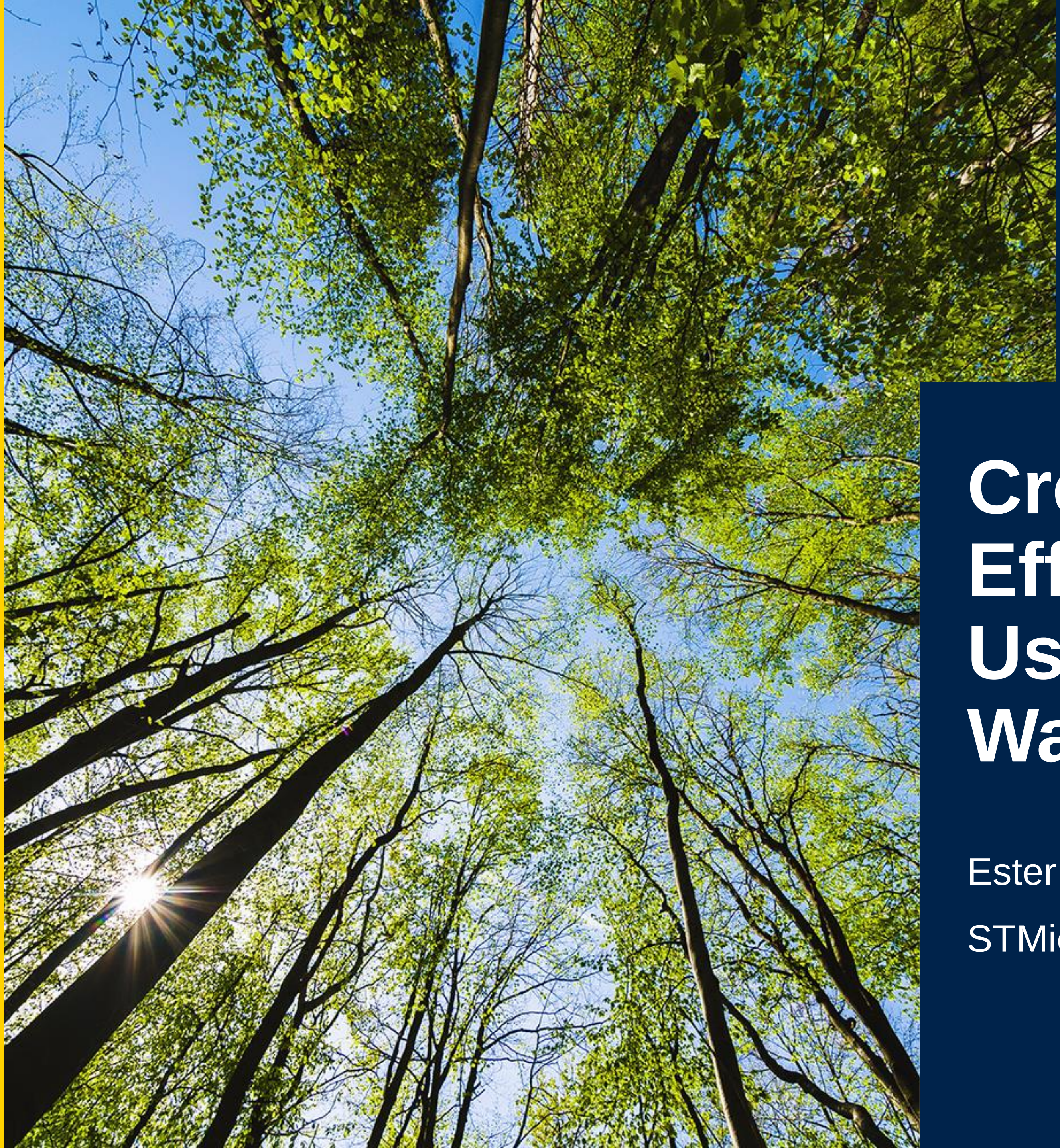

Creating Compact and Efficient Power Supplies Using GaN for Up to 100 Watts

Ester Spitale, Radek Sochor, David Kudelasek

STMicroelectronics

Agenda of the ST Presentation

1 Benefits of GaN in power conversion

2 Quasi-resonant flyback (QR) flyback topology

3 New VIPerGaN family with GaN switch

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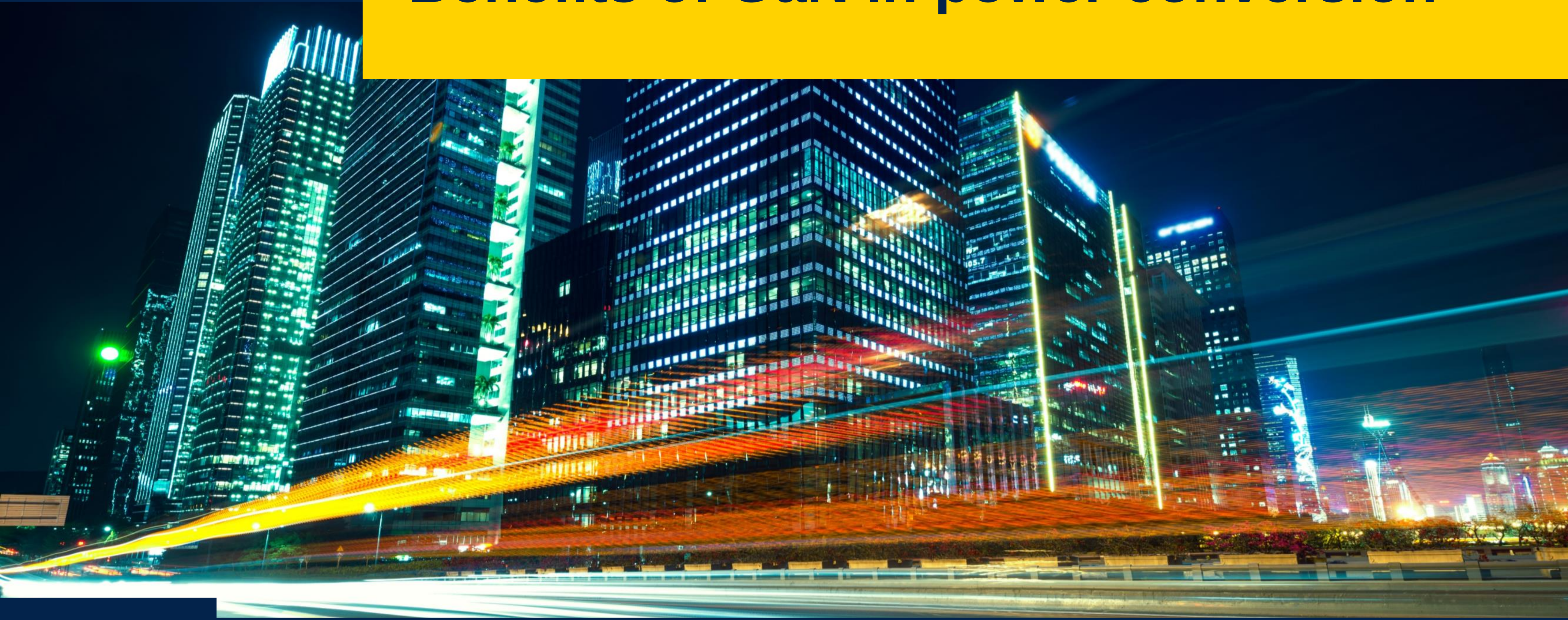
Benefits of GaN in power conversion



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GaN has dramatically lower gate charge

Gate charging is process of charging input capacitance of transistor from the voltage source through gate resistors. This process generate losses on this resistors. Losses are given by equation:

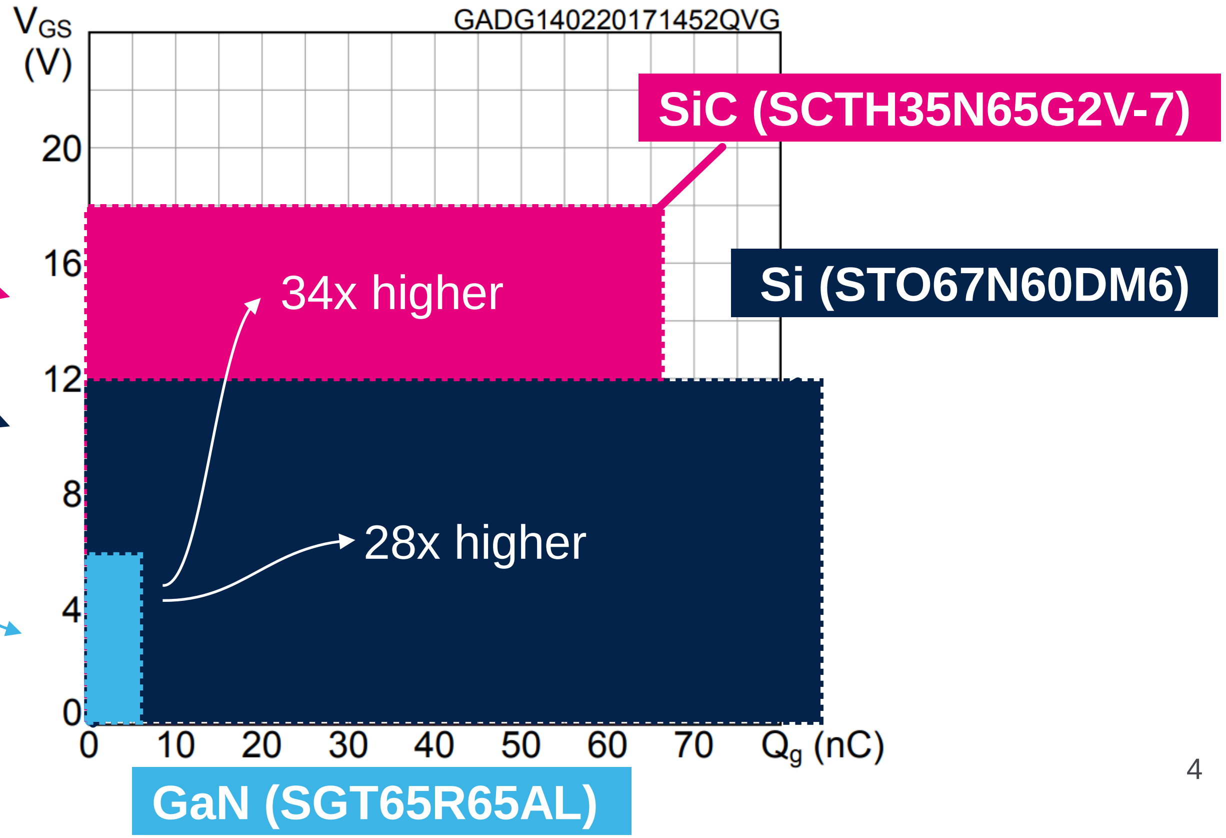
Rectangle of energy

- $P_{GateDrive} = f_{sw} * V_{CC} * Q_G$

- Q_G : extracted from datasheet
- V_{CC}: supply voltage of gate driver
- f_{sw} : switching frequency of the transistor

GaN transistors offer at the same Rdson ~30x lower gate charge compare to Si/SiC → lower gate driver losses

Gate charge chart



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GaN reduces output capacitance energy

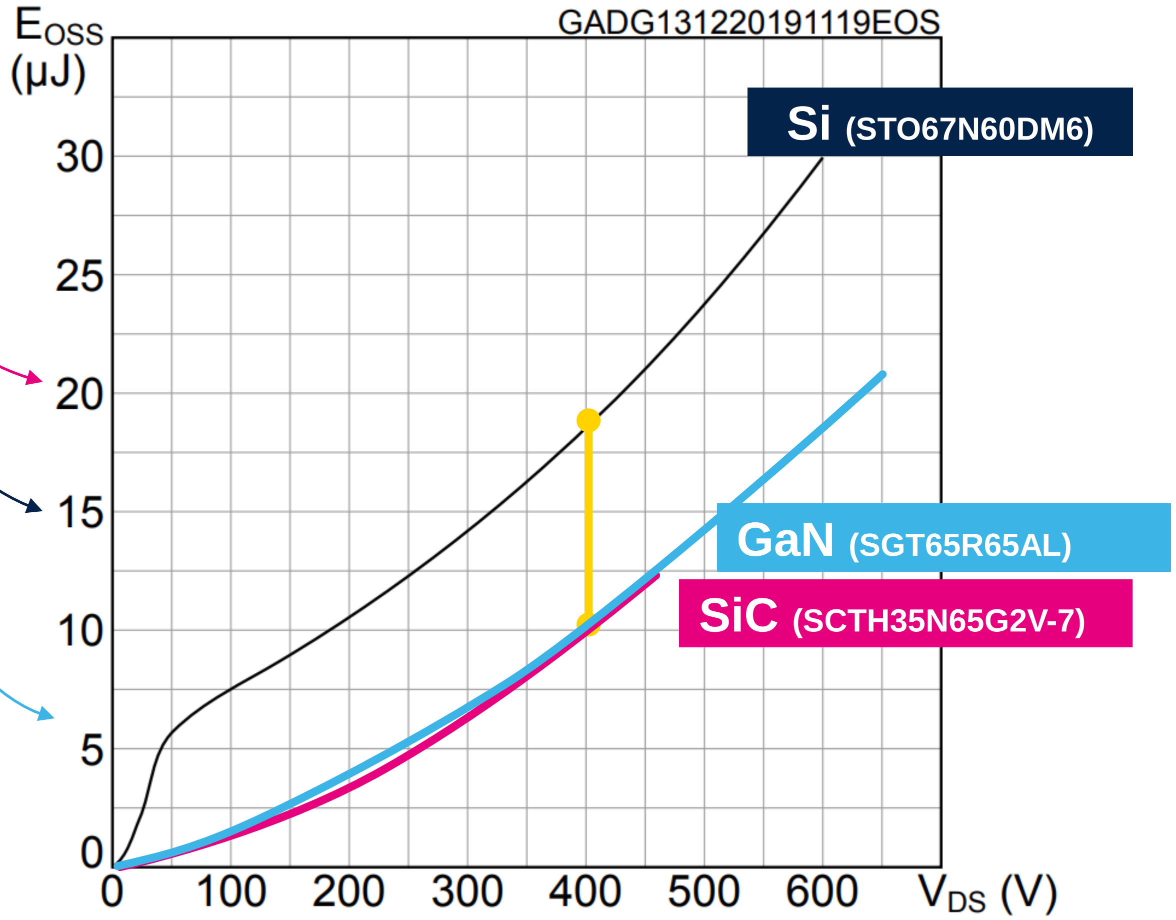
Output capacitance energy value is important parameter for many topologies where Coss energy is dissipating. During the hard switching, energy of output capacitance is being dissipated to the heat.

- $P_{LossCoss} = f_{sw} * E_{OSS}(V_{DS})$
  Nonlinear

- E_{OSS} : output capacitor stored energy
- f_{sw} : switching frequency of the transistor

At typical bus voltage 400V, Si MOSFET has ~2x higher Eoss than equivalent GaN

Output capacitance - Coss stored energy ~ 650V/50mΩ



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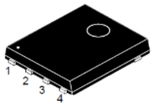
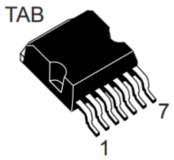
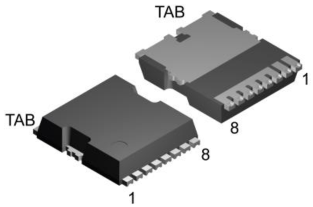
Q_{RR} comparison

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

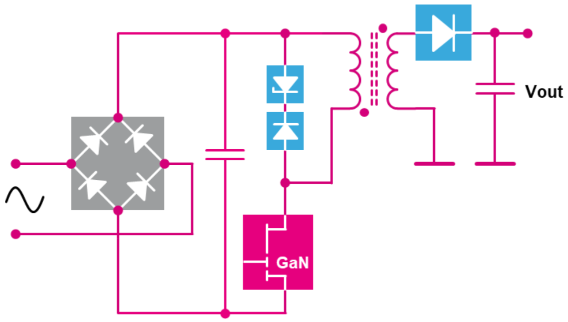
* RDS(on)max at 25°C

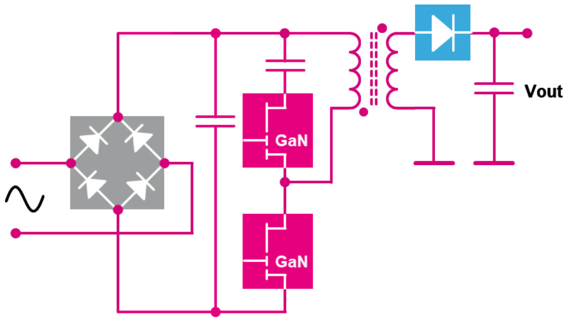
Usage of GaN in power conversion

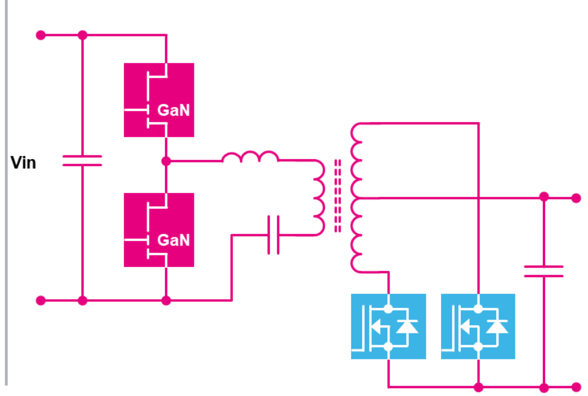
most common topologies

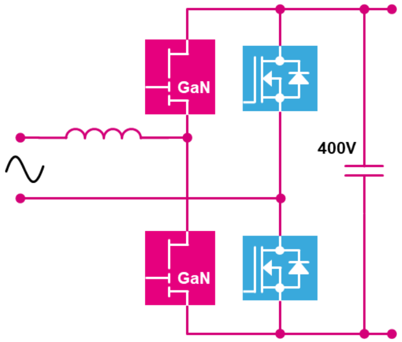
Power

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

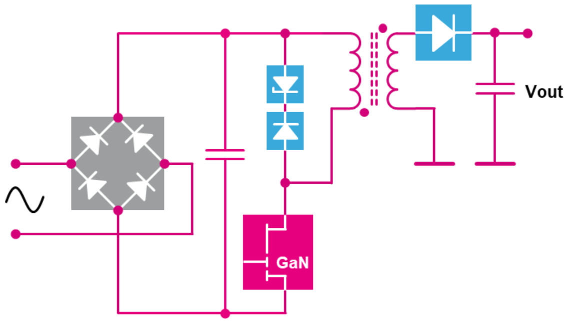
most common topologies

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))

Flyback QR

AC/DC



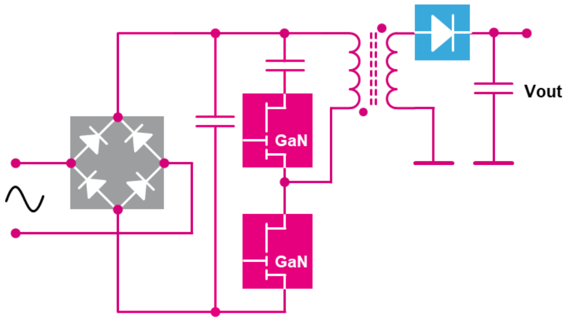
Why GaN?

- Lower parasitic capacitances
- Lower losses

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

Active Clamp Flyback (ACF)

AC/DC



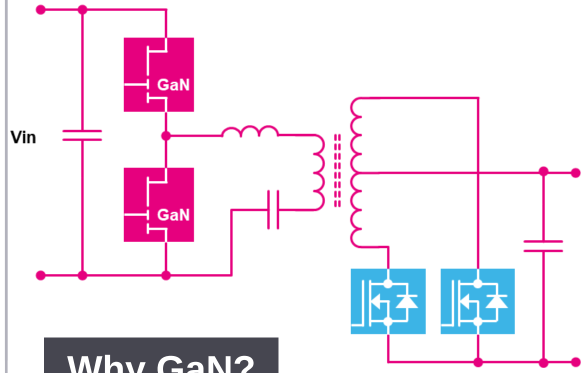
Why GaN?

- Lower parasitic capacitances
- Lower losses

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

Half-bridge LLC Resonant

DC/DC



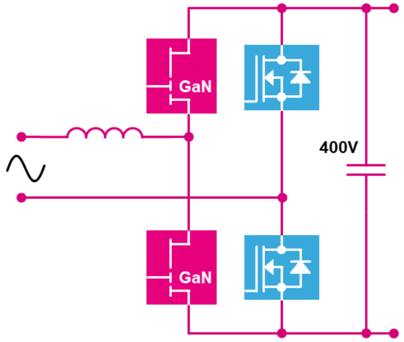
Why GaN?

- Lower parasitic capacitances
- Lower gate losses

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

Totem-Pole Bridgeless CCM

AC/DC (PFC)



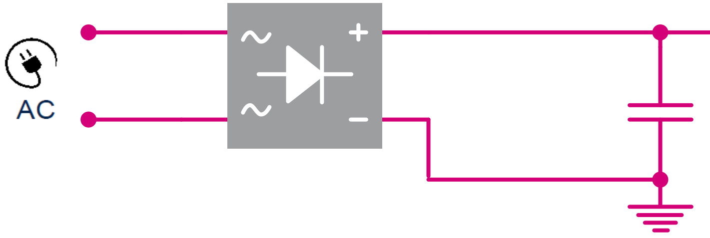
Why GaN?

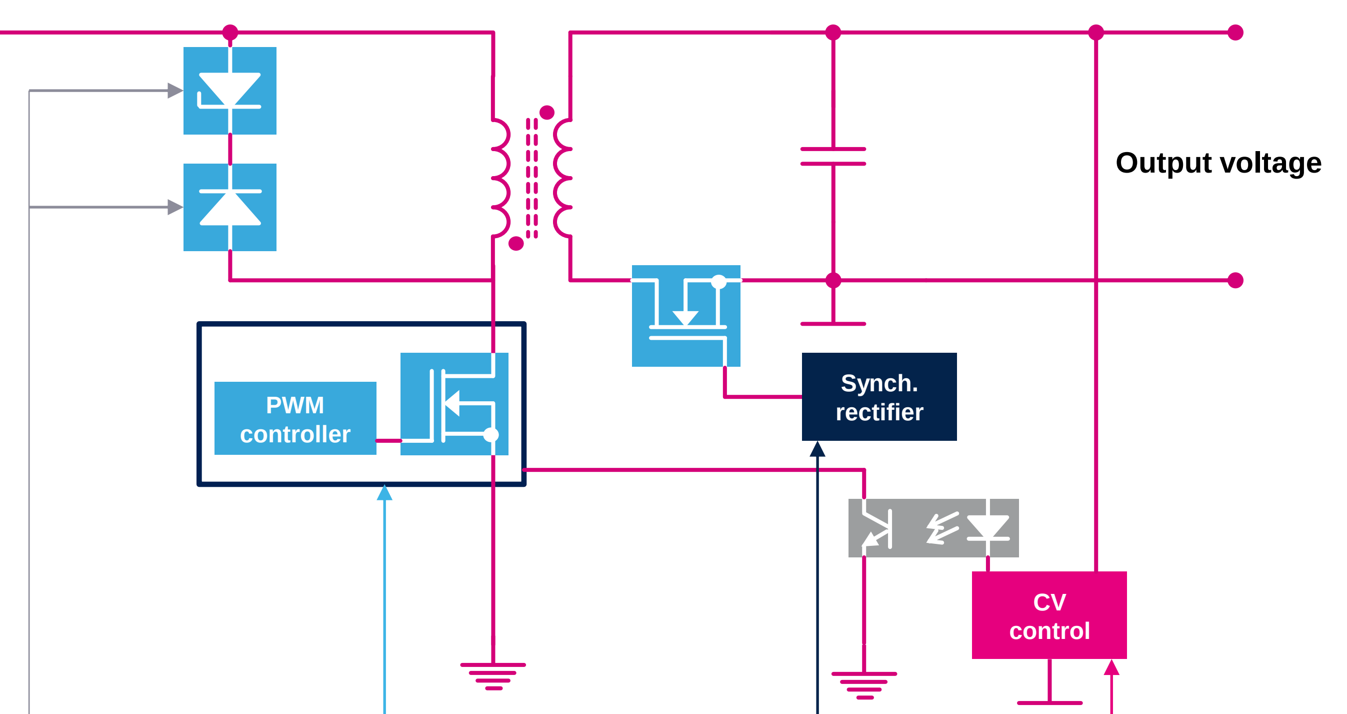
- No reverse recovery of the diode
- Lower parasitic capacitances
- Lower losses

→ **increasing efficiency**

Quasi-resonant flyback

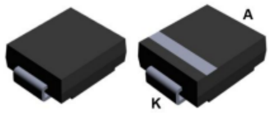
Quasi-resonant flyback topology



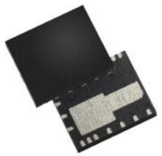


EVLVIPGAN50FL

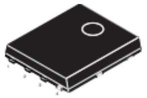
Transil + Ultrafast diode
STRVS142-280, STTH1L06



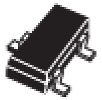
Offline converter
VIPerGaN, STCH03 + M5



Synchronous rectifier + MOSFET
SRK1000 + F7 series



Constant voltage controller
TS43x, TL43x10



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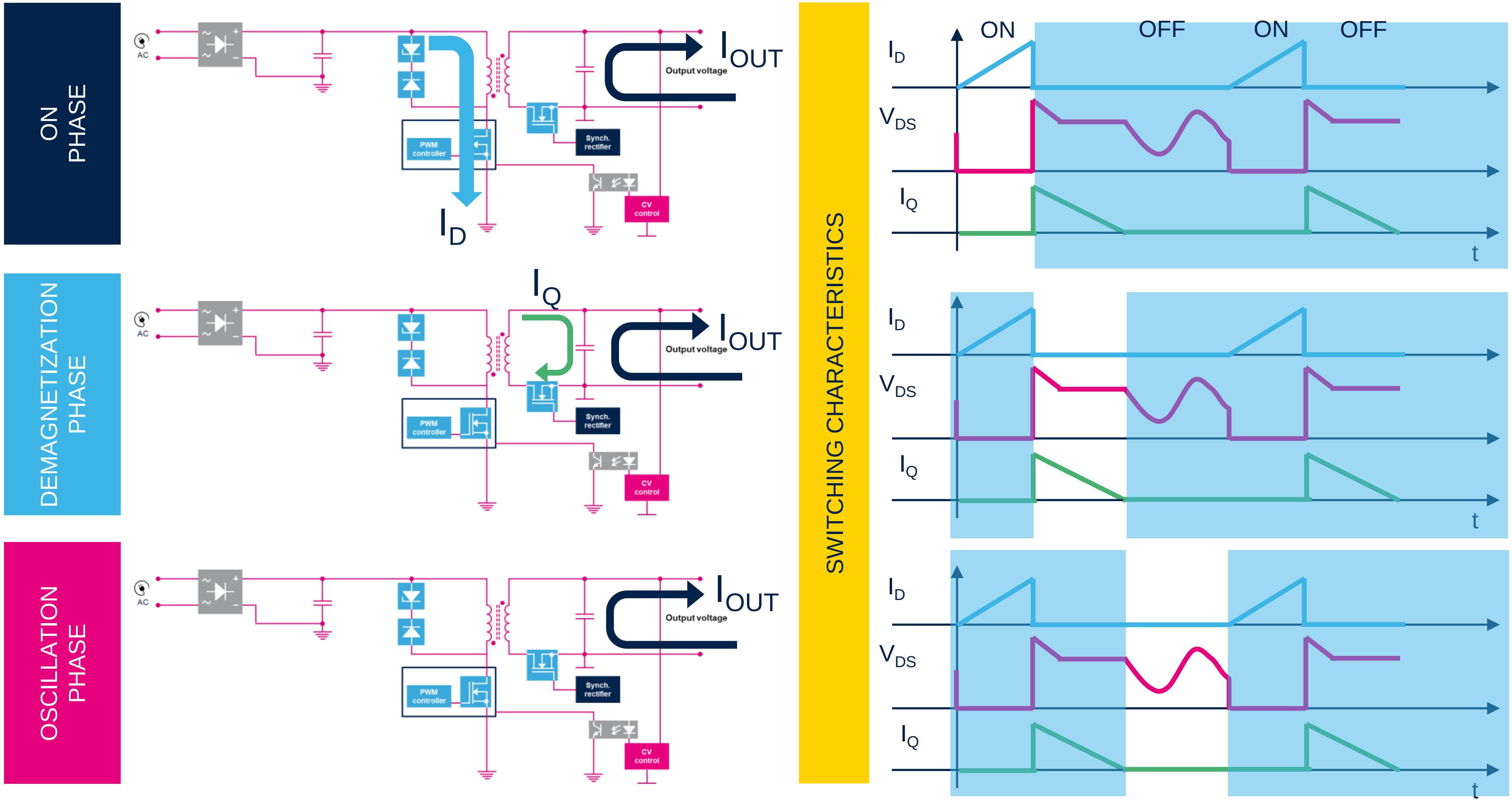
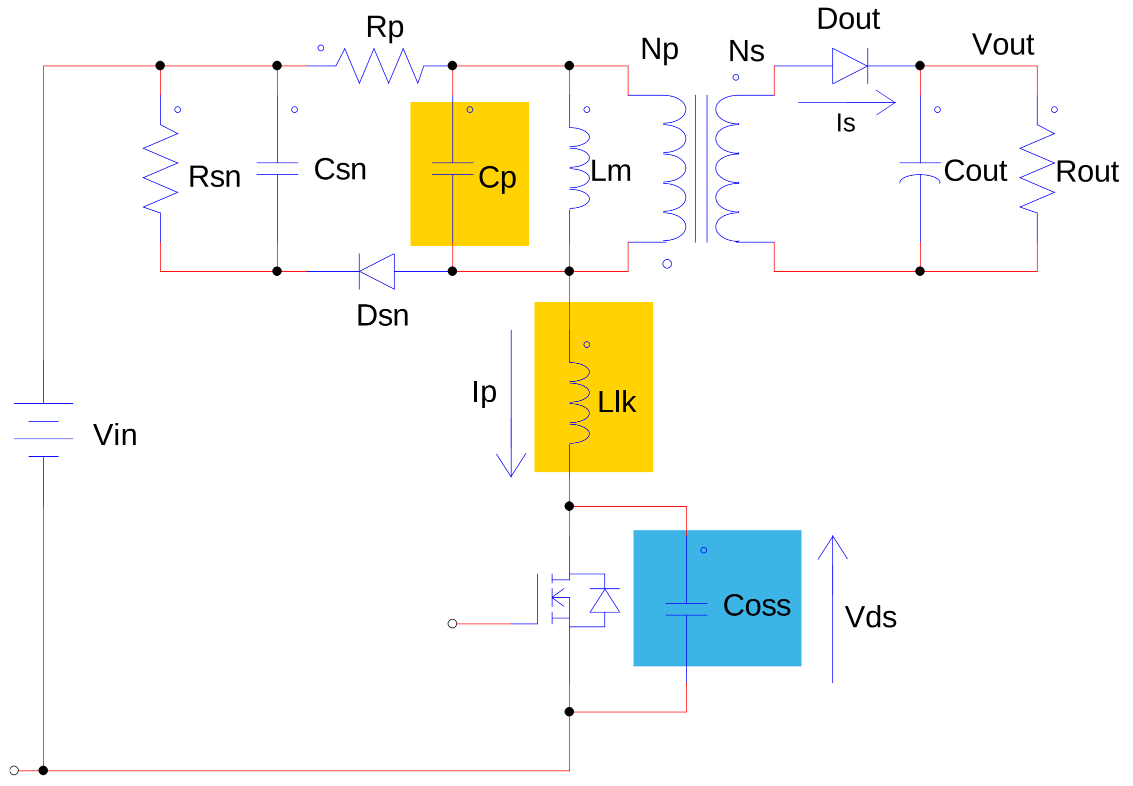
Quasi-resonant operation principle

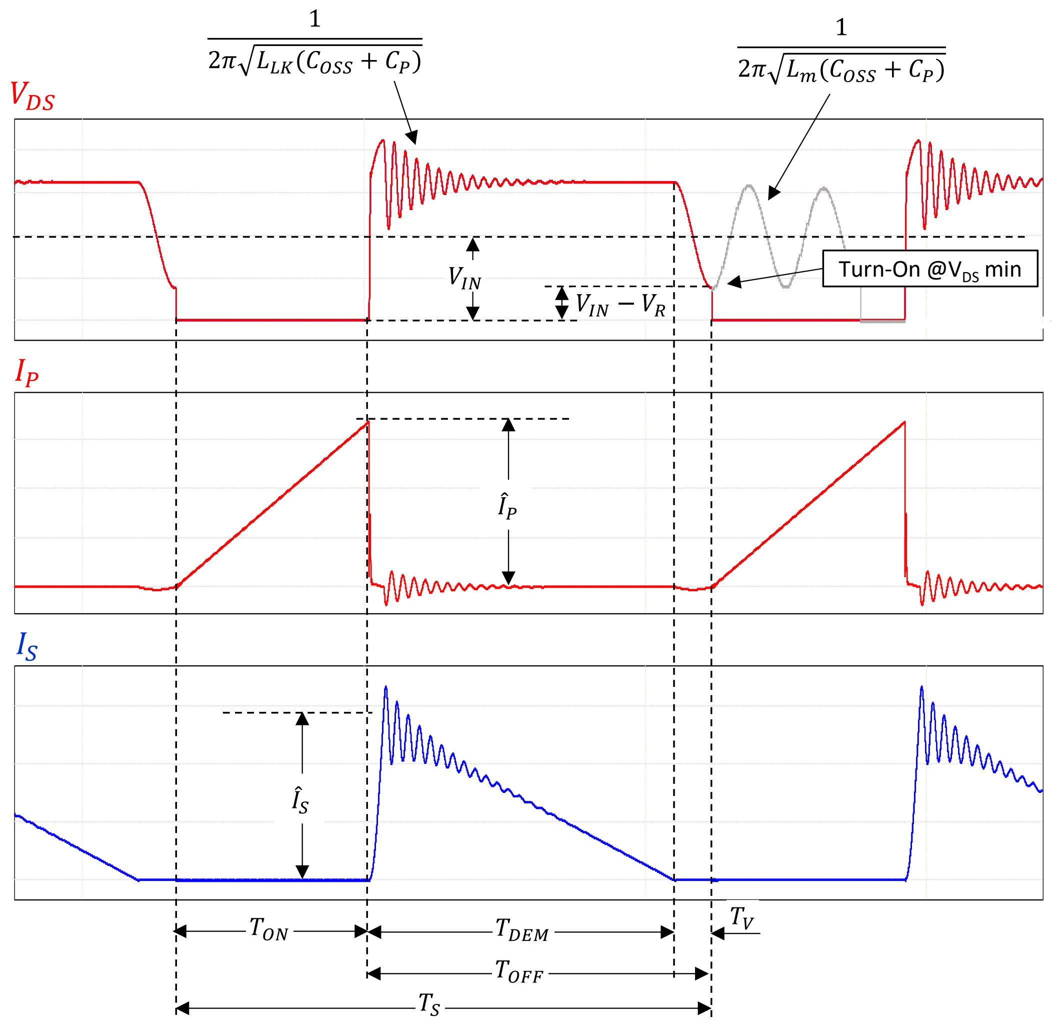


Features

- Standard flyback topology
- Transition mode converter (DCM/CCM)
- Zero current switching (switching in valley)
- Variable frequency operation

Main ICs losses in a traditional flyback converter

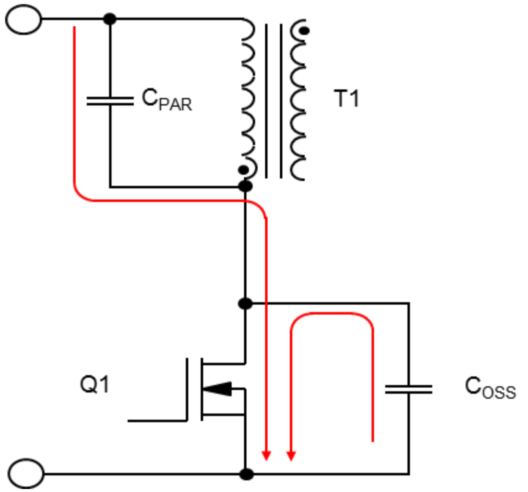




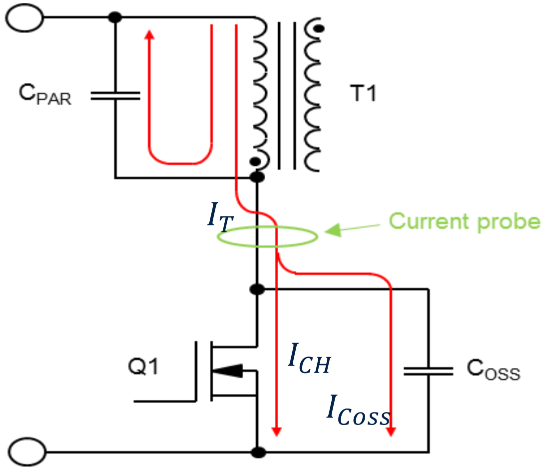
Topology-related

Power switch-related

Main ICs losses in a traditional flyback converter

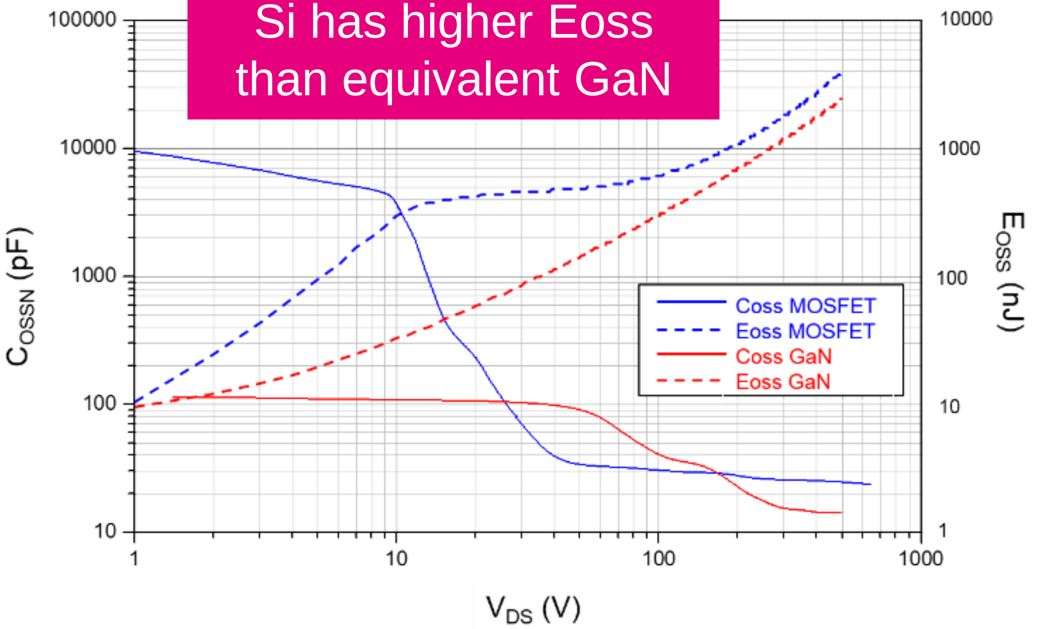


Turn-ON



Turn-OFF

Si has higher Eoss than equivalent GaN



Power switch-related

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

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

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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Variable frequency operation

- Higher input power = Different switching frequency

- Higher losses at wide range operation

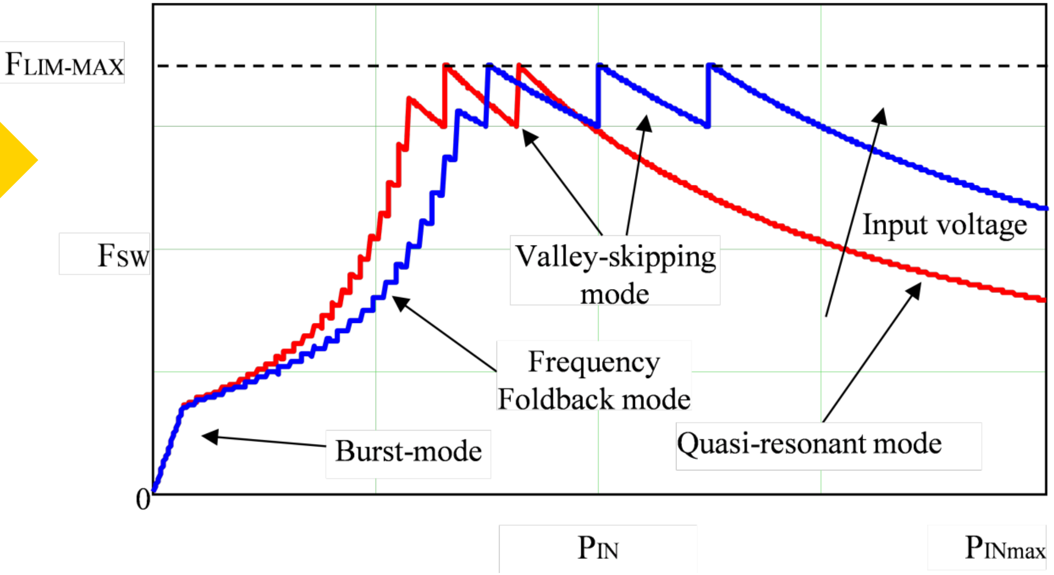
(max. input voltage = higher switching losses)

$$P_{CLOSS} = \frac{1}{2} V_{SW}^2 C_D f_{SW}$$

- Transformer design for lowest frequency

(min. input voltage, max. output power)

Quasi-resonant operation modes



$$f_{SW} = \frac{2f_t}{1 + \frac{f_t}{f_r} + \sqrt{\left(1 + 2\frac{f_t}{f_r}\right)}} \quad f_r = \frac{1}{2\pi\sqrt{L_p C_d}} \quad f_t = \frac{1}{2P_{in}L_p\left(\frac{1}{V_{in}} + \frac{1}{V_r}\right)^2}$$

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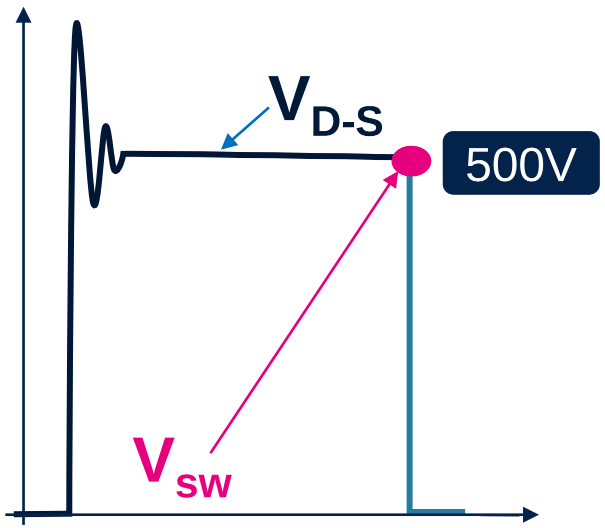
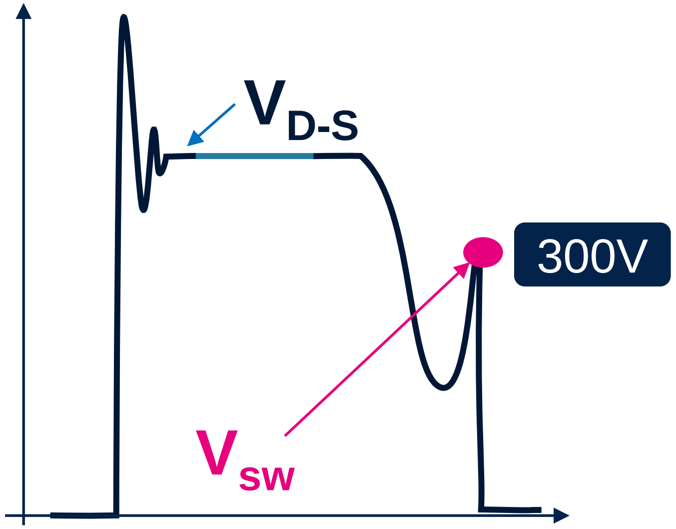
Quasi-resonant zero current switching

Switching losses: $P_{CLOSS} = \frac{1}{2} V_{SW}^2 C_D f_{SW}$

Example:
C_D=100pF, f_{SW} = 60kHz

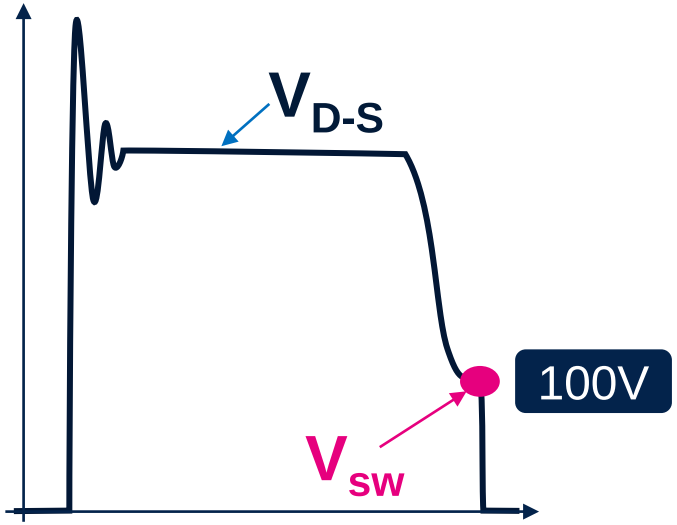


P = 750mW



64%
reduction

P = 270mW



96%
reduction

P = 30mW

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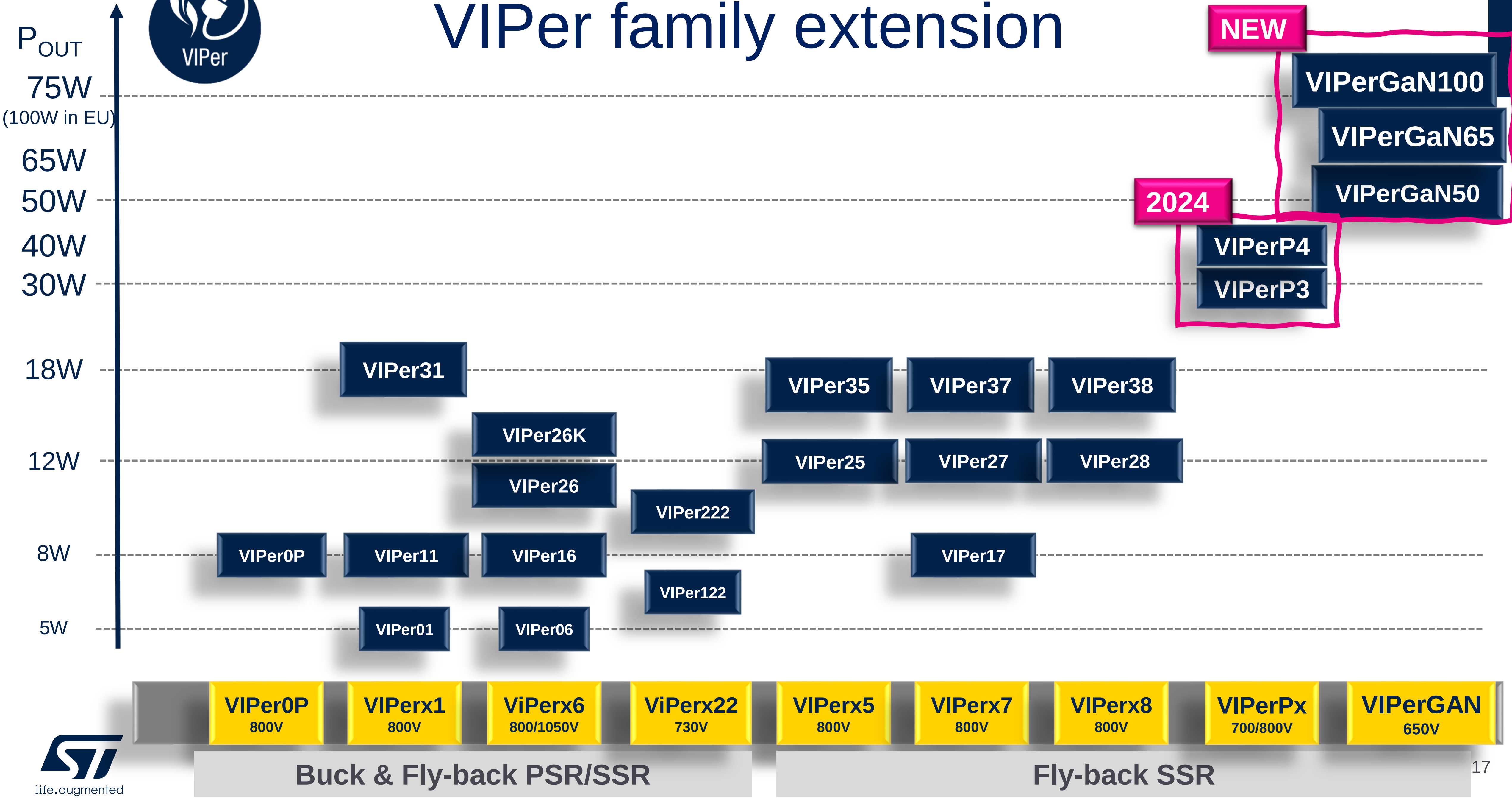
New VIPerGaN family with GaN switch

VIPer family extension



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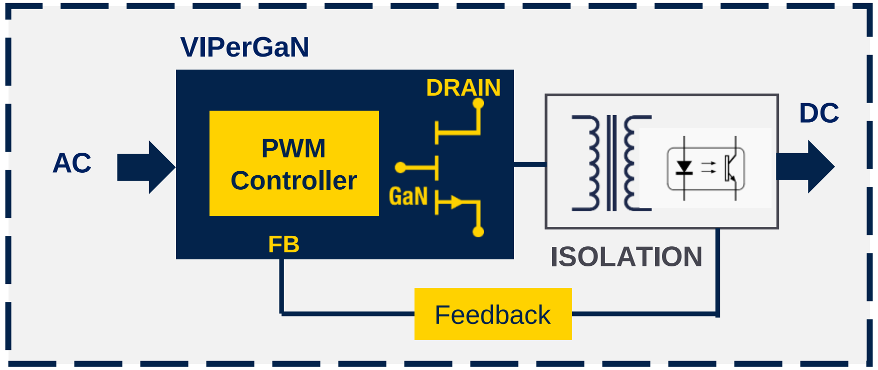
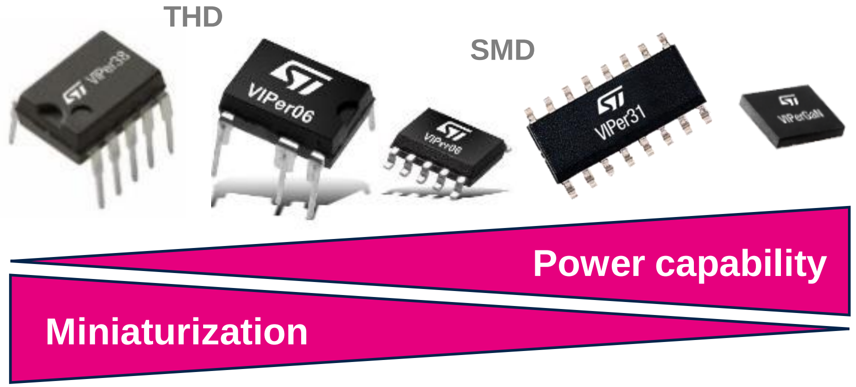
VIPerGaN: offline flyback converter with 650V GaN HEMT switch



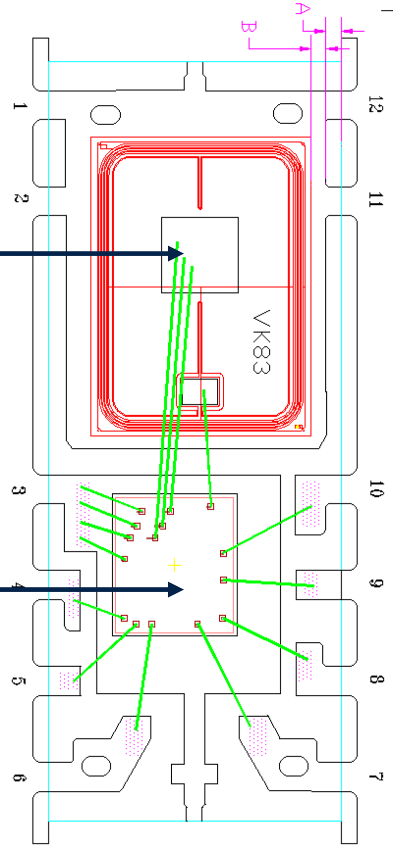


GaN HEMT

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

Advanced controller

- PWM controller
- Startup
- Current sensing



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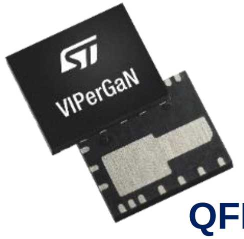
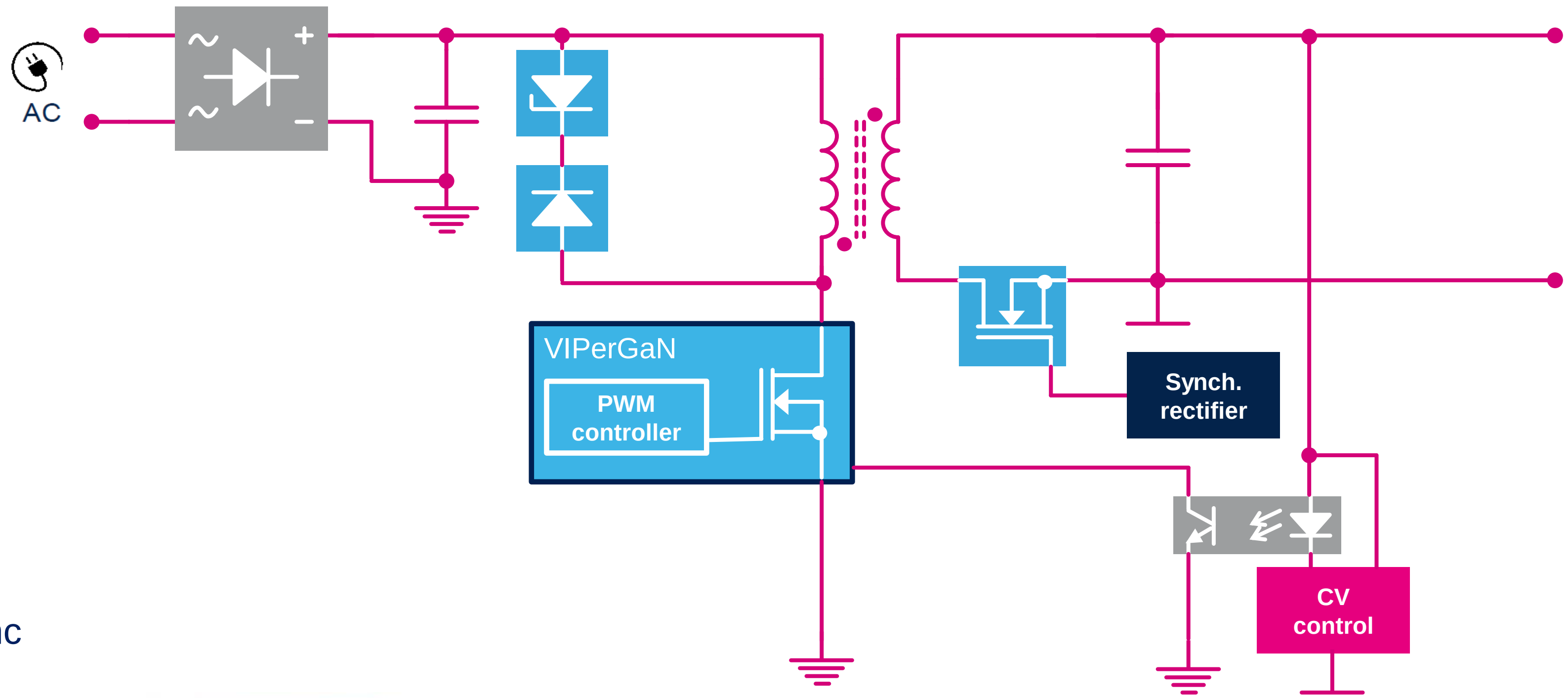


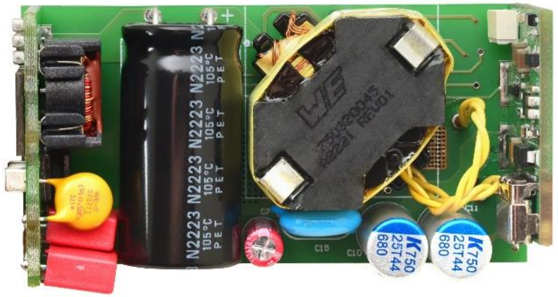
QFN 5x6

VIPerGaN quasi-resonant flyback topology

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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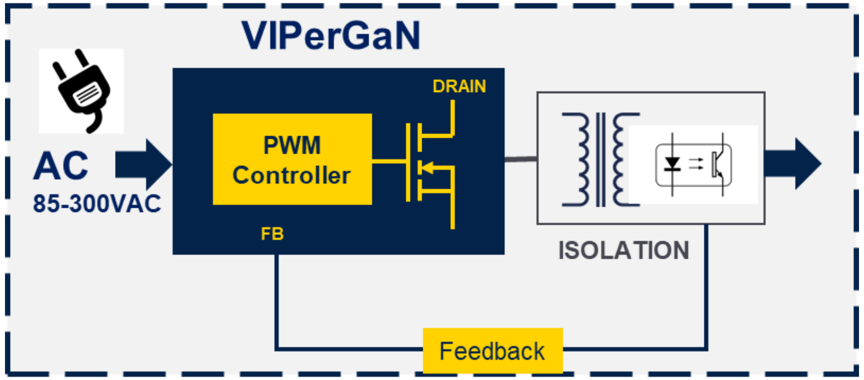
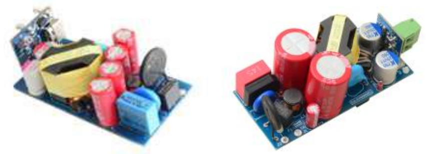
VIPerGaN: offline flyback converter with 650V GaN HEMT switch



Max output power		
	85-265 V_{AC}(*)	185-265 V_{AC}(*)
VIPerGaN50	50 W	75 W
VIPerGaN65	65 W	85 W
VIPerGaN100	75 W	100 W

** typical maximum output power rating adapter design at 50°C ambient with adequate heatsinking*

VIPerGaN50



EVLVIPGAN50PD: AN available
45W USB PD Type-C reference design**

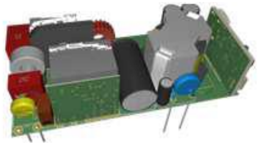
EVLVIPGAN50FL: AN available
5 V / 50 W QR flyback converter

VIPerGaN65

EVLVIPGAN65PD: AN available
65 W USB PD Type-C reference design**

Flyback board under development

VIPerGaN100



EVLVIPGAN100PD: AN available
100 W USB PD Type-C reference design** (with PFC in front)

Flyback board under development

*** with STUSB4761*

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VIPerGaN50 eval-boards

50W / 15V - QR flyback

Isolated QR flyback converter with adaptive synchronous rectification

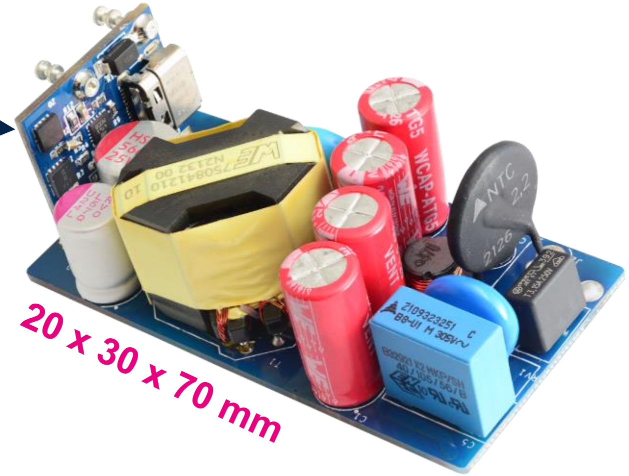
	115 V_{AC}	230 V_{AC}
No load cons.	49 mW	60 mW
Aver. Eff	**90.5%**	**90.1%**
Peak Eff.	**91.1%**	**92.2%**
Eff.@ 10% load	88.4%	84.6%

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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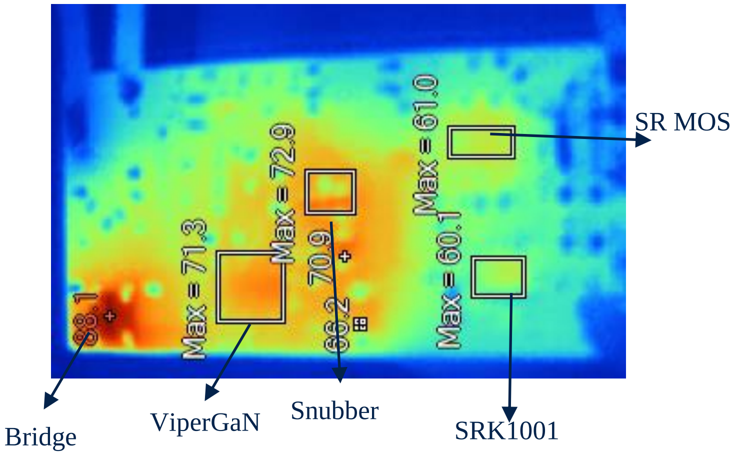
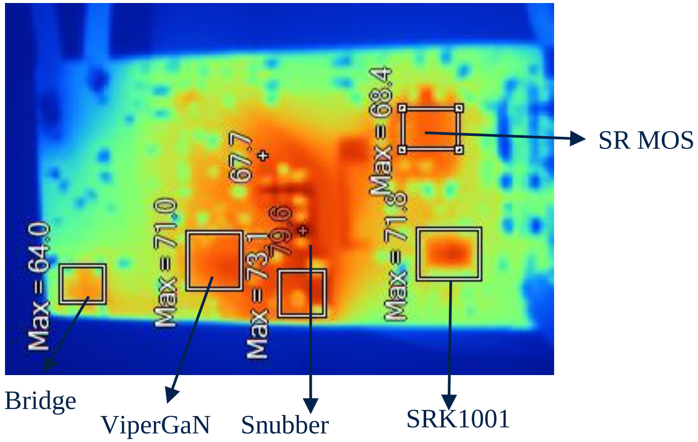
VIPerGaN50
45W USB-PD thermals and efficiency

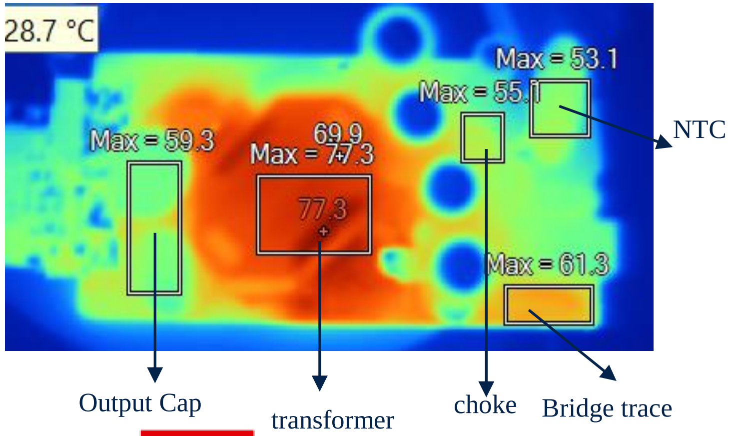
115Vac/20V@2.5A bottom view



230Vac/20V@2.5A bottom view

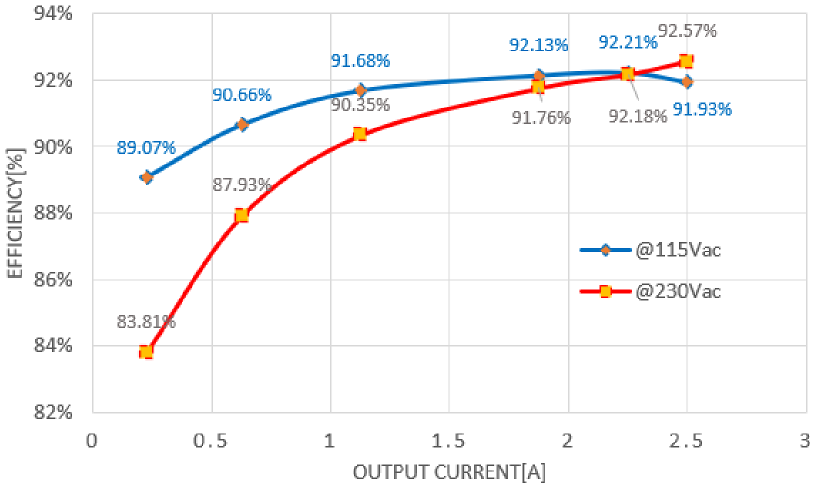


230Vac/20V@2.5A top view



	115Vac	230Vac
transformer	69°C	77°C
NTC	64°C	53°C
choke	58°C	55°C
SR MOS	61°C	68°C
SRK1001	60°C	72°C
Bridge	88°C	64°C
Snubber_pri	73°C	80°C
ViperGaN	71°C	71°C

Efficiency @ 20Vout



	efficiency	
load	115Vac	230Vac
10%	89.07%	83.81%
25%	90.66%	87.93%
50%	91.68%	90.35%
75%	92.13%	91.76%
100%	92.21%	92.18%
110%	**91.93%**	**92.57%**

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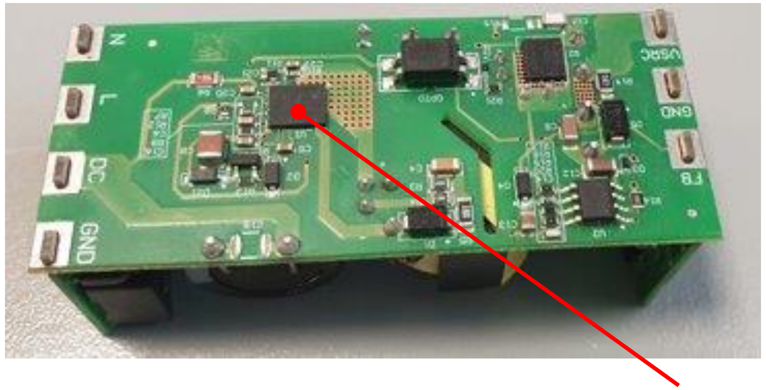
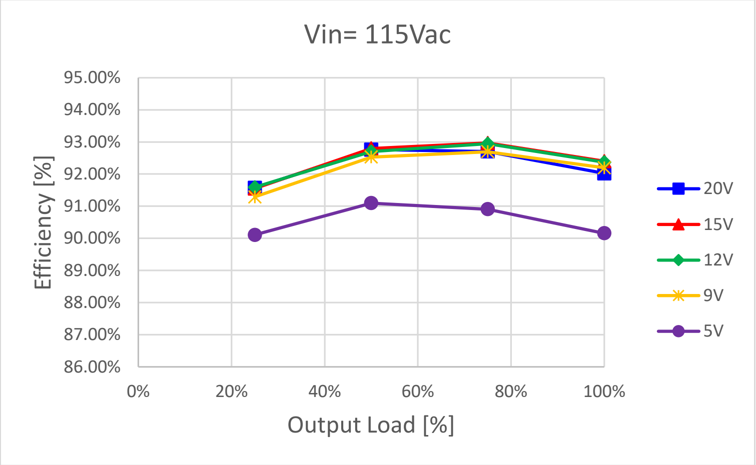
VIPerGaN65 USB-PD eval-board

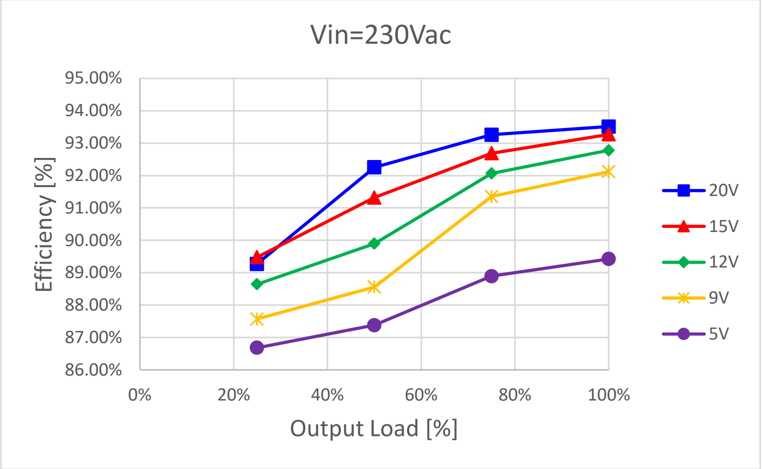
EVLVIPGAN65PD – 65W USB-PD

- 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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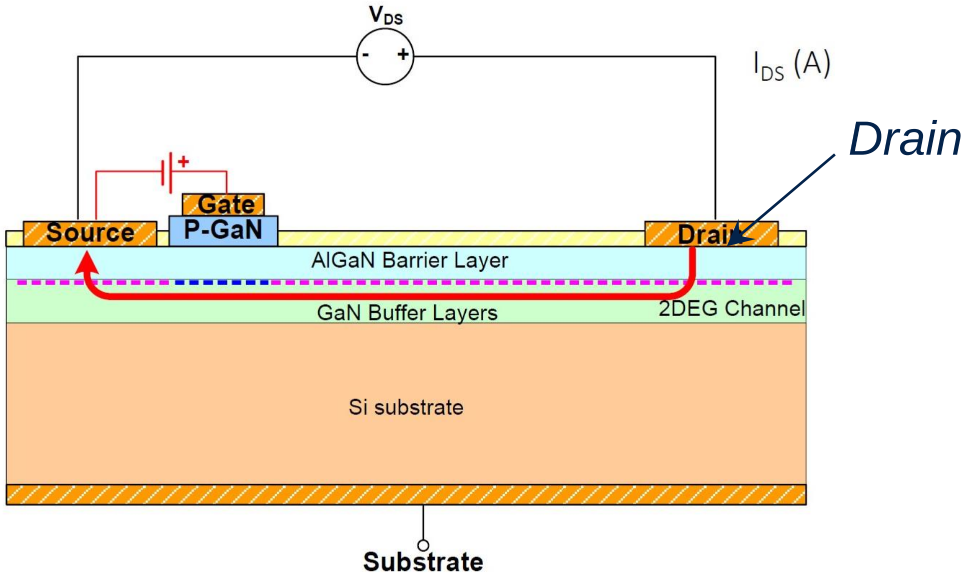
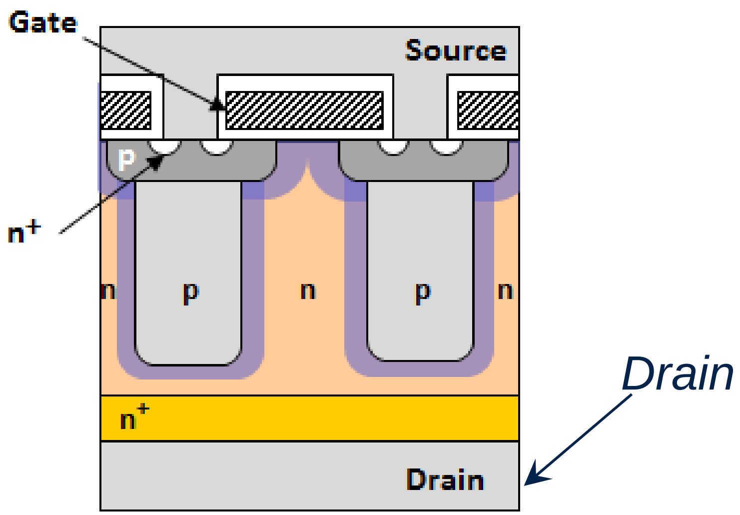
HEMT GaN vs. MOSFET
Device structure

HEMT GaN



Lateral structure

SJ Mosfet



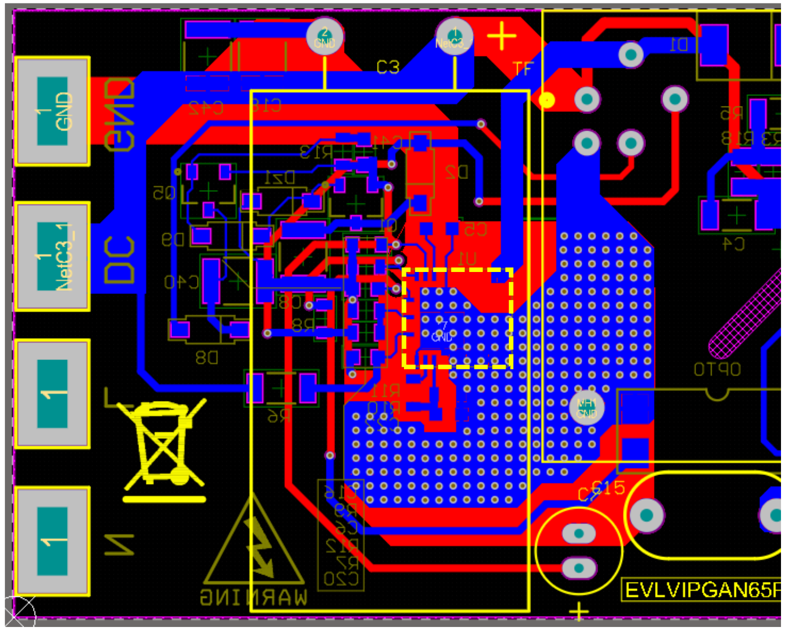
Vertical structure

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

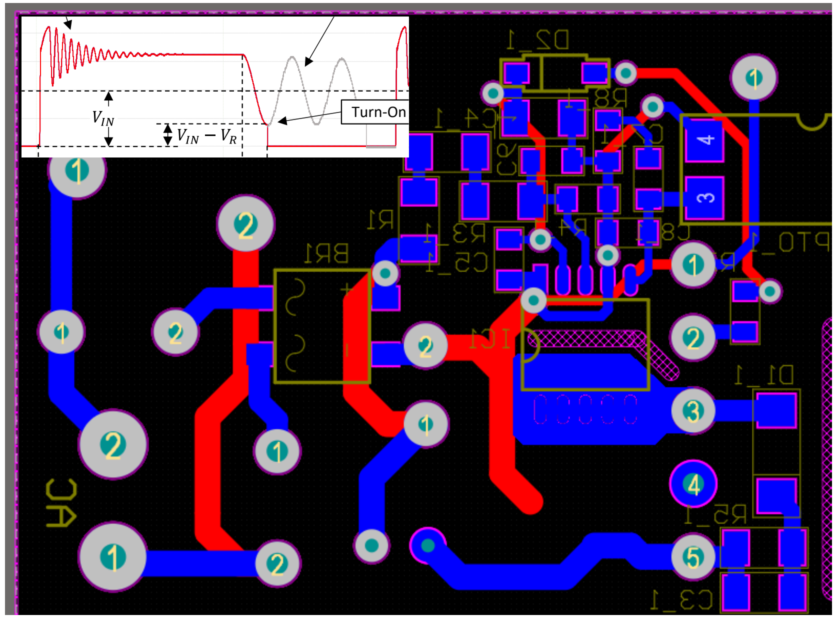
HEMT GaN vs. MOSFET

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

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

Blanking time and valley synchronization

Maximum efficiency solution

Dynamic Blanking Time	Valley Synchronization	Configuration
YES	YES	Figure a
NO	YES	Figure b
YES	NO	Figure c
NO	NO	Figure d

Dynamic Blanking Time and Valley Synchronization resistors config.

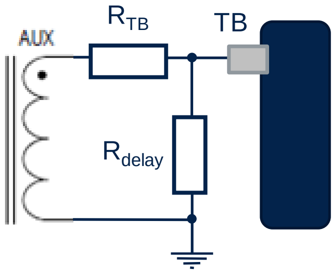


Figure a.

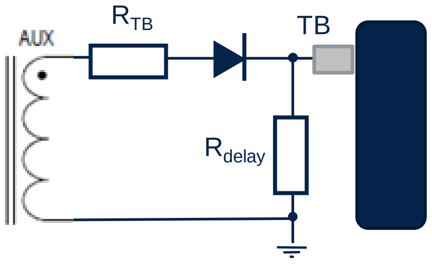


Figure b.

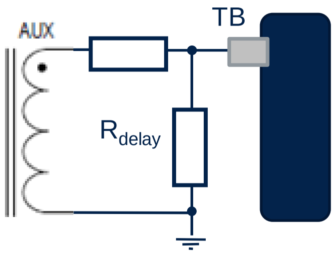


Figure c.

$$\text{With } R_{DELAY} < \frac{R_{TB}}{\frac{N_{AUX}}{N_{SEC}} \cdot \frac{V_{OUT}}{V_{D-ON(MAX)}} - 1}$$

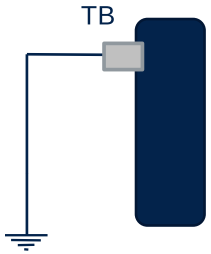


Figure d.

Minimized switching losses and maximized efficiency at any line and load condition.

Higher frequency operation

Benefits

- Reduce magnetics size
- Lower capacitor values

Challenges

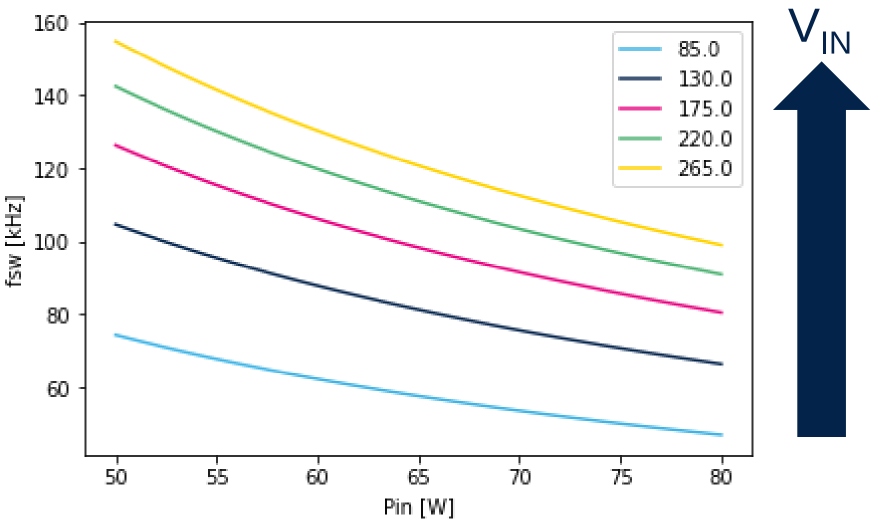
- Maintain high efficiency
- Low switching losses
- EMI

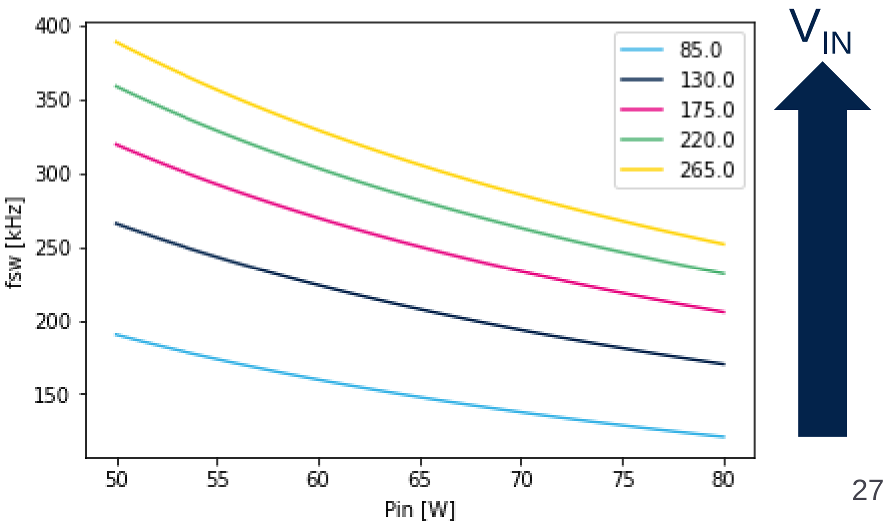
RM10 core
f_{SW}=55 – 110kHz

2.5x lower switching losses

50% size reduction

RM8 core
f_{SW}=120 - 275kHz





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Dynamic blanking time feature

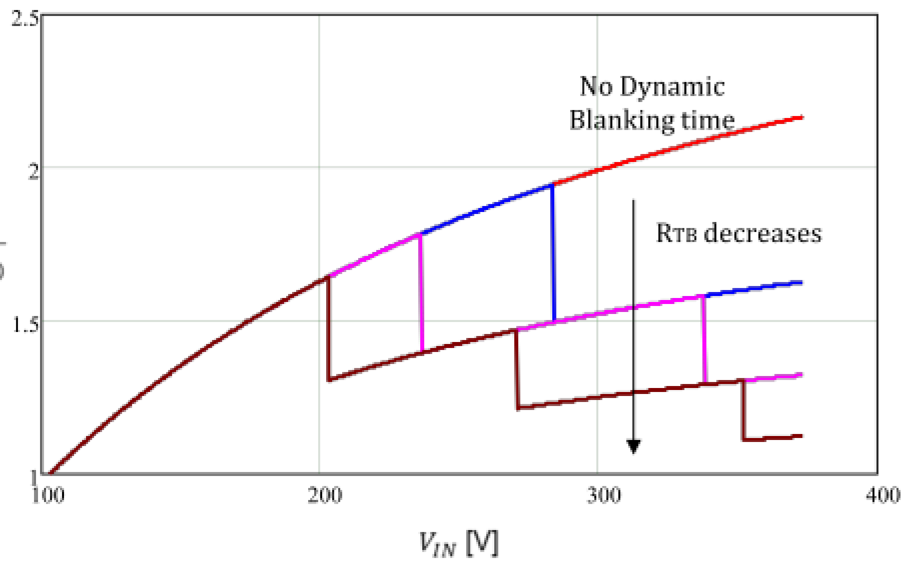
Maximum efficiency solution

- Frequency change with higher input voltage

Improvements

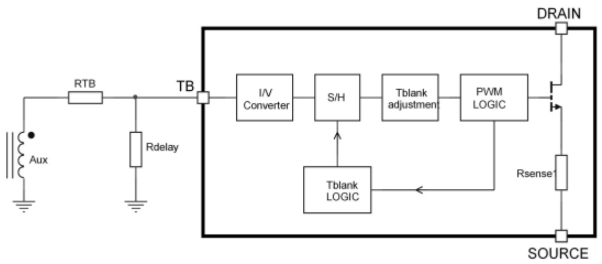
- Balanced switching losses!
- Smaller transformer!
- Less EMI issues (lower f_{SW})!
- Just two resistors added!

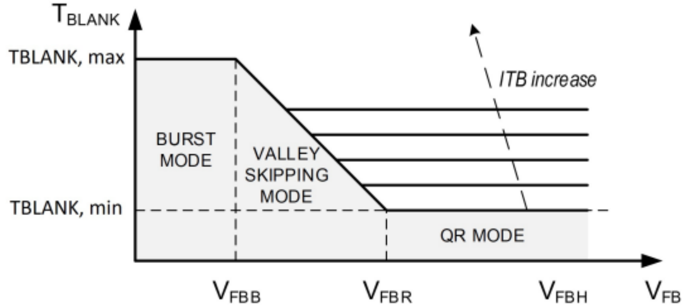
$$\frac{F_{SW}\ @\ V_{IN}}{F_{SW}\ @\ V_{IN(min)}}$$



I_{TB} changes with V_{IN}

$$R_{TB} = \frac{N_{AUX}}{N_{PRI}} \cdot \frac{K_{BLANK} \cdot V_{IN}}{T_{DYN} \cdot T_{BLANK}}$$





T_{BLANK} modes change

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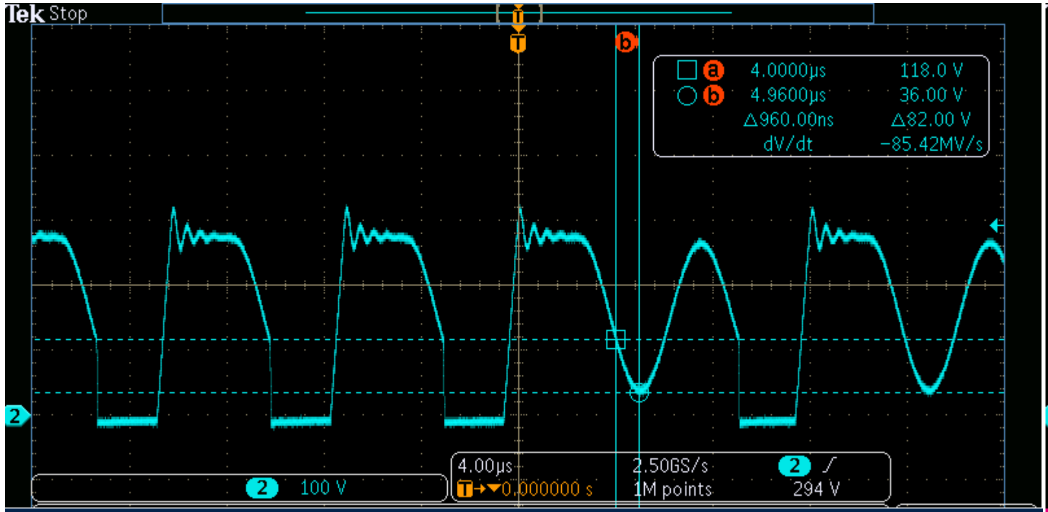
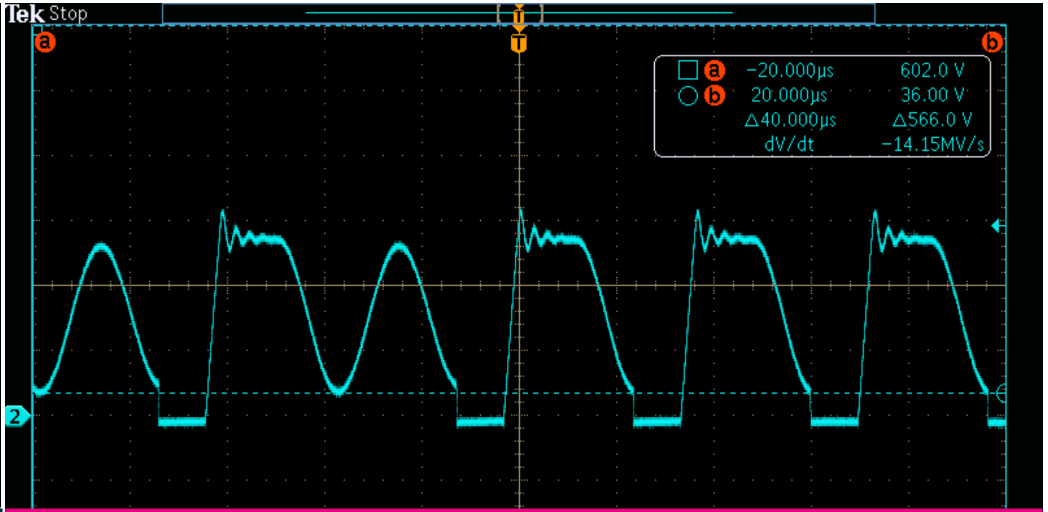
Valley synchronization feature

Maximum efficiency solution



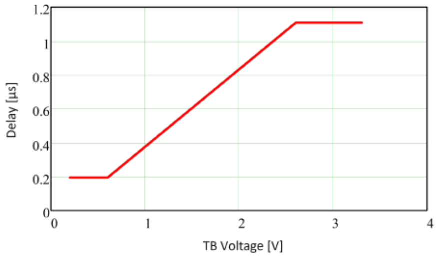
Synchronization OFF!



Synchronization ON!

V_{DS} is 80V lower with 960ns delay!

- Efficiency improvement (lower V_{DS} switching)
- Easy optimization of the design (voltage of TB pin)
- Settable by one resistor!



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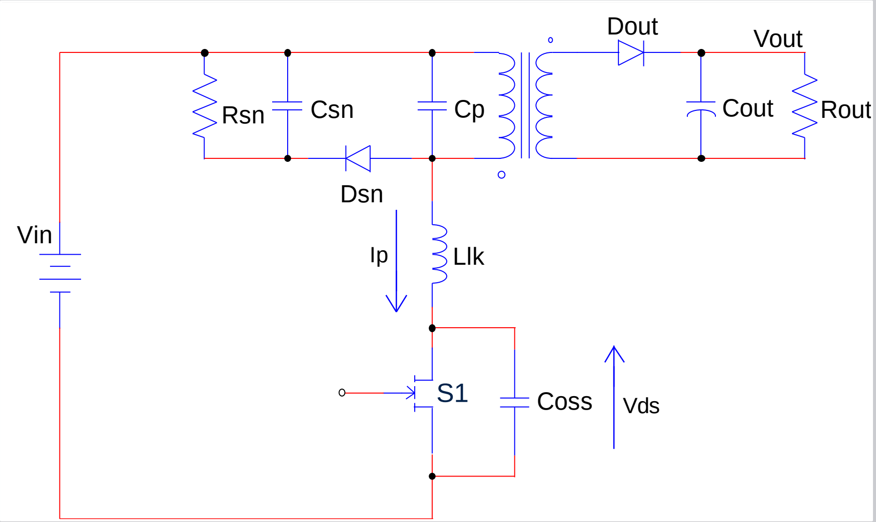
Comparison between QR flyback and AC flyback

<table>
<tr><th></th><th>Traditional Flyback (up to 50W)</th><th>Active Clamp Flyback (ACF)</th></tr>
<tr><td>Topology</td><td>


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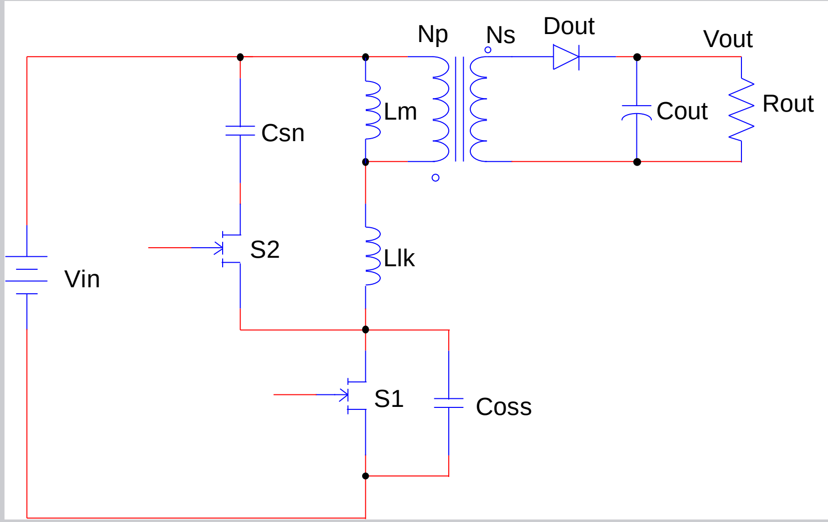


</td></tr>
<tr><td>Operation</td><td>

<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>

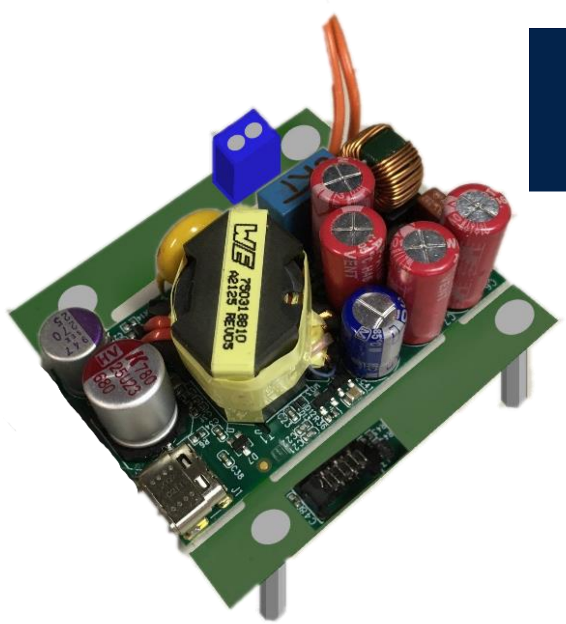
- Additional clamp power switch with dedicated high-side driver
- Increases the complexity of the controller

</td></tr>
</table>

GaN-based QR Flyback vs. ACF

Power density comparison

65W USB power delivery application



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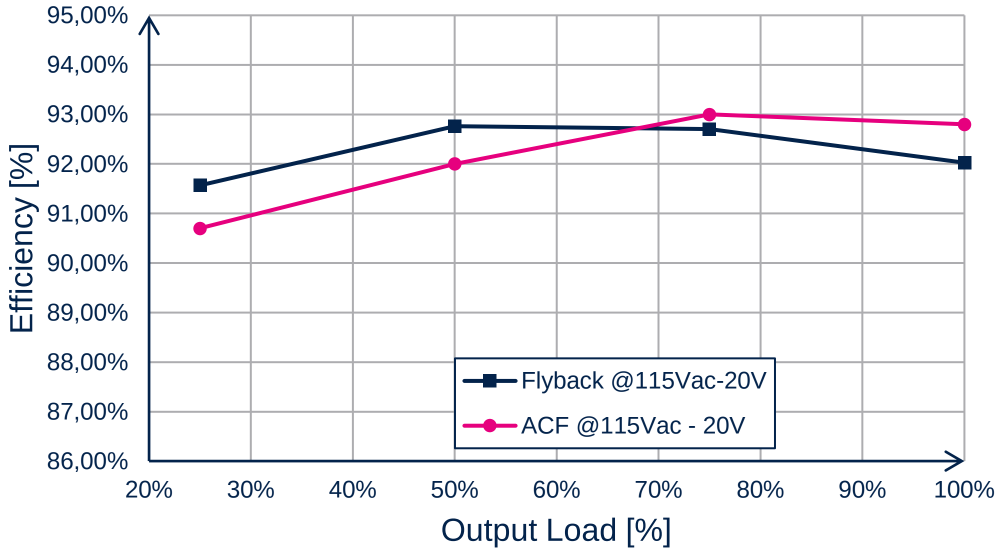
ACF has better power density due to the higher switching frequency operations

GaN-based QR flyback vs. ACF

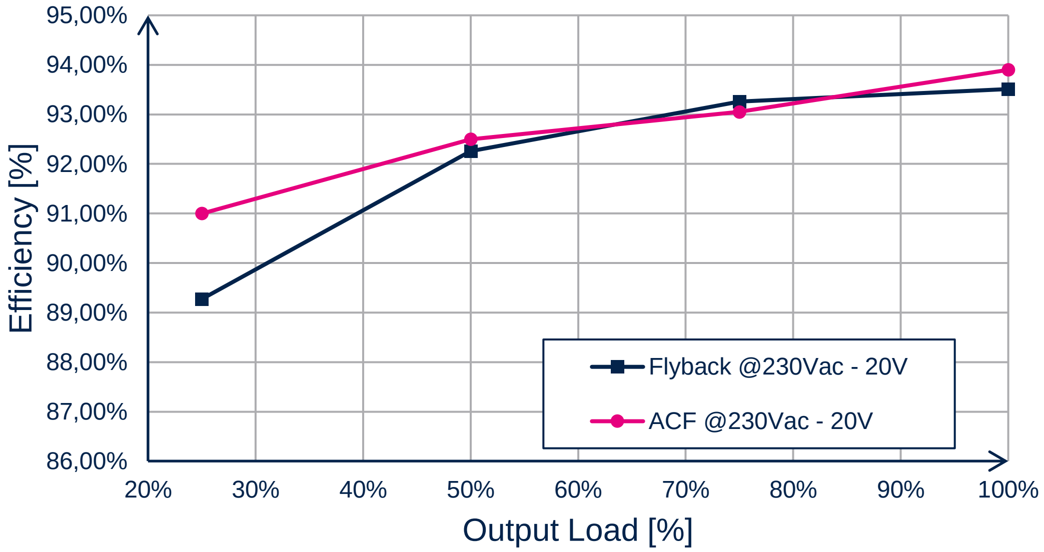
Efficiency comparison

65W USB power delivery application

Input voltage = 115Vac



Input voltage = 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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