GaN half-bridge integrated circuits for power converters

Authors: Deniz Aygün [3], Valérie Schillemans [3], Stefaan Decoutere [2], Paul MAYNADIER [1], Marc Fossion [1]
Co-authors: Jef Thone [3], Mike Wens [3], Martin Haug [5], Christophe DELEPAUT [4], Andrew Barnes [4] Fabio Vitobello [6]

[1] Thales Alenia Space in Belgium & France
[2] IMEC, 3001 Leuven, Belgium
[3] MinDCet NV, Researchpark Haasrode, 3001 Leuven, Belgium
[4] ESA @ ECSAT Harwell & ESTEC Noordwijk
[5] Wurth Electronics
[6] EC-Europe

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Template: 83230347-DOC-TAS-EN-010

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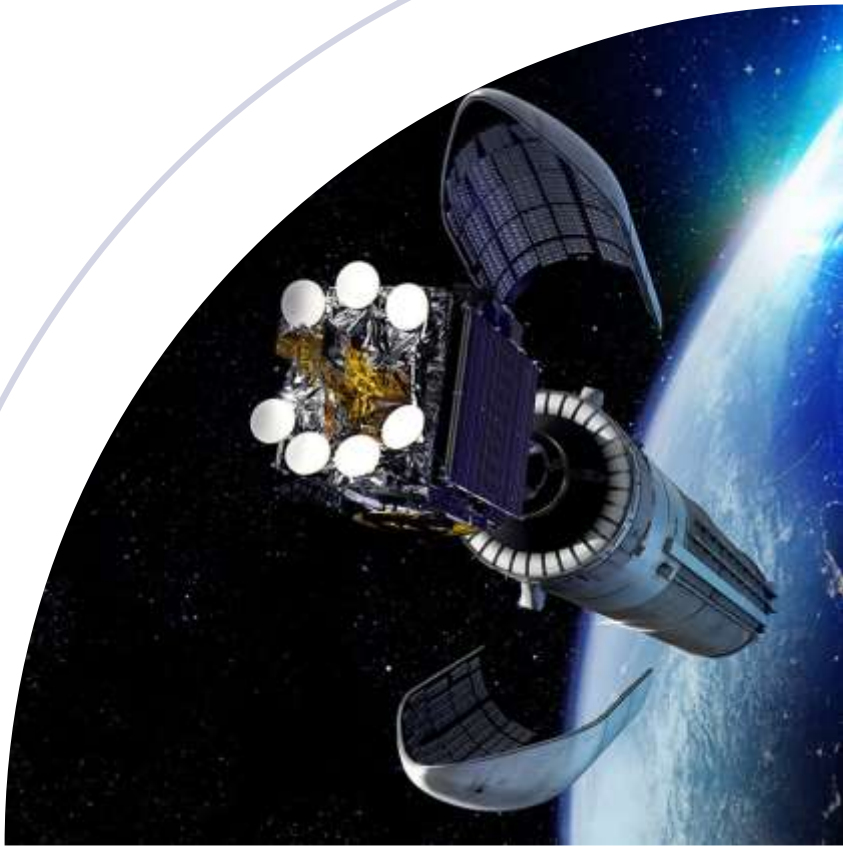


REVOLUTION IN POWER CONVERTERS : MOSFET ➔ GAN

///Silicon power MOSFET

- Specific transistor design for radiation hardening ➔ rare ➔ expensive & restrictive export control rules apply.
- Bulky ➔ easier to cool down.

///GaN

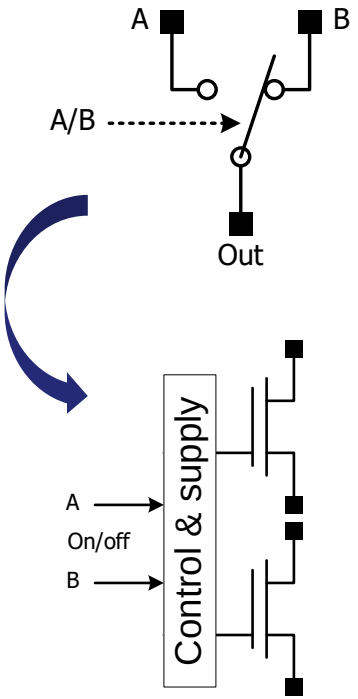
- Faster switching ➔ more compact design
- Lower losses ➔ better efficiency

- No (so far) specific transistor design required for radiation hardening
  - terrestrial automotive grade components produced in volume ➔ lower cost
  - Up-screening & specific SOA for space applications

- Very compact ➔ a lot more difficult to cool down

///Holy Grale for power converter designers = half-bridge module with GaN !

///Supply chain through Eu suppliers & foundries ➔ Eu independency



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CHALLENGES OF DRIVING GAN

Pitfalls:

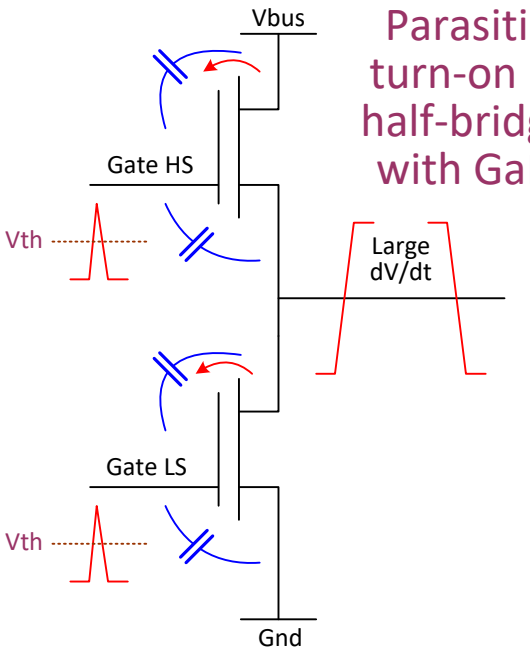
A GaN HEMT is not a MOSFET:

/// Lower and tighter controlled gate turn-on voltage

/// Lower threshold voltage (V_{th})

/// Significantly faster Turn On and Off times -> High dV/dt

/// Lower $C_{gate\text{-}source}$ / $C_{drain\text{-}gate}$ ratio



Parasitic turn-on in half-bridge with GaN

⇒ An ideal recipe for expensive fireworks

⇒ Needs an optimized gate-drive approach

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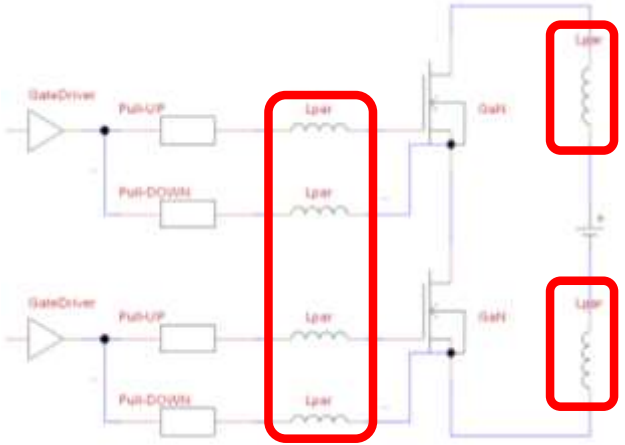
CHALLENGES OF DRIVING GAN

With an external gate driver:

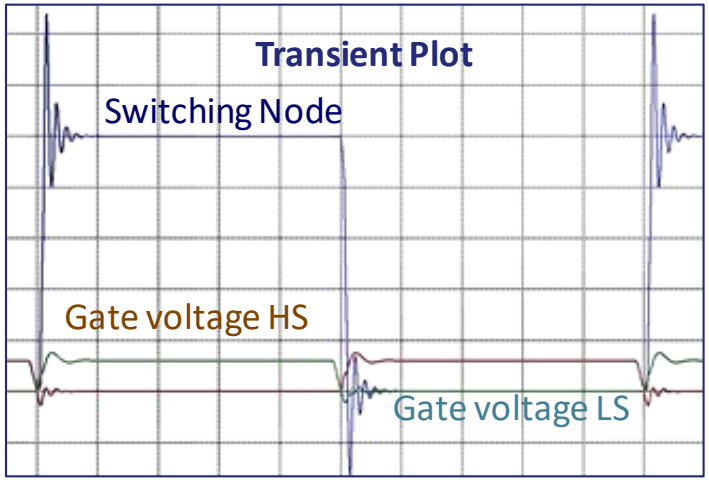
On PCB level:

- Gate-loop inductance
- Supply inductance
- Gate resistors
- Drain-source inductance



On Gate-driver IC level:

- Dead-time control
- LS/HS delay-matching
- dV/dt immunity
- Negative source voltage from GND inductance
- GaN gate stress with overvoltage



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MONOLITHIC GAN HALF-BRIDGE + GATE DRIVER

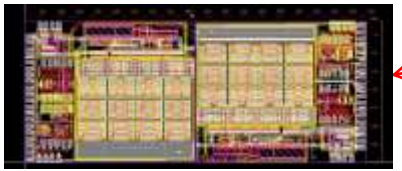
Challenges & differences :

/// Reduce # external components in the system ➔
Increasing the overall system power density

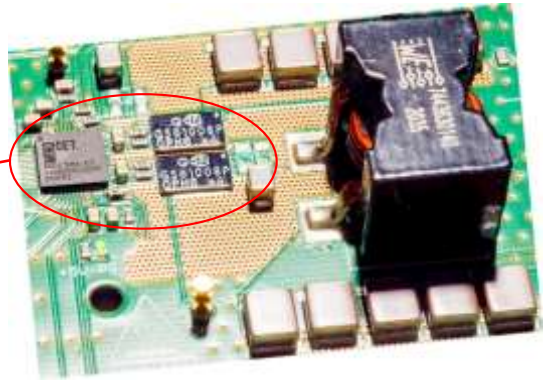
/// Strongly drive (high & **also low** !) GaN up to speed by killing gate-loop parasitics

/// Reliability: minimize the gate voltage overshoot

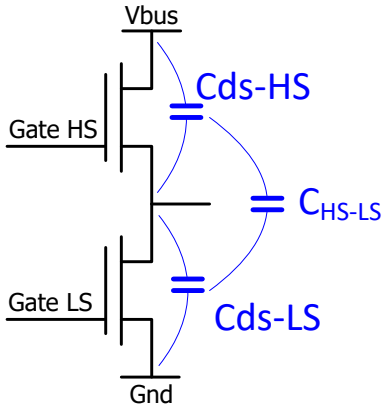
/// Require strong isolation between high side & low side power GaN



Design of full GaN ASIC !



Pictures courtesy of MinDCet



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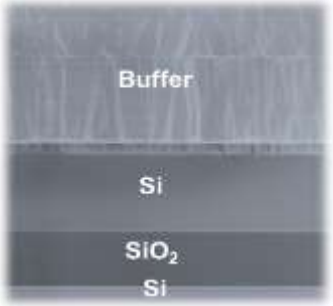
Technology Makes the Difference

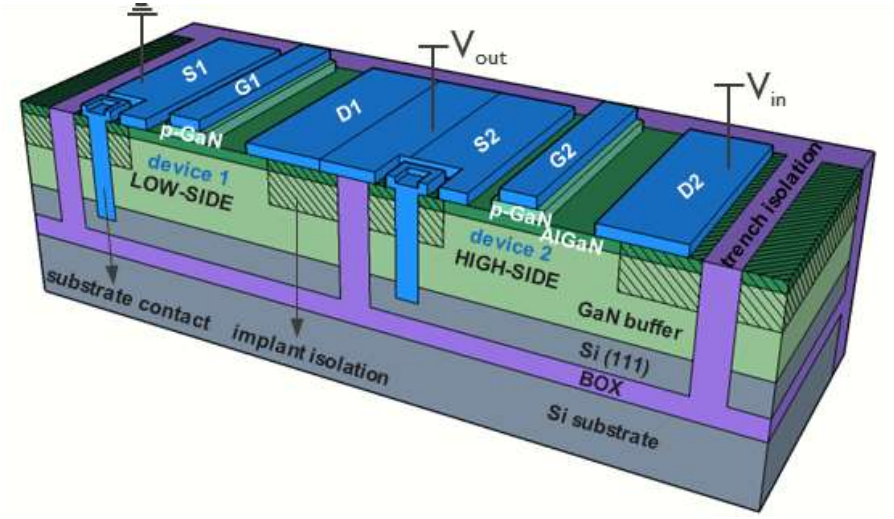
imec



TEM cross-section of GaN/AlGaN superlattice-based buffer on SOI substrate.

/// Low cost (vs. SiC) SOI wafer as base for GaN HEMTs

/// DTI to electrically insulate HEMTs from each other



Schematic cross-section of GaN-on-SOI structure, featuring buried oxide, oxide filled deep trench, local substrate contact and p-GaN HEMT devices.

Pictures courtesy of IMEC

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Multi-project wafer using GaN on SOI technology from IMEC*

* https://www.imec-int.com/en/what-we-offer/development/system-development-technologies/GaN/IC-prototyping

/// Multi-Project Wafer Service @ imec - GaN IC MPW Service

Maritza Tangarife Ortiz <Maritza.TangarifeOrtiz@imec.be>

https://www.youtube.com/watch?v=AwBA6gnw_xE

8-Inch GaN Power Device and GaN-IC Technology to Unleash Your Power IC

Denis Marcon, Senior Business Development Manager, IMEC:

https://www.youtube.com/watch?v=S3d3E4LosNY&t=23s

/// ASCENT+ Webinar: GaN IC for Power Electronics

Urmimala Chatterjee (imec)

https://www.youtube.com/watch?v=ILPLGivE-WY

NEW STEP FORWARD !

step by step within 5 design cycles

/// Power transistor size increase: 37 ➔ 22 ➔ 5/10 mOhms devices

Current: 3 ➔ 7 ➔ 25 Amperes

/// Combine 2 large transistor on 1 chip

coupling LS ➔➔ HS does not lead to additional switching losses as compared to discrete devices

/// On chip gate drivers & gate voltage regulators

/// On chip level-shifters to transfer PWM logic control signals to floating domains

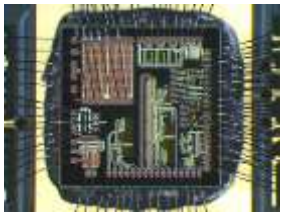
/// On chip deadtime generators

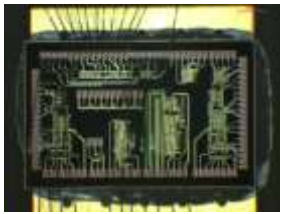
/// Radiation tests

/// On chip analog features towards integrated regulation

Current sensing, high speed comparator, clock generator

Operational (error) amplifier, …





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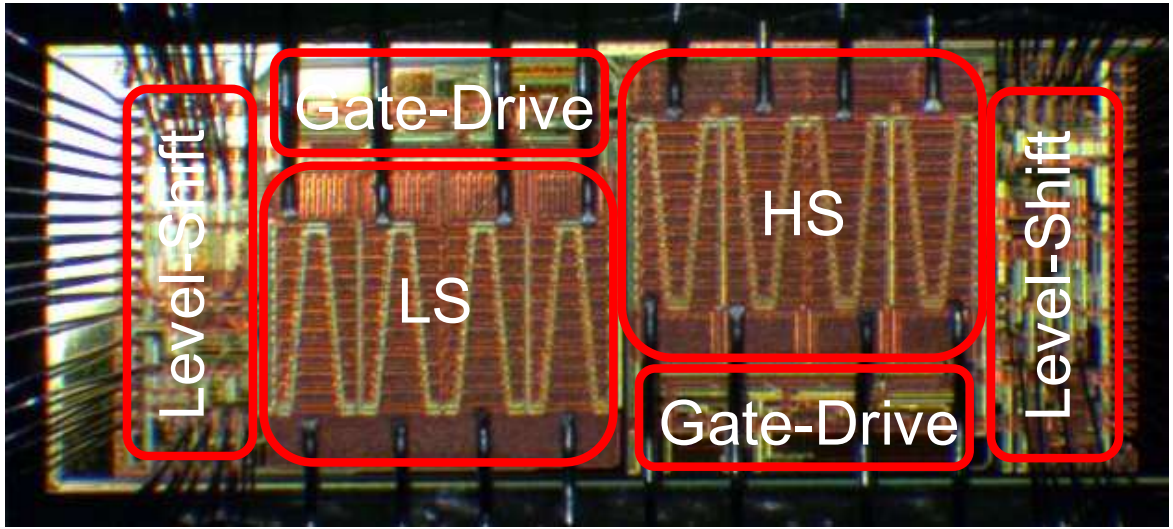
HALF-BRIDGE FROM GAN-IC4S

/// 7µm thick copper current redistribution layer at top

/// die size 9.3 x 3.8mm²

/// HS & LS GaN: ~22 mOhms each

note: ~40 mOhms @ 150°C



/// 200V Pgan HEMT
Ideally suited for 100Vbus main supply

/// Accessible freq. & currents:
Limitation = die cooling !

Switching frequency limited by switching losses @ high input voltage: typ. 300..1000 kHz

Current limited mostly by dissipation capability: typ. 3..7 A & max. 10 Amp.

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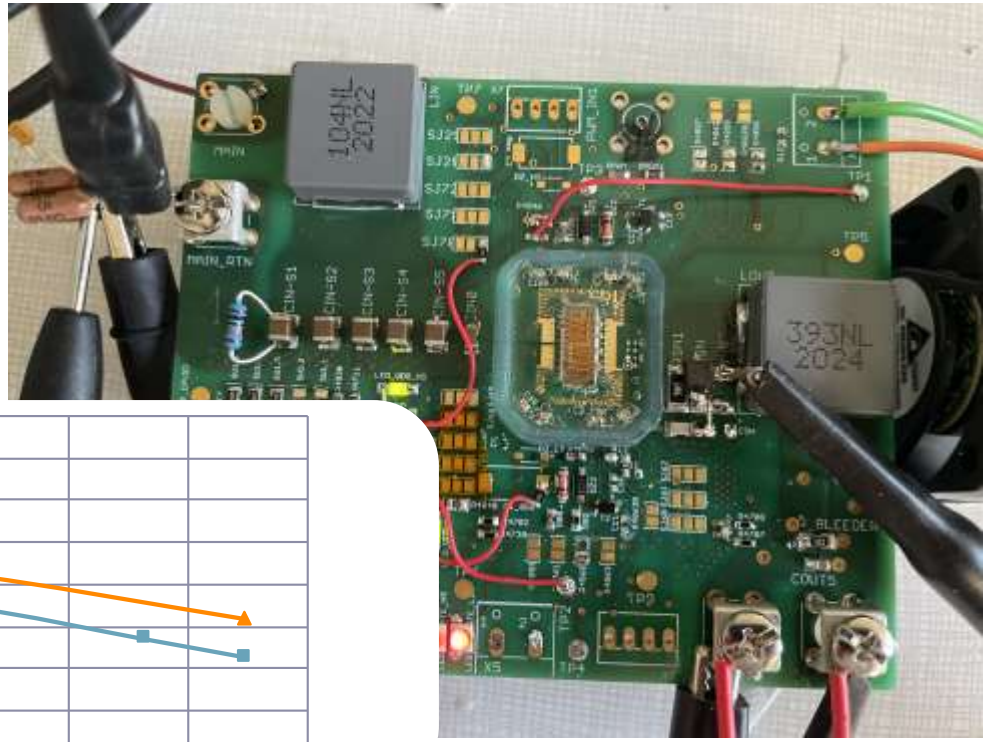
DC-DC CONVERTER TEST BOARD

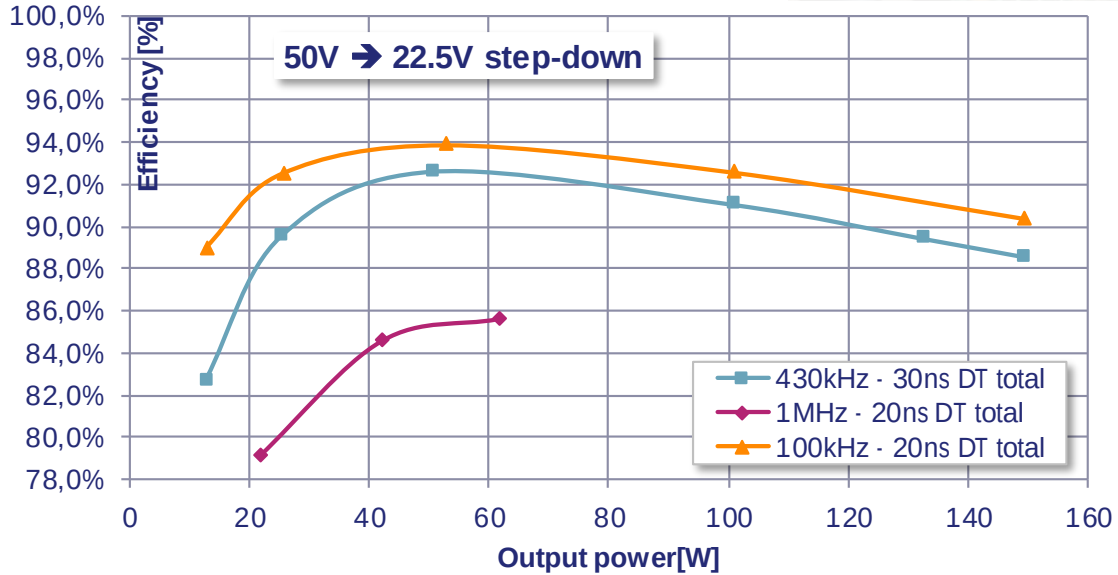
Converter design similar to flight PCDU

Efficiency includes input & output filters

➔ Ripple & noise compliant to ECSS rules !

With « small » inductors





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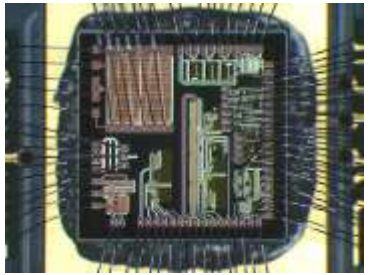
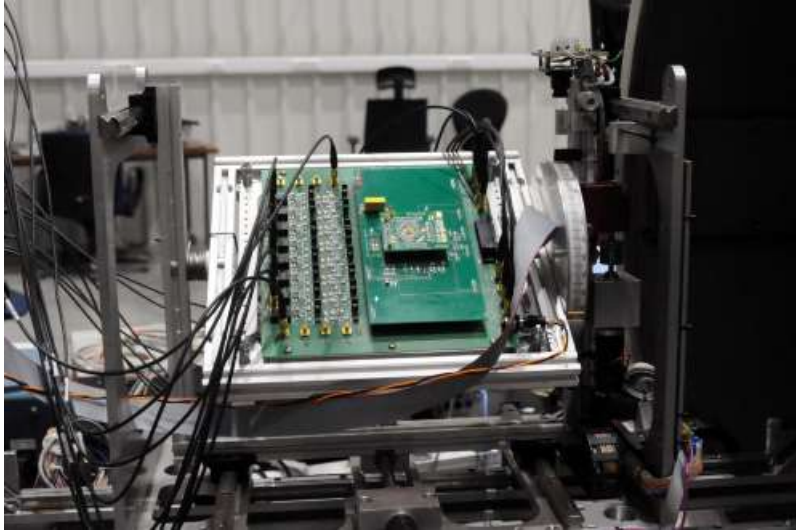
HEAVY IONS TEST

1st Run = Test structures

with dedicated test / observation accesses

- Power device 37 mOhms
- Flip-flop
- Gate driver
- Supply voltage regulator
- Deadtime generators





2nd Run die ➔ full converter

Status = waiting for 2nd run die with fix level shifters dV/dT immunity

RADECS 2022

IEEE TRANSACTIONS ON NUCLEAR SCIENCE

"Radiation and its Effects on monolithic GaN integrated half-bridge for dc-dc converters"

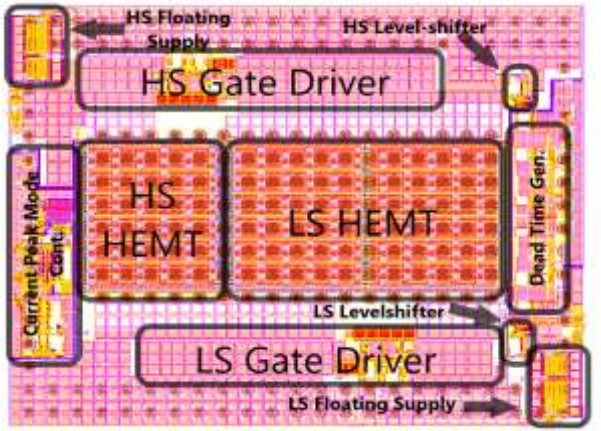
GAN INTEGRATED POINT OF LOAD

High current 25A/branch & low output voltage as low as 0,7V

Typical target applications: large CPU & FPGA with low technology nodes requiring up to 75A dc @ very low voltage.

- 10 mOhms high side + 5 mOhms low side HEMT
- 100V GaN buffer with transistor downsizing to 40V
- 7 x 3mm power cell
- Output current = sum from 2/3/4 phase shifted branches
- Each IC feature « on-chip » autonomous current peak control
- « Experimental » devices:
  - Oscillator + phase shift
  - Operational amplifer (main voltage regulation loop)
  - Under-voltage detector
  - High speed comparator & current sensing amplifier
  - Schmitt triggers

Test chip



Top level GaN IC layout

Tens of amp with low Rdc & no saturation !

GaN Ready High Current Flat Wire Coil Inductors Würth Elektronik

A new flavor of power ASIC: GaN !

Achieved ☺ !

Impacts for space dc-dc designs:

- Faster switching ➔ more compact
- Lower losses ➔ better efficiency
- Monolithic IC ➔ cheaper & very compact
  ➔ easy to use
- Radhard & European technology
  ➔ Eu export rules

HS & LS discrete GaN HEMT
Silicon gate driver IC
Silicon gate voltage regulators
Logic signal isolators & level shifters
Operational amplifiers
Comparators

Integrated GaN IC with on chip:
Half-bridge: HS & LS GaN
2x gate driver
2x gate voltage regulators
2x PWM logic signal level shifters
PWM & deadtime generator
Temperature sensor
Current sensing
Voltage regulation

ACKNOWLEDGMENTS

AGENTSCHAP INNOVEREN & ONDERNEMEN

Project N°1 = SloGaN

“System and GaN device co-design for fully optimized, efficient GaN-based power systems”

esa belspo

Project N°2 = GANIC4S

“Monolithic integration of GaN gate driver and power transistors witching functions”

ESA TDE Contract No.4000128515/19/NL/FE

Project N°3 = EleGaNT

“High-efficiency electronic devices based on gallium nitride”

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