Single chip GaN half-bridge with integrated drivers

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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

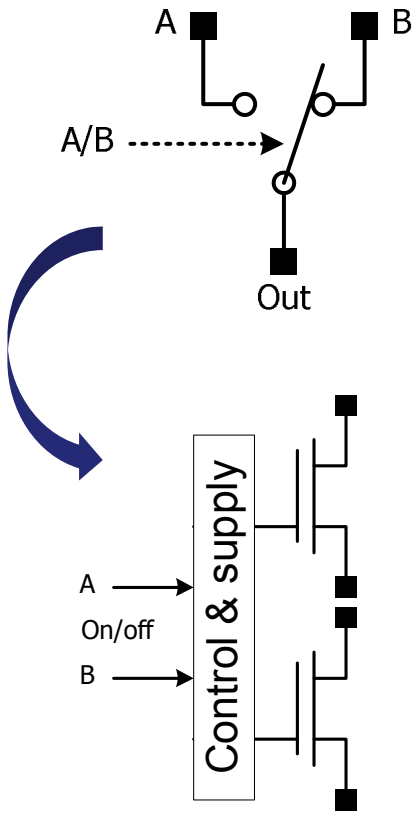
- Faster switching ➔ more compact design
- Lower losses ➔ better efficiency

- 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

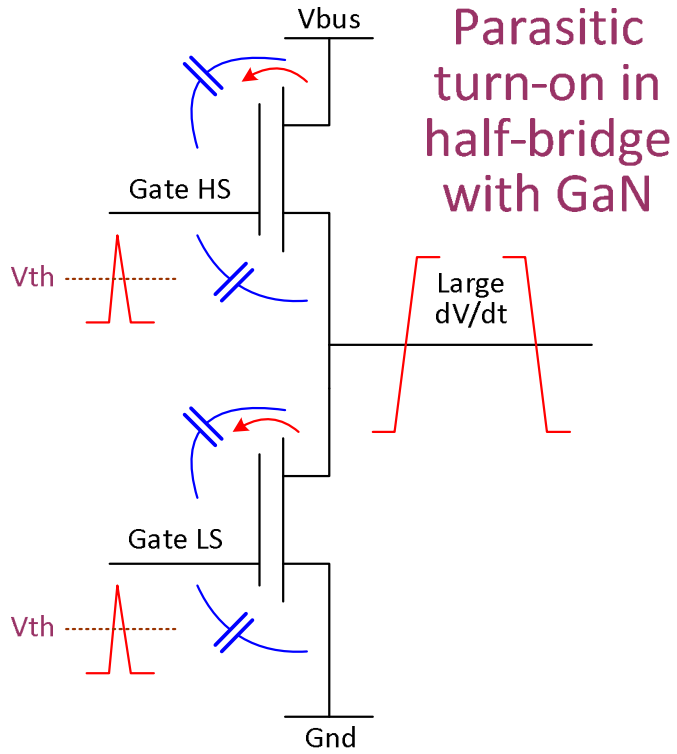
/// Lower threshold voltage (V_{th})

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

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

⇒ An ideal recipe for expensive fireworks

⇒ Needs an optimized gate-drive approach



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CHALLENGES OF DRIVING GAN

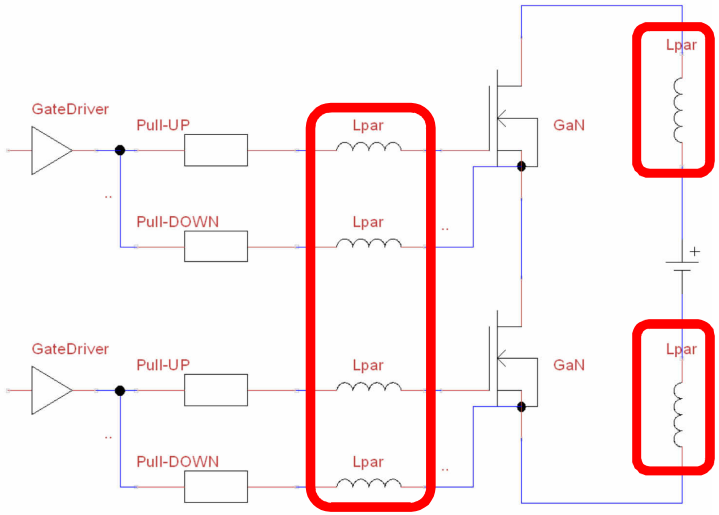
External gate driver:

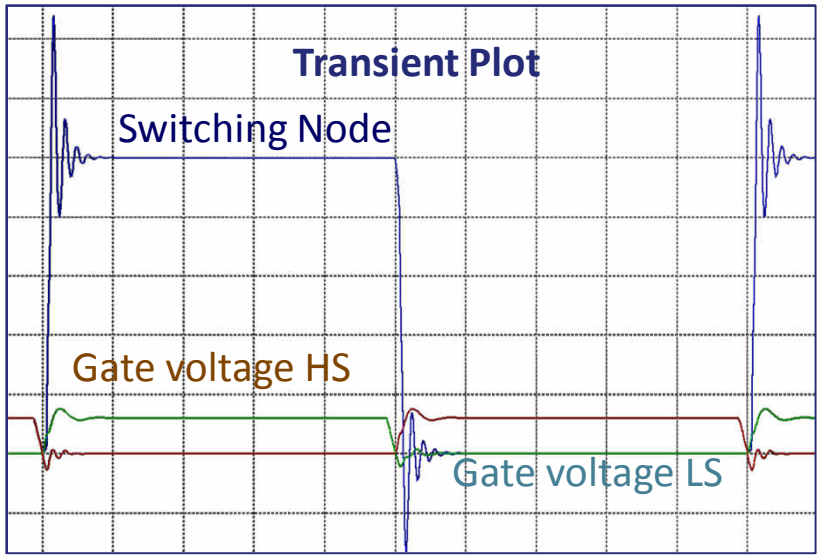
On PCB level:

/// 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 :

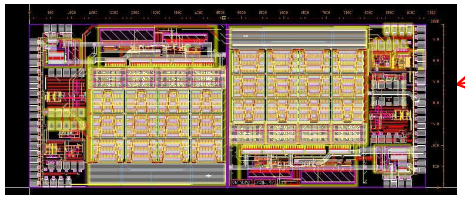
/// Reduce # external components in the system ➔

Increasing the overall system power density

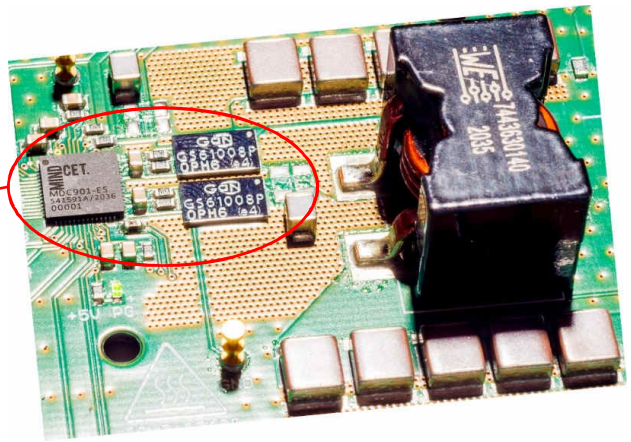
/// Strongly drive (high & **also low** !) GaN up to speed by killing gate-loop parasitics

/// Reliability: minimize the gate voltage overshoot

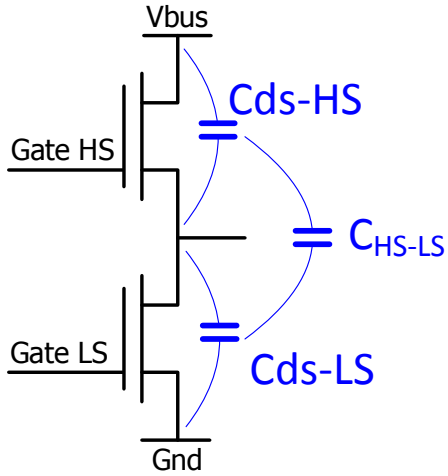
/// Require strong isolation between high side & low side power GaN



Design of full GaN ASIC !



Pictures courtesy of MinDCet



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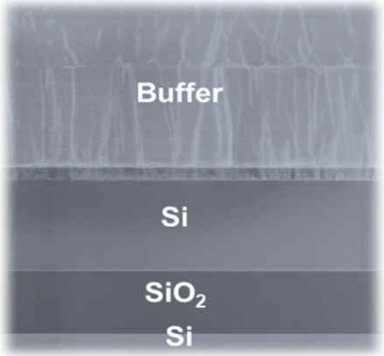
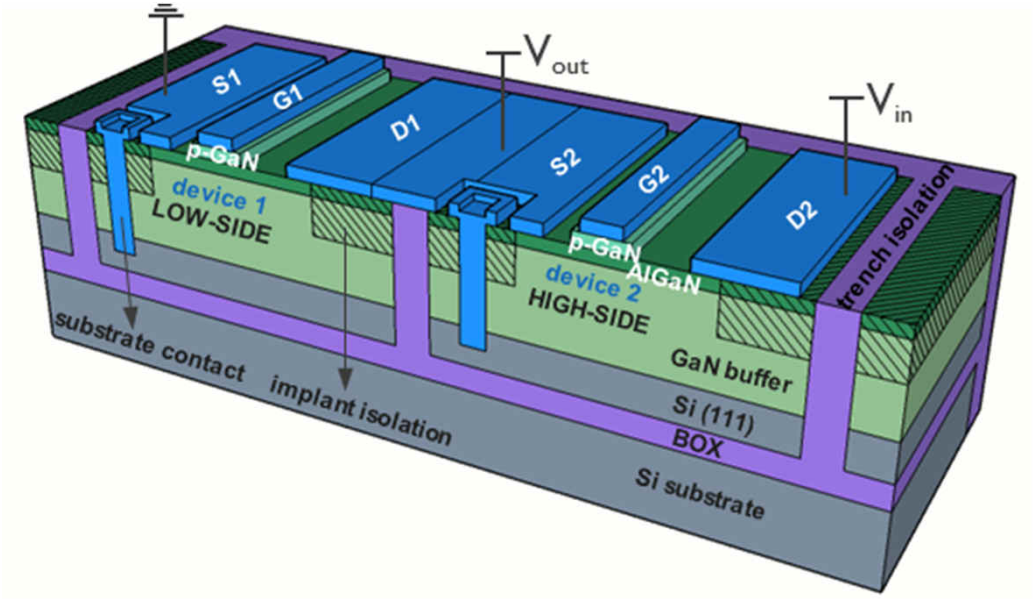
Technology Makes the Difference



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 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

DIE LAYOUT & MANUFACTURING

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

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

/// die size 9.3 x 3.8mm²

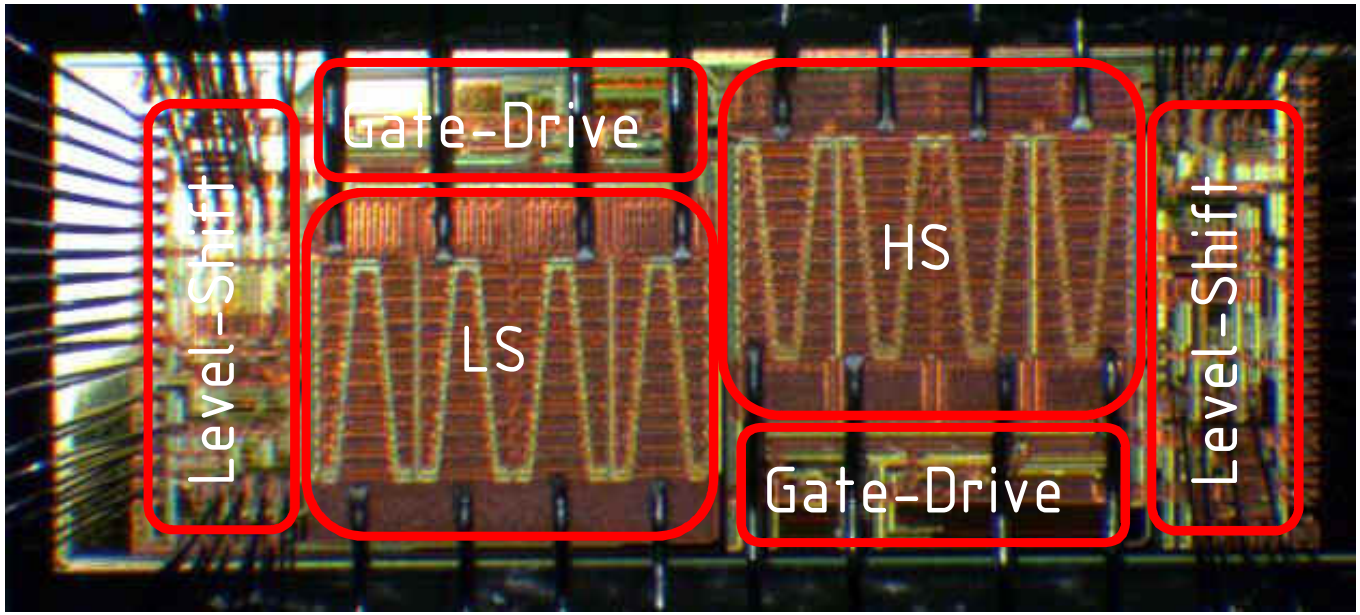
/// HS & LS GaN: ~22 mOhms each note: ~40 mOhms @ 150°C

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

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

5 MHz switching tested OK

10 Amp current tested OK



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BUCK POINT-OF-LOAD IMPLEMENTATION

Preliminary prototype assembly without package

/// Chip-on-Board: FR4 low cost PCB

/// 4x 5mils bond wires in // for power pads

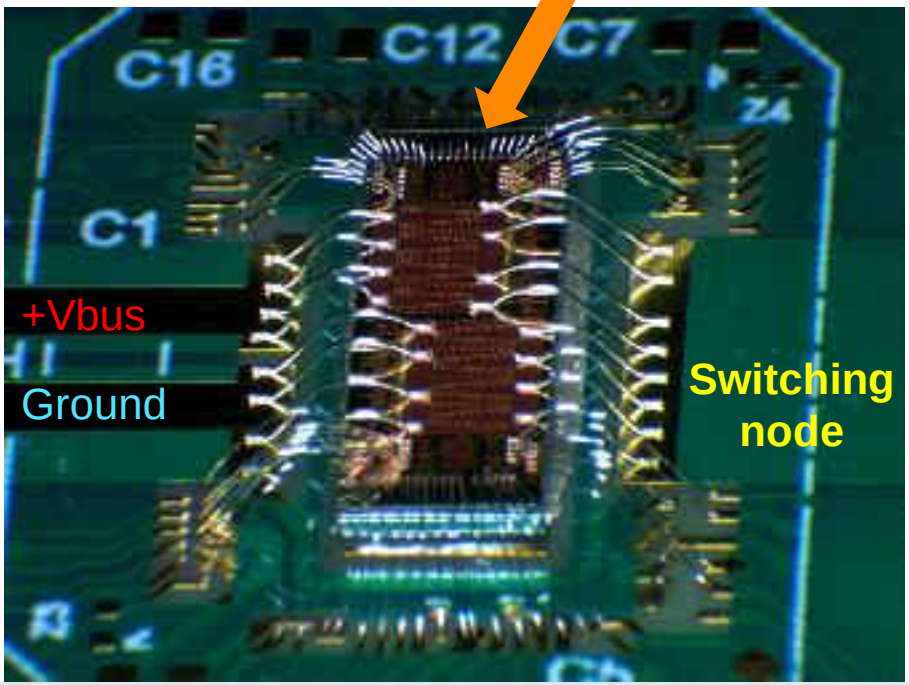
~1,4 & ~2 mOhms extra due to bond wires

/// 2mils bond wires for signals & test pads

/// Thermally conductive glue

/// Array of via throughout the whole PCB to transfer heat to opposite side ➔ heatsink

/// Silicone dam & fill for mechanical protection



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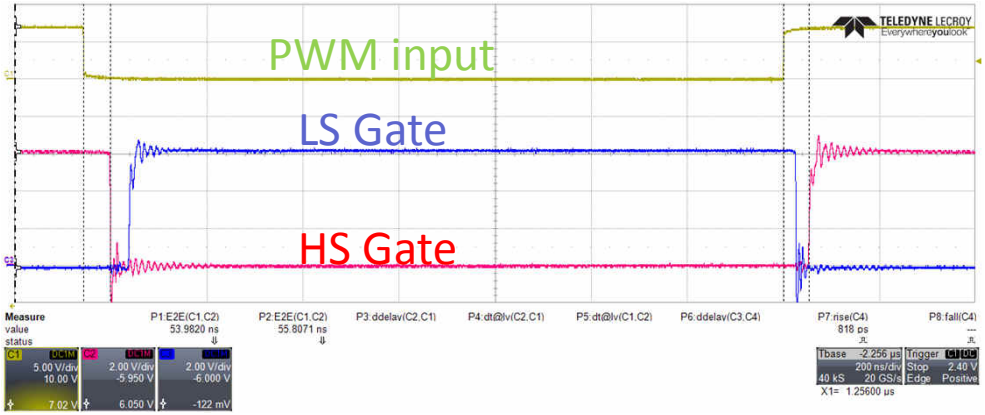
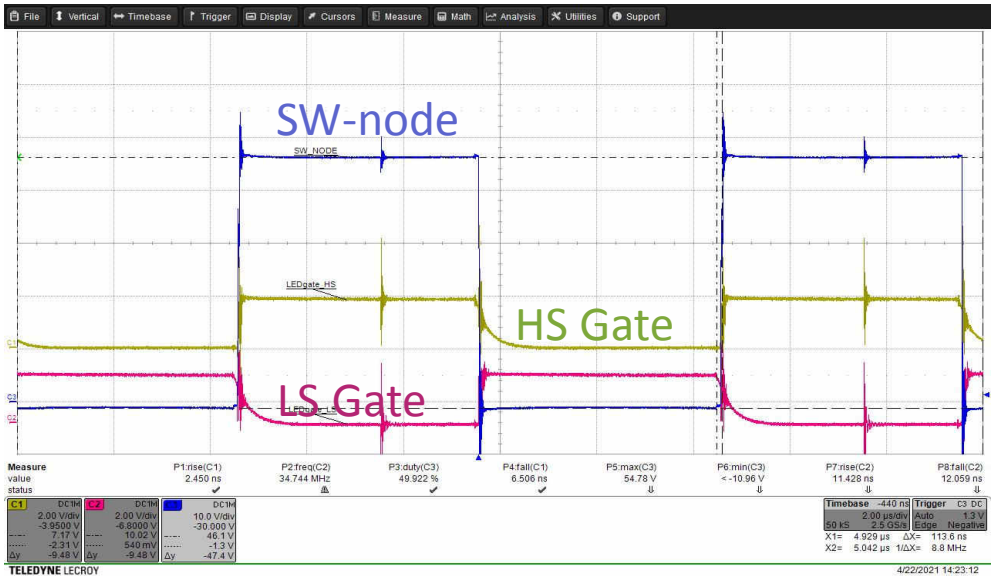
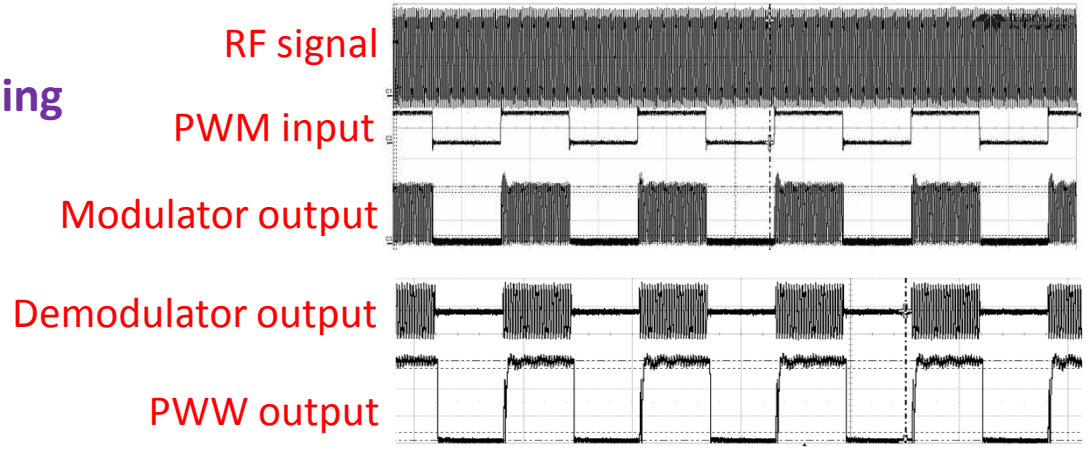
GAN IC MEASUREMENTS

On-chip dead-time generation:





Isolated Level-Shifter using off-chip transformer :



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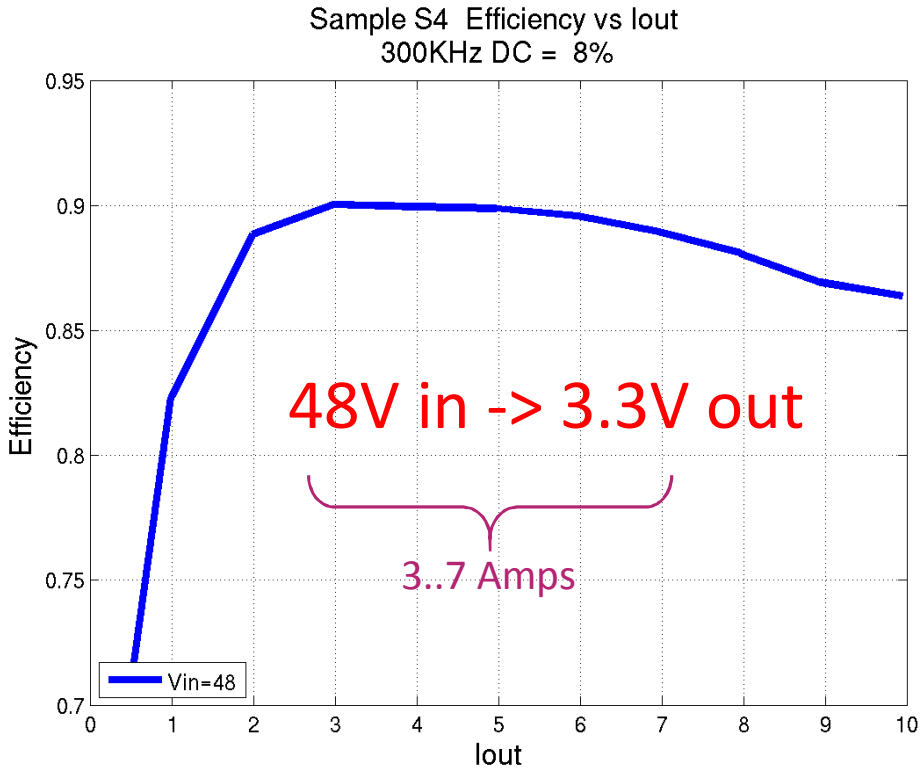
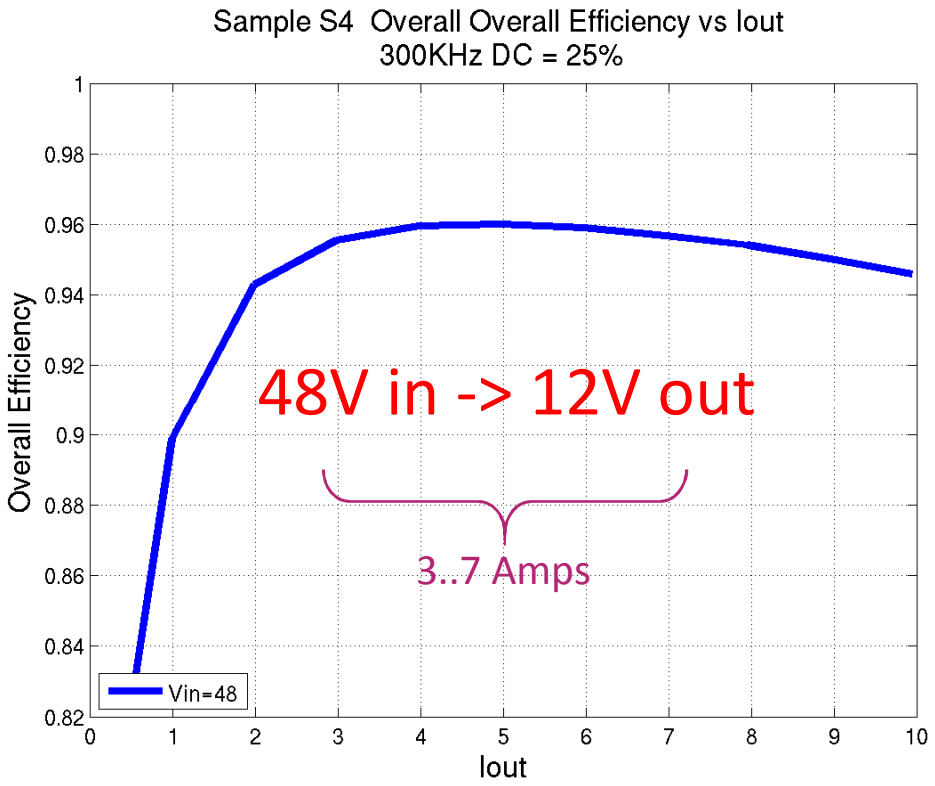
GAN IC MEASUREMENTS

Efficiency vs. output current





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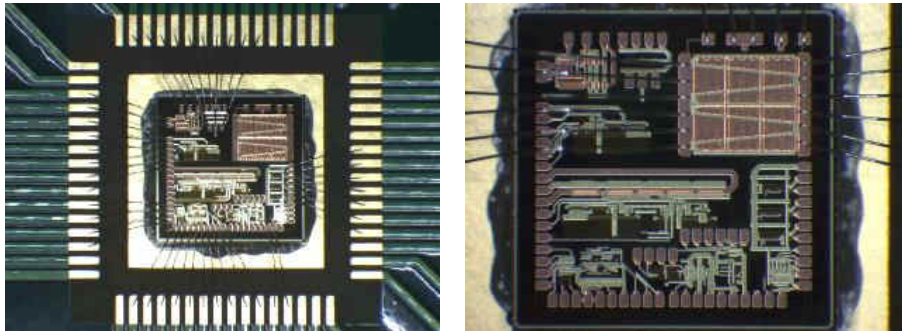
ONGOING & FUTURE WORK

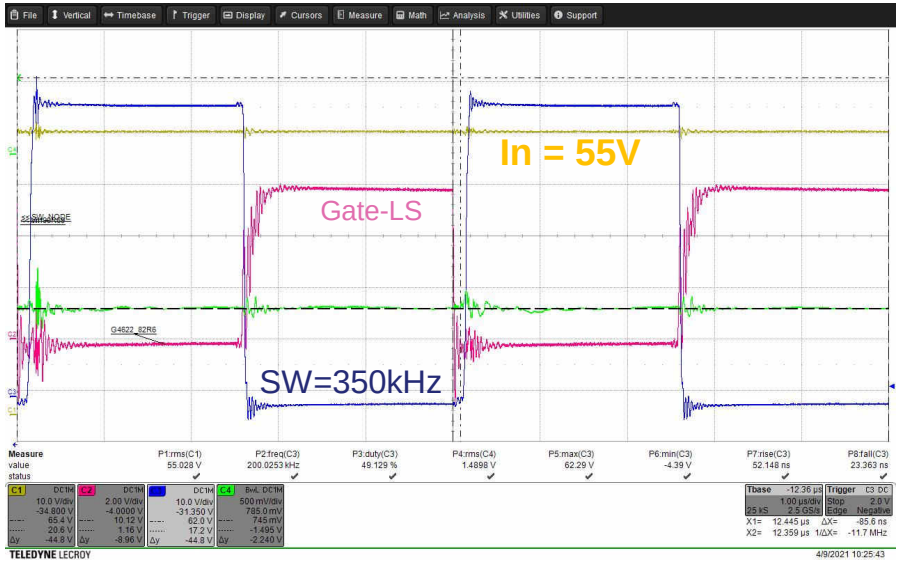
/// Tape-out run2 ➔ 19 may 2021

Level shifter with improved dV/dt immunity

/// Radiation heavy ions testing



/// die characterization in PCDU like buck dc-dc



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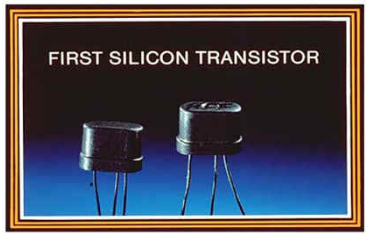
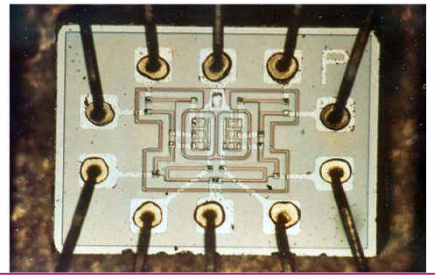
A new flavor of ASIC: GaN !

In 1954, Texas Instruments was the first company to start commercial production of silicon transistors instead of using germanium.

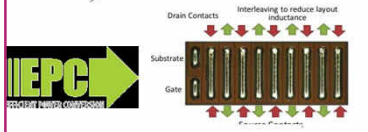


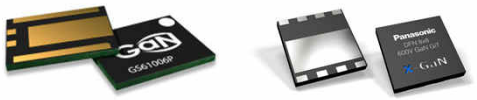
Fairchlid 1961: logical NOR IC from the computer that controlled the Apollo spacecraft



Discrete power transistors

2012





2021

Integrated GaN IC with on chip:
Half-bridge: HS & LS GaN
200V / 3..7 Amp

- 2x gate driver
- 2x gate voltage regulators
- 2x PWM logic signal level shifters

Deadtime generator
Temperature sensor

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

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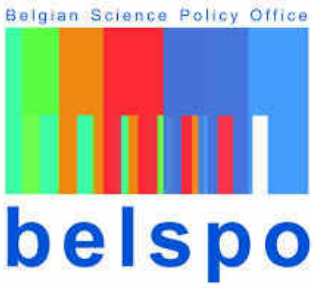
ACKNOWLEDGMENTS



Project = GANIC4S

“Monolithic integration of GaN gate driver and power transistors witching functions” ESA TDE Contract No.4000128515/19/NL/FE