DIGITAL WE DAYS 2023

BENEFITS OF GAN IN QR FLYBACK

Partnered with STMicroelectronics

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

Today's speakers

PRESENTATION
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MODERATION
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Marketing Department

Information about the Webinar

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Agenda

1 GaN technology in the market

2 GaN characteristics and benefits of GaN in power conversion

3 GaN-based quasi-resonant flyback & comparison with GaN-based ACF

4 ST's GaN system-in-package overview

5 Conclusions

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GaN technology in the market

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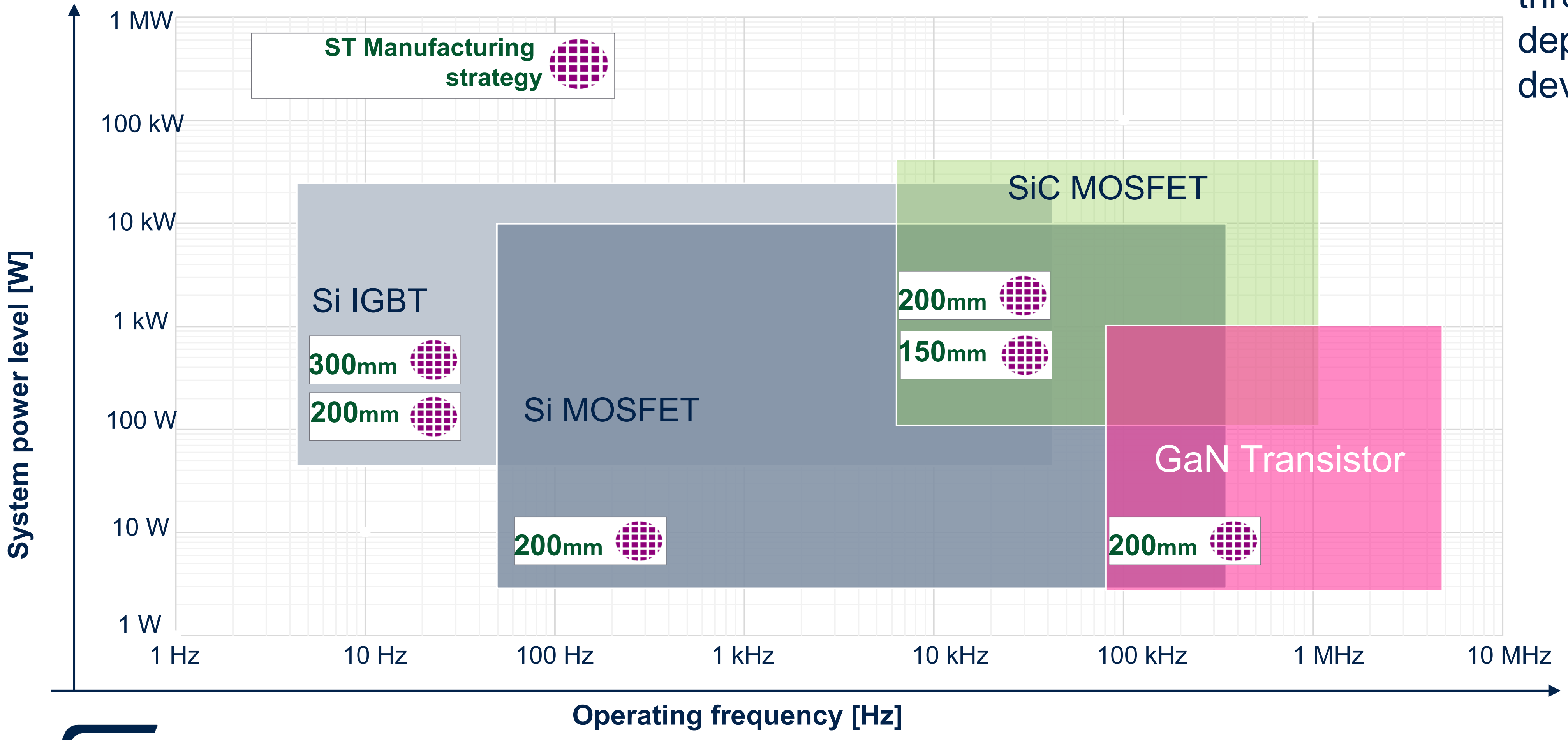
Silicon & wide-bandgap
Power devices positioning



Higher power is achieved through modular deployment or paralleling devices

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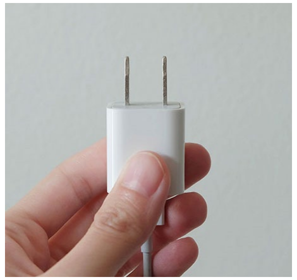
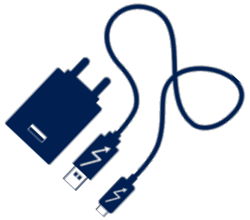
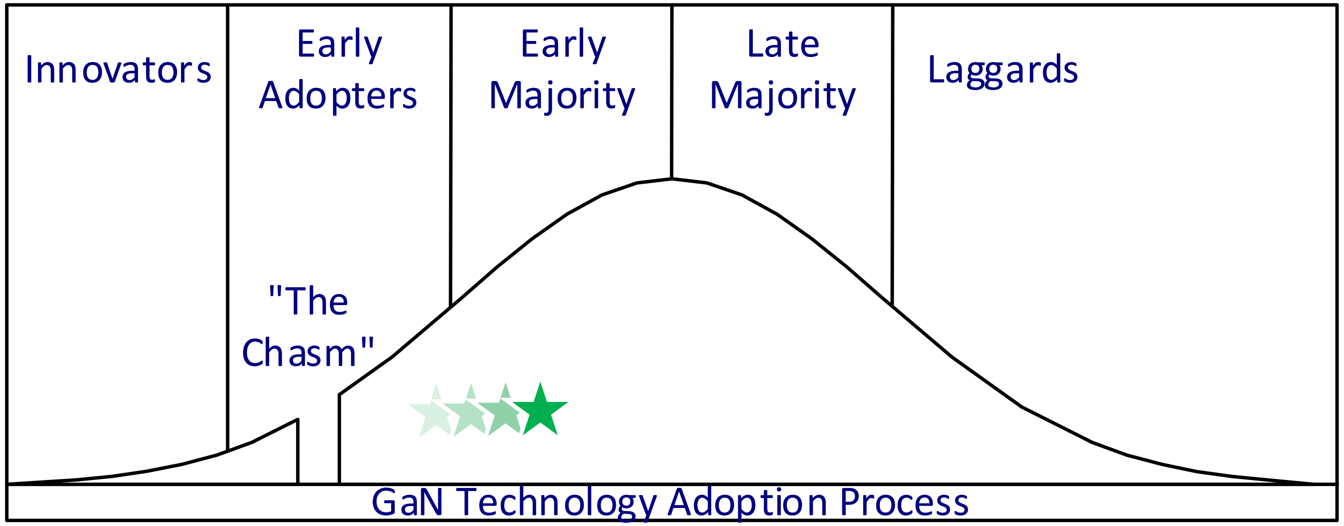
Wide-bandgap trends vs technology adoption

- In consumer, GaN crossed the chasm in 2020-2021 due to rapid growth in fast chargers, and is now being deployed in other AC/DC applications.
- System-in-package with embedded drivers/controllers will contribute to adoption due to simplicity of integration.

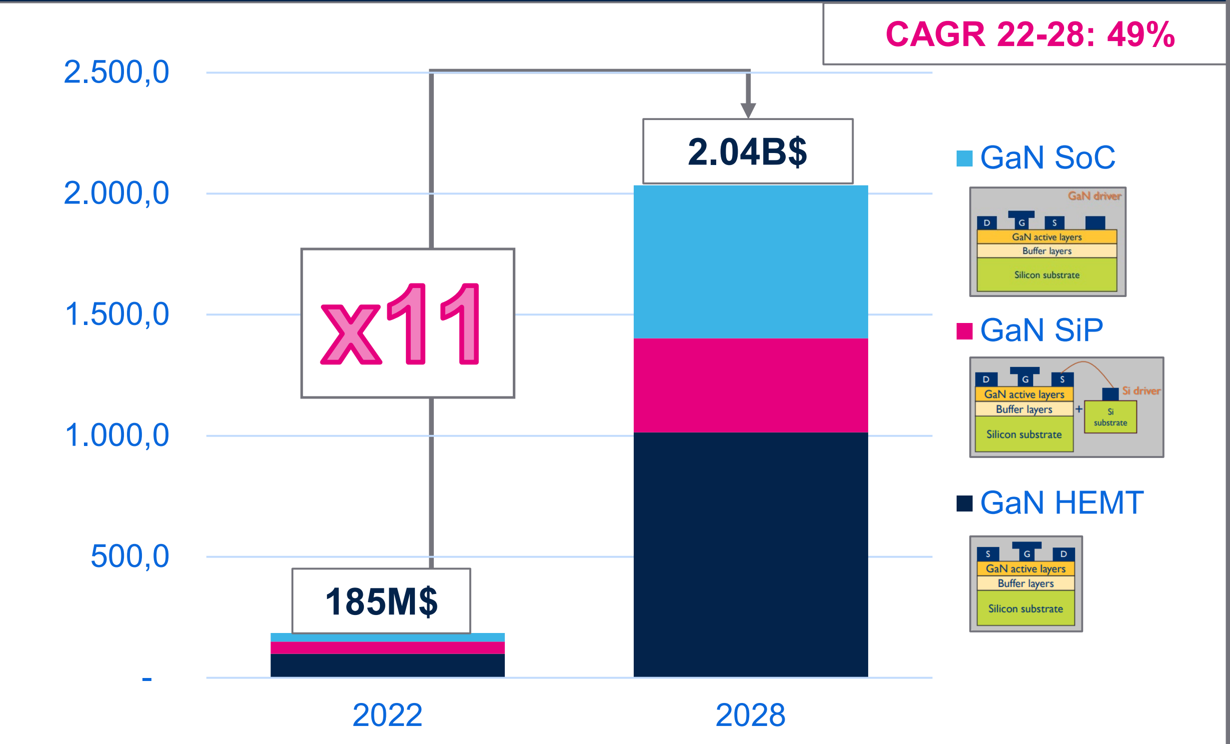




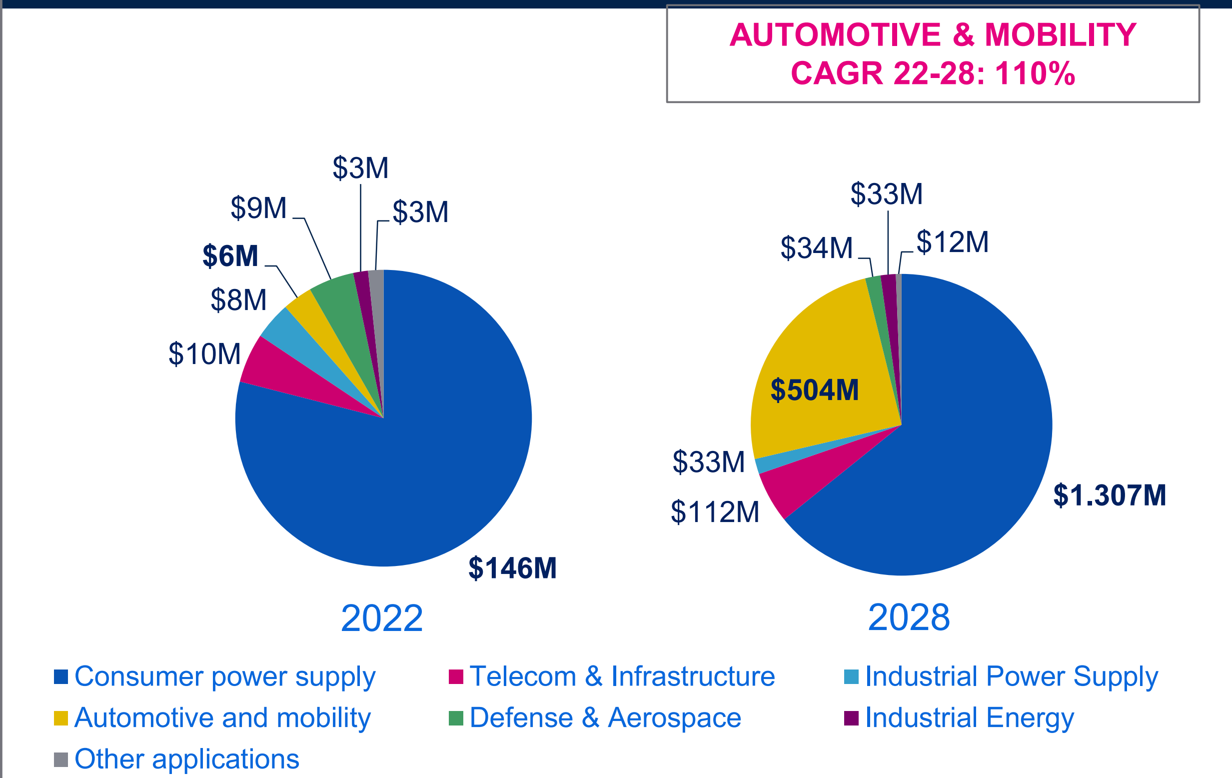


GaN market outlook

GaN by products



GaN by major applications



Other applications = includes power supplies for medical applications and high-power (few kWs) ones for gaming and crypo-mining, and some R&D activities.

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Sources: Yole - Power GaN 2023: Market and Technology Report

GaN characteristics and benefits of GaN in power conversion

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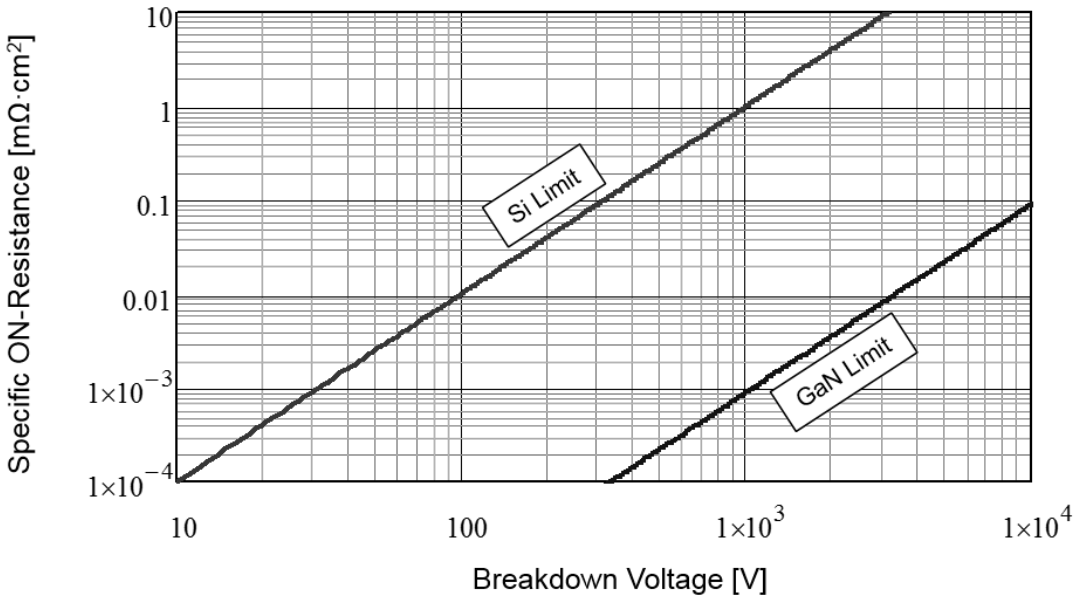
Specific $R_{DS\text{-}ON}$: GaN vs. Si

Property	Si	GaN
E_g (eV) – band gap	1.1	3.39
E_c (MV/cm) – critical electric field	0.3	3.33
ε_r – dielectric constant	11.9	9
μ_n (cm^2/Vs) – electron mobility	1350	1700

$$BFoM\big|_{GaN} \gg BFoM\big|_{Si}$$



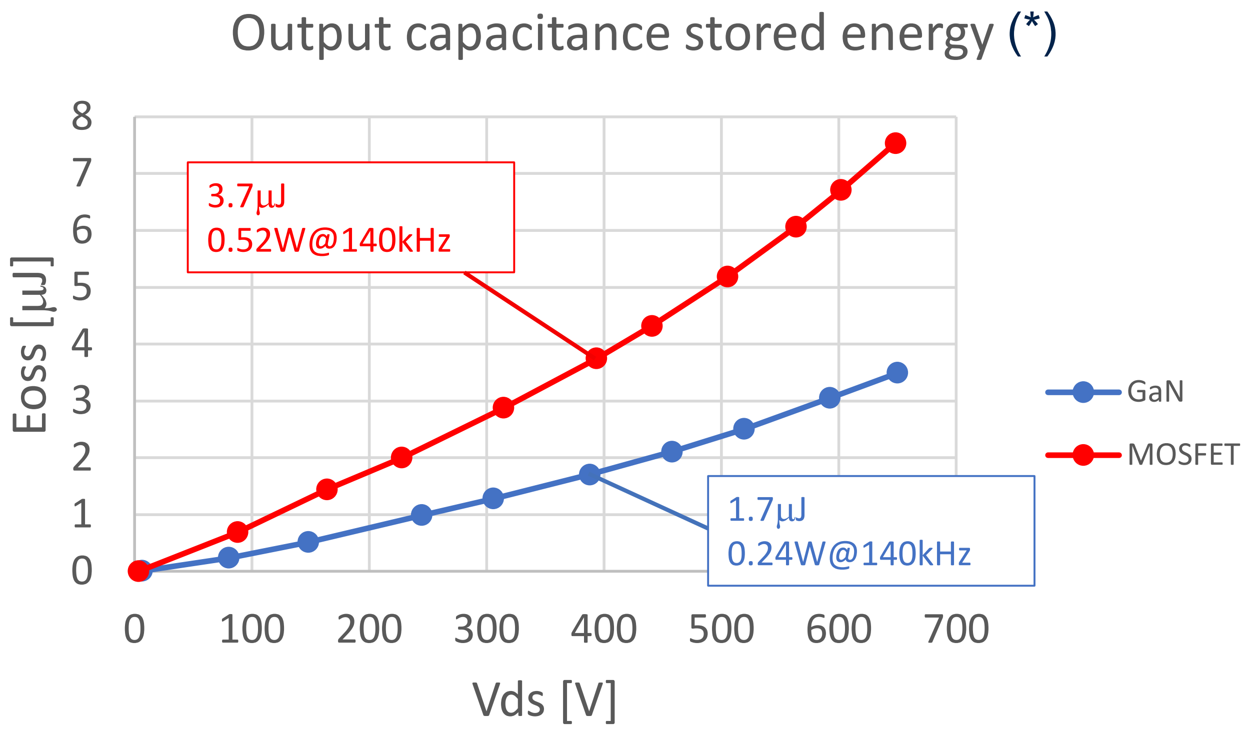
- GaN offers lower specific Ron vs. breakdown voltage limit

  → the technology allows to achieve lower Ron * cm2

- GaN transistor is typically 4 to 10 times smaller than equivalent MOSFET*

(*) Depending on the MOSFET technology used

E_{OSS}: GaN vs. Si



- ✓ During the switching, energy of output capacitance is being dissipated to the heat
- ✓ GaN transistor has much lower Eoss than equivalent Si MOSFETs

$$P_{Coss} = E_{OSS} \cdot f_{SW}$$

Benefits:

- ✓ Lower switching losses
- ✓ High switching frequency permitted
- ✓ High system's efficiency
- ✓ Higher power density compared to silicon-based transistors

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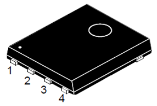
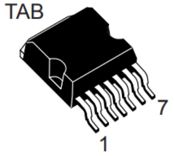
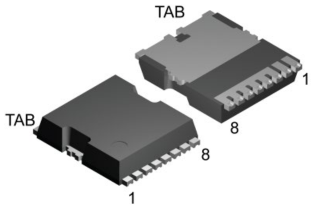
(*) 650V / 225mΩ GaN vs. 650V / 230mΩ MD Mesh M5 MOSFET

Q_{RR} comparison

	SGT65R65AL	SCTH35N65G2V-7	STO67N60DM6
	 PowerFLAT 5x6 HV for GaN	 H^2PAK-7	 TO-LL HV
	65 mΩ *	67 mΩ *	59 mΩ *
Parameter	**GaN–650V**	**SiC–650V**	**Si–600V**
Total gate charge Q_G [nC]	**5.4**	**73**	**72.5**
Reverse recovery charge **Q_{RR} [nC]**	**0**	**85**	**> 600**

GaN transistors have zero reverse recovery charge
→ less losses in hard switching

* RDS(on)max at 25°C

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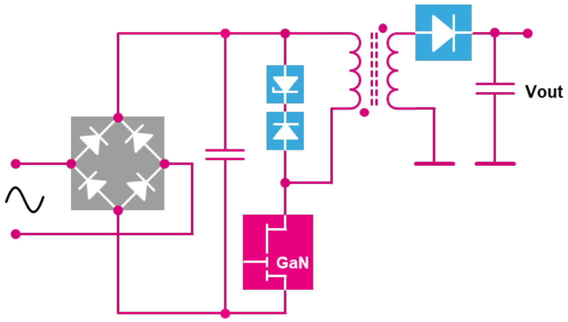
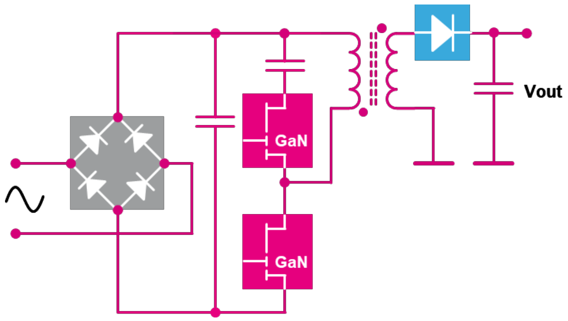
Usage of GaN in power conversion

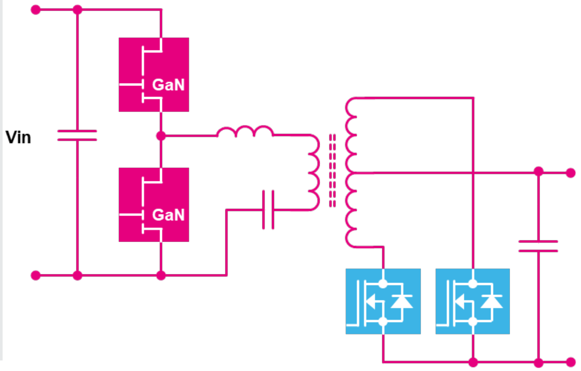
most common topologies

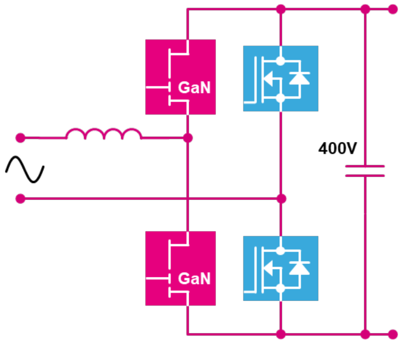
Power

Zero current switching	Soft switching		Hard switching
Flyback QR (AC/DC)	**Active Clamp Flyback (ACF)** (AC/DC)	**Half-bridge LLC Resonant** (DC/DC)	**Totem-Pole Bridgeless CCM** (AC/DC (PFC))









Auxiliary SMPS | Chargers / LED drivers | Industrial / lighting / telecom SMPS

Power supplies **< 100W** | Power supplies **> 100W**

Power supplies **> 1kW**

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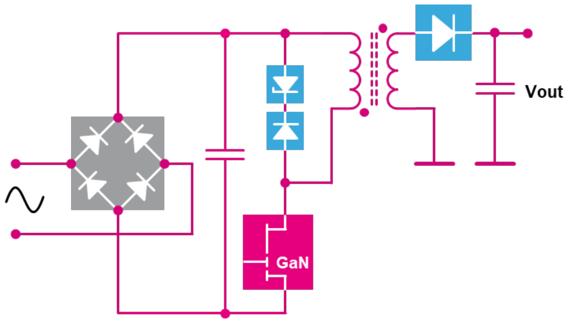
Usage of GaN in power conversion

most common topologies

Power

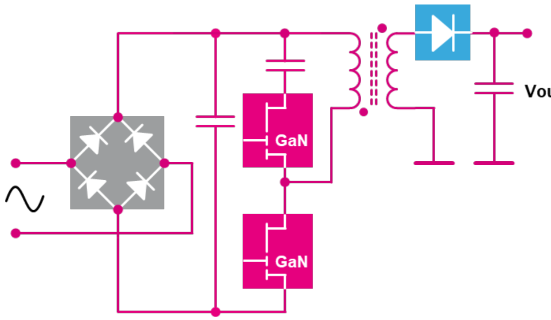
Zero current switching	Soft switching		Hard switching
Flyback QR AC/DC	Active Clamp Flyback (ACF) AC/DC	Half-bridge LLC Resonant DC/DC	Totem-Pole Bridgeless CCM AC/DC (PFC)



Why GaN?

- Lower parasitic capacitances
- Lower losses

→ **increasing efficiency**
→ **increasing frequency**
(to reduce size of magnetic)



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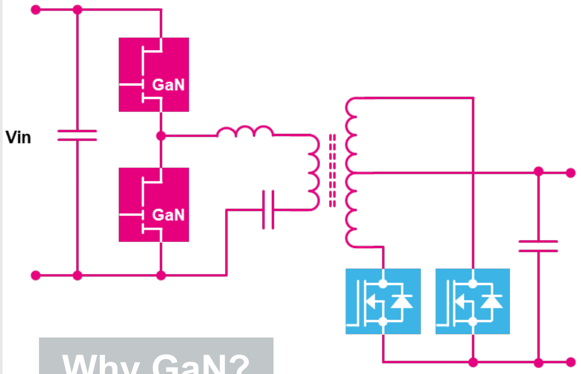
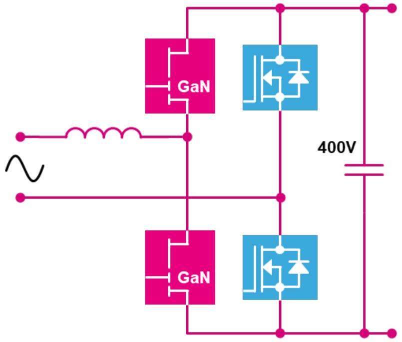


Why GaN?

- Lower parasitic capacitances
- Lower gate losses

→ increasing efficiency
→ **increasing frequency**
(to reduce size of magnetic)

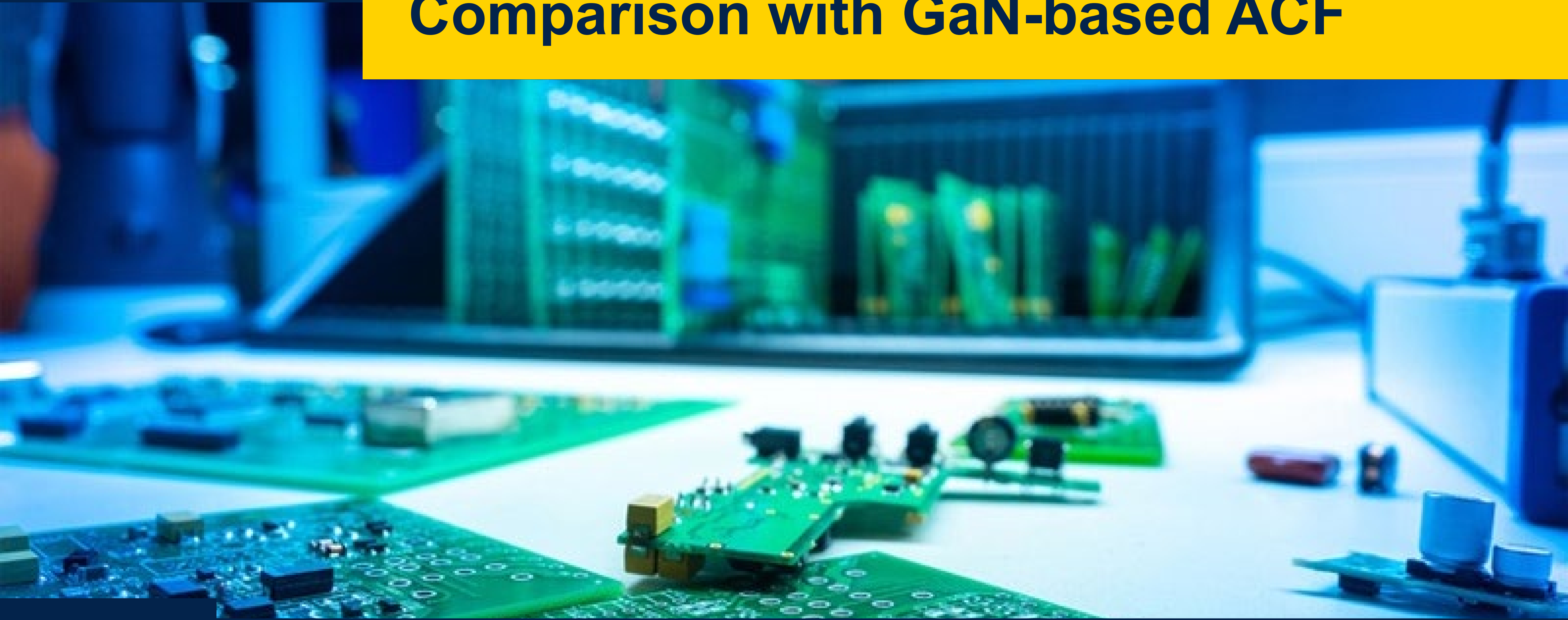


Why GaN?

- No reverse recovery of the diode
- Lower parasitic capacitances
- Lower losses

→ **increasing efficiency**

GaN-based quasi-resonant flyback & Comparison with GaN-based ACF



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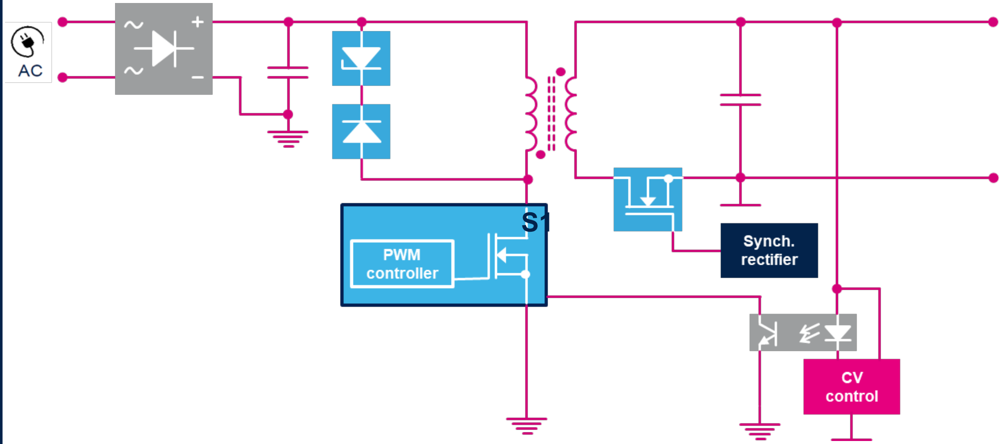
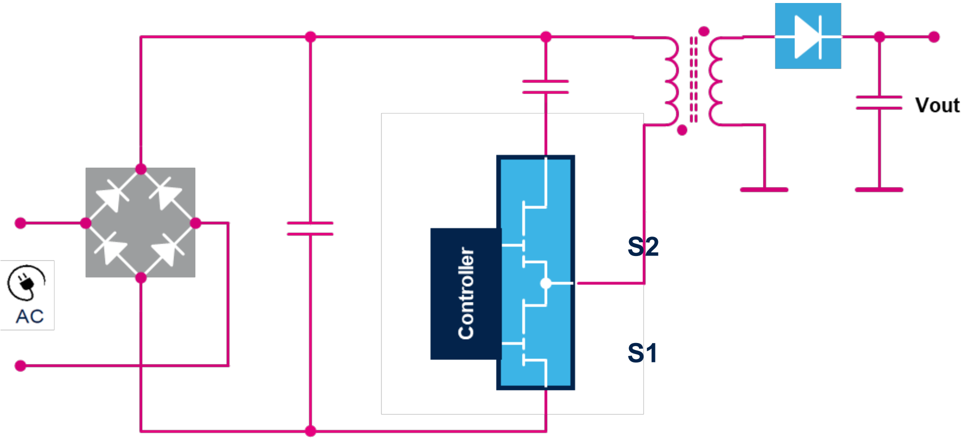
Commonly used topologies up to 100W

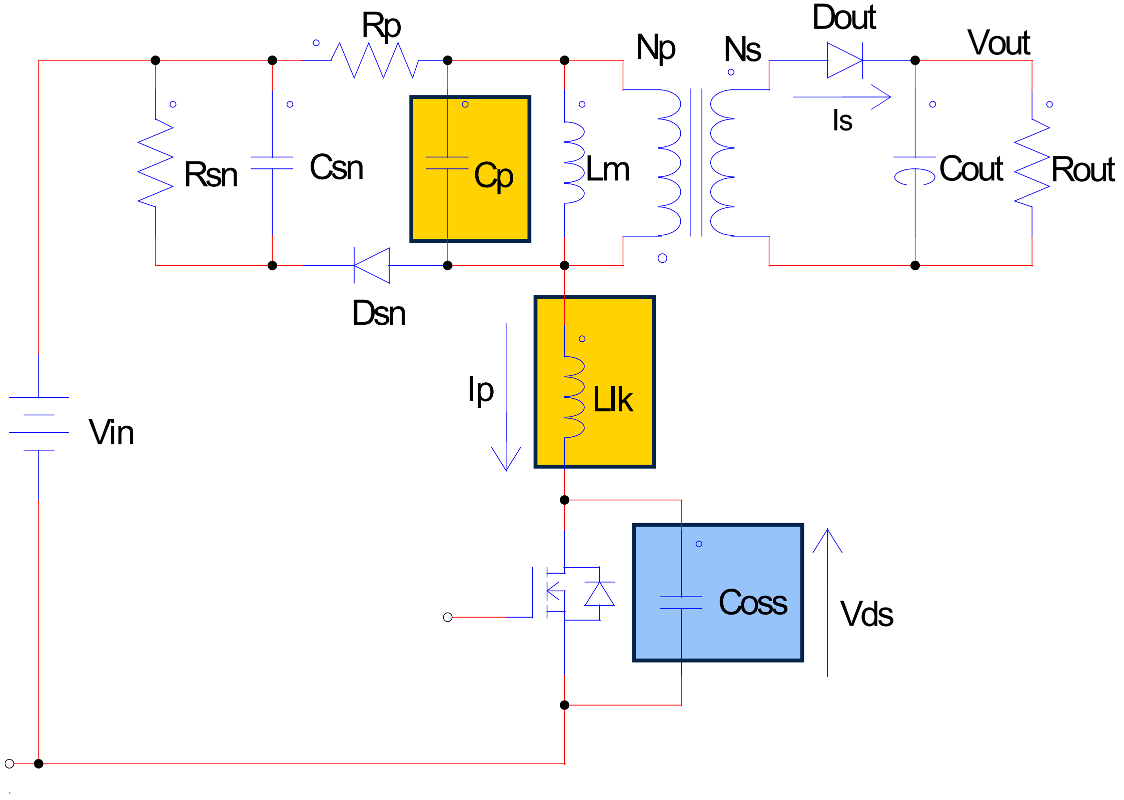
<table>
<tr><th></th><th>Traditional Flyback (up to 50W)</th><th>Active Clamp Flyback (ACF)</th></tr>
<tr><td>Topology</td><td>
</td><td>
</td></tr>
<tr><td>Operation</td><td><u>Stage1</u>: S1 turn-on, the transformer stores energy

<u>Stage2:</u> S1 turn-off, the energy is transferred to the secondary; the leakage inductance energy is absorbed by RCD snubber</td><td><u>Stage1</u>: S1 turn-on, the transformer stores energy

<u>Stage2</u>: S1 turn-off, the energy is transferred to the secondary, S2 turn-on and the leakage inductance energy transfers to Csn

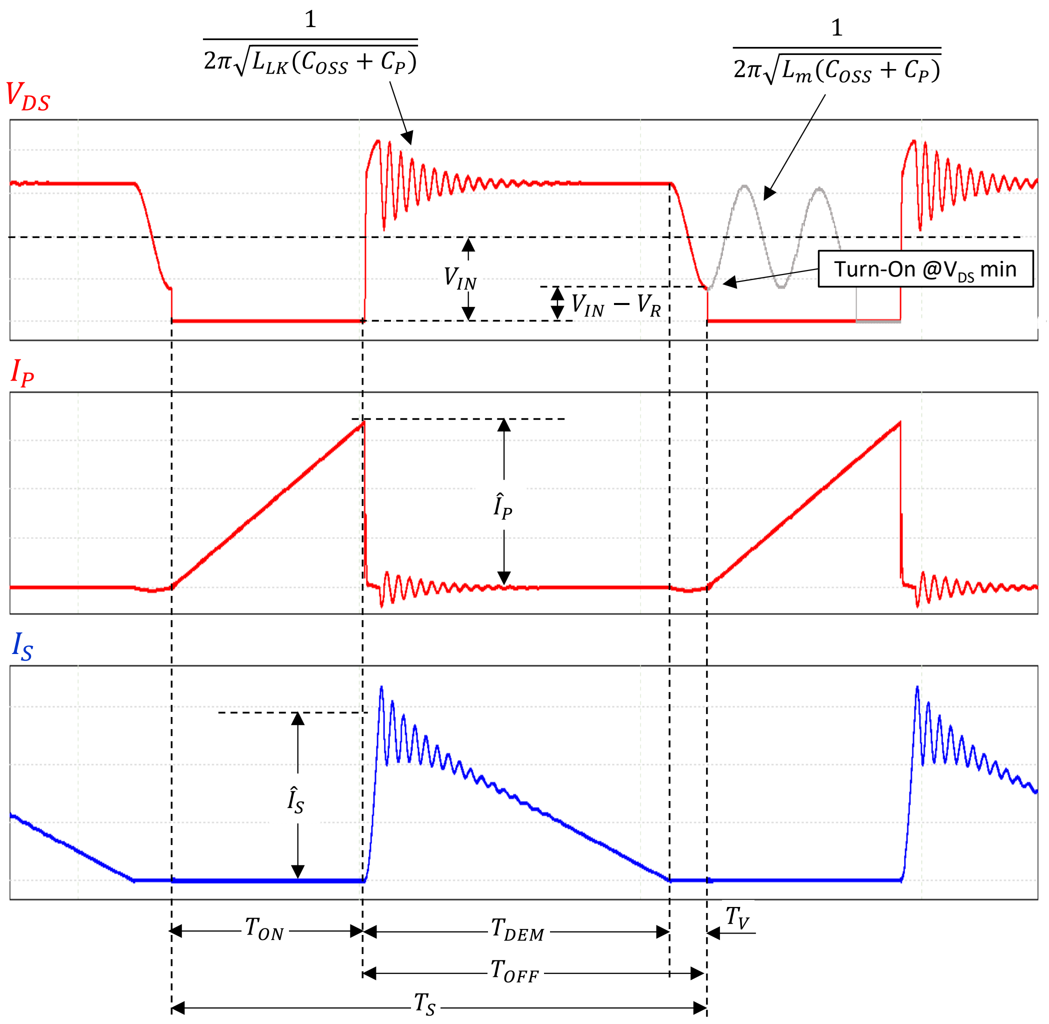
<u>Stage3</u>: S2 turn-off, the energy stored in Csn discharges Coss to achieve ZVS for S1</td></tr>
<tr><td>PROs</td><td>• Low cost
• Easy to design</td><td>• The energy of the leakage inductance is recycled
• ZVS is achieved and switching losses are minimized → High efficiency and high switching frequency achievable</td></tr>
<tr><td>CONs</td><td>• High power losses and spike caused by leakage inductance of the transformer
• High switching losses of the main MOSFET</td><td>• Additional clamp power switch with dedicated high-side driver
• Increases the complexity of the controller</td></tr>
</table>

QR Flyback converter



Topology-related

Power switch-related



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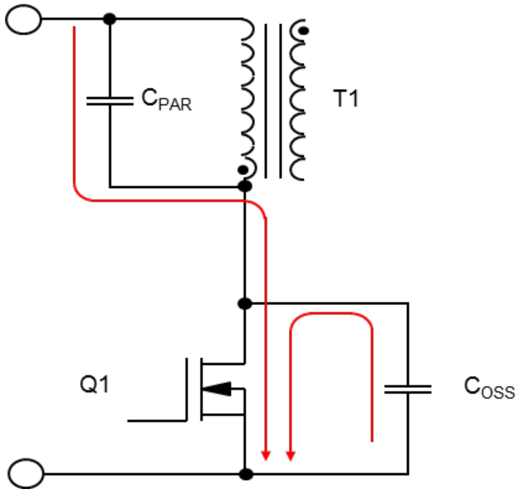
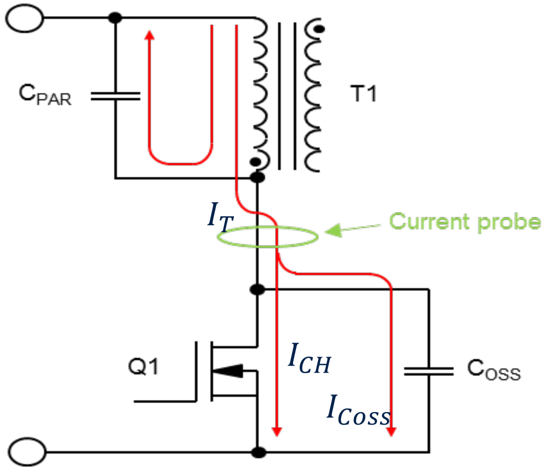
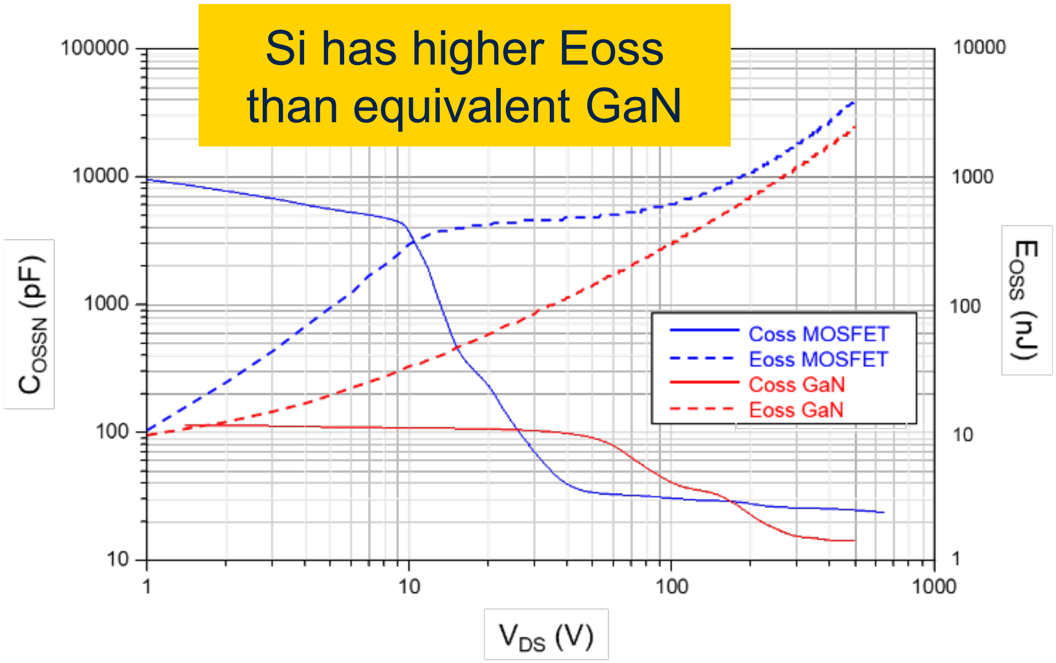
Main ICs losses in a traditional flyback converter



Turn-ON



Turn-OFF



Transistor-related losses

$$P_{ON} = I^2_{P(RMS)} R_{DS(ON)}$$

$$P_{SW-ON(Coss)} = f_{SW} \int_0^{V_{DS(OFF)}} C_{OSS}(V_{ds}) V_{ds} dV_{ds}$$

Topology-related losses

$$P_{SW-ON(Cp)} = \frac{1}{2} C_P V^2_{DS(OFF)} f_{SW}$$

$$P_{sn} = \frac{1}{2} L_{LK} I_P^2 \frac{V_{LK} + V_R}{V_{LK}} f_{SW}$$

$$P_{SW-OFF} = (V_{IN} + V_R) I_P t_{OFF} f_{SW}$$

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Single switch flyback with GaN: VIPerGaN50 eval-boards

50W / 15V - QR flyback

Isolated QR flyback converter with adaptive synchronous rectification

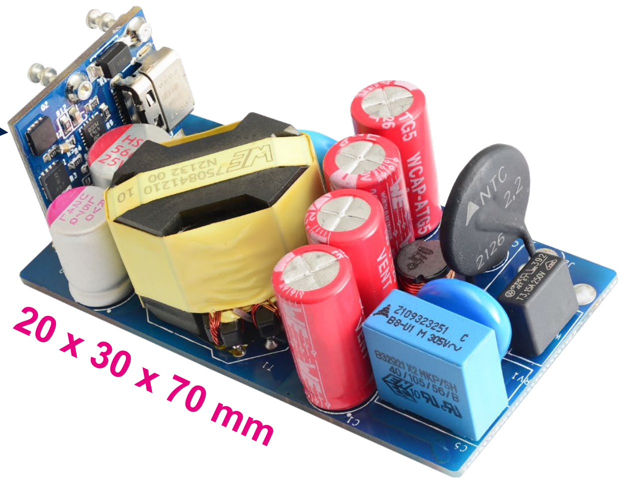
	115 V_{AC}	230 V_{AC}
No load cons.	49 mW	60 mW
Aver. Eff	**90.5%**	**90.1%**
Peak Eff.	**91.1%**	**92.2%**
Eff.@ 10% load	88.4%	84.6%

VIPerGaN50 PWM controller with 650V GaN

- V_{IN} = 90VAC ~ 265VAC
- V_{OUT} = +15V
- I_{OUT} = 3.3A
- P_{OUT_tot} = 50W
- T_{AMBmax} = 60°C

45W / USB PD - QR flyback

USB Type-C® output
On daughter board



45W USB Type-C® Power Delivery 3.0 charger based on VIPERGAN50, SRK1001, and STUSB4761

	115 V_{AC}	230 V_{AC}
No load cons.	< 30 mW	
Max. Eff @full load	**91.5%**	
Eff.@ 10% load	88%	83%

- V_{IN} = 90V_{AC} ~ 265V_{AC}
- PD output profile =
  - 5V/9V/12V/15V @ 3 A
  - 20 V @ 2.25 A
- P_{OUT_max} = 45W
- T_{AMBmax} = 60°C

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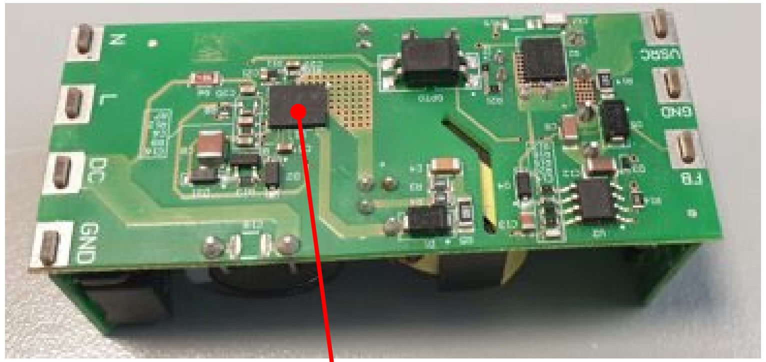
Single switch flyback with GaN: VIPerGaN65 USB-PD eval-board

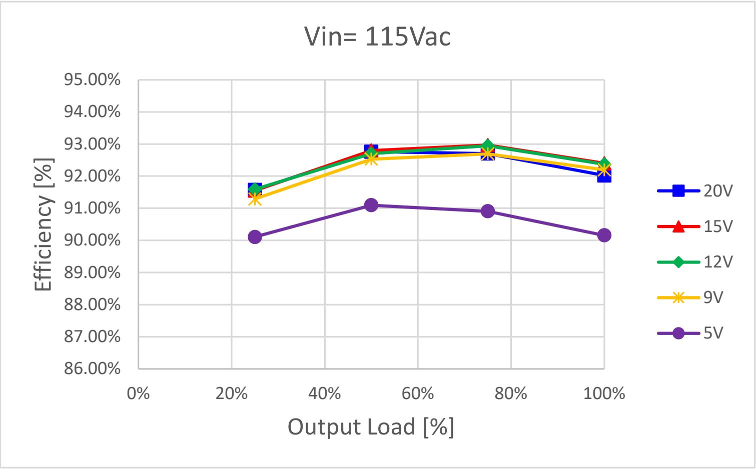
> 93.5% peak efficiency

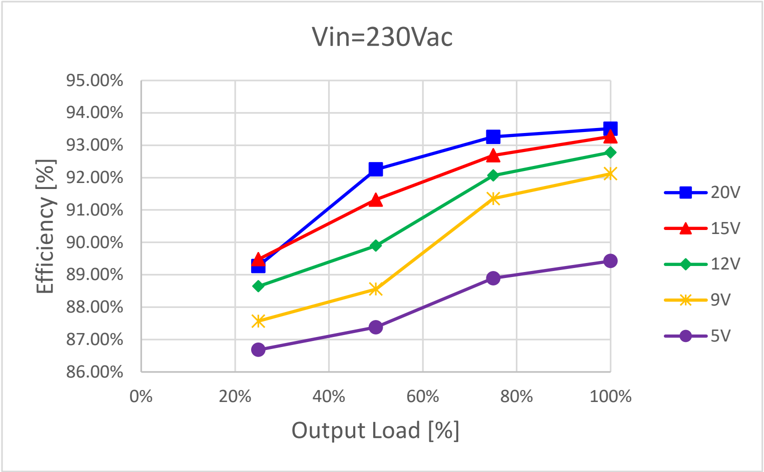
EVLVIPGAN65PD – 65W USB-PD

- Input Voltage: Universal AC from 90 VAC to 264 VAC with 47 Hz up to 63 Hz
- Support for 65W Type-C USB-PD (5V, 9V, 12V, 15V@3A – 20V@3.25A)
- Efficiency: Meets CoC Tier 2 and DoE Level 6 efficiency requireme
- EMC Compliance: CISPR22B / EN55022B
- Power density: 22.1 W/in^3 (unboxed) - (69x20x35) mm



VIPerGaN65





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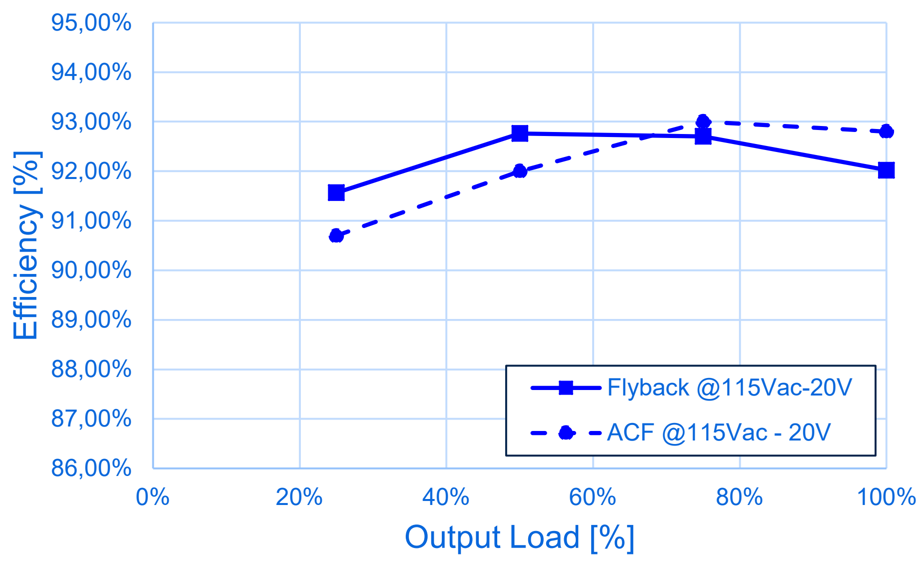
GaN-based Flyback vs. ACF

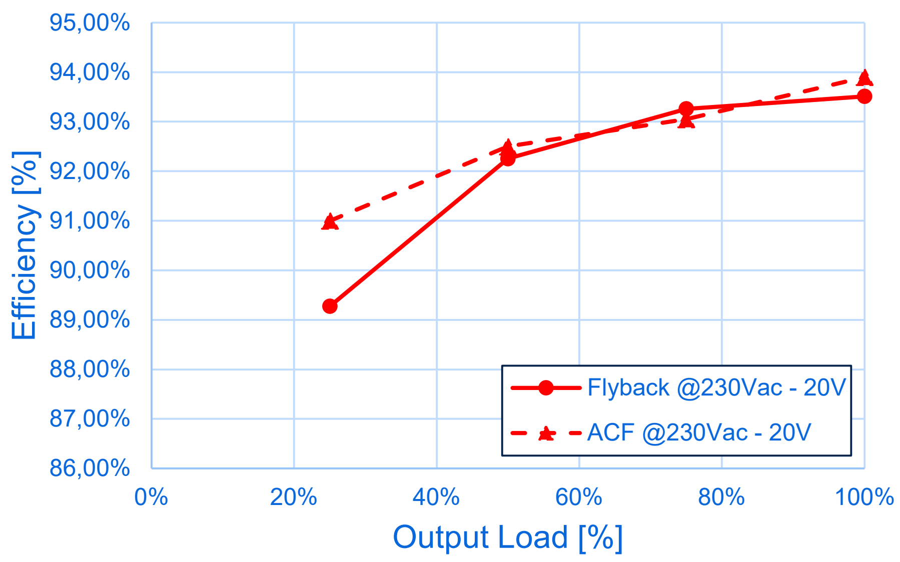
Efficiency comparison

65W USB-PD application – 20V profile

115Vac



230Vac



- ✓ Gan-based QR flyback efficiency is comparable with ACF efficiency in most of operative conditions
- ✓ ACF is better where switching losses have greater impact → high input voltage/medium-light load

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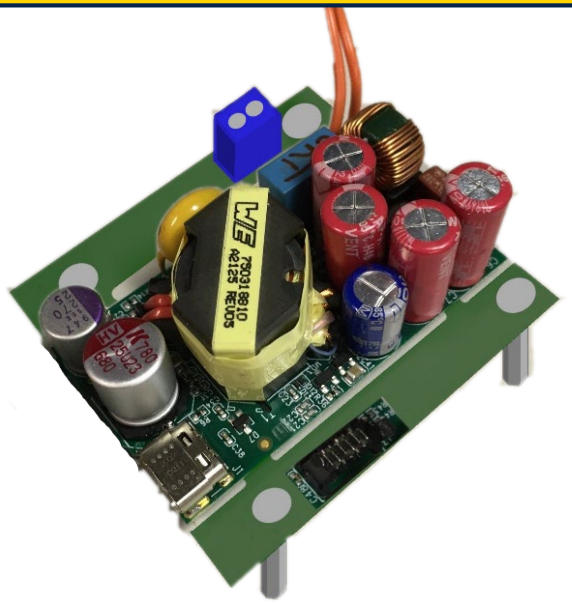
GaN-based Flyback vs. ACF

Power density comparison

ACF has better power density due to the higher switching frequency operations



EVLONE65W (ACF)	
Dimensions	(58 x 32 x 20) mm
Power density	28.7 W / in3
Switching frequency	Up to 250 kHz

EVLVIPGAN65PD (QR flyback)	
Dimensions	(69 x 20 x 35) mm
Power density	22.1 W / in3
Switching frequency	Up to 140 kHz

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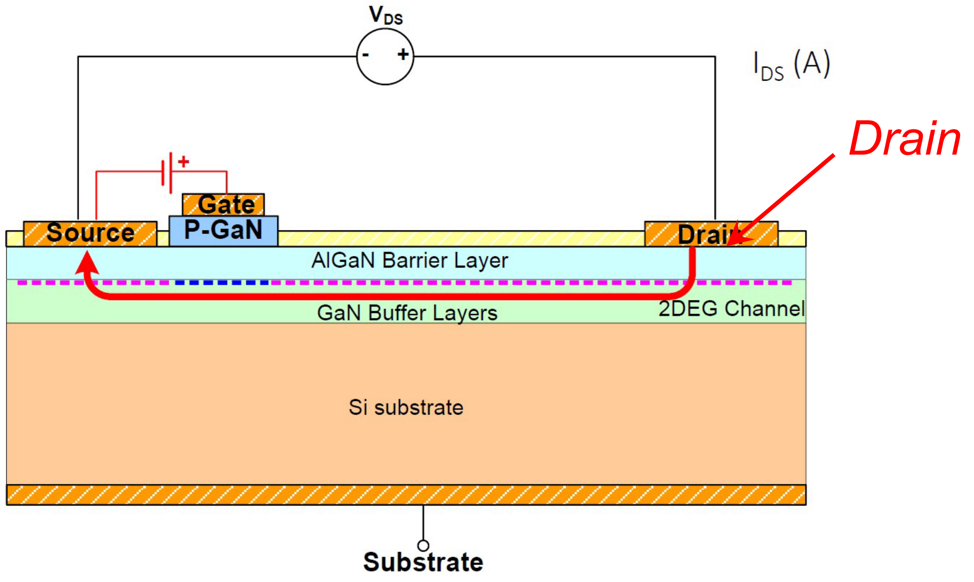
HEMT GaN vs. MOSFET

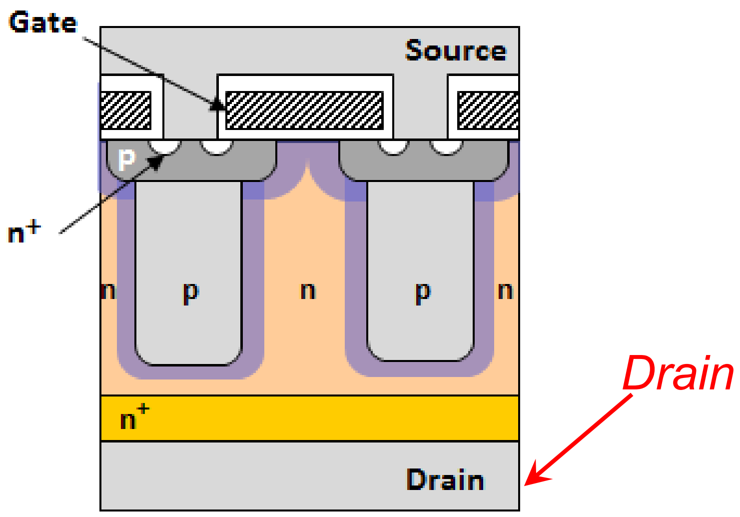
Device structure

HEMT GaN



Lateral structure

SJ Mosfet

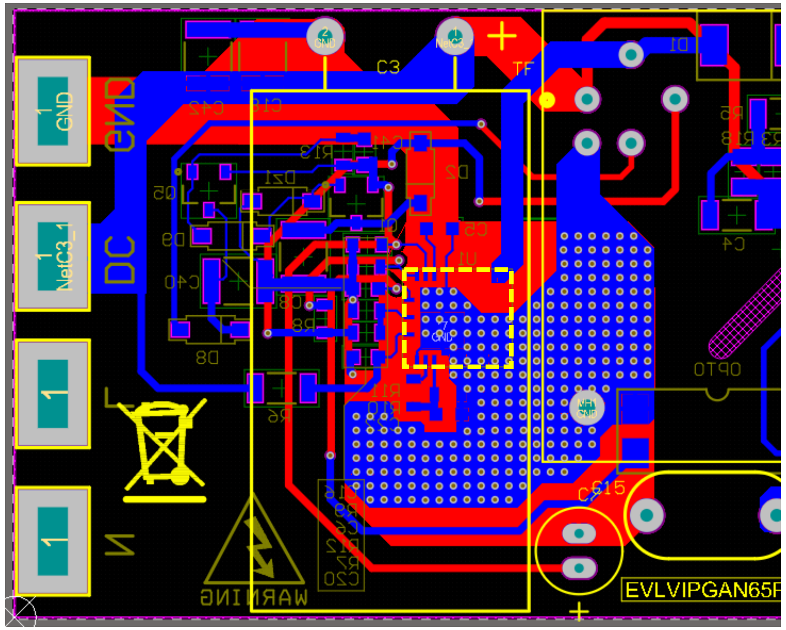


Vertical structure

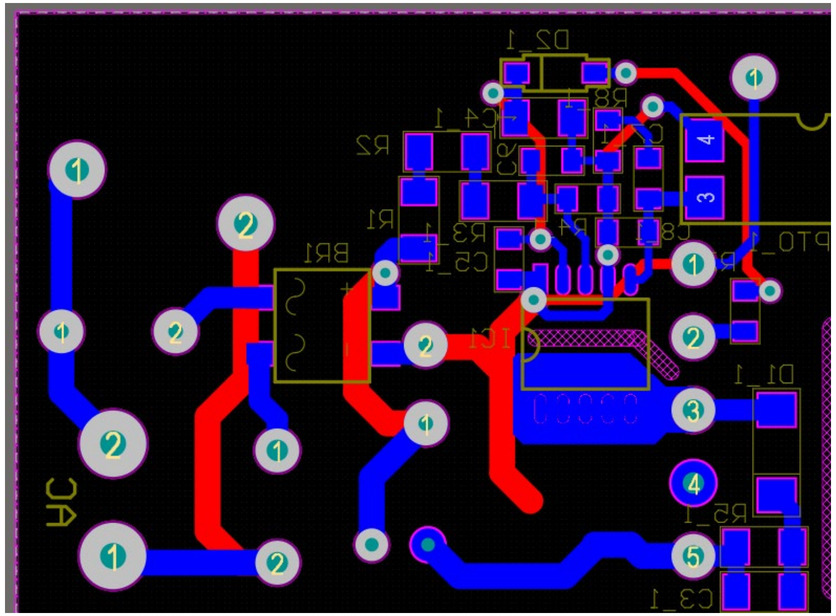
- The substrate of the GaN can be connected to GND to cool-down the chip

HEMT GaN vs. MOSFET
Device structure

GaN-based chip



Mosfet-based chip



- The substrate of the GaN can be connected to GND to cool-down the chip
  - ✓ Simplified package → Lead-frame with single die pad required
  - ✓ Better package thermal performances → Small package required and lower cost
  - ✓ Simplified PCB design → Dissipation pad can connect to a ground plane without affecting the EMI performances

Beneficial especially in topologies with LS switch only, like single switch flyback

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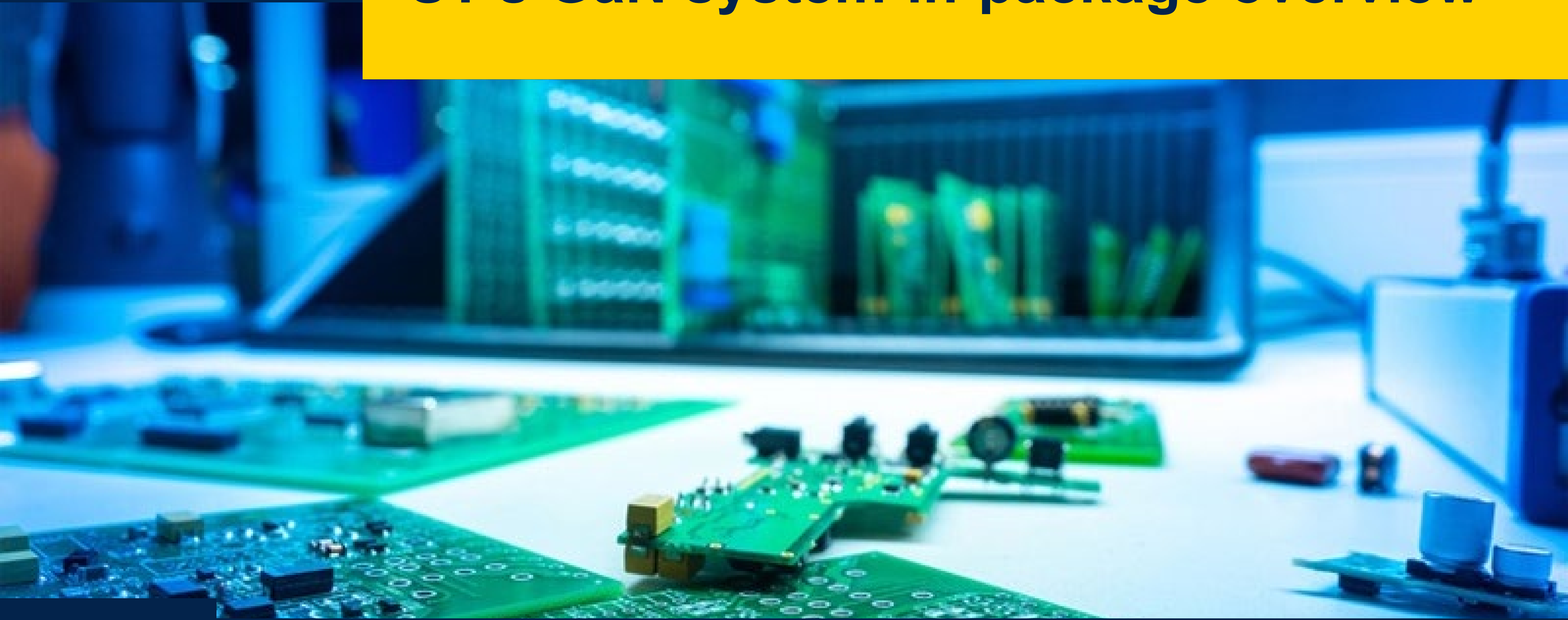
VIPer

MasterGaN

ST’s GaN system-in-package overview



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GaN System-in-Package Overview

Innovative 600V and 650V GaN HEMT products

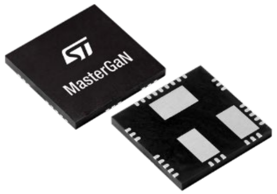
VIPerGaN

VIPerGaN50	VIPerGaN65	VIPerGaN100
450mΩ GaN HEMT	260mΩ GaN HEMT	225mΩ GaN HEMT

Quasi-resonant Flyback

QFN 5x6 mm^2, pin-to-pin scalable

MasterGaN



GQFN 9x9 mm^2, pin-to-pin scalable

MasterGaN3	MasterGaN2	MasterGaN5	MasterGaN4	MasterGaN1
225mΩ + 450mΩ	150mΩ + 225mΩ	450mΩ + 450mΩ	225mΩ + 225mΩ	150mΩ + 150mΩ

Active Clamp Flyback (MasterGaN3, MasterGaN2)

LLC Resonant (MasterGaN5, MasterGaN4, MasterGaN1)

Up to 500W

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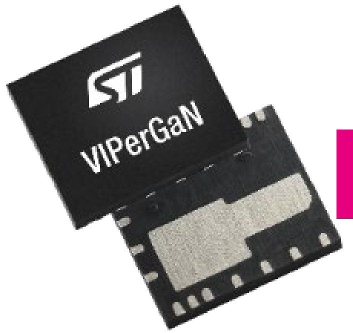
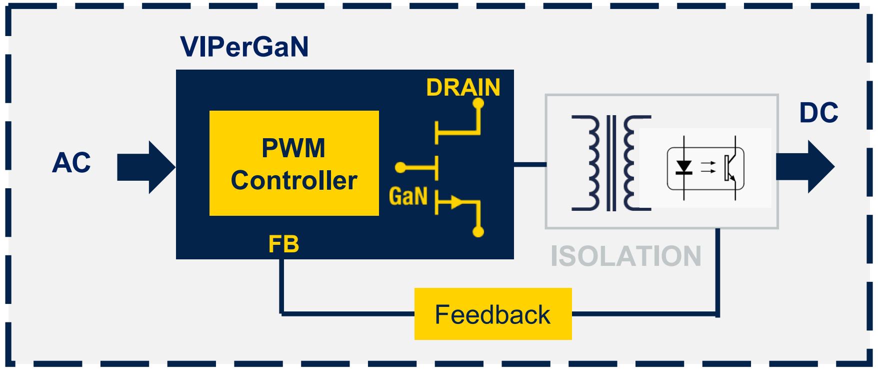
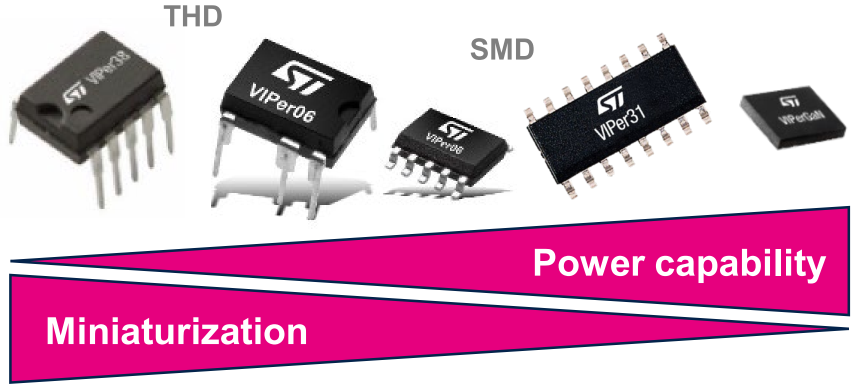
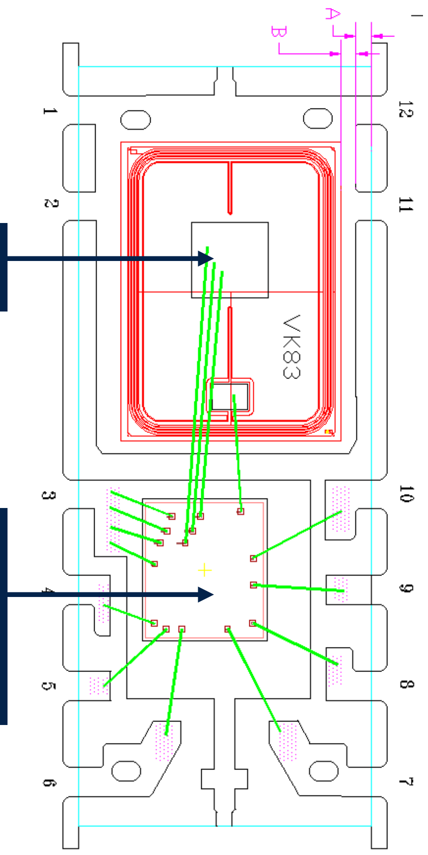
VIPerGaN: offline flyback converter with 650V GaN HEMT switch



QFN 5x6 mm², pin-to-pin scalable







GaN HEMT

- 650 V E-mode power GaN transistor
- 850 V transients allowed for Tpulse < 1 µs

Advanced controller

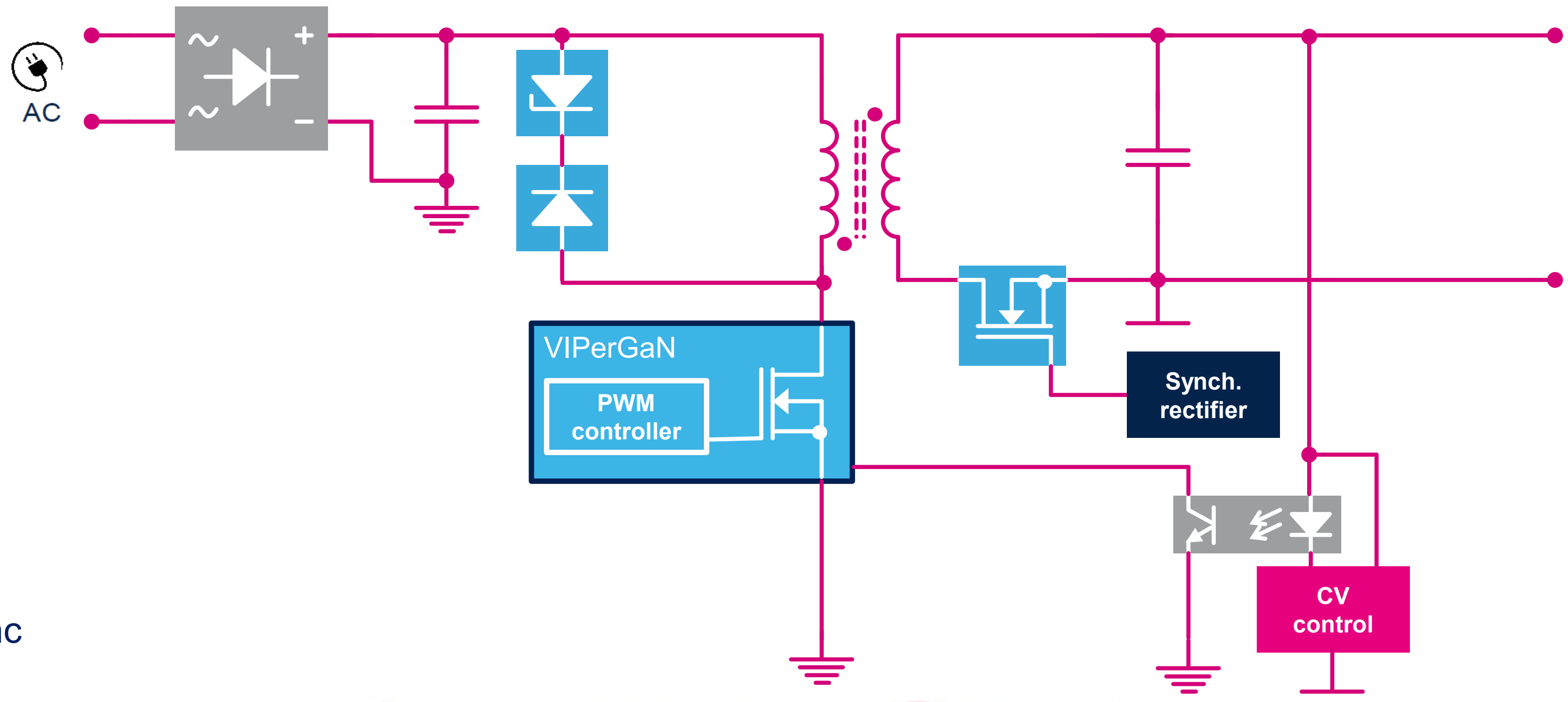
- PWM controller
- Startup
- Current sensing

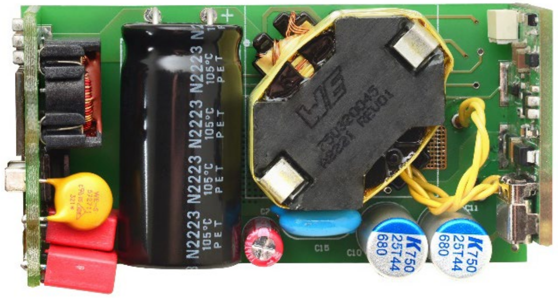
VIPerGaN quasi-resonant flyback topology

QFN 5x6

VIPerGaN family

- Integrated controller + 650V GaN HEMT
- R_{DSON} = 225 – 450 mΩ
- Advanced quasi-resonant flyback up to 100W
- Embedded HV start up generator
- Embedded protections
- **Up to 240kHz switching frequency** + jittering
- Less than 30mW standby power consumption
- Dynamic blanking time and adjustable valley sync
- Adaptive burst mode
- Easy entry to wide bandgap
- Minimized magnetic components
- Cost-effective BoM
- Energy saving regulations





EVLVIPGAN65PD
65W USB PD Charger

EVLVIPGAN50FL
50W Quasi-resonant

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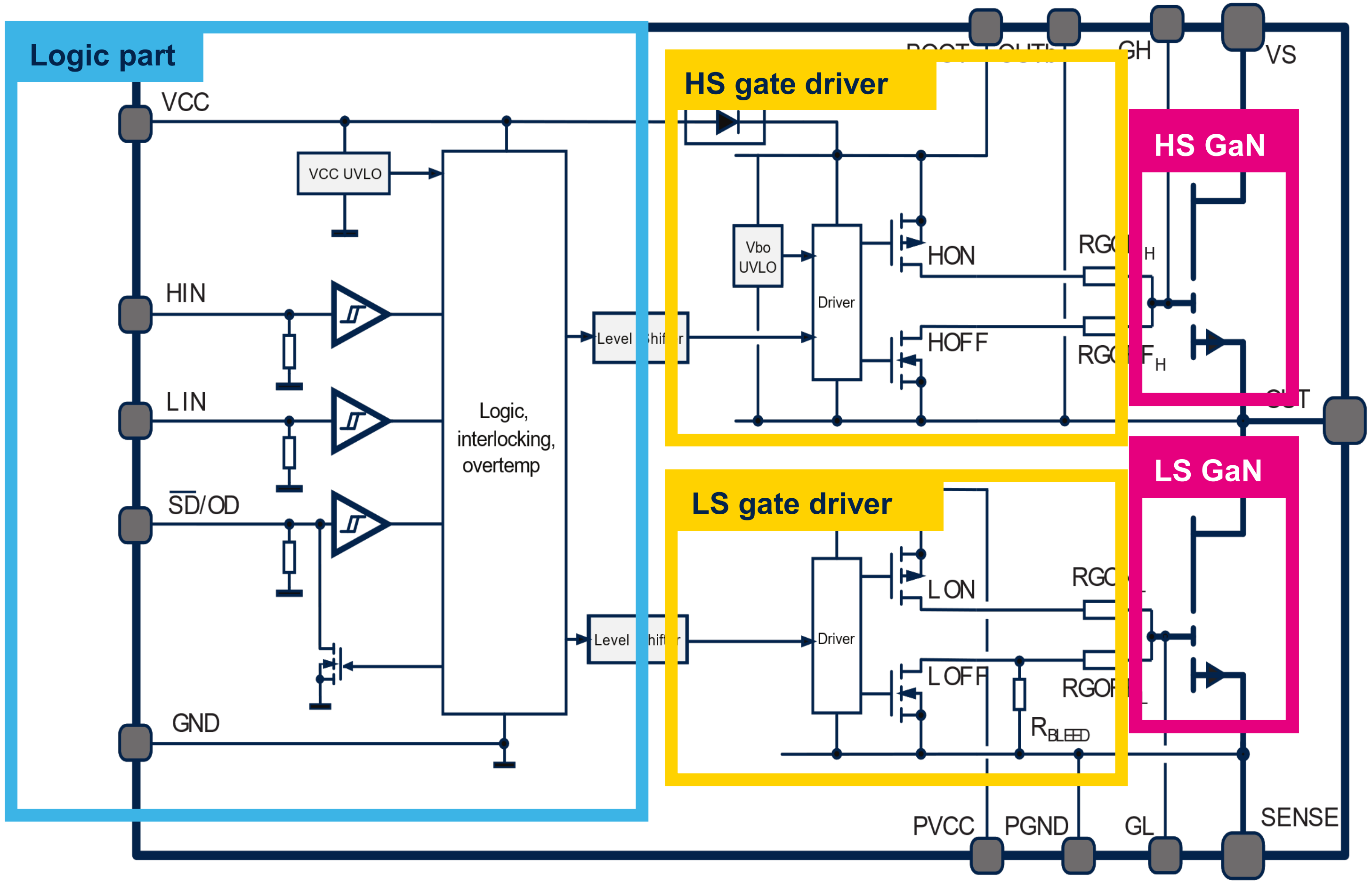
MasterGaN block diagram

The world first solution combining 600 V half-bridge driver with GaN HEMT: compact, robust & easy to design

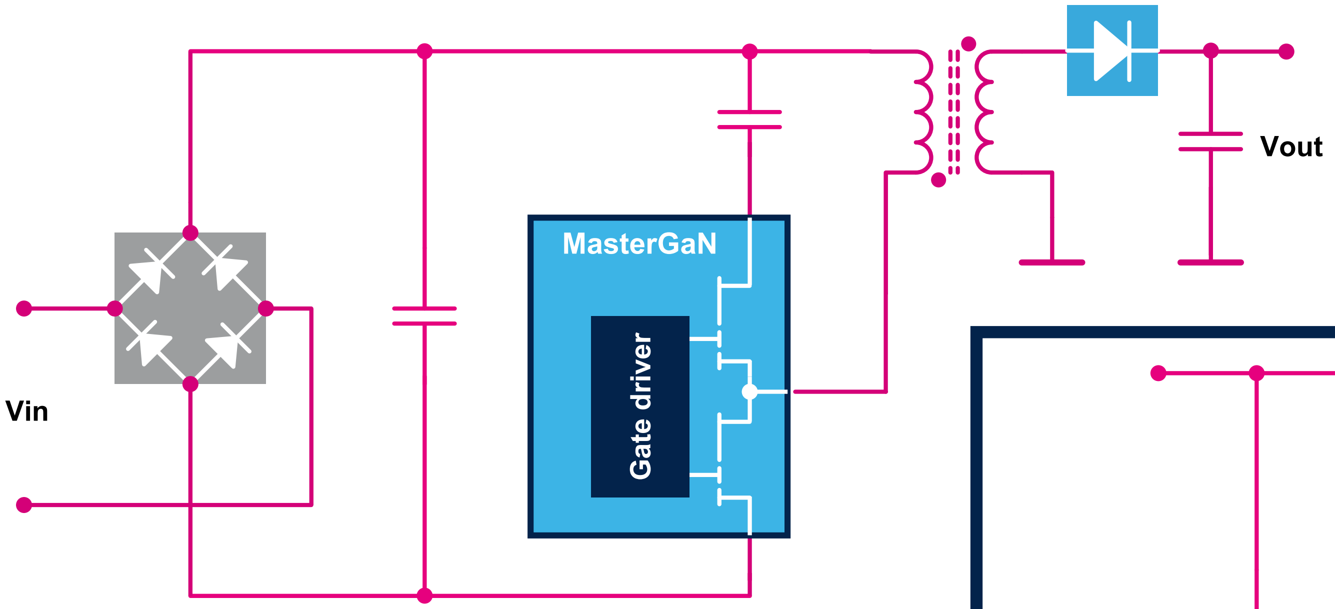
GQFN 9x9 mm², pin-to-pin scalable



MasterGaN family

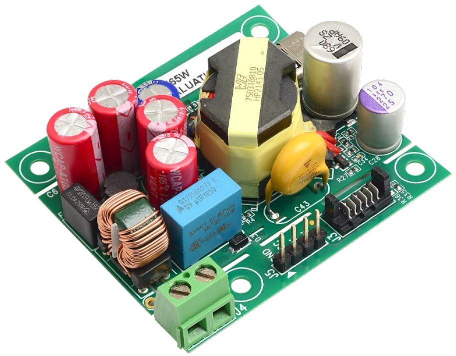
- 600V GaN HEMT
- Integrated half-bridge
- Integrated gate driver
- R_{DSON} = 150 – 450 mΩ
- Up to 500W
- Active-clamp flyback, LLC, LCC...
- High power density applications
- High efficiency
- Minimized size of magnetics

MasterGaN ACF and LLC topology



Active clamp flyback

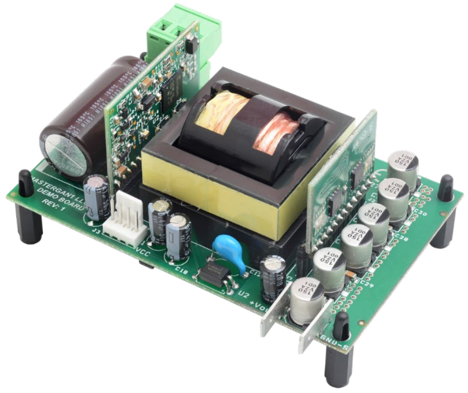
- AC/DC converter
- Soft switching
- Two switch topology
- Up to 150W



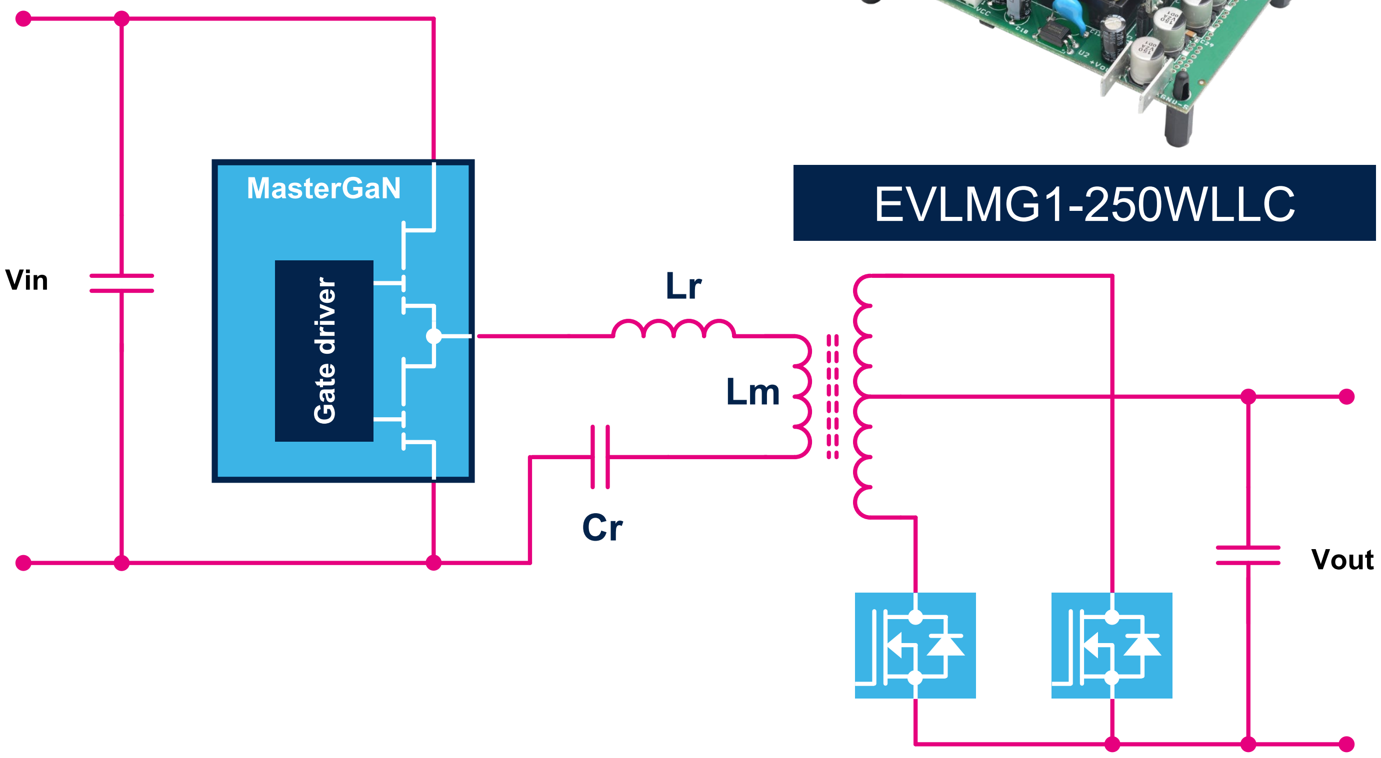
EVLONE65W

LLC converter

- DC/DC converter
- High efficiency
- Soft switching



EVLMG1-250WLLC



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Conclusions

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Conclusions

- Thanks to the lower E_{OSS}, QR flyback with GaN offers much higher efficiency than QR flyback with Silicon (typically 3-4% more) and the possibility to work at higher switching frequency, thus leading to much higher power density
- Efficiency of GaN-based QR flyback is similar to the one of GaN-based ACF in most operating conditions
- Active clamp flyback with GaN shows better efficiency at high input voltage and light-medium loads
- Active clamp flyback with GaN is the best solution when the highest power density is required (~30% higher than in QR flyback)
- GaN-based QR flyback represents the best trade-off performance - cost

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Questions

& Answers

We are here for you now!
Ask us directly via our chat or via E-Mail.

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Thank you

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