# GaN Transistor Design for Transient-Overload Power Applications

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## Problem Statement

- Transient, intermittent, and pulsed load is essential in industrial and medical applications as well as scientific instrumentation, such as particle accelerators, noninvasive brain stimulation techniques
- IGBTs / thyristors are conventional candidates for over-loading situations due to their ability of processing large mounts of power
- Cutting-edge biomedical stimulators need high power and high bandwidth (~MHz)[1], demanding Gallium Nitride (GaN) transistors (see Fig. 1)
- GaN transistors are popular for high power density and efficiency
- Existing design patterns of GaN focus on steady-state thermal status [2]
- Transient pulse applications propose different transistor thermal profile
  - Being intensely heated during pulses
  - Cooling down during pulse intervals
- Challenges on steady thermal status design patterns
  - An assumption of a constant heat source of maximum power over-designs the system with unjustified cost and causes issues due to increased stray parameters of the over-designed circuit.
  - An assumption of a power-matched average heating power can lead to failure of transistors during a pulsed or transient load.
- Applying GaN transistors to overloading / pulsing applications requires transient thermal analysis and design patterns.

## Solution

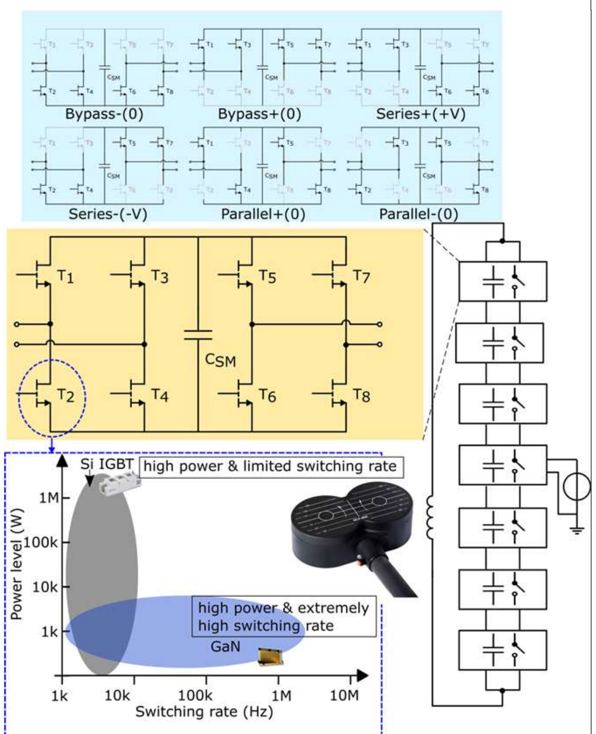


Fig. 1. Topology of GaN based ultra-wide-bandwidth pulse generator.

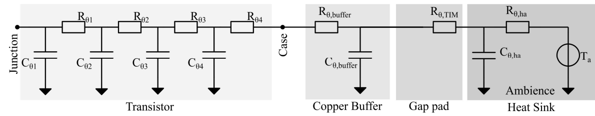


Fig. 2. Thermal network of transistors.

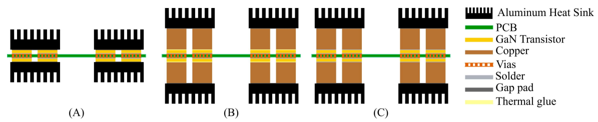


Fig. 3. Different thermal configurations of GaN, respectively traditional design, copper buffer attached by thermal glue, copper buffer soldered.

- Objective: Ultra-wide-bandwidth high-power series-parallel submodule design for Magnetogenetic pulse generators [1] (Fig. 1)
- Keys of thermal design pattern
  - Aiming to improve transient thermal performance
  - Use of thermal mass to buffer heating of transistors
- Our contribution is to insert copper mass between transistors and heat sink, see $R_{\theta,\mathrm{buffer}}$and $C_{\theta,\mathrm{buffer}}$ in thermal network (Fig. 2), providing a low-resistance path to a moderate heat capacitance.
- Thermal buffer restrains semiconductors' transient temperature without significant increase in size or cost. This design pattern can also deal with thermal stress incurred from other short-term overload situations.
- Traditional way to control overloading transistor temperature is to reduce the thermal interface material resistance. Limited exposure area of GaN leads to overwhelming cost of electric and mechanical manufacturing.
- Different implementations of installing copper mass are proposed (Fig. 3) with thermal material options such as thermal glue or soldering

## Results

- Simulation of Magnetogenetic pulse in Ansys (Fig. 4 & 5)
  - Copper buffer reduced transistor temperature rise by > 40 °C
  - Installation of thermal buffer has little influence on temperature, which is expected due to the small thickness of the interface.

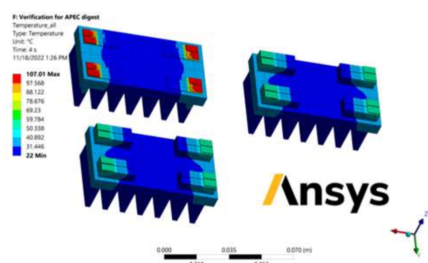


Fig. 4. Thermal transient simulation of different onfigurations

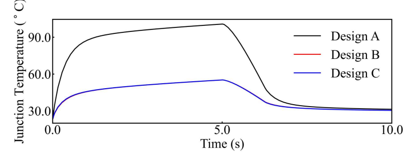


Fig. 5. Transient junction temperatures during the pulse

- Prototype built with E-mode GaN transistors (more details in Table 1).
- Loss performance of prototypes is influenced by switching rates and conducting current, which is estimated by measurement and data fitting.
- Operation boundaries of different thermal configurations are obtained by Trial-and-Error method (Fig. 6).
  - Traditional thermal design fails typically at transient loss level of 100 W
  - Thermal buffer added thermal scheme survives near loss level of 350 W

Table 1. Summary of prototype specifications

| Item | Value |
|---|---|
| GaN transistor | GS61008T |
| Copper mass material | Copper 101 |
| Copper mass dimension | 19 mm × 5 mm × 12 mm |
| Thermal glue | GENNEL G109 |
| Heat sink material | Alloy 6063-T5 |

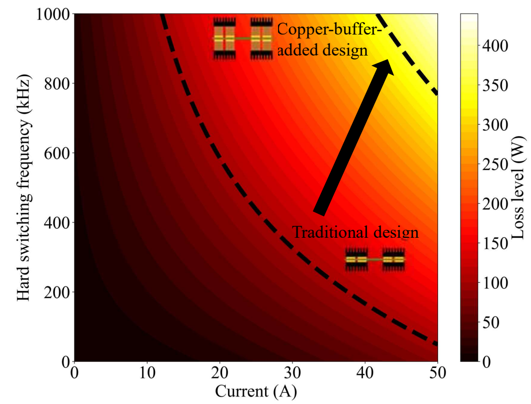


Fig. 6. Power processing boundaries of different thermal configurations

## Conclusion

- For transient over-loading applications, focusing only on steady thermal status leads to either failure during overloading pulses or over-designing of system. GaN transistors' compact package exacerbates the challenge.
- We propose adding a copper mass between transistors and heat sink as a heat buffer to relieve the stress during the over-loading moments without over-designing the system.
- Simulation and experimental results prove the thermal mass can extremely extend the operation boundary of a modular Magnetogenetic pulse generator and endure nearly 250 % more transient loss level.

## References


[1] B. Wang, Z. Li, C. Sebesta, D. Torres Hinojosa, Q. Zhang, J. T. Robinson, G. Bao, A. V. Peterchev, and S. M. Goetz, "Multichannel power electronics and magnetic nanoparticles for selective thermal magnetogenetics," Journal of Neural Engineering, vol. 19, http://dx.doi.org/10.1088/1741-2552/ac5b94DOI 10.1088/1741-2552/ac5b94, no. 2, p. 026015, Apr. 2022.

[2] R. Quay, R. Reiner, B. Weiss, S. Mueller, F. Benkhelifa and P. Waltereit, "Overview and Recent Progress on the Development of Compact GaN-based Power Converters," Power Electronic Components and their Applications 2017; 7. ETG-Symposium, 2017, pp. 1-6.