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(PwrSoC 2016)

Monolithic integration of GaN power transistors integrated with gate drivers

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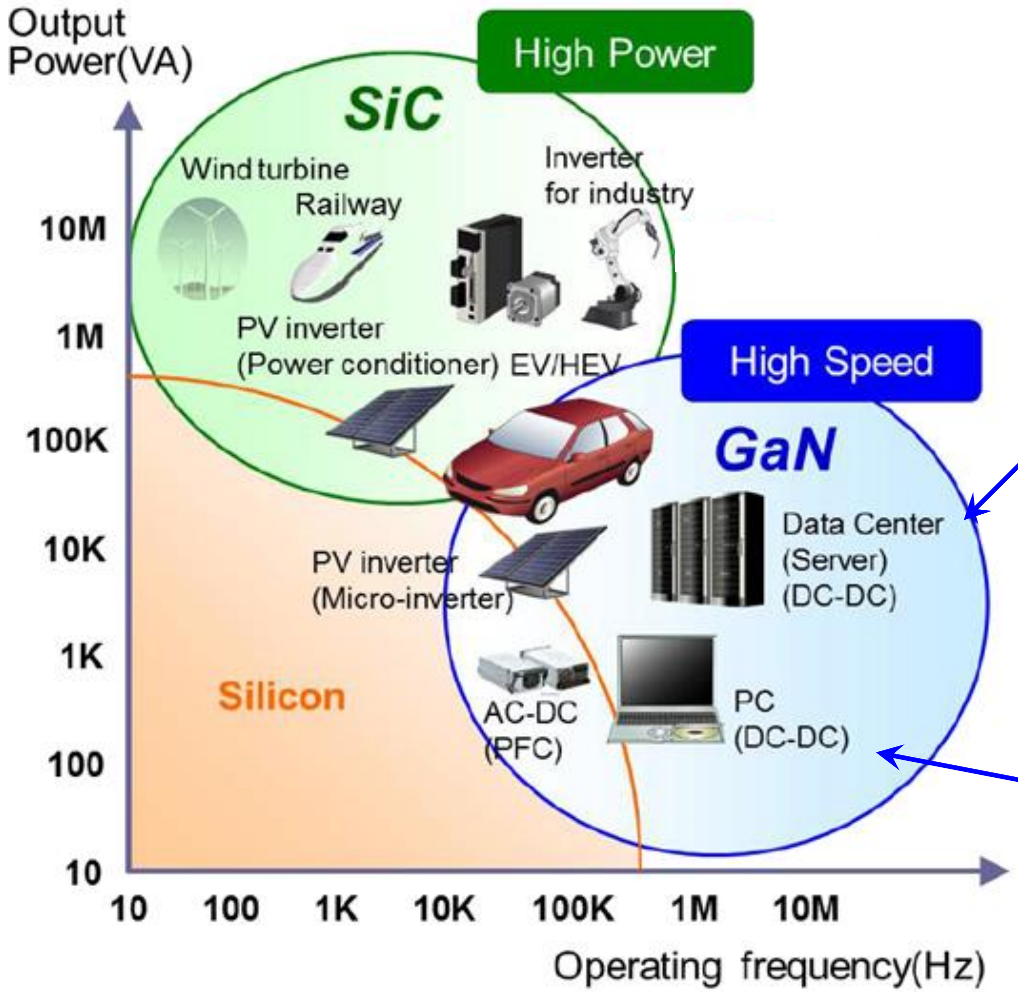
Potential Application for WBG semiconductors

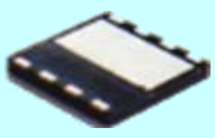
- **GaN power transistors are suited for high-frequency applications.**



Production

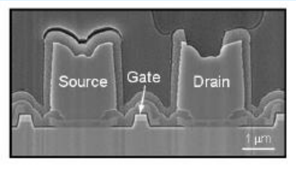
Normally-off GaN Gate Injection Transistor (GaN-GIT)

600V/15A TO-220



600V/15A SMD

Proto-type



30V normally-off GaN-GITs (developed in 2014)

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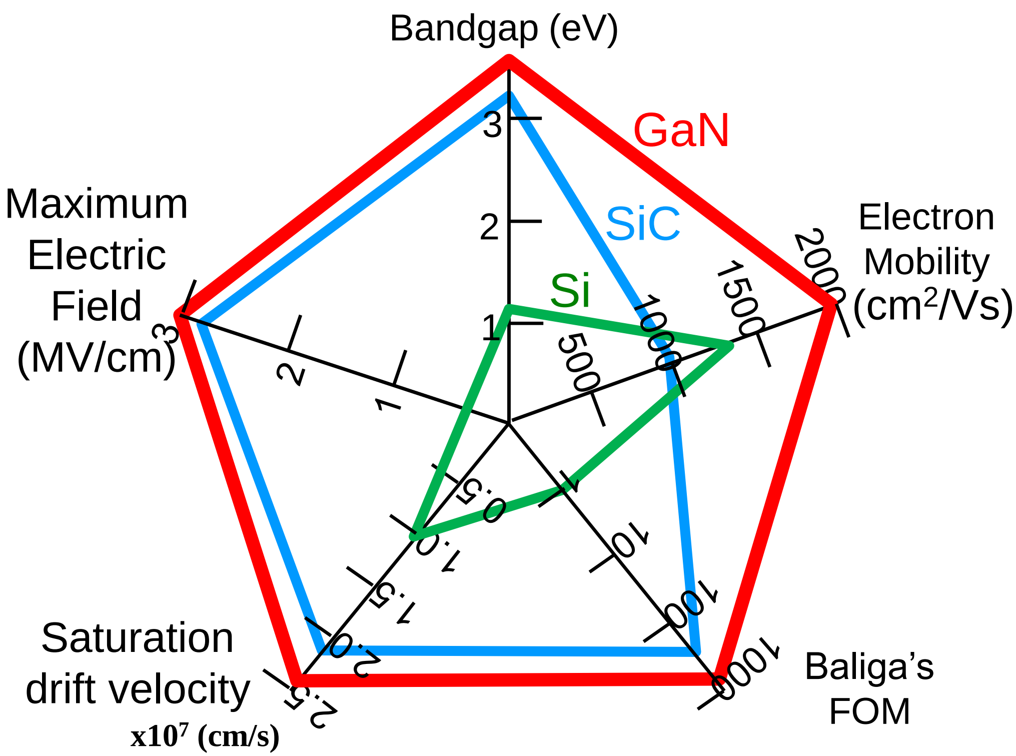
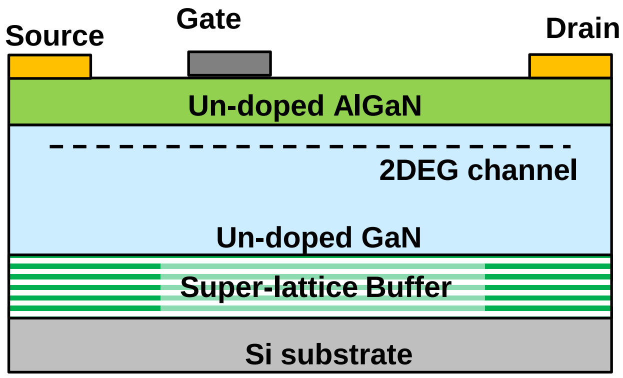
Advantages of GaN for Power device

- **GaN inherently has superior material properties for Power switching device**
- **Unique feature of GaN is 2-Dimensional Electron Gas(2DEG) which serves both high electron density and high electron mobility**

Comparison of material properties



AlGaN/GaN Hetero-junction FET



- High sheet carrier density induced by polarization effects at the AlGaN/GaN hetero-interface without any doping
- GaN-FET can be fabricated on cost-effective Si-substrates
- Normally-on operation

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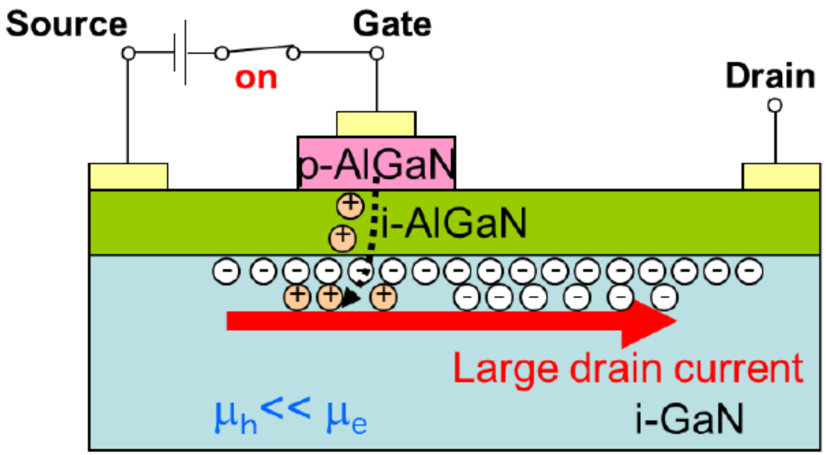
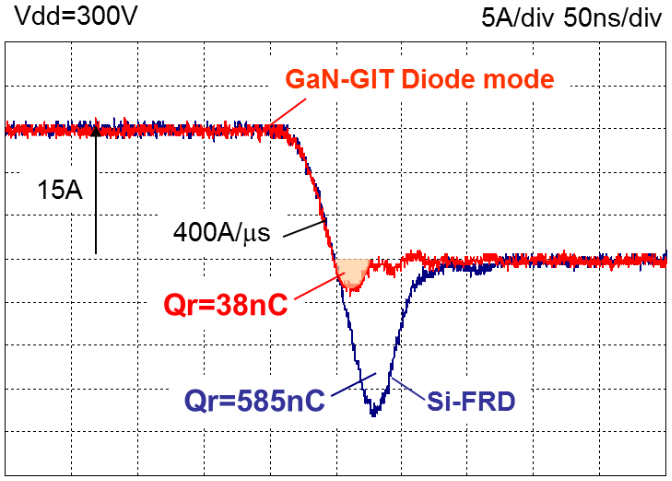
Normally-off GaN Gate Injection Transistors - GIT -

Gate Injection Transistor (GIT)



Recovery characteristics



Normally-off operation

Vg=0V: p-AlGaN lifts up the potential at the channel.

Vg>Vf: Hole injectction → Electron generation →Large Drain current

Very low RonQg

RonQg of 600V GIT is 0.7 ΩnC which is 1/13 of that of the latest SJ-MOSFET.

Good Recovery characteritics

GIT can be operated as a free-wheeling diode with very small charging current.

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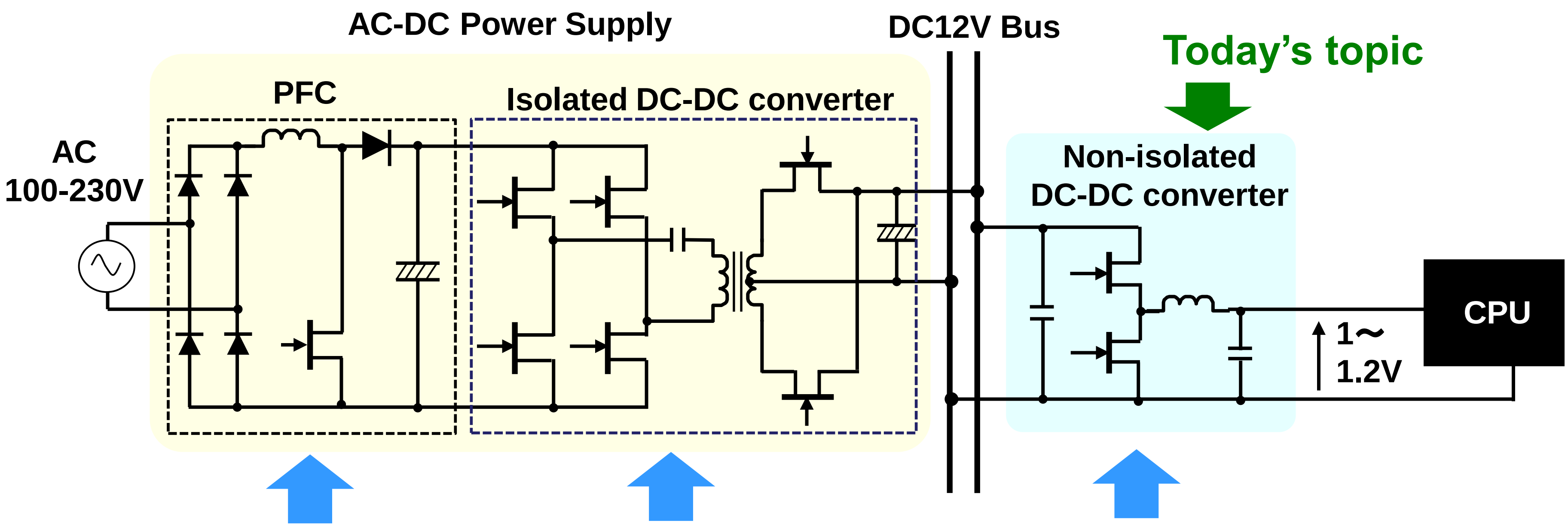
Power supply

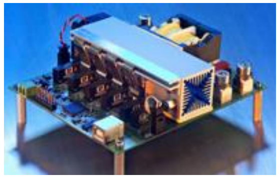
- Power converter have progressed with overcoming design trade-off among power density and efficiency, cost.
- To make more advanced, GaN-FETs have been actively investigated.

GaN power devices used in Power supply

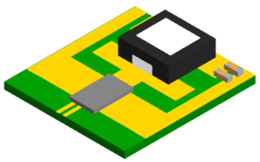


Totem-pole PFC using GITs reported by Panasonic on PCIM2014

1MHz resonant converter using 600V normally-off GaNs reported by Fraunhofer ISE on ECSCRM2012



- 5MHz/50A GaN POL converter reported on PCIM2014
- GaN POL power IC integrated with gate drivers reported on ISPSD14



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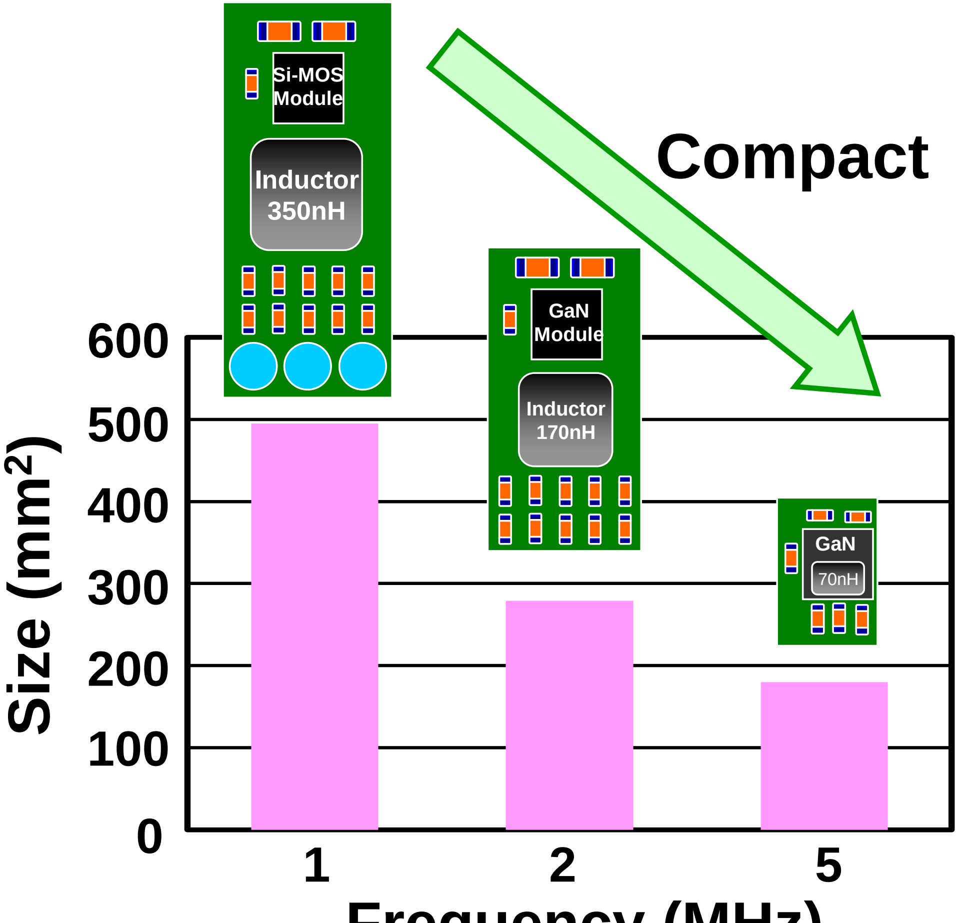
For smaller POL converter

- Increasing frequency greatly helps to reduce the system size.
- Low RonQg power device and low parasitic inductance are key factors.

Advantage by increasing frequency



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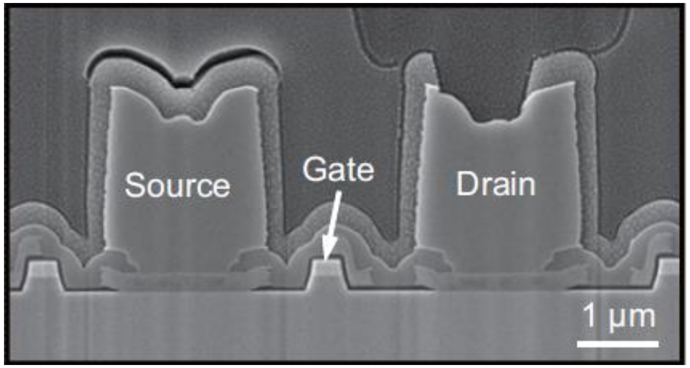
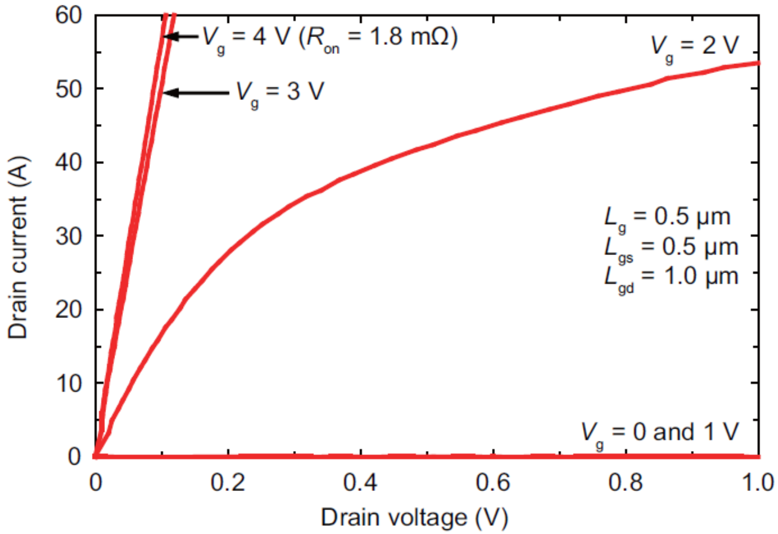
30V-class normally-off GaN-GITs

- **RonQg of developed 30V GaN-GIT is reached to 19.1mΩnC[*1]. -> 36% smaller than that of reported Si-MOSFET[*2].**





R_{on} (mΩ)	Q_g (nC)	$R_{on}Q_g$ (mΩnC)	Breakdown voltage (V)
1.8	10.6	19.1	30

***1 H. Umeda, et al., PCIM2014**

***2 S. Xu, et al., International Electron Devices Meeting (IEDM) Technical Digests, 145(2009)**

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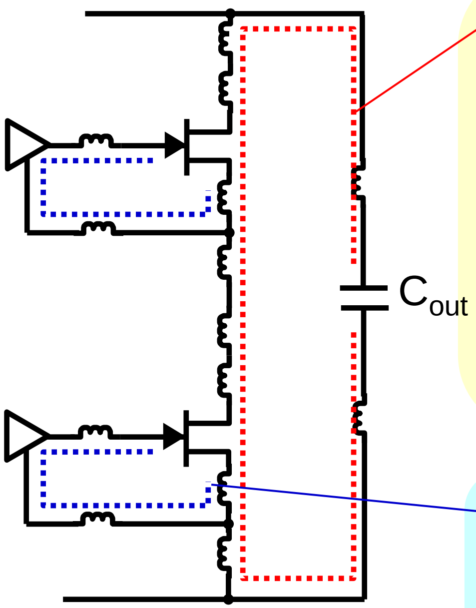
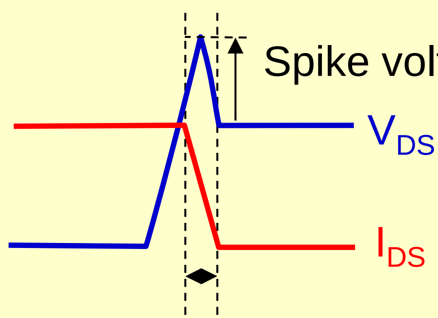
Impact of the parasitic inductance

- **Parastic inductance on power loop (L_{Power_Loop}) increase the spike voltage**
  →It limits di/dt and causes gate oscillation, increase noise.
- **Parastic inductance on gate loop (L_{Gate_Loop}) increase the gate charging time.**



Parasitic inductance on Power Loop L_{Power_Loop}



Spike voltage $$V_{Spike} \propto L_{Power\_Loop} \bullet \frac{\Delta I_{DS}}{\Delta t}$$

→limit di/dt to keep Vds under BVds
→causes gate oscillation
→generate Noise

Parasitic inductance on Gate Loop L_{Gate_Loop}

→Reduction of Lgate_Loop also effectively increase gate charging speed

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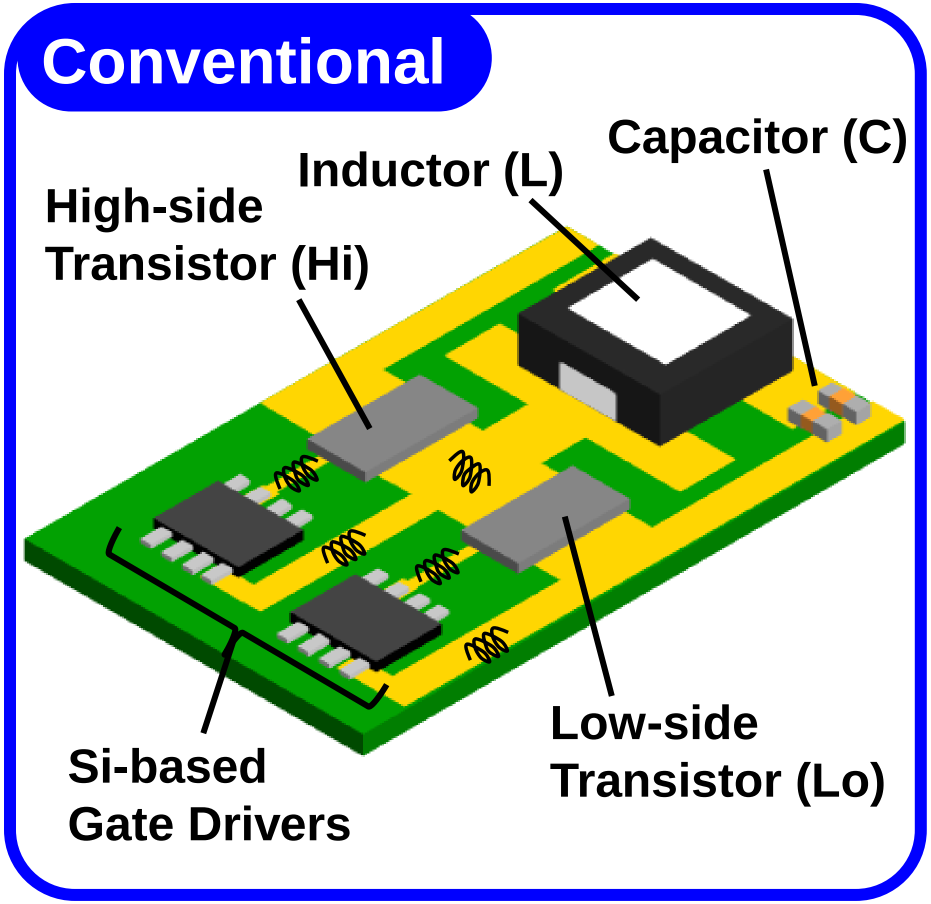
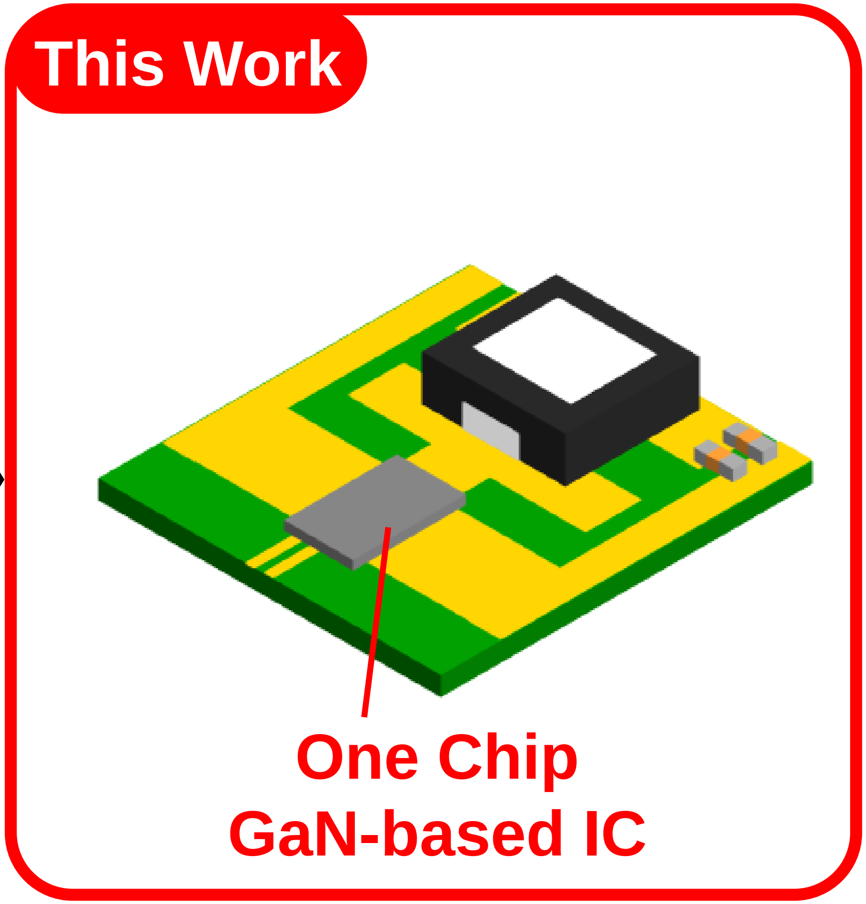
This Work : GaN-based IC with gate driver

- **GaN transistors and GaN gate drivers are integrated to a compact chip**





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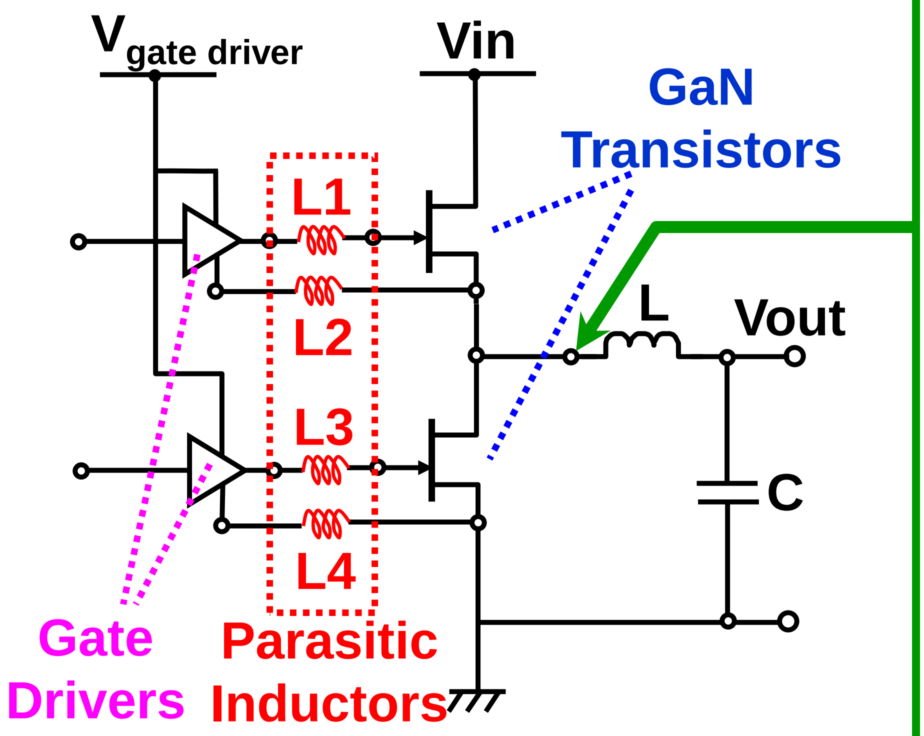
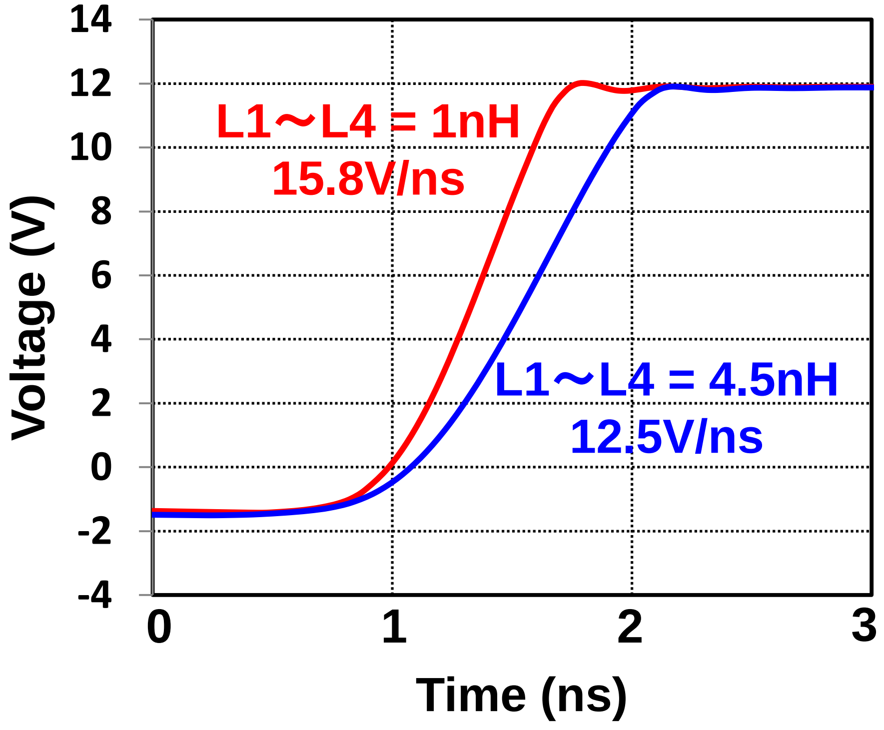
Impact of Integration : Small Parasitic Inductances

- Switching speed is increased by reduction of parasitic inductances

Simulated turn-on switching waveform





12V ⇒ 1.8V Iout = 6A
2MHz operation

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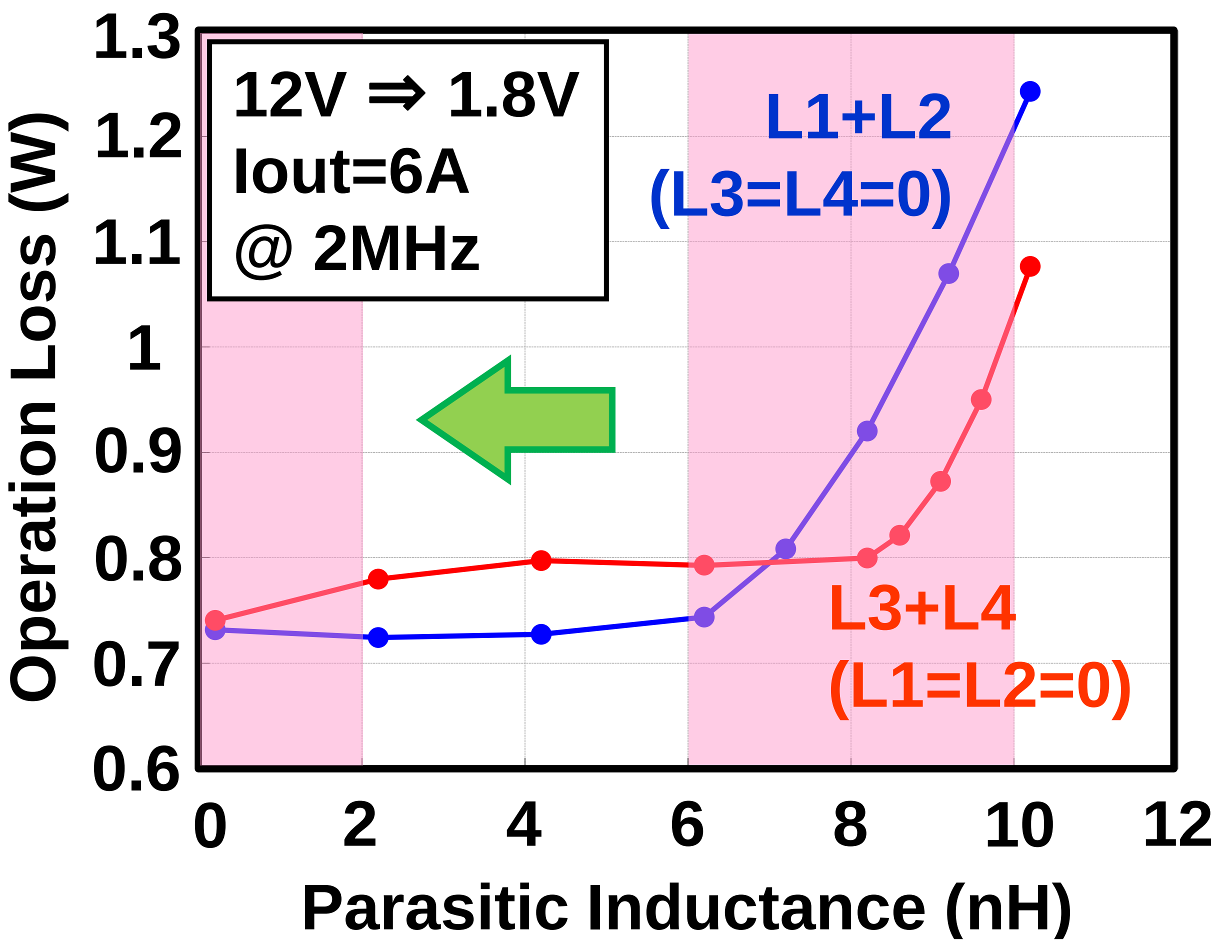
Impact of Integration : Small Parasitic Inductances

- **Operation loss is reduced by the reduction of parasitic inductances.**

Simulated operation loss



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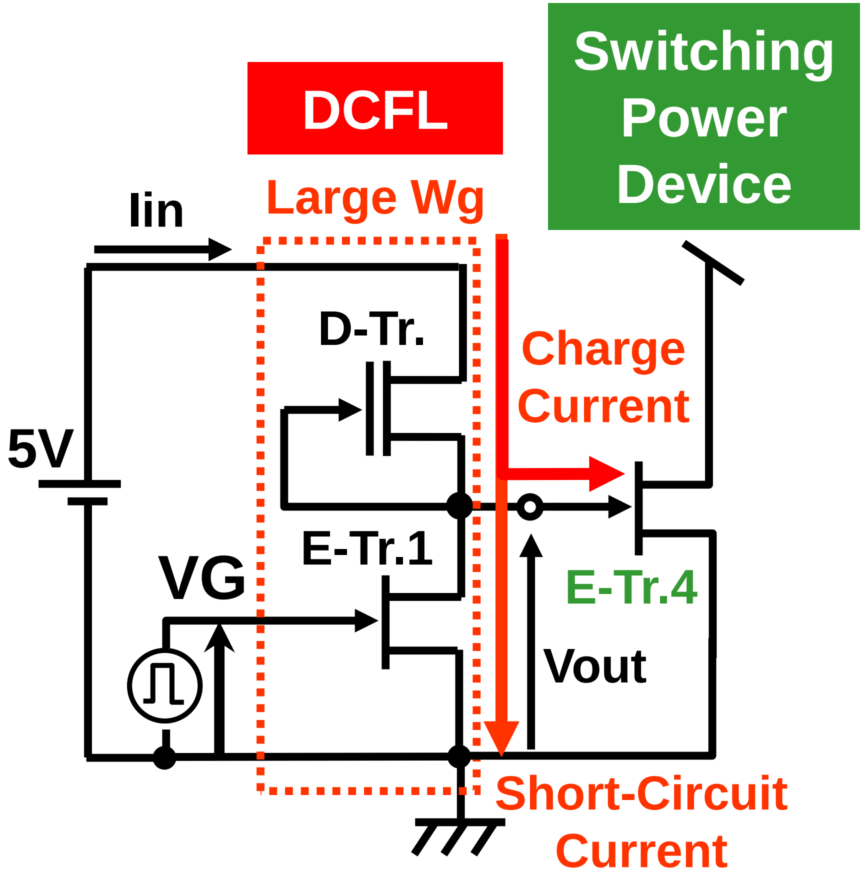
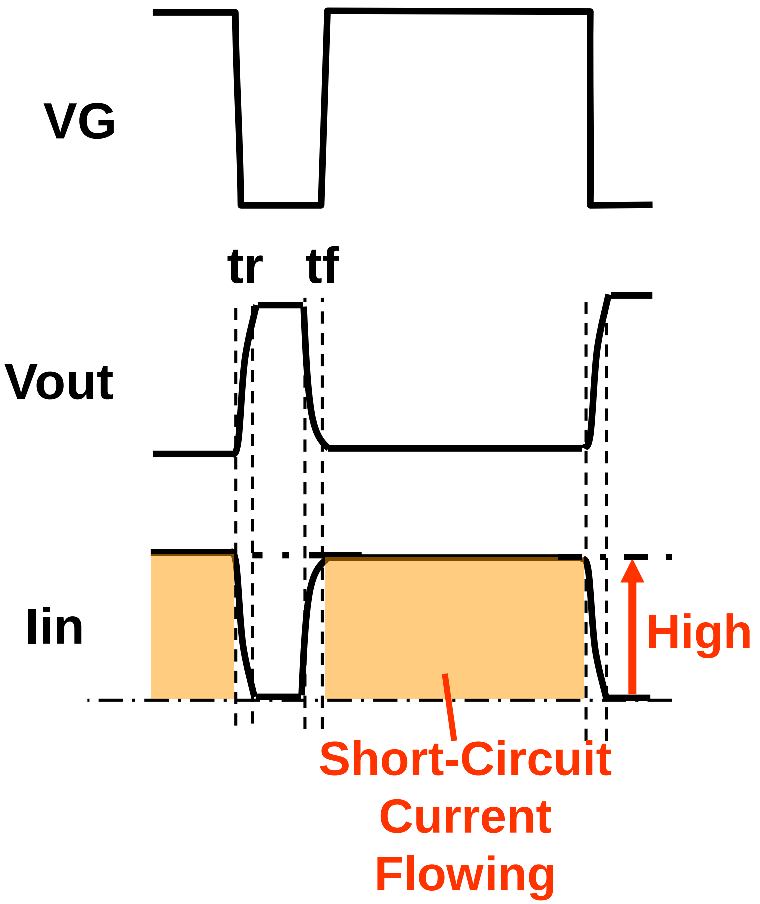
GaN Gate Driver : DCFL (Direct Coupled FET Logic)

- High power consumption in GaN gate driver of DCFL.

Circuit Design



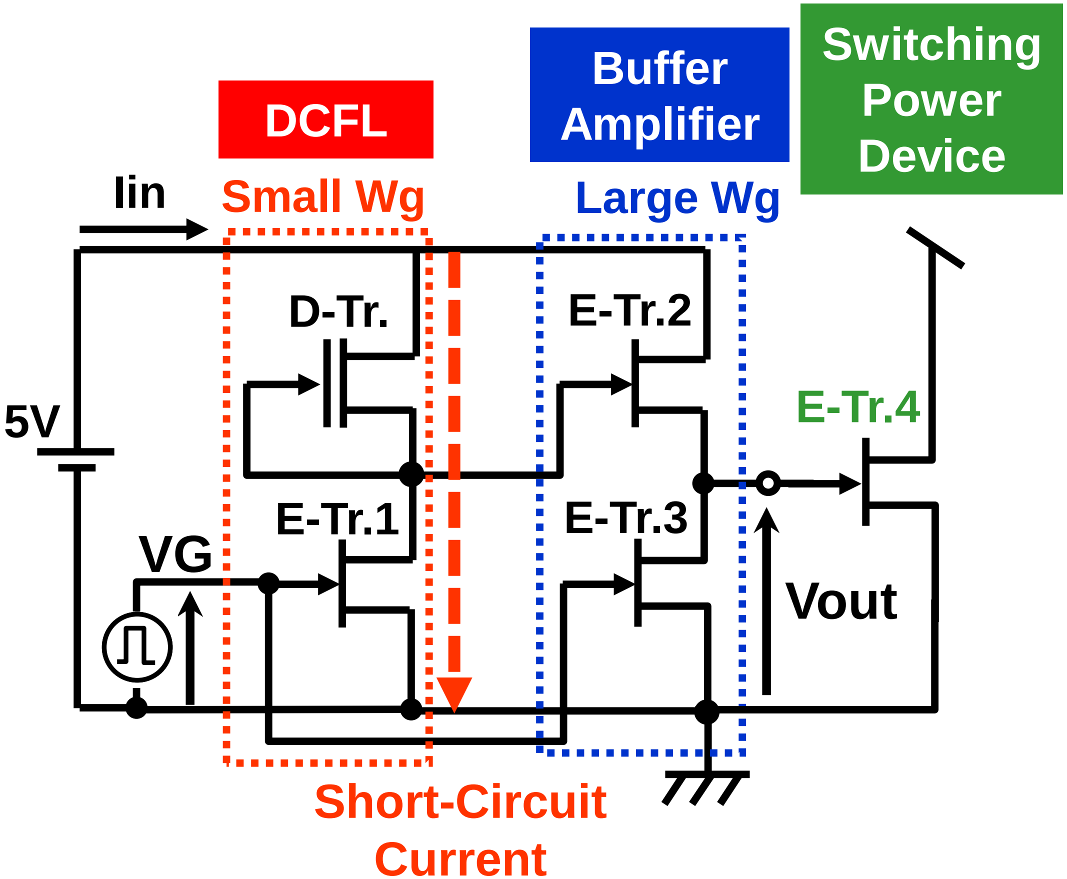
Time Chart



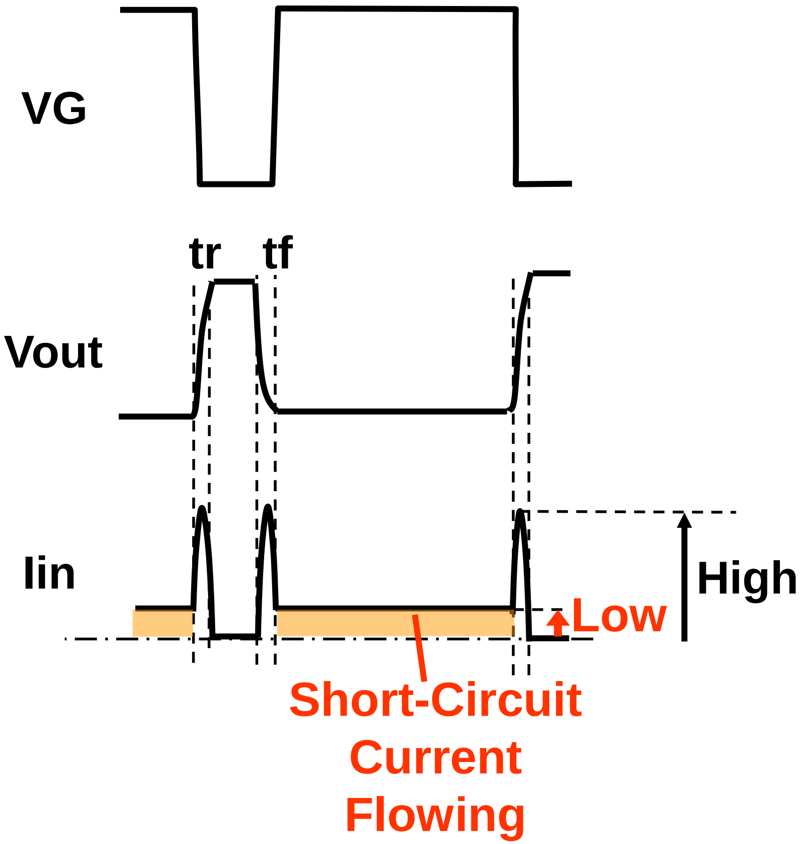
GaN Gate Driver : DCFL with Buffer Amplifier

- Low power consumption in GaN gate driver by buffer amplifier.

Circuit Design



Time Chart



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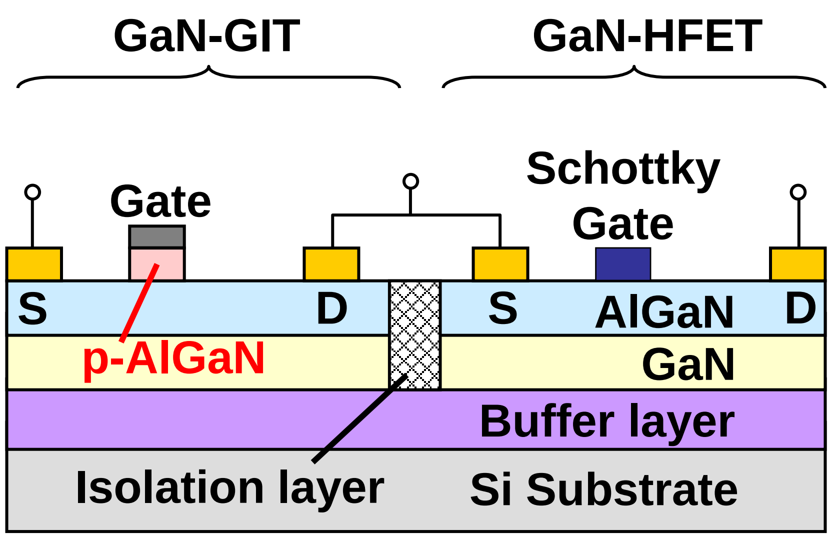
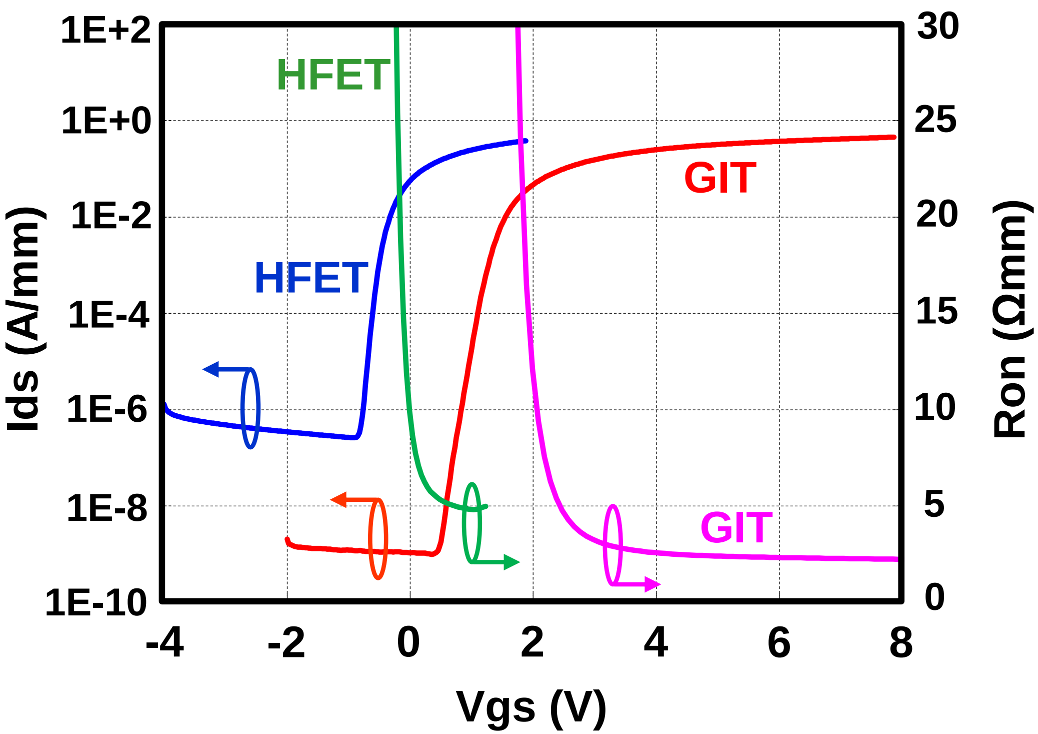
GaN Device Structure and Characteritics

- D-mode HFET and E-mode GIT are monolithically fabricated.

Device Structure



Device Characteristics



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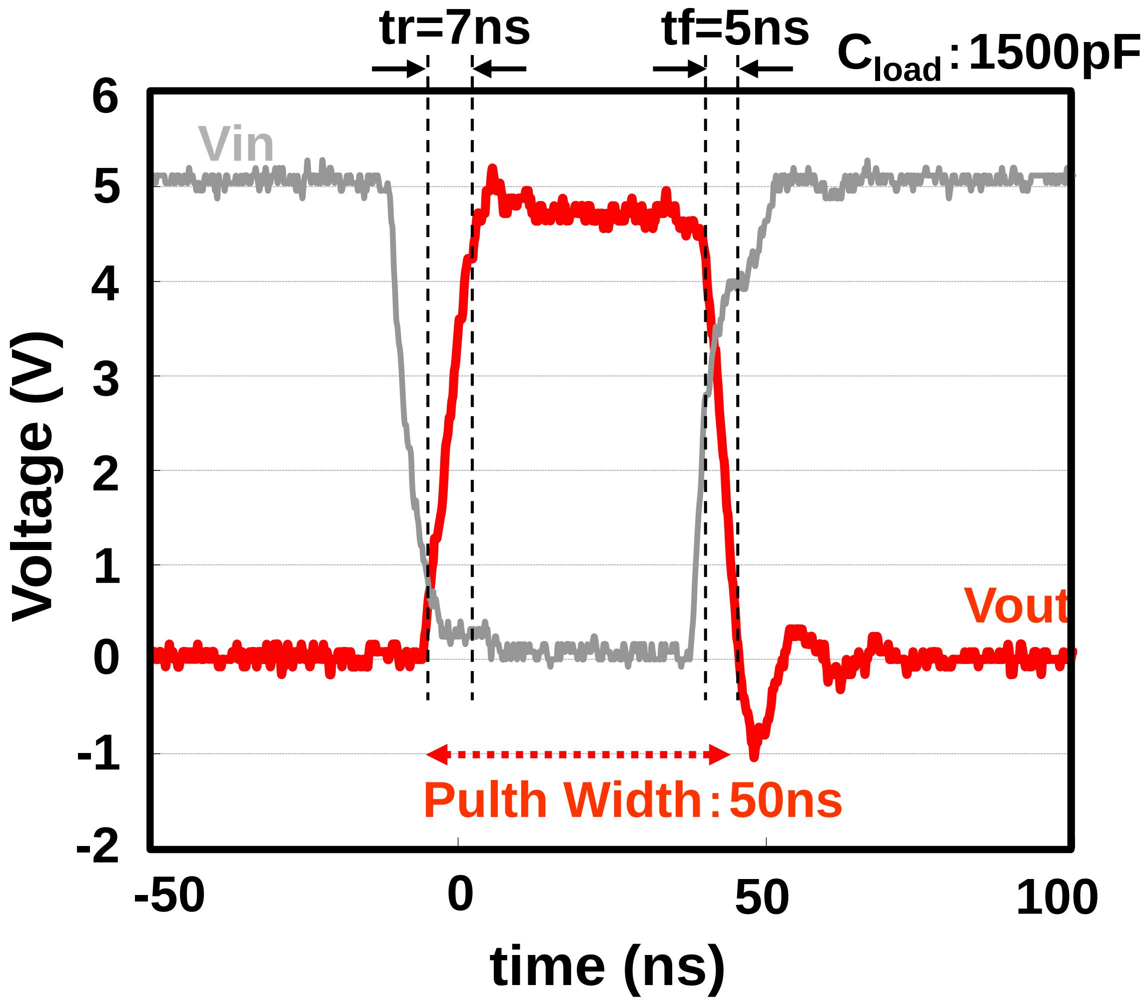
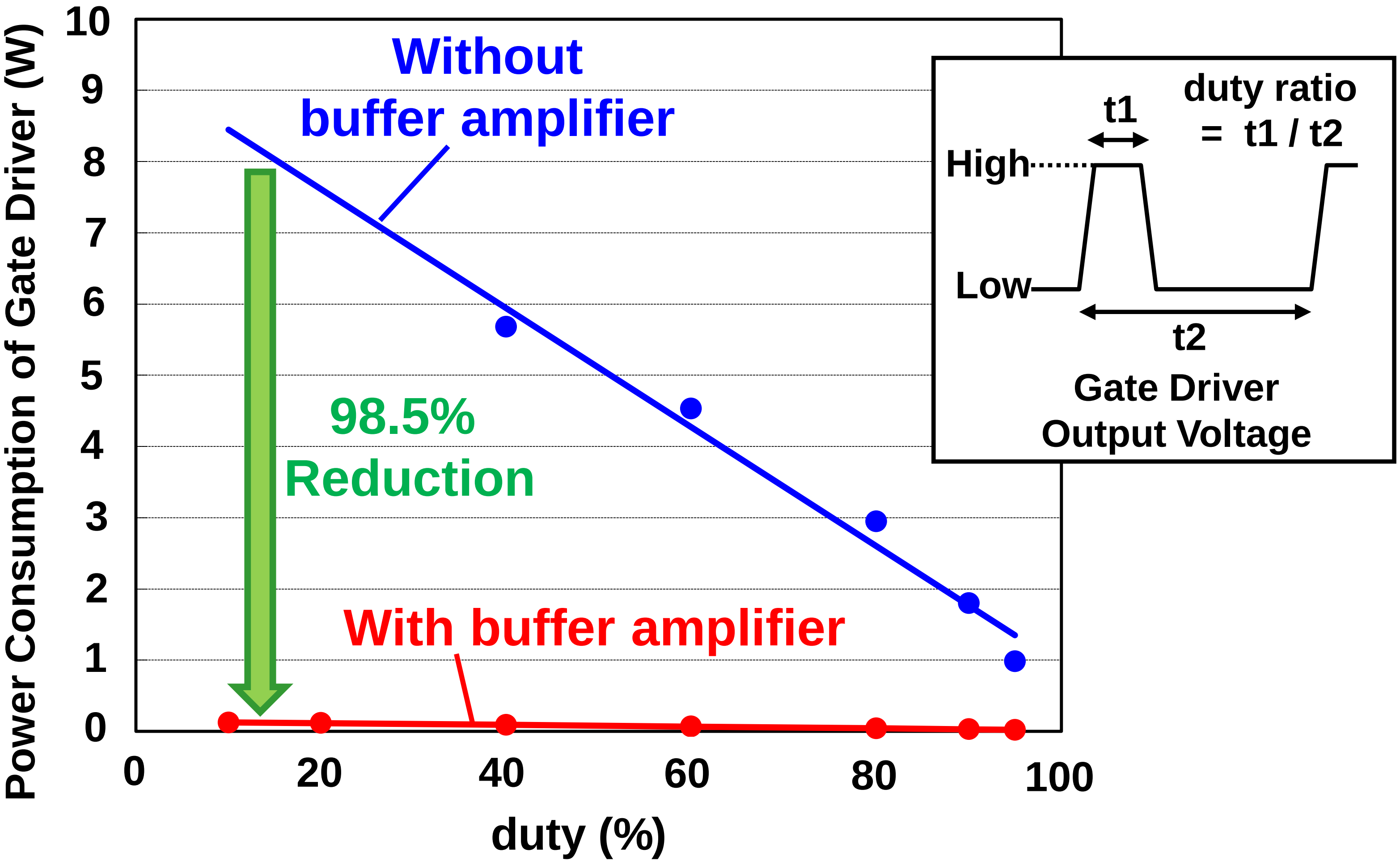
Operation Characteristics of GaN Gate Driver

- **GaN gate driver is about 40% faster than Si gate driver.**



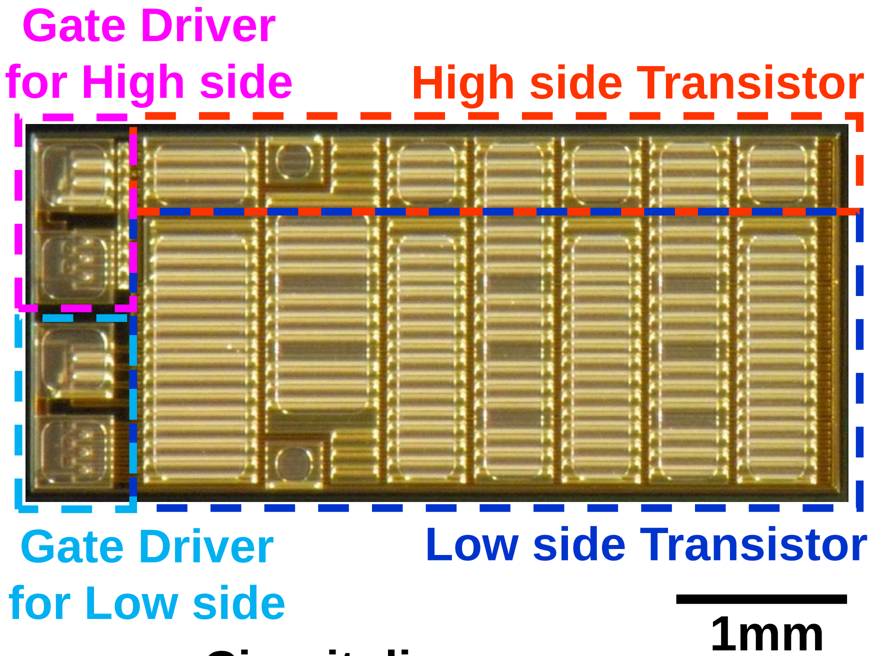
Low Consumption of GaN Gate Driver

- Power consumption is reduced about 98.5% by using GaN DCFL with buffer amplifier.

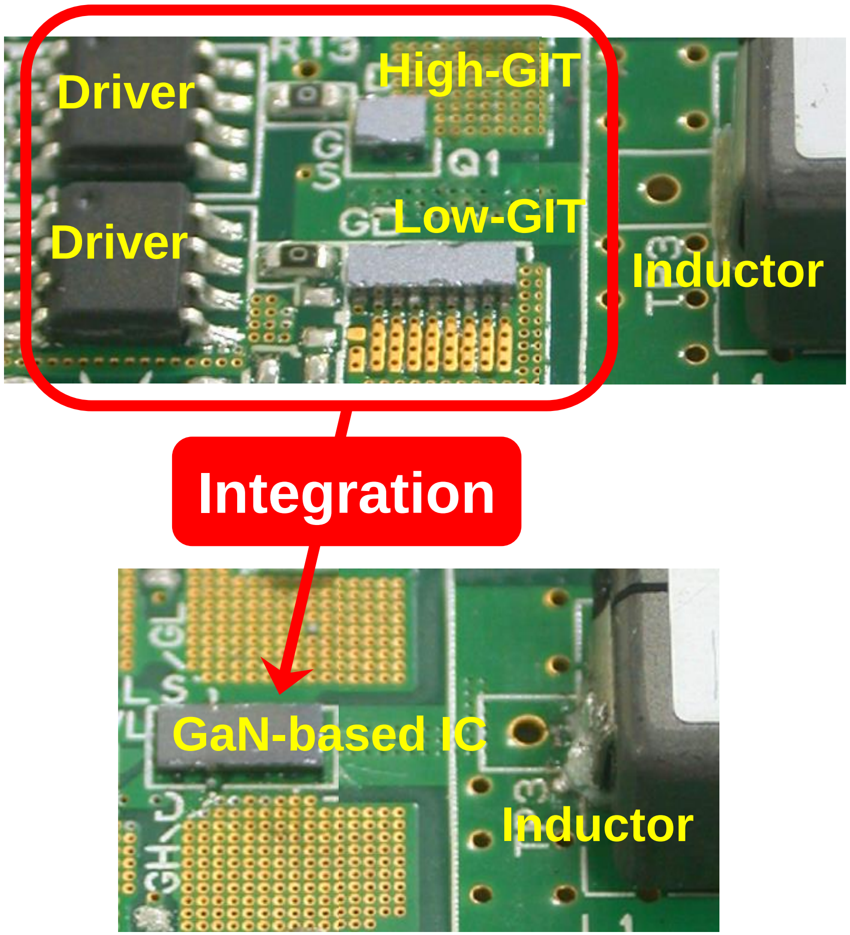


GaN-based DC-DC Converter IC

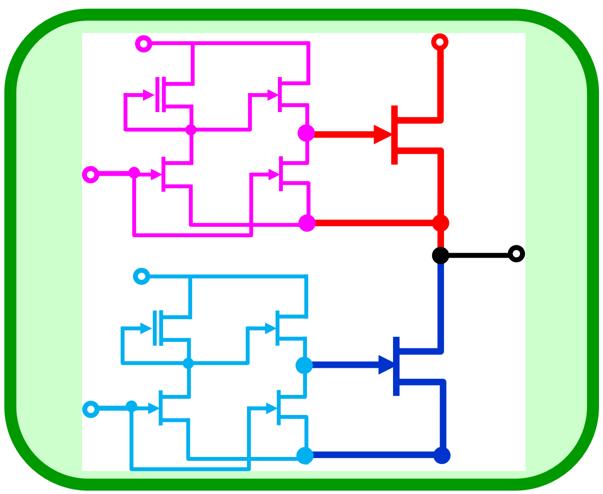
Chip photograph



Module layout with GaN-based IC



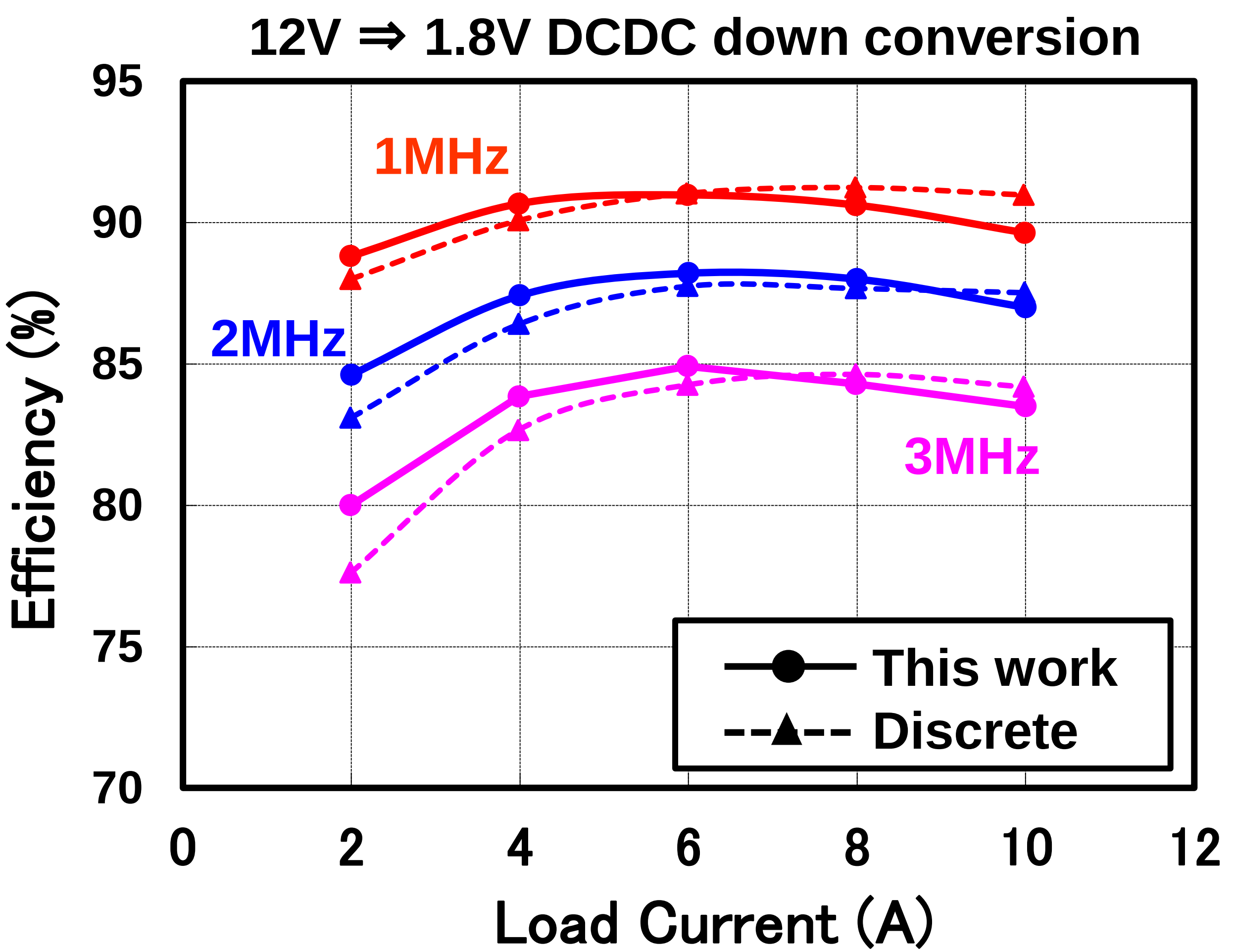
Circuit diagram



- Compact chip size is 5.1mm x 2.3mm
- GaN-based IC reduces the system size

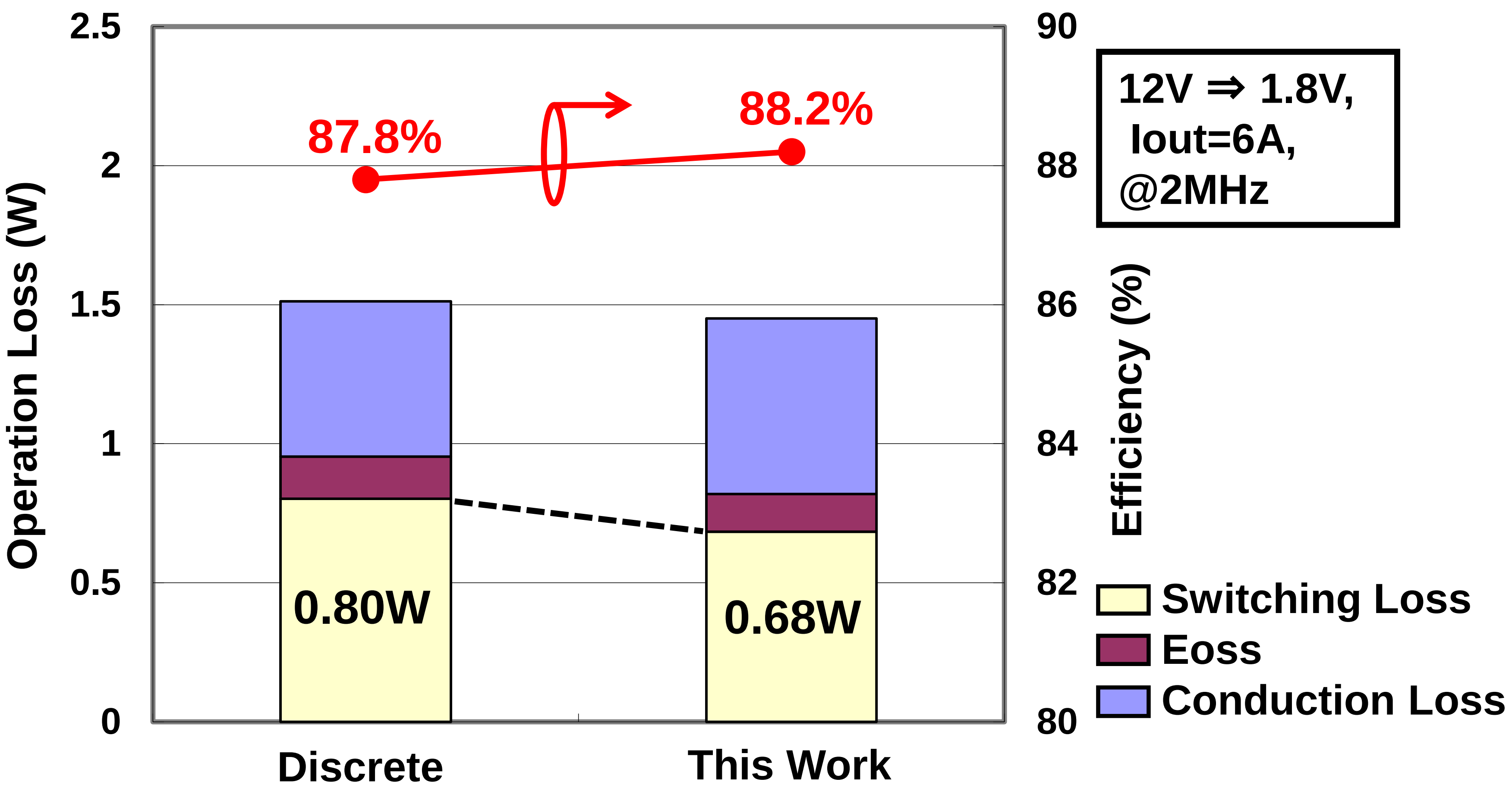
Operating Efficiencies of DC-DC Converter

- **Peak efficiency of 88.2% is achieved with 12V - 1.8V DC-DC conversion at 2MHz**



Analyzed operating loss of GaN-based IC

- Switching loss have been reduced 15% by using GaN-based DC-DC converter IC.



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Summary

Compact GaN-based DC-DC Converter IC with High Speed Gate Drivers for Highly Efficient DC-DC Converters

■ **GaN Gate Driver**	**DCFL with buffer amplifier**
	Monolithically fabrication of HFET and GIT
	High speed switching (tr + tf = 12ns)
■ **GaN-based IC**	**5.1mm X 2.3mm Compact chip size**
	Peak Efficiency (12V-1.8V) : 88.2%@2MHz

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