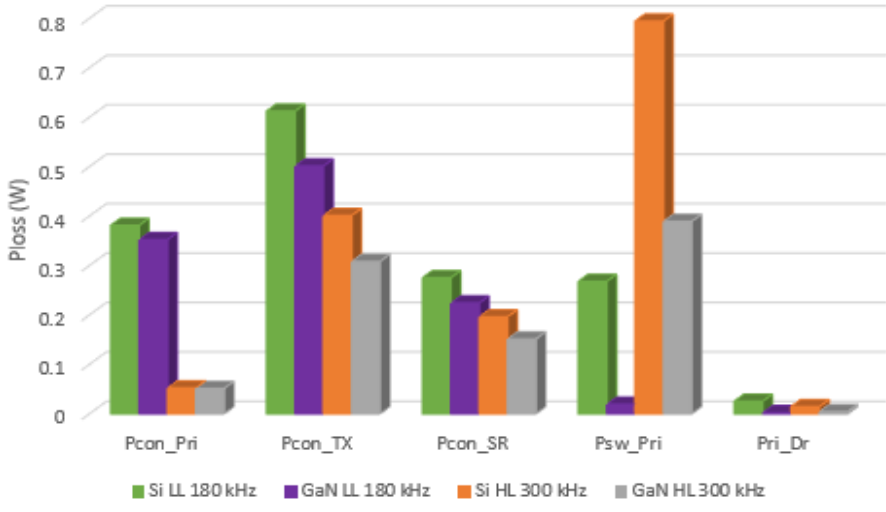


	IPL65R195C7	GS-065-011-2-L
Vac = 90V/ 265V (up to 150kHz)		
Ip_rms (A)	1.11 / 0.39	1.08 / 0.33
Isr_rms (A)	7.09 / 5.89	7.00 / 5.35
Vac = 90V/ 265V/ (up to 300kHz)		
Ip_rms (A)	1.12 / 0.41	1.08 / 0.33
Isr_rms (A)	7.41 / 6.26	7.01 / 5.50

Assumption: Design under different Co_tr

Condition	Power loss analysis
IPL65R195C7 VS GS-065-011-2-L (Up to 150kHz design)	~0.33W+ Loss Reduction with GaN
IPL65R195C7 VS GS-065-011-2-L (Up to 300kHz design)	~0.5W+ Loss Reduction with GaN



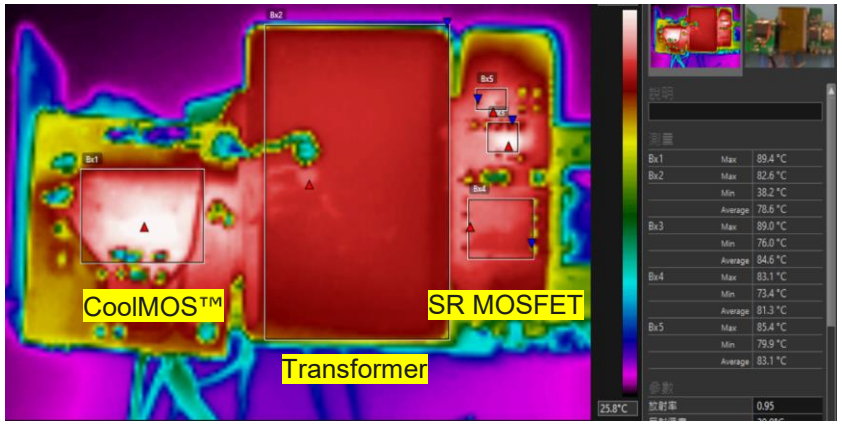


Assumption: Rds Thermal Coefficient, GaN =2, Si =1.6

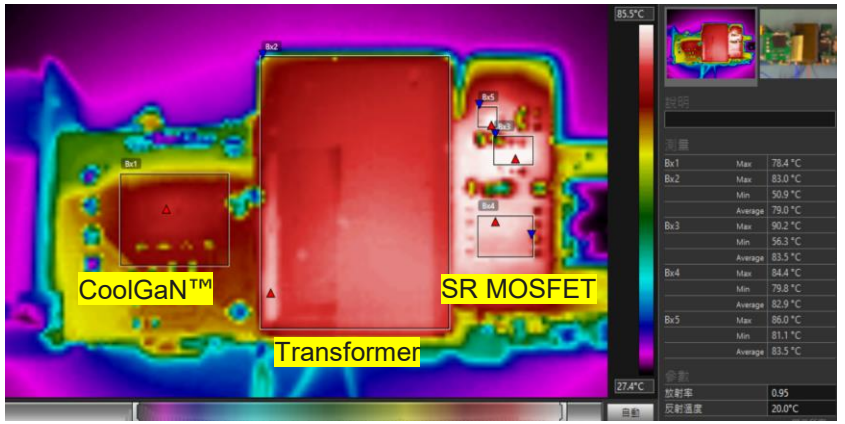
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Thermal Evaluation in 45W Platform (GaN Vs Si)

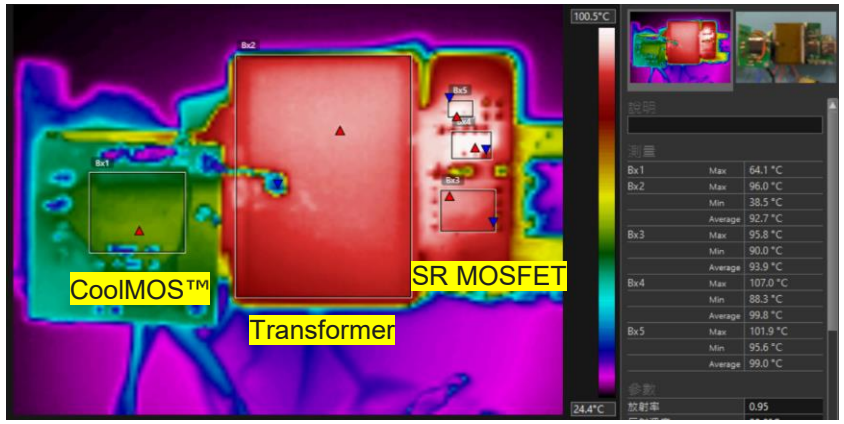
CoolMOS™ Tc=89.4°C at 115Vac



CoolGaN™ Tc=78.4°C at 115Vac



CoolMOS™ Tc=64.1°C at 230Vac



CoolGaN™ Tc=52.2°C at 230Vac



*IPL60R185C7 **CoolMOS™** ; IGLD60R190D1 **CoolGaN™**

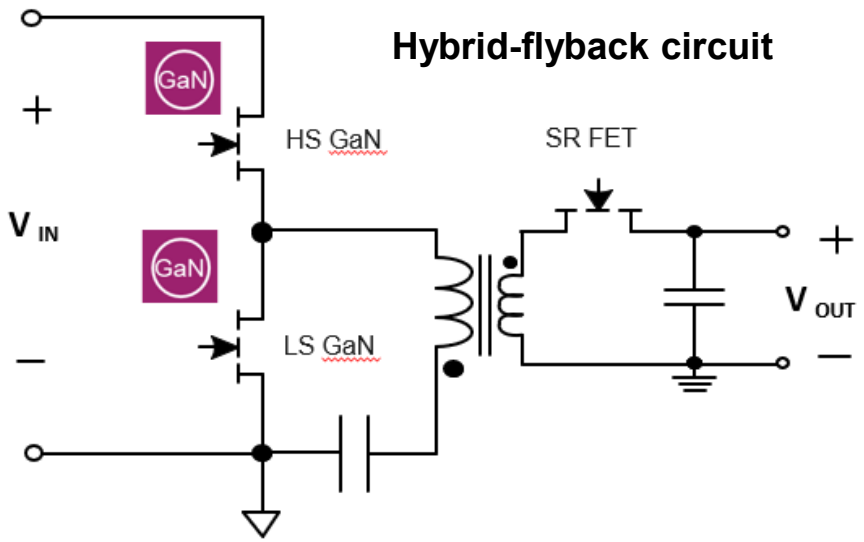
*Output setting are Vo=20V, Io=2.25A

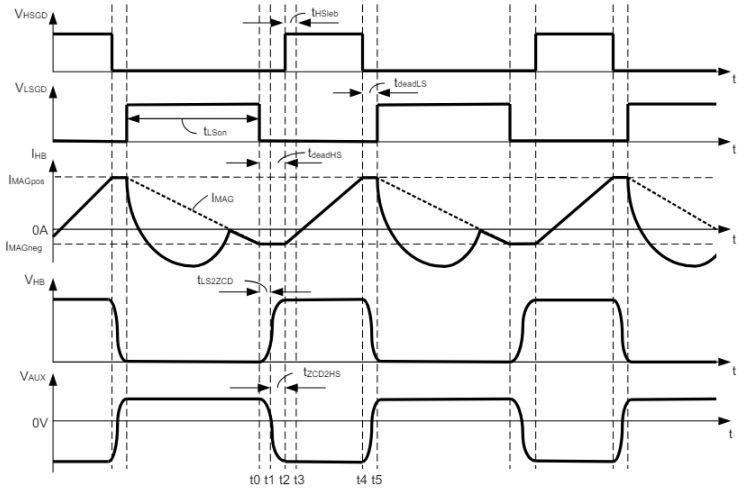
Aging time for 30 min.

GaN is about 10°C cooler than Si.

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Charger adapter market 100 W – 300 W
Basic Hybrid-Flyback Structure and Operation





Particular :

- Hybrid-flyback converter use leakage inductor and capacitor assemble as resonant tank.
- Base on magnetizing current could easily get dead time to achieve LS ZVS; for HS ZVS need to have enough negative current and sufficient dead time to discharge HS capacitor.
- To achieve highest efficiency, using GaN have smaller Coss which could have benefit on current dip and get smaller primary and secondary current.

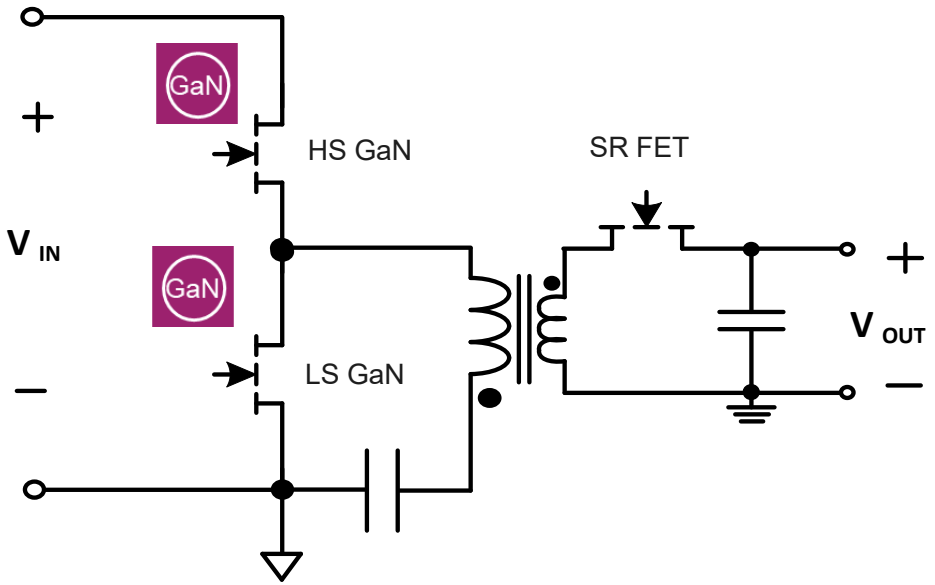
Operation :

- HS switch turn on charged magnetic inductor energy after achieve peak reference, then HS OFF.
- During dead time ILR discharge LS and charge HS switch
- LS ZVS turn ON magnetic inductor transfer energy to secondary side , ILR resonant with resonant capacitor. When ILM=ILR decoupling LS would turn additional time to get negative current to ZVS HS switch.
- During dead time negative current would discharge HS and charge LS switch, at next period HS would achieve ZVS turn ON.

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GaN Value for Hybrid-Flyback Application

Hybrid-flyback circuit



In HS & LS PWM are asymmetric

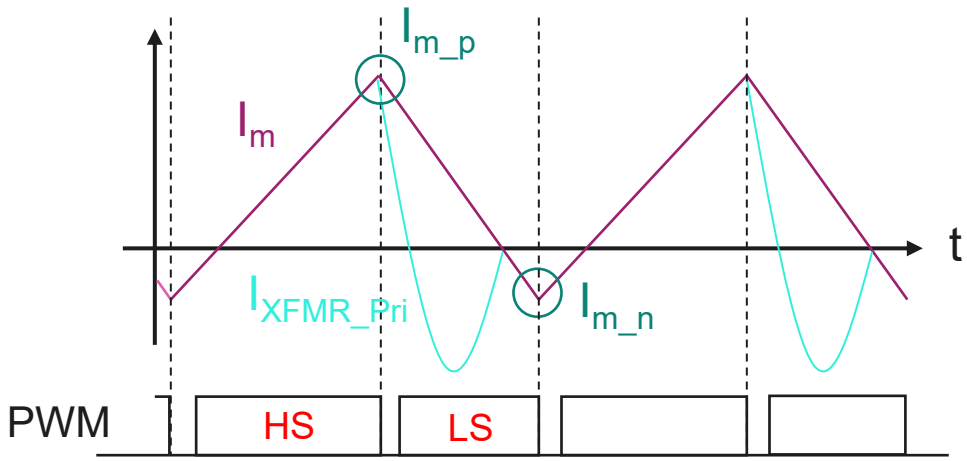
1. LS's ZVS condition: $I_{m_p} * T_{Dead} > 2 * C_{sw} * V_{DS}$
2. HS's ZVS condition: $I_{m_n} * T_{Dead} > 2 * C_{sw} * V_{DS}$

GaN's low Coss with AHB

- Getting lower deadtime requirement for ZVS
- Getting lower RMS current to improve conduction loss both PRI & SEC
- Getting lower I_{m_n} requirement for ZVS
- Because of shorter dead time could push PSU to higher frequency

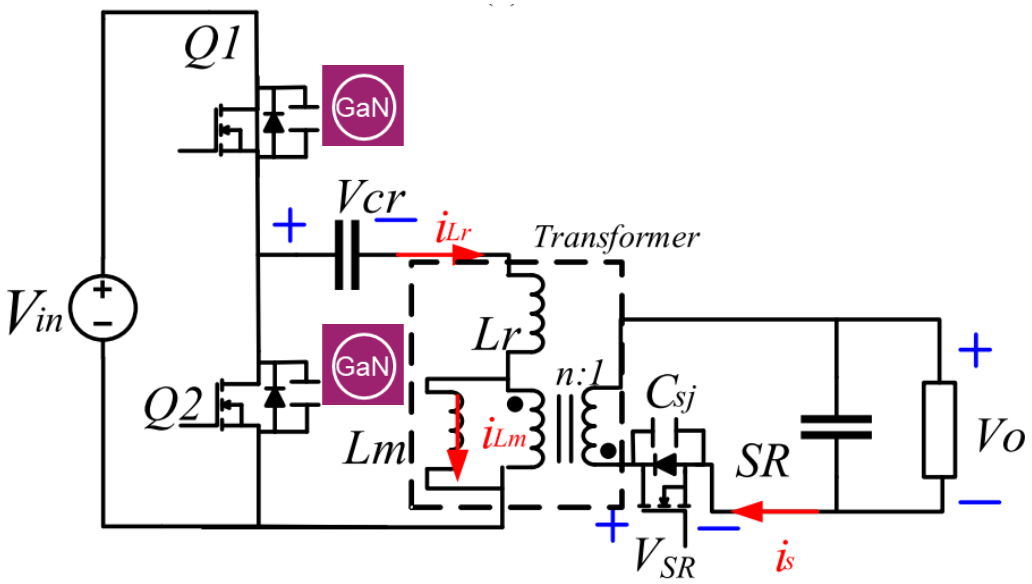
GaN's low Cgd improves turn-off loss

GaN's low Cgs improves turn-off loss



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GaN and Si Comparison on 140W by Simulation



Item	GS-065-011-2-L	IPL65R160CFD7	Unit
Package	PDFN 8x8	PDFN 8x8	
Rds,on@25C	150	132	mOhm
Rds,on@150C	380	293	mOhm
Ciss	70	1283	pF
Coss(tr)	47	512	pF
Qg	2.2	28	nC
Qgs	0.7	7	nC
Qgd	0.7	9	nC
$R_{\Theta JC}$	1.4	1.27	(°C/ W)

Item	IPL65R160CFD7	GS-065-011-2-L	Unit
P_{HScon}	0.369	0.248	W
P_{LScon}	0.622	0.322	W

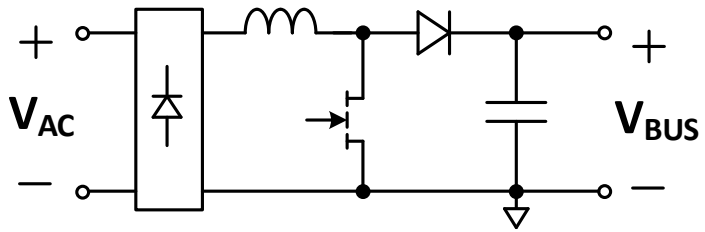
Calculate with 100C R_{DSON}

Operate 120kHz and modify Lm to make sure ZVS turn ON is achieved

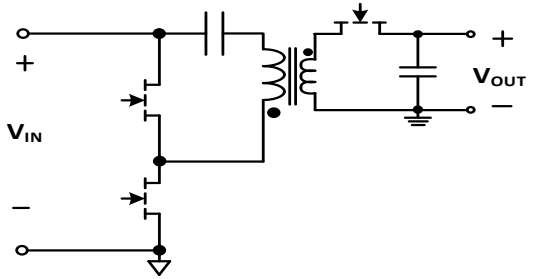
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140W PD Adapter Design – 150kHz

CrM Boost PFC



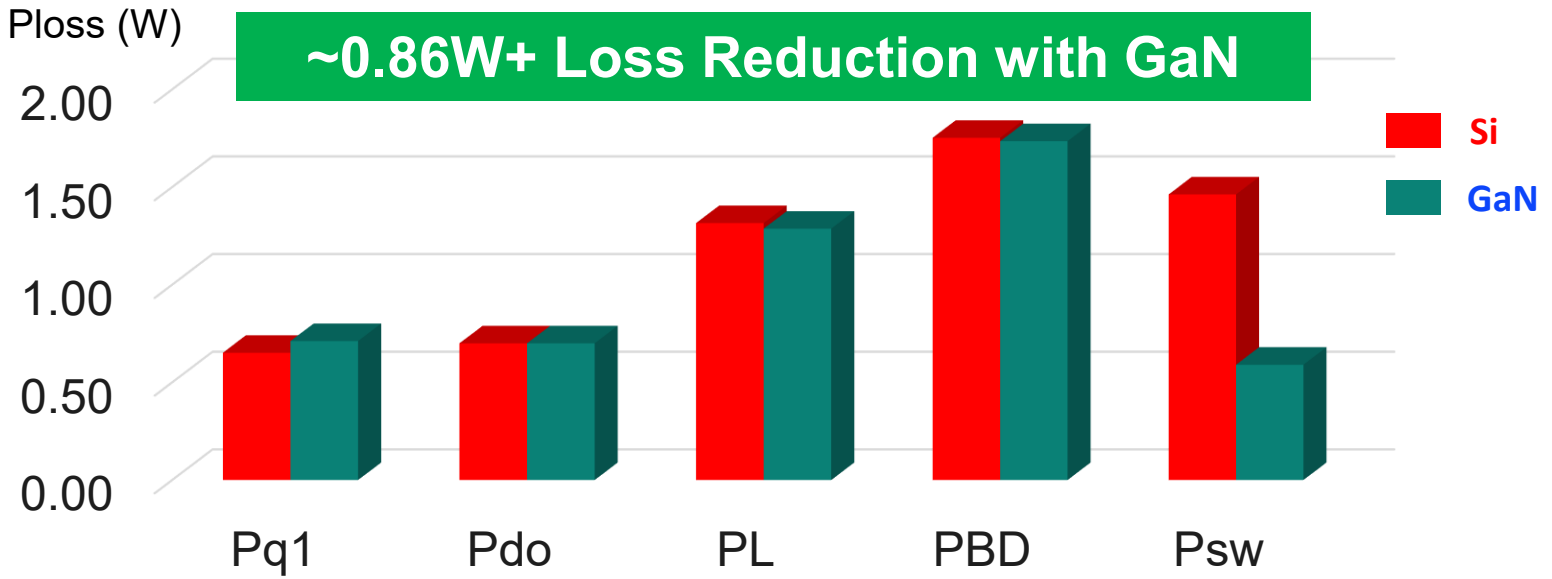
AHB Flyback



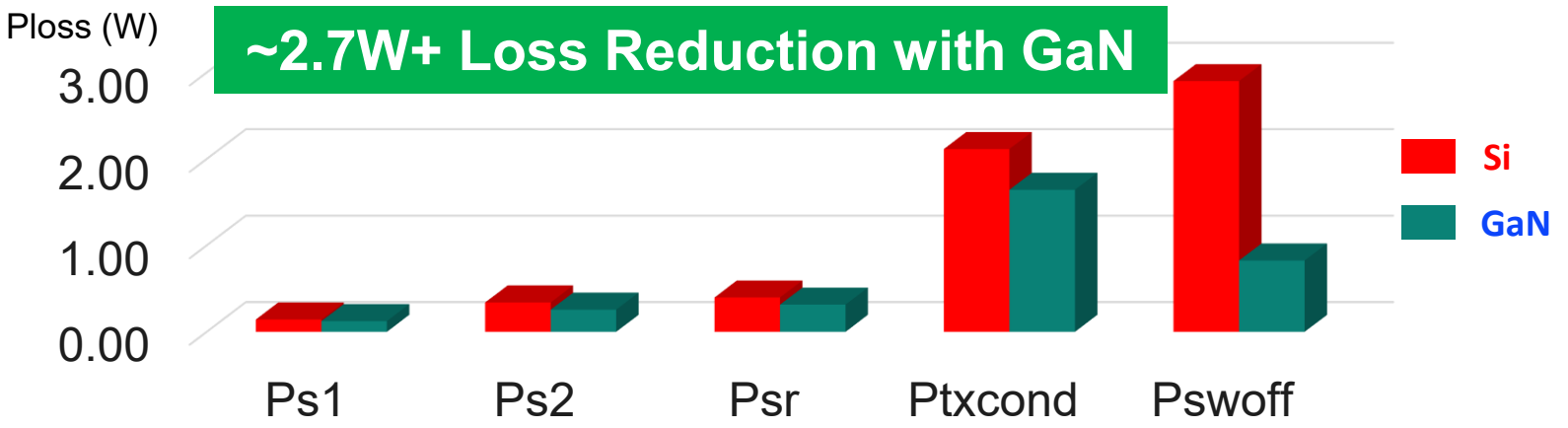
	IPL60R185C7	GS-065-011-2-L
IPFCS_rms (A)	1.56	1.54
IL_rms (A)	2.09	2.07
ISL_rms (A)	0.73	0.64
ISH_rms (A)	1.12	0.92
Isr_rms (A)	7.05	6.27

Assumption: Same L_m design, ignore driving loss

IPL60R185C7 vs GS-065-011-2-L in CrM PFC (V_{BUS}=380V)

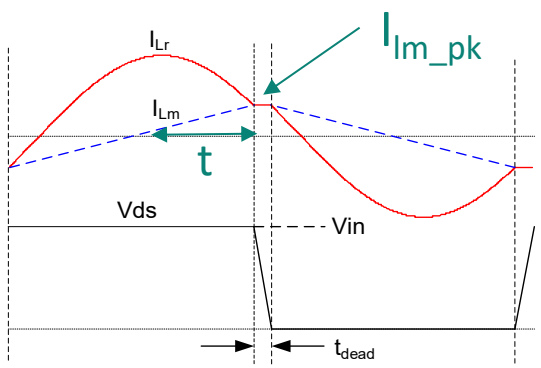


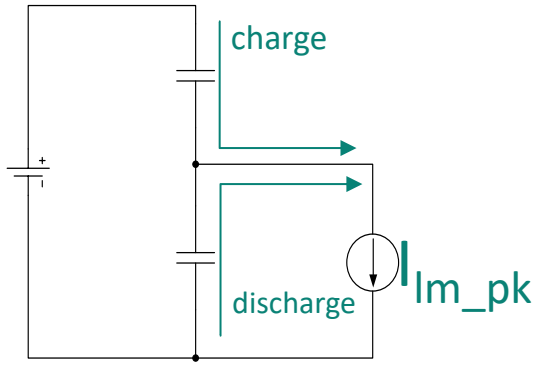
IPL60R185C7 vs GS-065-011-2-L in AHB Flyback (V_{BUS}=380V)

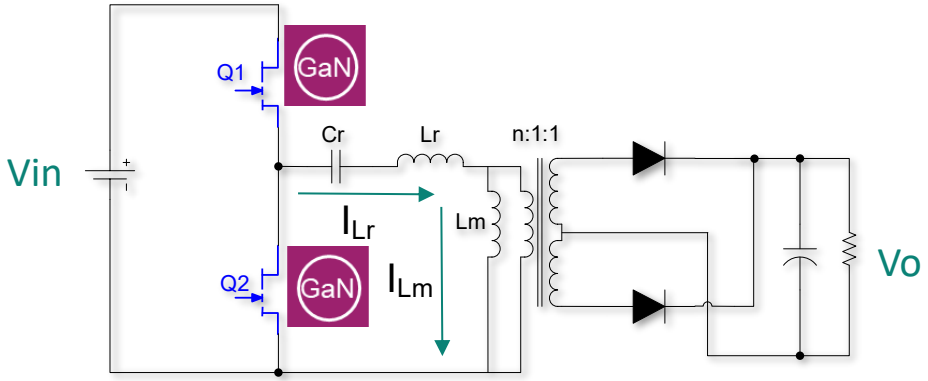


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Power supply 150 W up to few kW
LLC Converter's ZVS Achievement Conditions







$$Lm \cdot \frac{I_{lm-pk}}{t} = \frac{Vin}{2}$$
t=Ts/4, Ts=1/fs

$$I_{lm-pk} = \frac{Vin \cdot Ts}{8 \cdot Lm}$$

$$2 \cdot Co(tr) \cdot Vin = I_{lm-pk} \cdot t_{dead}$$

$$I_{lm-pk} = \frac{2 \cdot Co(tr) \cdot Vin}{t_{dead}}$$

Minimum dead time:

$$t_{dead_{min}} = 16 \cdot C_{o(tr)} \cdot L_m \cdot f_s$$

Parameters	Si/SiC	GaN	GaN Value Proposition
Co(tr)	↑	↓ ↓	Lowest Co(tr)

① if same f_s and t_{dead} → $L_m \propto \frac{1}{Co(tr)}$ → L_m ↑ → **η** ↑

② if same L_m and t_{dead} → $f_s \propto \frac{1}{Co(tr)}$ → f_s ↑ → **w/m³** ↑

③ if same f_s and L_m → $t_{dead} \propto Co(tr)$ → t_{dead} ↓ → **η** ↑

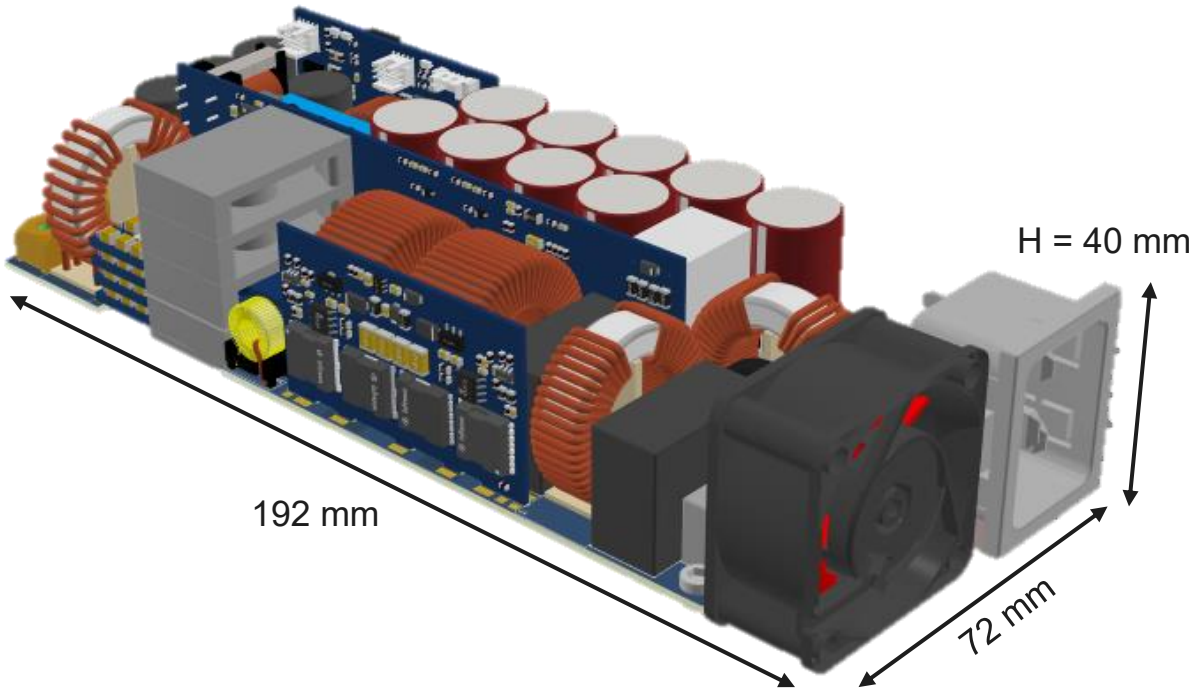
$C_{o(tr)}$ is the key parameter for high density and high efficiency

* Co(tr) is the charging/ discharging time of the output capacitance ($C_{OSS} = C_{GD} + C_{DS}$). A smaller Co(tr) results in a faster charging/ discharging time, which is desirable.

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3k3W High Frequency and High Power Density PSU

REF_3K3W_HFHD_PSU



Technical details

Parameter	Value
Input voltage range	180 V_{AC} ~ 275 V_{AC}
Output voltage range	51 - 48 V_{DC}
Output current nominal	@ 51 V = 65 A @ 50 V = 66 A @ 48 V = 69 A
Output power maximum	3300 W
Efficiency	~97.5 % (without fan)
Power factor (load > 10%)	PF > 0.95 @ 180 ~ 275 V_{AC} iTHD < 10 % @ 180 ~ 275 V_{AC}
Ambient temperature	0 °C to 50 °C
LLC switching frequency	530 kHz@ 50 V_{DC}
Learn More	
Infineon components	IMT65R057M1H, IGT60R042D1, IPT60R022S7, IPT60R080G7, IDL10G65C5, 2EDB9259Y, 1EDN8511B, 1EDN8550B, 1EDB8275F, IQE046N08LM5, ICE2QR2280G, BAT46WJ, BAT165, BSS138N, XMC4200, TLS4120D0EPV33, 4DIR1400H
Controller	XMC4200-Q48K256 for PFC dsPIC33CK256MP203 for LLC
Application	Industrial SMPS, Telecom Rectifier

Features

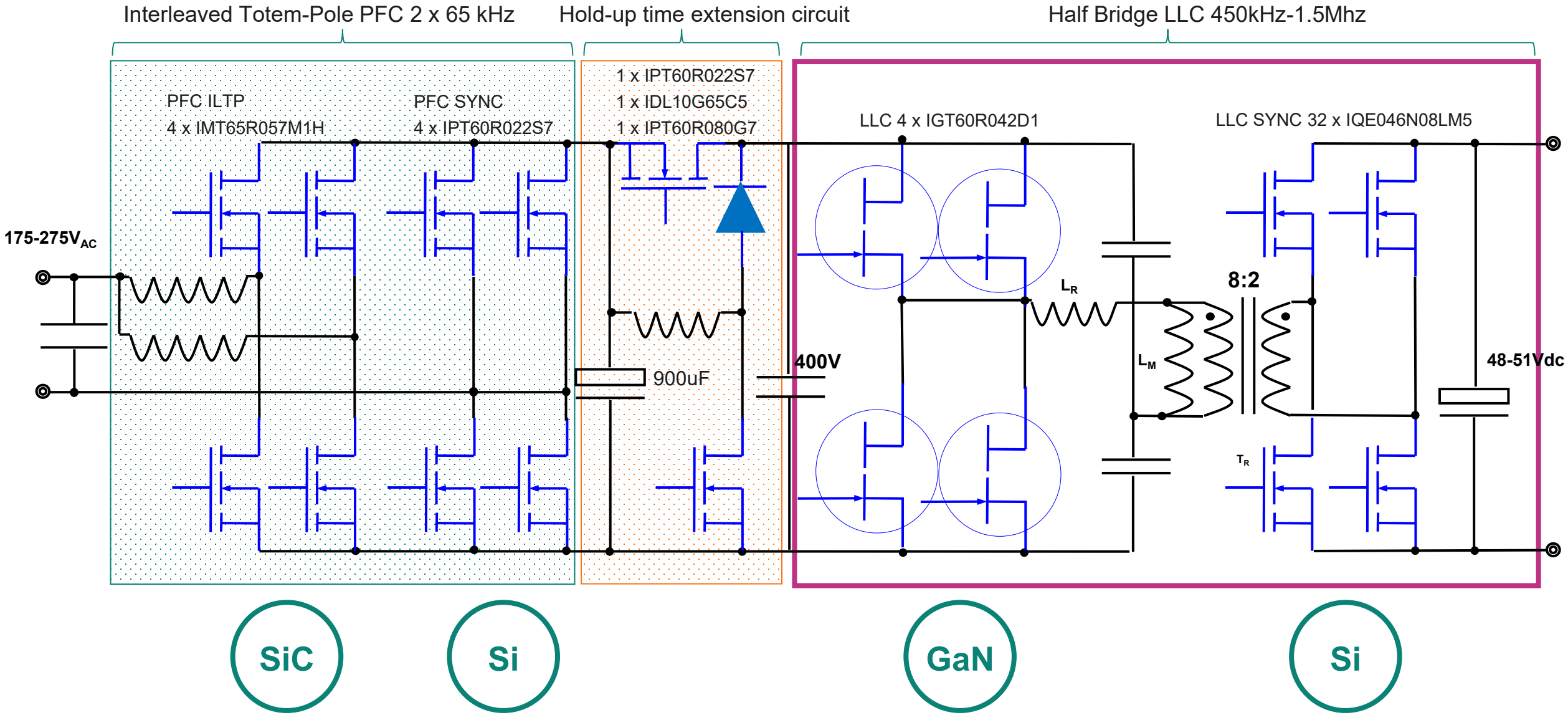
- **Benchmark 97.4% of efficiency @ ~96W/in³** in 1U form-factor
- Highest efficiency & power density with CoolMOS™, CoolSiC™, CoolGaN™
- Custom integrated planar magnetic construction
- Full digital control (PFC and DCDC)
- Totem-Pole SiC PFC + Half-Bridge GaN LLC

Benefits

- Full Infineon‘s semiconductor solution
- Complete Power Supply Unit (PSU) including PFC + DCDC
- High efficiency, custom and in-house design integrated magnetics
- Hold up time extension circuit

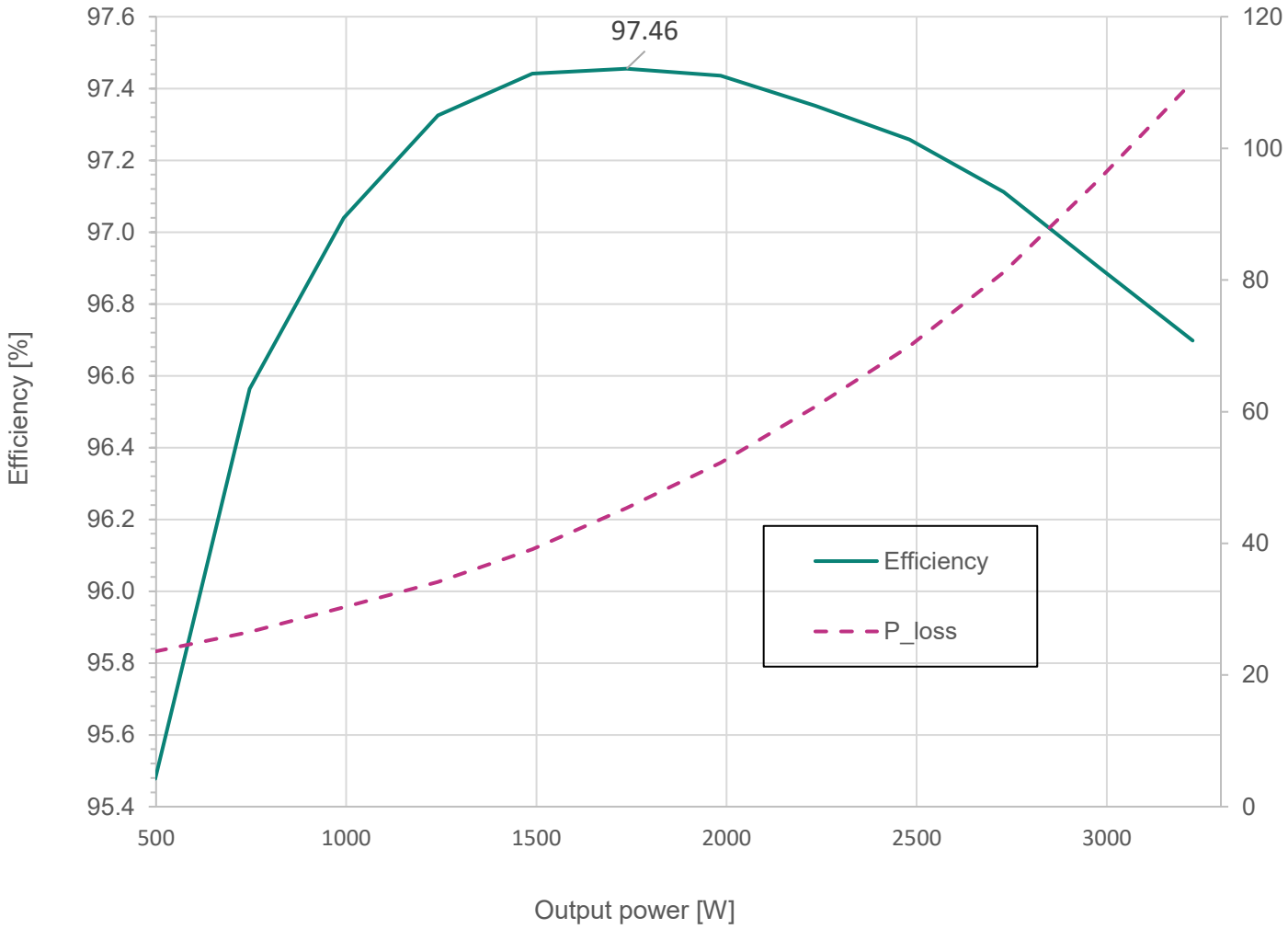
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3k3W High Frequency and High Power Density PSU



GaN enables high switching frequency

3k3W High Frequency and High Power Density PSU





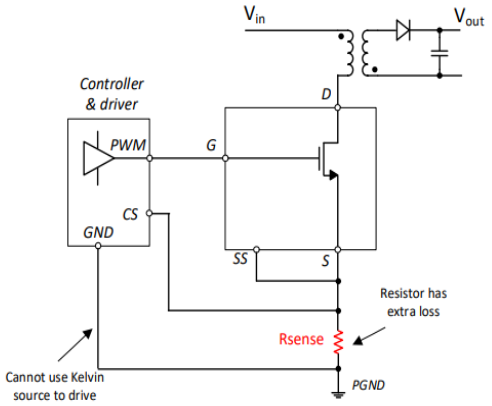
Measurement conditions:

- V_{in} = 230 V_{ac}
- V_{out} = 50 V_{dc}
- I_{out} up to 65 A

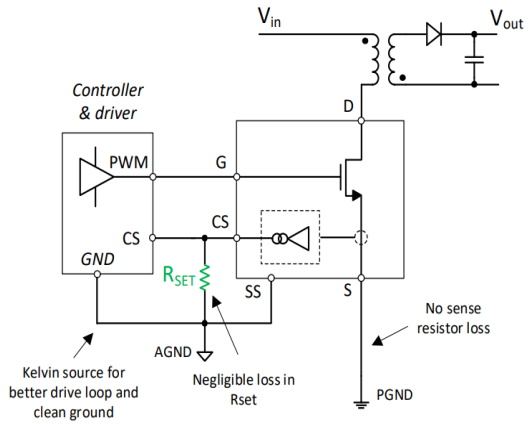
Integrated GaN value proposition
CoolGaN™ Smart Sense in flyback converter

Application example in QR flyback converter

Conventional solution of discrete FET + Rshunt

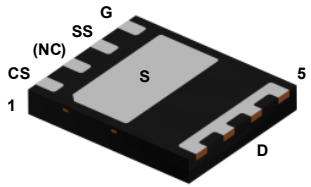


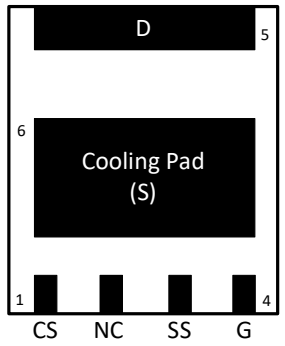
CoolGaN™ Smart Sense with integrated current sense

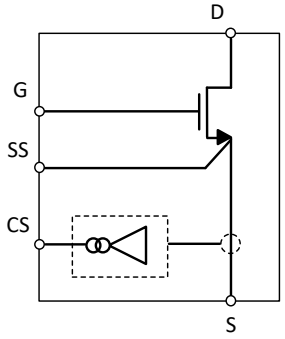


Pin		Type	Description
Number	Name		
1	CS	O	Current sense output
2	NC		Not connected
3	SS	P	Kelvin source pin for driving
4	G	I	Gate pin
5	D	P	Drain pin
6	S	P	Source pin and thermal pad

Product outline







- Integrates high-performance E-mode GaN FET with advanced loss-less current sense technology
- Eliminates need for external current sensing resistors
- Improved thermal enabled by larger copper expansion on source pad
- Enables real-time, accurate sensing of Drain-to-Source current
- Improves system efficiency, reduces losses, and enhances reliability

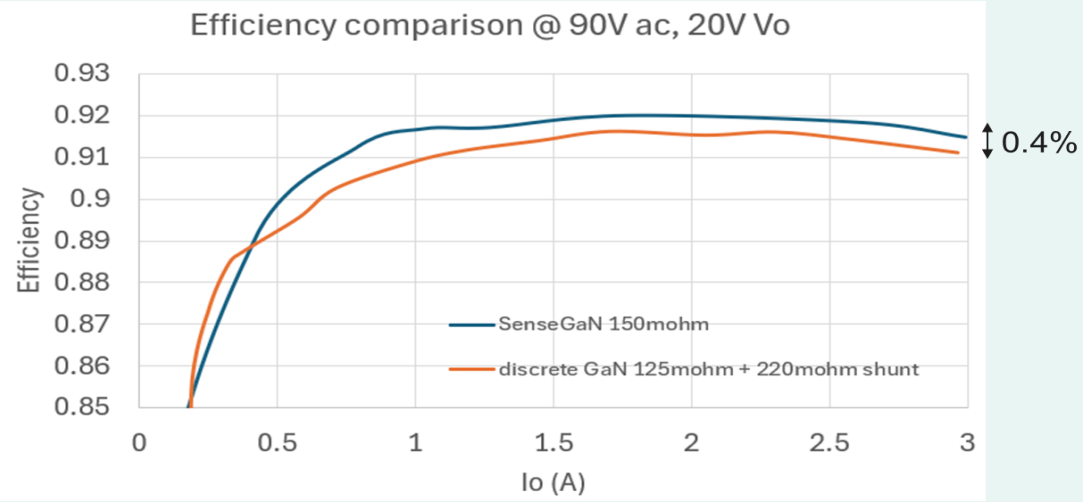
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Value Proposition and System Benefit with CoolGaN™ Smart Sense

Lossless current sensing

System Efficiency Improvement

*Efficiency comparison is done in **60W Flyback Prototype** with original design using **125mΩ GaN discrete** and shunt resistance sensing of **220mΩ***



New CoolGaN™ Smart Sense solution provides:

- Efficiency improvement by 0.4% at full load 90 V_{ac}
- Power saving of 0.29 W
- Lower device temperature by ~17.4°C assuming R_{thja} = 60 K/W.

System Cost Down

60W QR Eval @ 125°C	Rdson (mΩ)	Rshunt (mΩ)	Total discrete Rdson+Rshunt (mΩ)	Calculated conduction loss
Discrete 125 mΩ + Rshunt	262.5 (2.1x of 25°C)	230 (+0.1mΩ per +1°C)	492.5	0.582
CoolGaN™ Smart Sense 225 mΩ	472.5	-	472.5	0.557

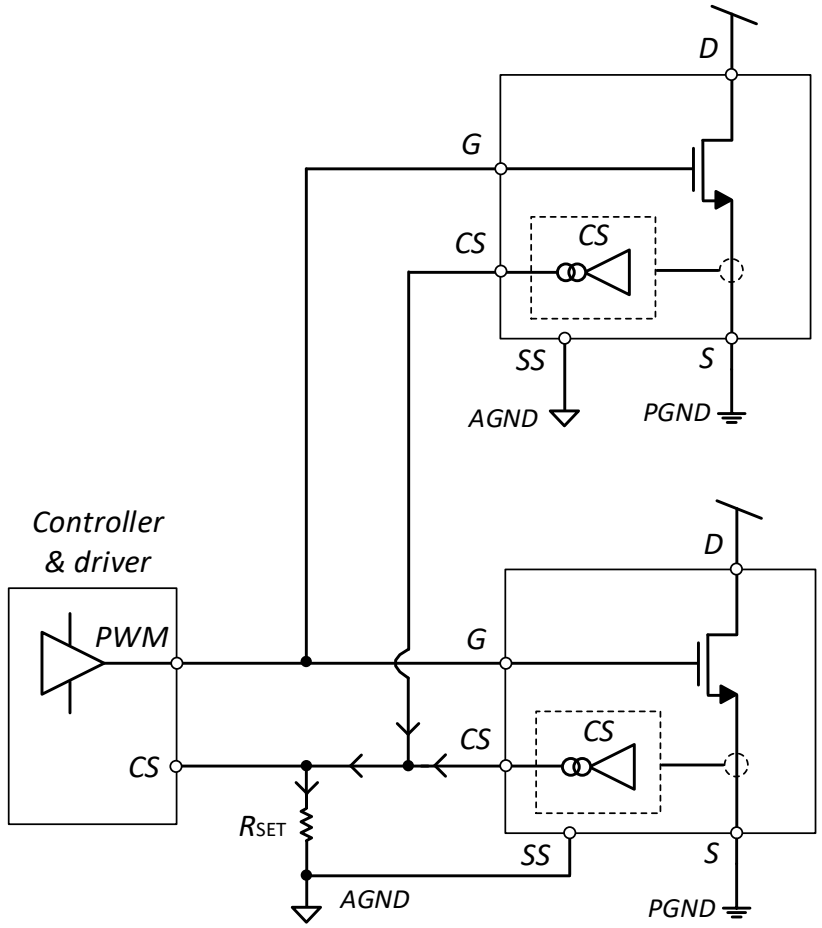
With **225mΩ CoolGaN™ Smart Sense**, we can achieve same efficiency as original **125mΩ discrete GaN solution**.

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Value Proposition and System Benefit with CoolGaN™ Smart Sense

Ease for device parallel to support high power

CoolGaN™ Smart Sense in parallel connection



Device parallel for power handling capability

- Parallel device configuration is frequently used to increase a circuit's power handling capability.
- CoolGaN™ Smart Sense provides a convenient and easy-to-implement solution.
- This approach eliminates the concern of propagation delay mismatch.
- The CS pin, being is a current source output, enables:
  - Consolidating multiple currents into a single flow
  - Unified current measurement through a single R_{SET}

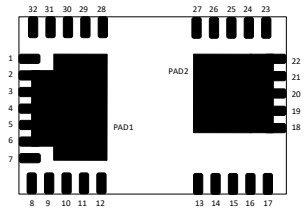
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Value Proposition and System Benefit with CoolGaN™ HB Drive

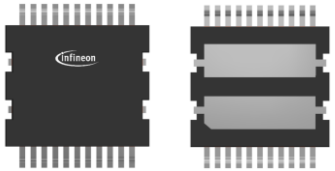
Enable high power density motor drive applications

CoolGaN™ HB Drive
with CS/OCP/OTP and bootstrap switch

– PQFN 6x8, 8x8 package

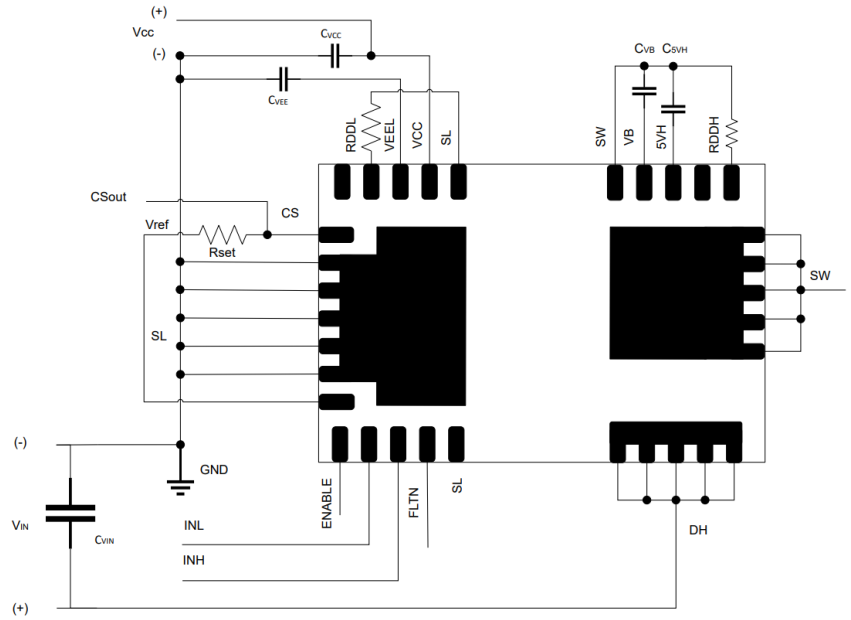


– QDPAK package



Top view

Bottom view



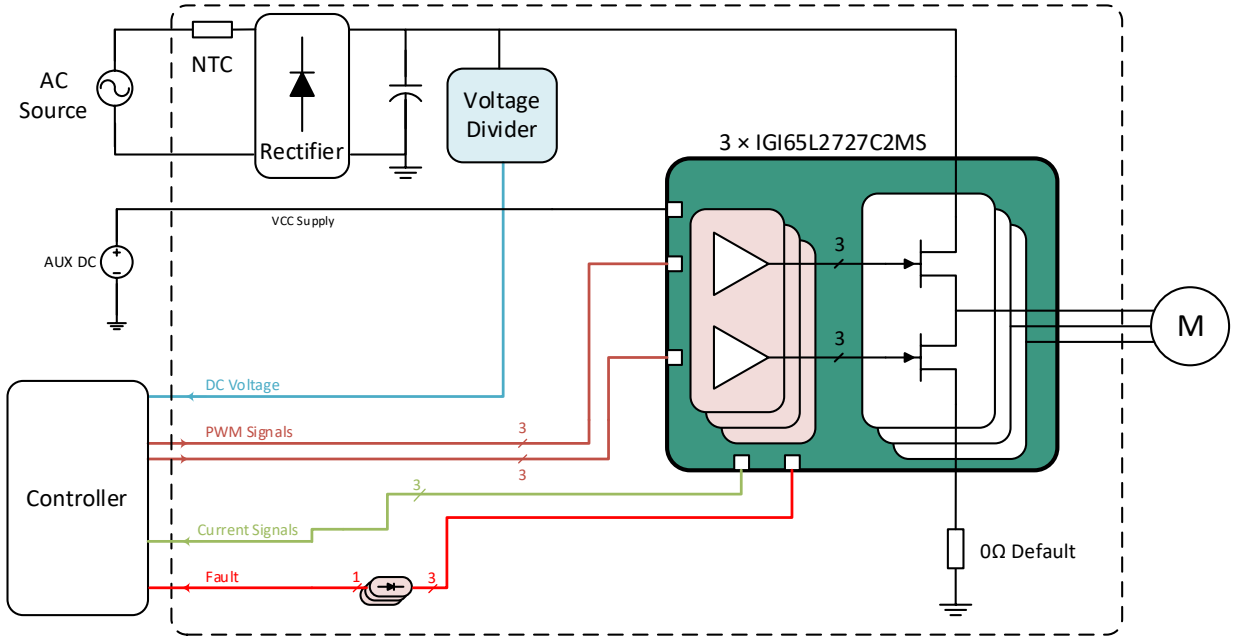
- Integrated bidirectional loss-less current sense with high accuracy and low delay
- Integrated half-bridge driver and bootstrap switch
- Slew rate control of turn-on & off for both HS and LS HEMTs
- Fast protection of OCP/SCP/OTP
- Auto standby ~ 200uA Iq with fast wake up
- 55-270mΩ in PQFN 6x8, 8x8, QDPAK

650 V CoolGaN™ HB Drive G5			
Half-Bridge Bi-di CS, OCP, OTP, bootstrap switch			
$R_{DS(on, typ)}$ [mΩ]	PQFN 6x8	PQFN 8x8	QDPAK BSC
270	IGI65L2727C2MS		
200	IGI65L2020C2MS	IGI65L2020C2LS	
140	IGI65L1414C2MS	IGI65L1414C2LS	IGI65L1414C2QC
95		IGI65L0909C2LS	IGI65L0909C2QC
70			IGI65L0707C2QC
55			IGI65L0505C2QC

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Value Proposition and System Benefit with CoolGaN™ HB Drive

Enable high power density motor drive applications

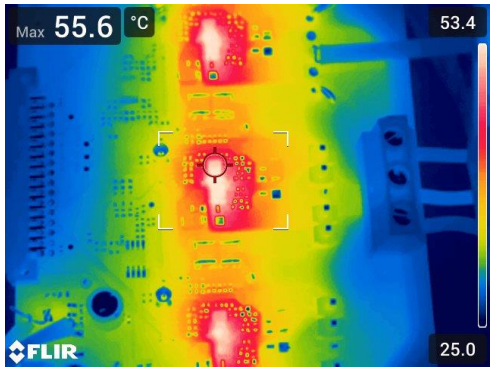


System Conditions:

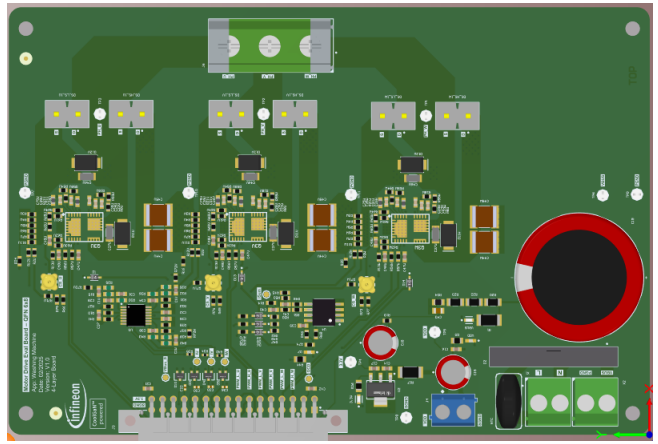
- 16kHz switching Frequency
- 320V DC bus
- 100Ω load per Phase
- 900uH inductance
- 33Hz output frequency
- Output power = 220W

System benefits

- **Improved efficiency** by removing the sense resistor
- **Meet stringent system standby spec** with the ultra low standby power
- **Cost and size savings** via integrated driver & bootstrap switch



w/o heat sink



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Summary

- Introduction
  - GaN material and device basics
- Gate drive
  - GIT and SG gate drive
  - Univeral driving circuit design
- Dynamic $R_{ds(on)}$
  - Definition
  - Measurement results
  - Impact on system performance
- GaN HEMT application
  - Boost PFC, QR flyback
  - Hybrid flyback, LLC
  - Integrated GaN value proposition



Thank you for your attention!

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