Google/IEEE requirements

GAN implementation
95% weighted efficiency
EMC Class B (RF noise < 1 mV)
DC voltage ripple (100 Hz) < 0.1 V
Enclosure Max Temp < 60°C
Volume < 600 cm³
How to achieve It?

* Robust GaN driving sustaining high dV/dt (130V/ns)

* Active filter & MLC storage

* Soft switching (ZVS)

* Output current limitation

* High speed Current Measurement

* Cu Honeycomb heatsink

* Sandwich PCB structure

* Shielded N-order filter
Filters & 5 legs topology

EMC Earth Shielding

Differential filter

Common mode filter

Shielding potential

Earth connection (copper enclosure)
ZVS & Phase shift

Leads voltage:
- Duty L = 75%
- Duty N = 25%
- Phase shift = 0°

Differential inductor current
Common mode inductor current

Leads voltage:
- Duty L = 50%
- Duty N = 50%
- Phase shift ≠ 0°

Differential inductor current
Common mode inductor current

Lower current ripple
High current ripple

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How to use New Switches?

GaN

IGBT

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Challenge : Size Reduction

• No electrolytic capacitor (too big & less reliable)
• Use of MLCC -> compacity, efficiency, lifetime
Simulations: Output Inductor
Simulations: Circuit & Control
Thermal analysis : max 60°C enclosure
Airflow : simulation:

Pierre
GAN implementation
95% weighted efficiency
EMC Class B (RF noise <1mV)
DC voltage ripple (100hz) < 0.1V
Enclosure Max Temp < 60°C
Volume < 220 cm³ for 2kW
How to Reuse Results?

* No cost limit on Google Challenge
* Single DC/AC => «Energy Router»
  Bidirectionnel AC/DC + DC//DC + DC//AC
From IGBT to GaN ...

On Energy Router
AC/AC OF Energy Router
...to GaN w/ H2020 InRel NPower

**Goals:** Test Reliability of GaN on real application

Compare OnSemiconductor GaN Cascode / E-mode types with IGBT on AC/AC working conditions:
+ Virtual Prototyping of GaN switches with U/I working conditions from Spice simulation [done]
+ Real Prototyping for max Efficiency comparison (CE+T)
  3 demoboards : Cascode & E-mode GaN and SiC [in progress]

+ Evaluate Reliability on small batch (10 pieces) at high [to be done]
- \( V_{DC} = 400V, \ P = 1900W \)
- \( V_{AC} = 230V_{RMS}, \ 50Hz \)
- 3 Half-bridges: input, neutral and output
  - 6 voltage controlled switches with hysteresis:
    \( V_{gs} > 9.5V \rightarrow R_{on} = 20\Omega \)
    \( V_{gs} < 5.5V \rightarrow R_{off} = 1G\Omega \)
  - 6 diodes: \( V_f = 0.6V \)
- \( R_{load} = 28 \Omega \)
- \( 2xC = 4uF \)
- Control signals (\( H_{in}, L_{in}, H_n, L_n, H_{out} \) and \( L_{out} \)) are generated by means of a modulation function (see back-up slides) and achieve partial soft-switching in the input/output HB and complete ZVS turn-on in the neutral HB
- Spice simulations provide the boundary conditions for the virtual prototyping methodology
  - \( V_{DC} = 400V \)
  - Inductor currents: \( I_{i_n}, I_{n}, I_{out} \)
  - Voltage switch control signals: \( H_{in}, L_{in}, H_n, L_n, H_{out}, L_{out} \)
Conclusions:

- Identical conduction losses between E-mode and GaN cascode (same Ron devices)
- E-mode shows lower switching losses (keep in mind that current TCAD deck is very optimistic in terms of e-mode device capacitance)
- However, lower Qoss of the device will postpone the transition from full ZVS turn-on to partial ZVS turn-on and hence reduce the switching losses
- In addition Eoss is also important when operating in the range of the hard switched transition.
- The neutral HB leg benefits the most by selecting a lower Ron device since conduction losses dominate and total switching losses are practically not affected by the larger device size.
- When operating the converter at Tj=75°C and with a fsw=140kHz, the total losses in the converter, between a 45mΩ e-mode and a 22.5mΩ e-mode solution, are roughly identical in the input HB and output HB.
Conclusions

1. On AC/AC converter, GaN losses@70kHz Cascode/140kHz e-mode evaluated w/ Virtual Prototyping are about half of IGBT losses @20kHz but magnetics losses are not yet included.

2. For the user, GaN implementation needs more EMC filter introducing extra losses so efficiency shall be considered globally.

3. GaN switches are still expensive (compare to IGBT & MOS) to be used in Industry but since Google challenge the reduction is about 10 but still need a 5 ratio if focusing on switch.