An Ultra-High Efficiency High Power Density 140W PD3.1 AC-DC Adapter Using GaN Power ICs

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Outlines

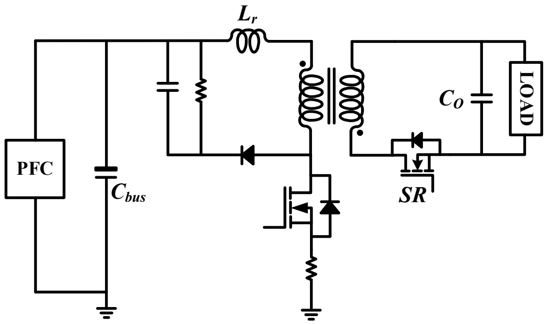
- Background
- Design Considerations of PFC Converter with GaNSense IC
  - How GaNSense IC benefit the PFC converter
  - Efficiency optimization by using Follower Boost PFC
- Design Considerations of AHB Converter with GaN Half-bridge IC
  - GaN half-bridge IC benefits AHB converter
  - AHB efficiency optimization
  - A novel design of V_{CC} power supply circuit for synchronous rectifier
- Experimental Results
- Summary

>100W Adapters

	Xiaomi 120W	Realme 160W	Vivo 120W	Huawei 135W	UGREEN 140W	Apple 140W
Image						
Topology	PFC + QR flyback	PFC + QR flyback	PFC + ZVS flyback	PFC + ACF	PFC + LLC + DC-DC	PFC + Buck + LLC DCX
Efficiency	Low	Low	Medium	Medium	Medium	High
Complexity	Simple	Simple	Medium	Medium	Complex	Complex
Cost	Low	Low	Medium	Medium	High	High

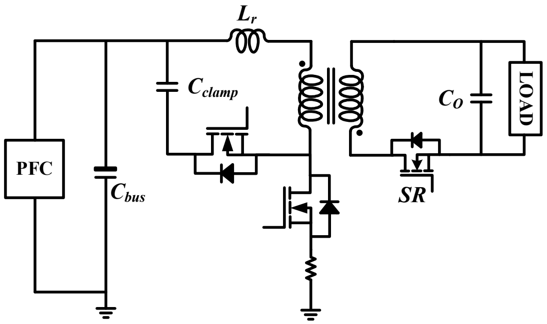
Topology Consideration for >100W PD3.1 Adapter

PFC + QR flyback



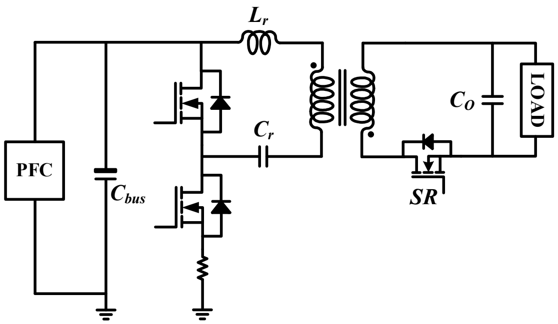
- ✓ Mature and simple
- ✗ High voltage spike and EMI issue
- ✗ Hard to design Tx turns ratio with PD3.1 output

PFC + ACF



- ✓ Voltage clamp and soft switching
- ✗ Primary device voltage increases with higher output voltage
- ✗ Hard to design Tx turns ratio with PD3.1 output

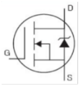
PFC + AHB



- ✓ Voltage clamp and soft switching
- ✓ Two energy storage elements
- ✗ Control complexity

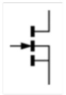
Innovation of GaN Device: Highly Integration

Silicon FET



- Old, slow
- High Q_g
- High C_{OSS}
- F_{SW} < 100 kHz

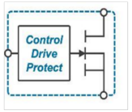
Discrete GaN



- Exposed gate
- External gate drive
- dV/dt sensitivity
- Layout sensitivity
- ESD sensitivity
- Unknown reliability
- Unknown robustness

GaNFast™

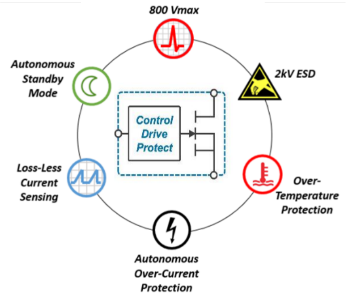
200-300 kHz



- ✓ Internal Gate
- ✓ Integrated Gate Drive
- ✓ dV/dt Immunity
- ✓ Layout Insensitive
- ✓ 2 kV ESD rating
- ✓ Proven Reliability
- ✓ Proven Robustness

GaNSense™

500 kHz

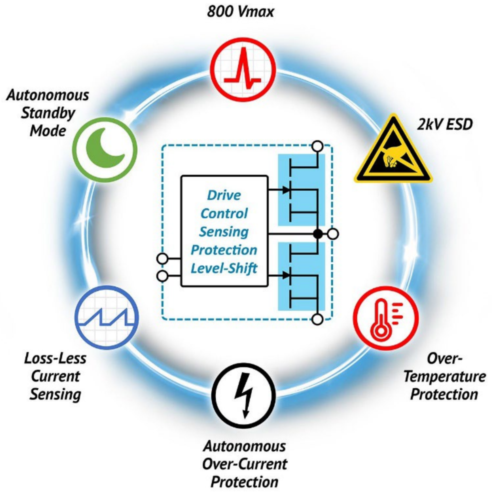


GaNFast plus:

- ✓ Autonomous Standby
- ✓ Autonomous Protection
- ✓ Loss-less Current Sensing
- ✓ High Precision
- ✓ High Efficiency

GaNSense Half-Bridge

1 MHz



GaNSense plus:

- ✓ Highest integration
  - ✓ integrated HS and LS FETs
  - ✓ Integrated level-shift isolation
  - ✓ integrated boot-strap
  - ✓ Shoot-through protection
  - ✓ Enlarged cooling pads
- ✓ Fastest switching
- ✓ Highest efficiency

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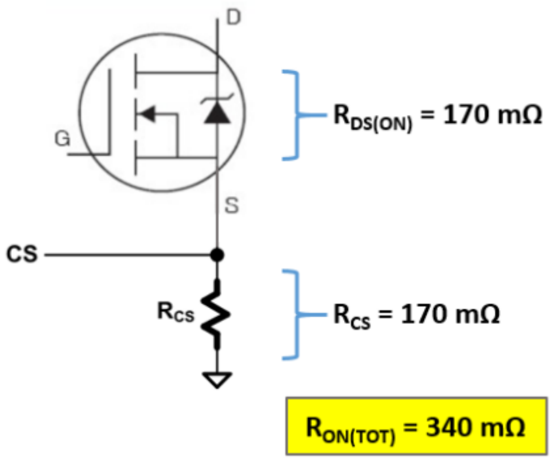
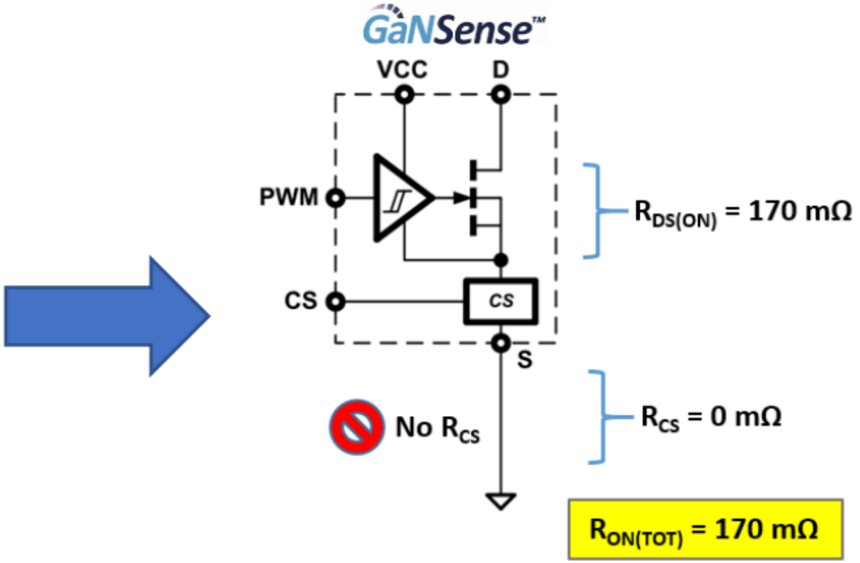
Benefit of GaNSense Technology

External Resistor Sensing Method

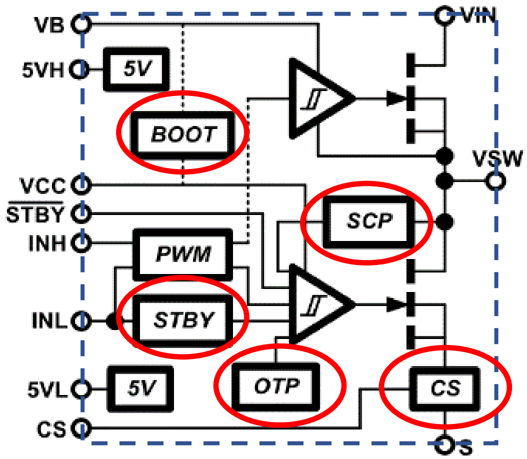




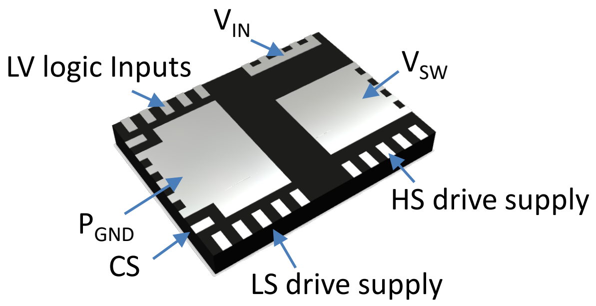
- **Greatly reduced conduction loss**
- **50% reduction of $RDS_{(ON)\ TOTAL}$**
- **Efficiency increases up to 0.5%**
- **Save more than $30mm^2$ PCB space**

Features of GaNSense Halfbridge

Simplified schematic



PQFN 6x8



- **Integrated HS and LS FETs**
- **Integrated lossless current sensing**
- **Over current protection**
- **Over temperature protection**
- **Integrated level shift**
- **Autonomous low-current standby mode**

Comparison between Discrete and Integrated GaN Half-bridge

Discrete GaN Half-Bridge

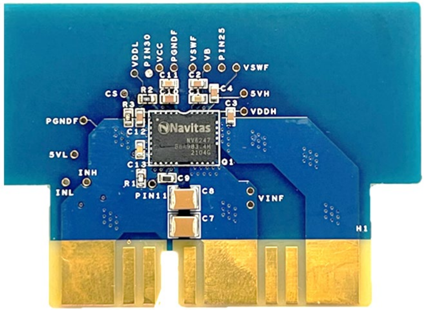
- × 33 components
- × 250 mm^2 footprint
- × External HB driver HVIC
- × External. HV bootstrap
- × 2x HV bypass diodes
- × 2x external gate drives
- × Exposed gates

61% fewer components

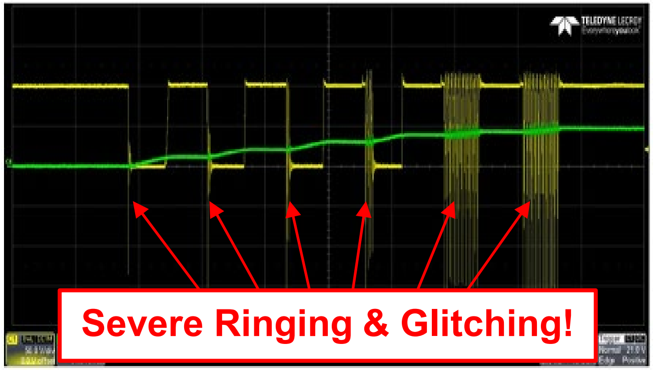
64% smaller footprint

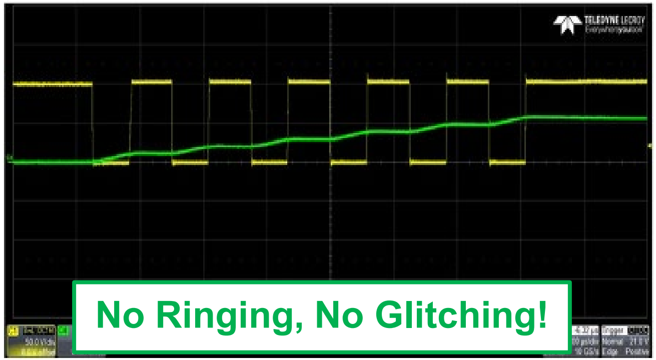
Complete integration

GaNSense Half-Bridge IC

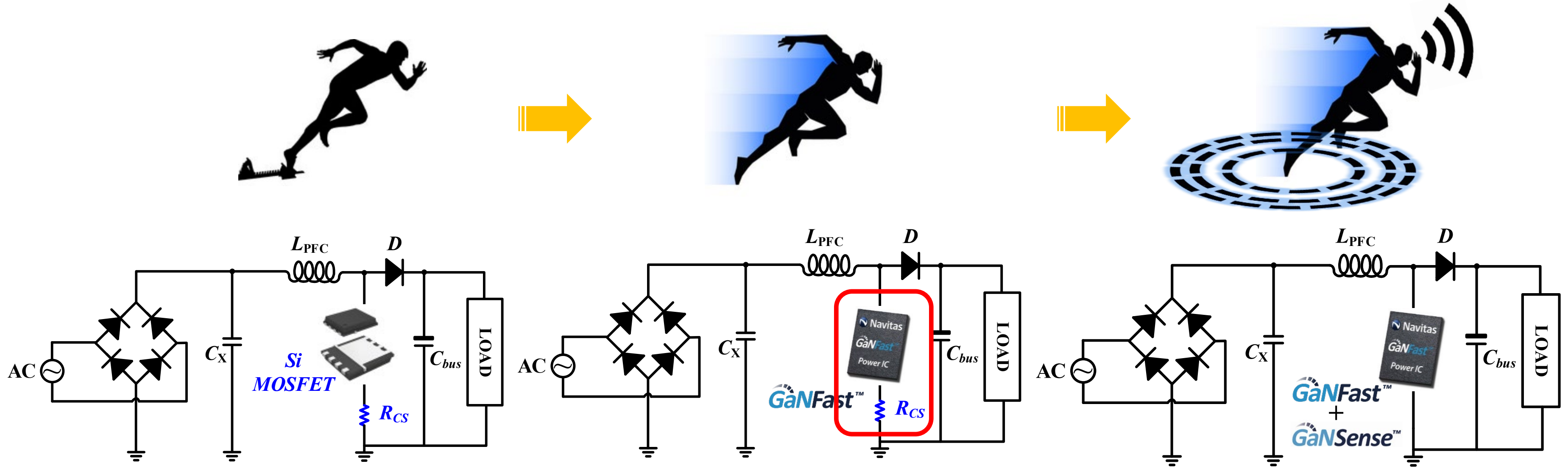


- ✓ 13 components
- ✓ 90 mm^2 footprint
- ✓ Level shifters
- ✓ Bootstrap
- ✓ Gate drivers
- ✓ No exposed gates





How GaNSense IC Benefit the PFC Converter



Boost PFC with Si MOSFET

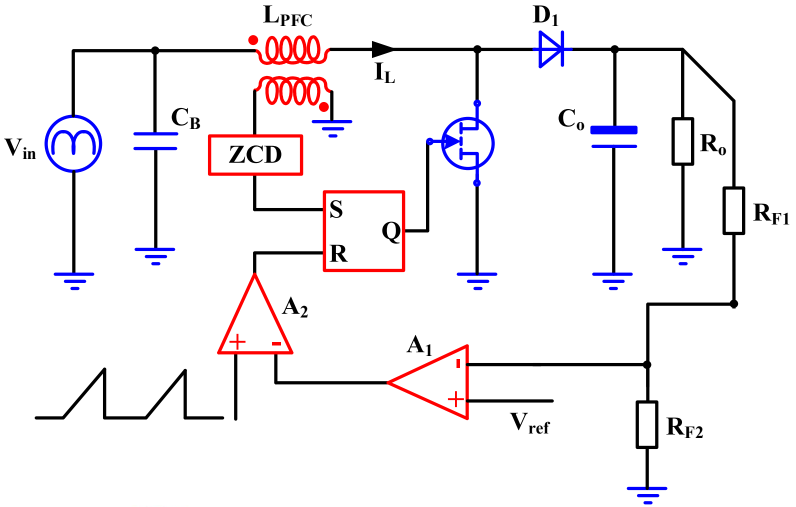
with GaN device

with GaNSense IC

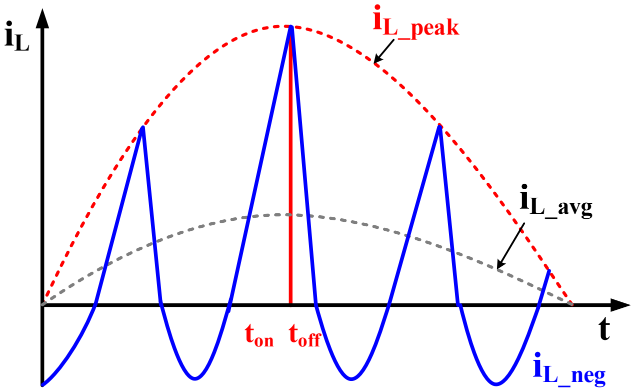
- Switching loss is significantly reduced with GaNFast™
- GaNFast™ with GaNSense™ Completely removed the current sensing loss

Traditional Boost PFC with Fixed Output Voltage

Traditional CRM/DCM Boost PFC



V_{in}=90Vac, V_{BUS}=400V

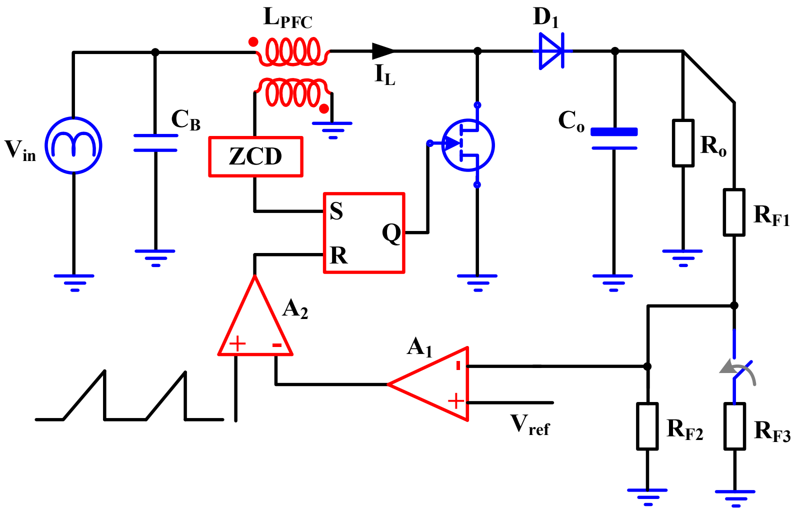


- ✗ **High core loss**
- ✗ **High device conduction loss**
- ✗ **High circulating current**
- ✓ **Low diode conduction loss**

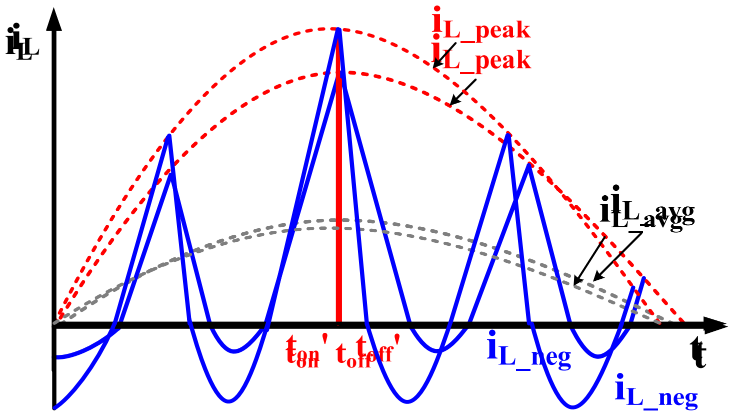
❑ **Low efficiency @ low line input w/ fixed output**

Follower Boost PFC Benefits

Follower Boost PFC

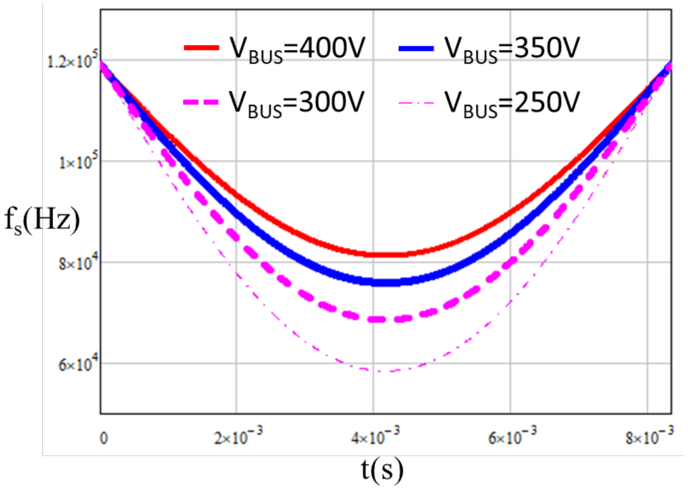


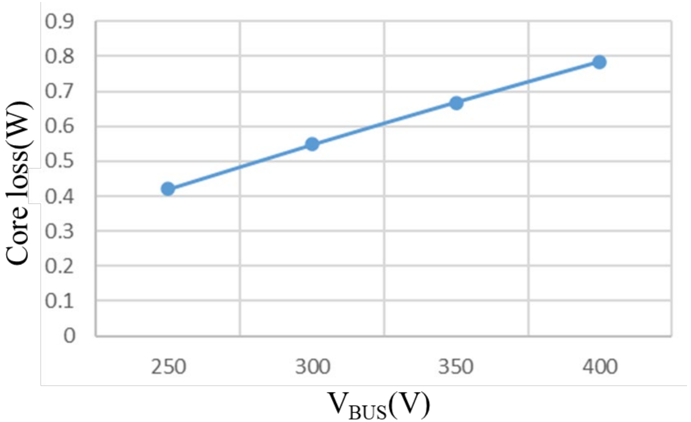
e.g. V_{in}=90Vac, V_{BUS}=260V



- ✅ Output voltage varies according to the input voltage
- ✅ On-time and off-time is more balanced
- ✅ Lower resonant current and circulating energy
- ✅ Lower device conduction loss
- ❌ Higher diode conduction loss

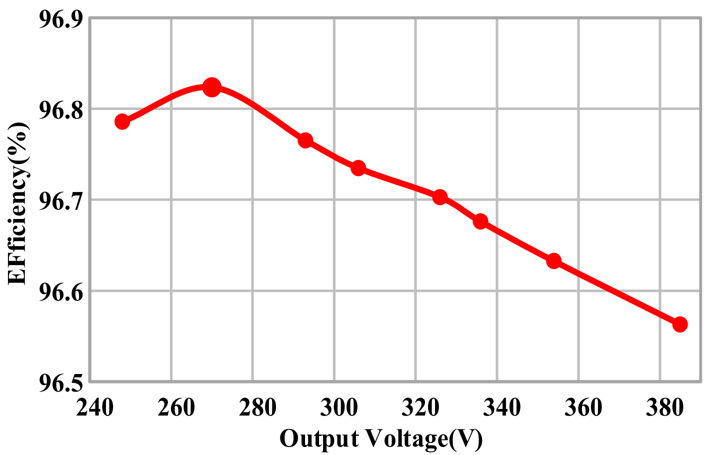
Follower Boost PFC Benefits





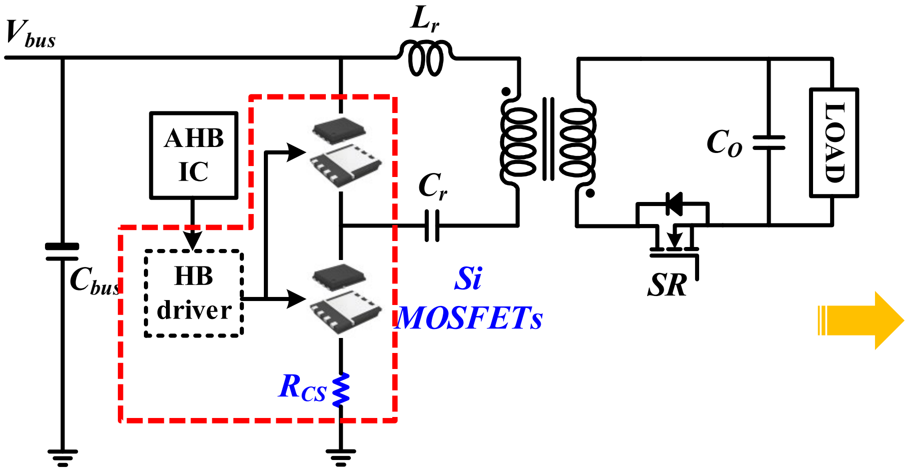
- Lower switching frequency
- Lower core loss

Tested PFC efficiency @ 90Vac 140W

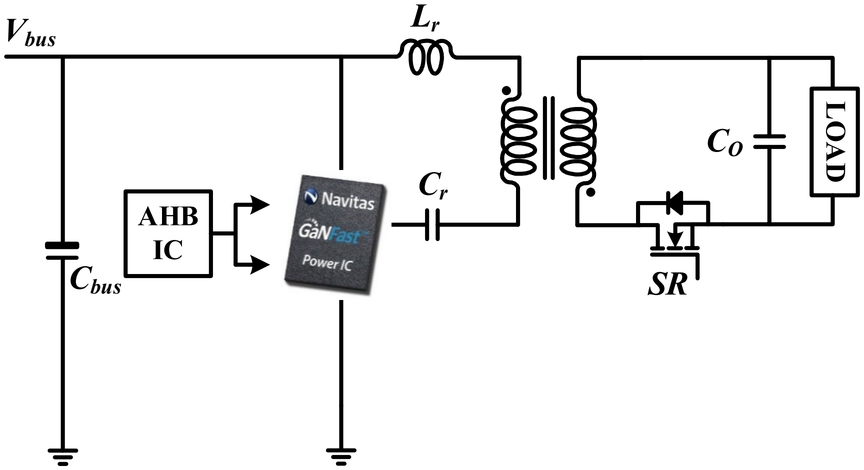


- ❑ **V_{BUS} should be chosen based on the whole system performance**

GaN Half-Bridge IC Benefits AHB Converter



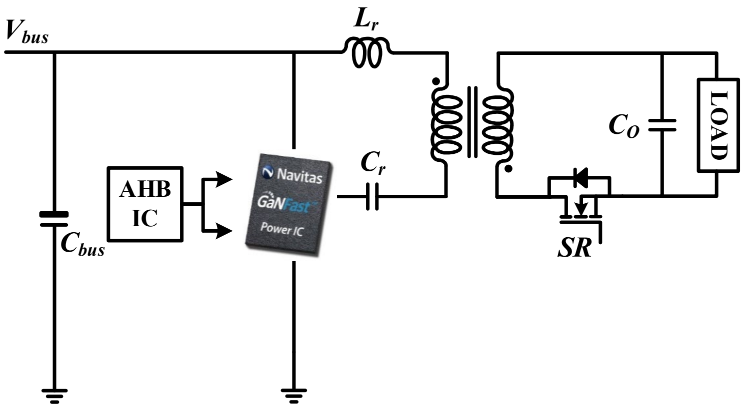
AHB with Si MOSFET



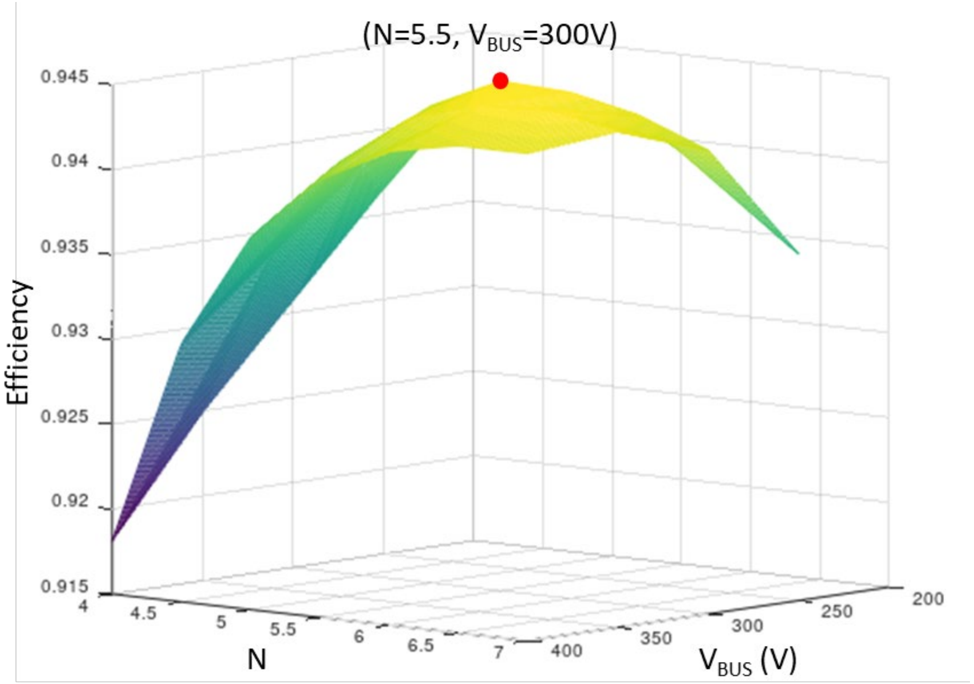
AHB with GaN half-bridge IC

- **Significantly reduces system complexity**
- **Increase system efficiency**
- **More compact PCB design**

Efficiency Optimization & V_{BUS} Selection



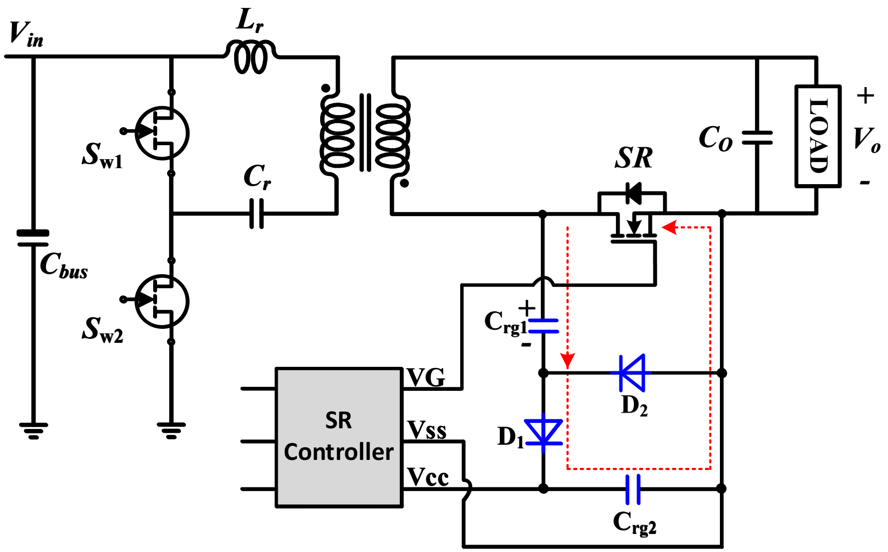
$$V_{Cr} = DV_{in} \qquad V_o = \frac{DV_{in}}{N}$$

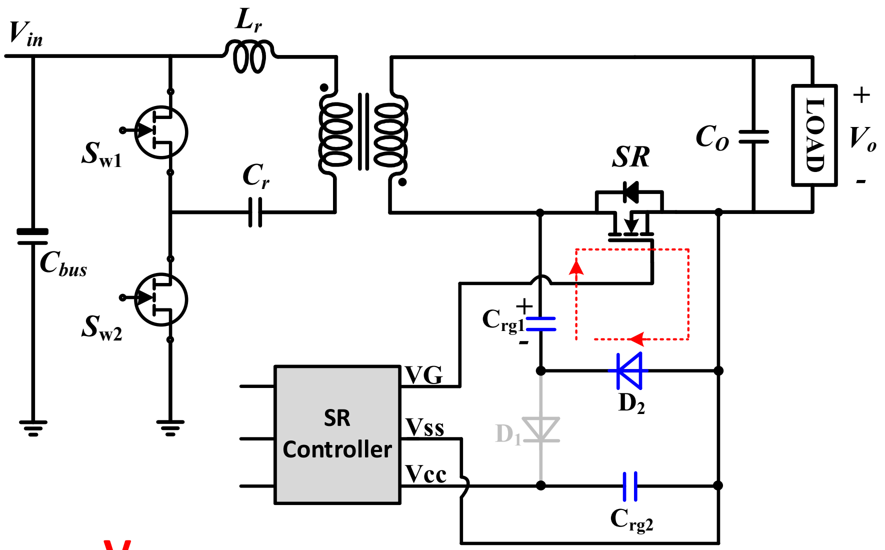


Estimated system efficiency @ 90Vac

- ❑ **Both N and V_{BUS} impact system efficiency**

Proposed V_{CC} Power Supply Circuit

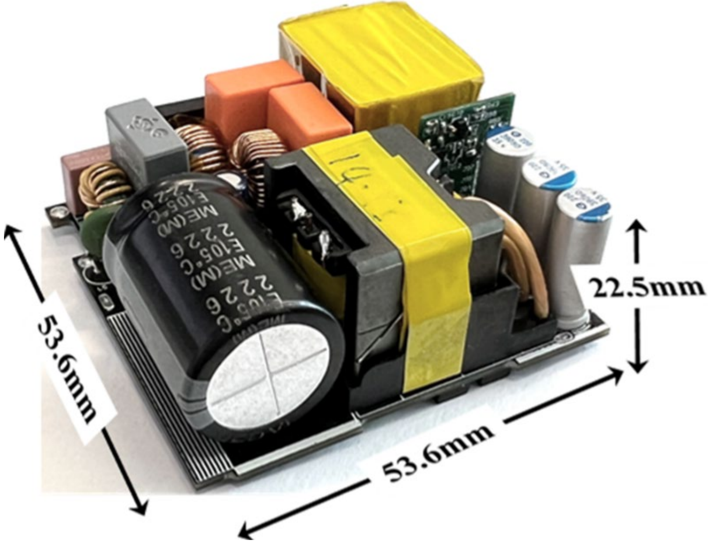


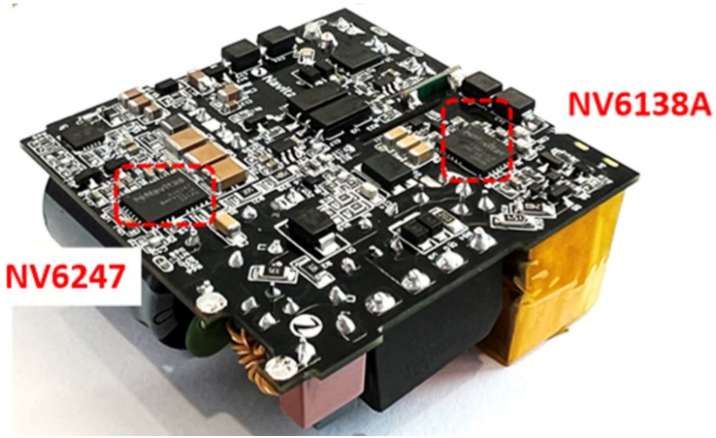


$$V_{DS\_SR} = V_{rg1} + V_{F\_D1} + \underbrace{V_{rg2}}_{V_{CC}} = \frac{V_{in}}{N}$$

- V_{CC} is decoupled with Vo compared with traditional methods
- V_{CC} range is narrowed and suitable for PD3.1 application

140W PD3.1 AC-DC Adapter

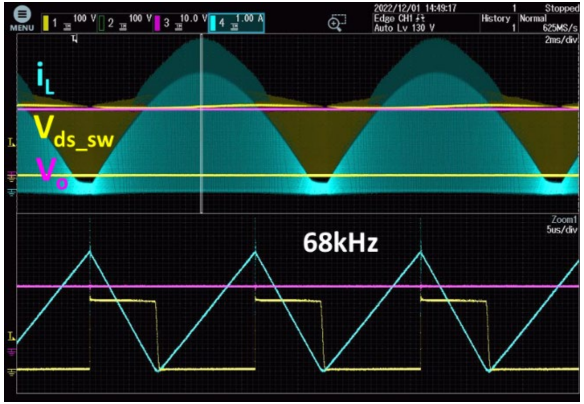




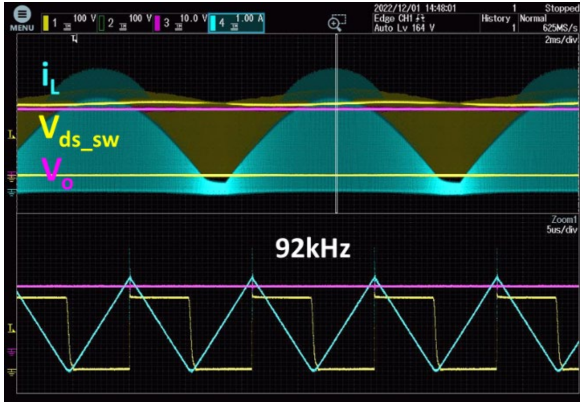
- ❑ **Power density is 35W/in^3 (excludes the case)**

Key Waveforms of PFC Converter

90Vac
140W



115Vac
140W

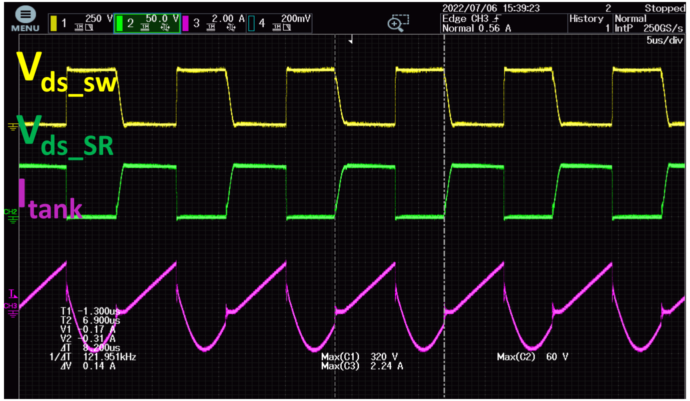


230Vac
140W_1

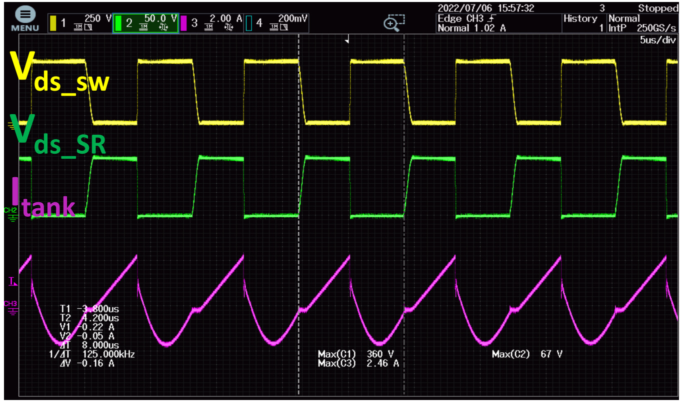
230Vac
140W_2

Key Waveforms of AHB Converter

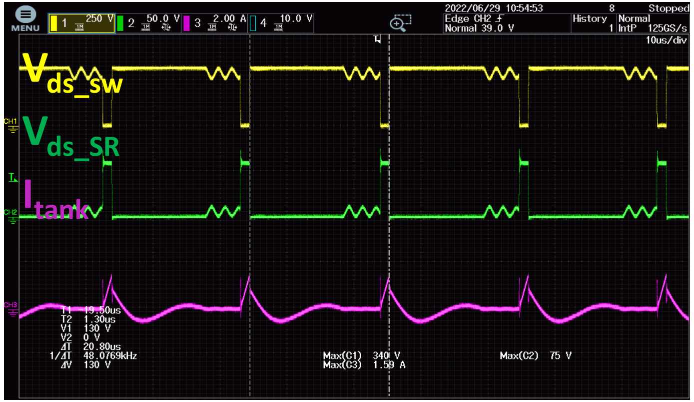
115Vac
28V/5A



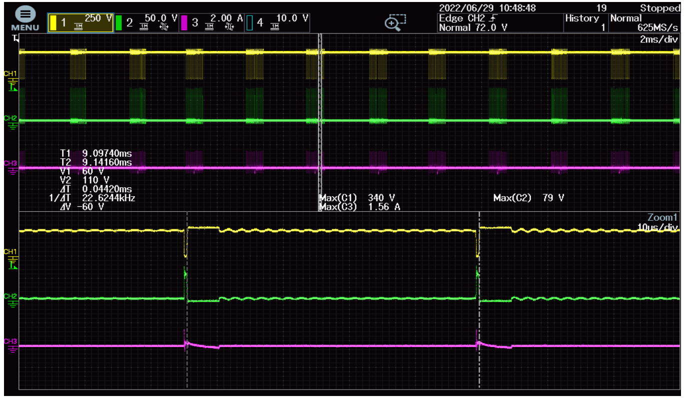
230Vac
28V/5A



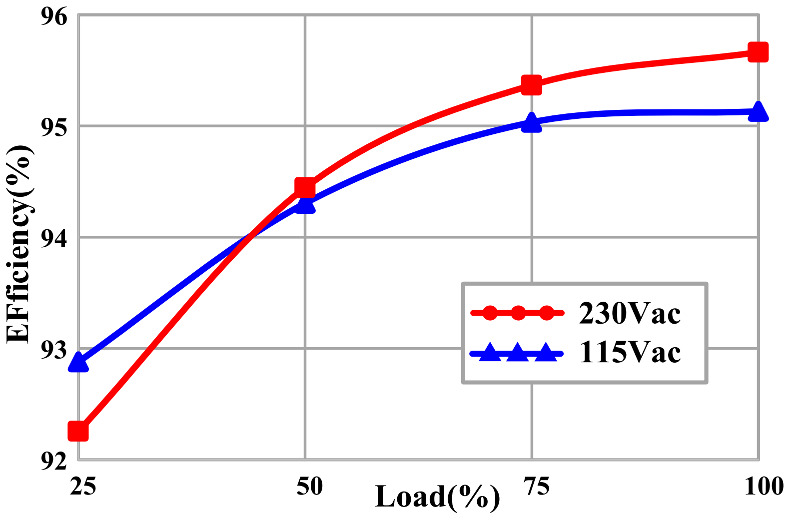
230Vac
5V/3A



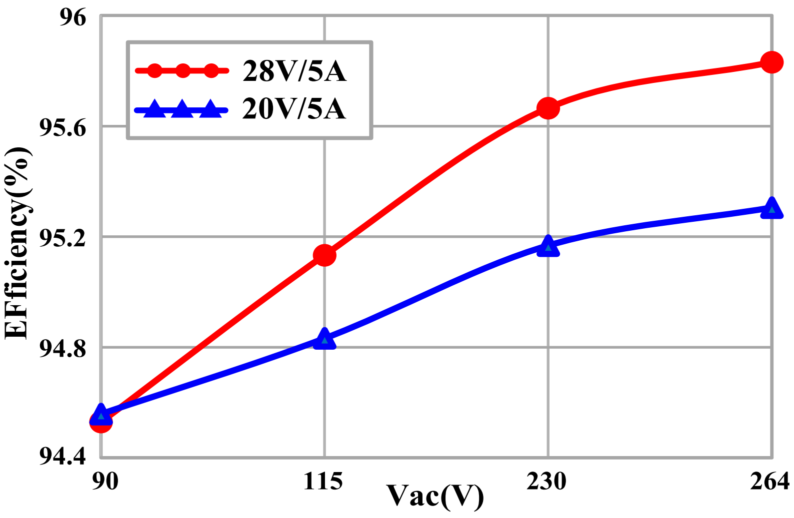
230Vac
5V/0A



System Efficiency



Four-point efficiency @ 115Vac and 230Vac

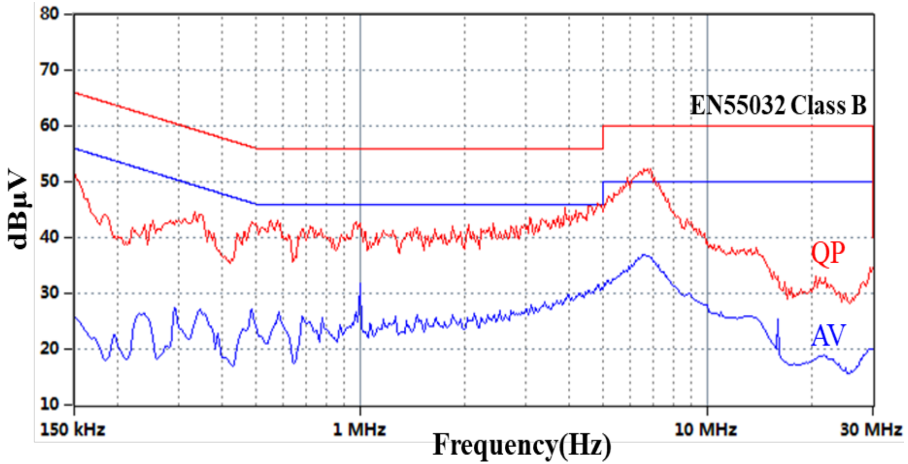


Efficiency at different input voltages

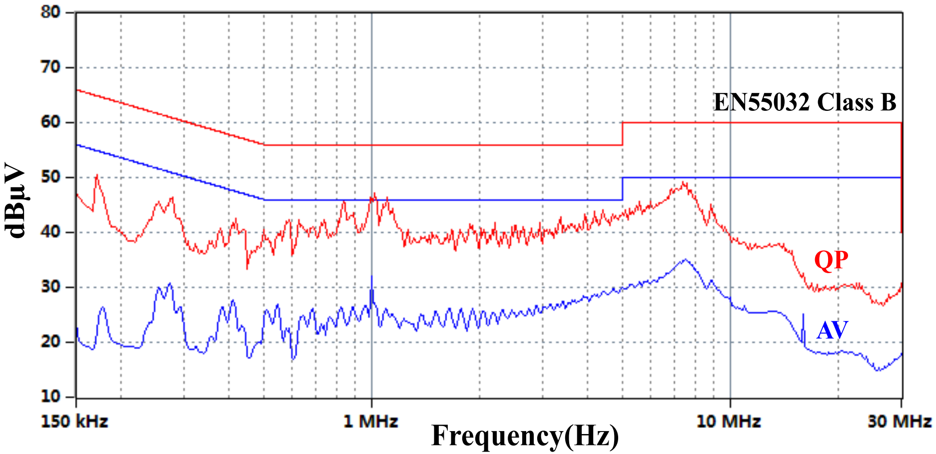
- ❑ **Achieves 94.5% full load efficiency @ 90Vac**
- ❑ **At least 1% higher than the state of art product.**

Conductive EMI Spectrum

115Vac 140W



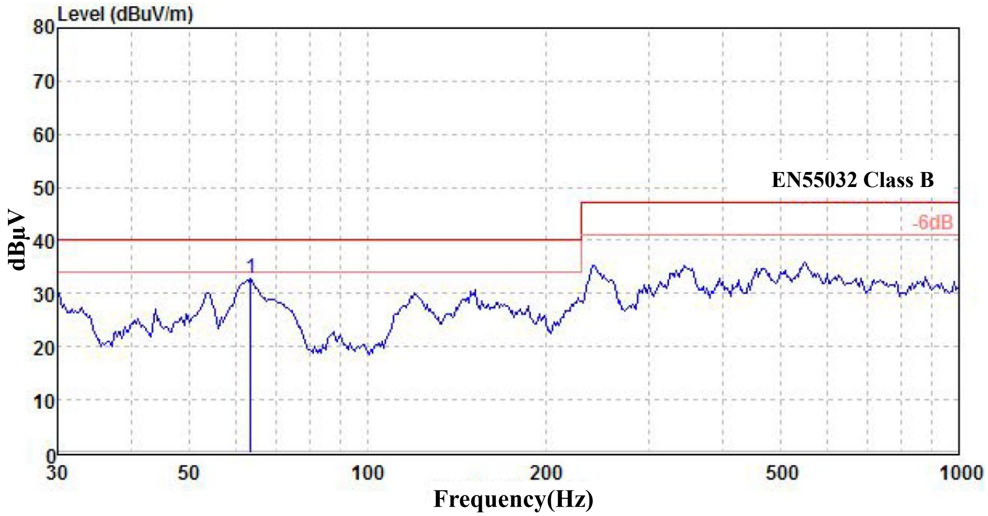
230Vac 140W



- ❑ **Pass the CE standard with more than 8dB margin**

Radiation EMI Spectrum

230Vac 140W



- ❑ **RE margin is more than 6dB**

>100W Adapters

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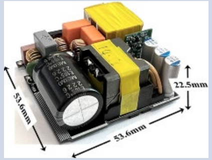
Image							
Topology	PFC + QR flyback	PFC + QR flyback	PFC + ZVS flyback	PFC + ACF	PFC + LLC + DC-DC	PFC + Buck + LLC DCX	PFC + AHB
Efficiency	Low	Low	Medium	Medium	Medium	High	High
Complexity	Simple	Simple	Medium	Medium	Complex	Complex	Medium
Cost	Low	Low	Medium	Medium	High	High	Medium

Summary

- The boost follower PFC improves low line efficiency by adjusting bus voltage
- The new SR V_{CC} supply circuit simplifies the complexity and reduces the driving loss significantly at high output voltage condition
- the new GaNsense and GaN half-bridge power ICs reduce switching loss and circulating energy, improves system efficiency and power density significantly
- This design achieves 35W/in^3 power density, 94.5% full load efficiency @ 90Vac, and passes CE and RE standards with enough margin.

Thank You

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