GaN Systems

GN007 Application Note

Modeling the Thermal Behavior of GaN*PX*® packages Using RC Thermal SPICE Models

Updated February 15, 2018

Overview

- GaN Systems provides RC thermal models allowing customers to perform detailed thermal simulation using SPICE
- Models are created based on FEA thermal simulation and have been verified by GaN Systems
- The Cauer model has been chosen allowing customers to extend the thermal model to their system by including interface material and heat sinks
- The RC thermal models of GaN Systems' devices are available in the datasheets.

Contents

RC network definition

Thermal network

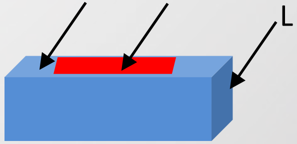
- Thermal resistance (R_θ)
- Thermal capacitance (C_θ)
- Time dependent temperature distribution

Analogy between Electrical and Thermal Parameters

Electrical Parameters	Thermal Parameters
Voltage V (V)	Temperature T (°C)
Current I (A)	Power P (W)
Resistance R (Ω)	Thermal resistance R_θ (°C/W)
Capacitance C (F)	Thermal capacitance C_θ (W·s/°C)

Equations for calculating R_θ and C_θ:

- $R_\theta = L/(k \cdot A)$ (1)
- $R_\theta = L/(k \cdot A_{active})$ (2)
- $R_\theta = \Delta T/P$ (3)
- $C_\theta = C_P \cdot \rho \cdot L \cdot A$ (4)
- $C_\theta = C_P \cdot \rho \cdot L \cdot A_{active}$ (5)



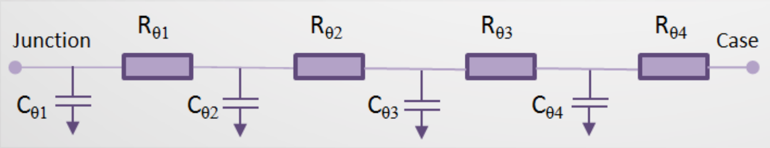
where:
L – layer thickness (m)
k – thermal conductivity (W/m·K)
A – layer area (m^2)
A_{active} – device active area (m^2)
T – temperature (°C)
C_P – pressure specific heat capacity (W·s/kg·K)
ρ – density (kg/m^3)

Thermal time constant: $\tau_\theta = R_\theta \cdot C_\theta$

Cauer and Foster RC network

Cauer Model

- Cauer RC network is based on the physical property and packaging structure
- The RC elements are assigned to the package layers



Pros:

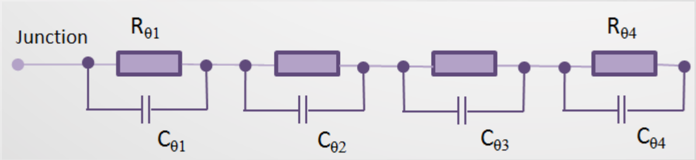
- Cauer RC model reflects the real, physical setup of the device
- Allows to add extra R_θ and C_θ to simulate the Thermal Interface Material (TIM) or Heatsink

Cons:

- Detailed thermal analysis using FEM
- Challenge to extract the thermal capacitance

Foster Model

- Foster thermal model is not based on the physical property and packaging structure
- R_θ and C_θ are curve-fitting parameters



Pros:

- Can be extracted from the datasheet transient respond curve
- Can be extracted form a measured heating or cooling curves

Cons:

- Valid only for measured conditions
- Adding extra resistance and capacitance requires a new curve fitting

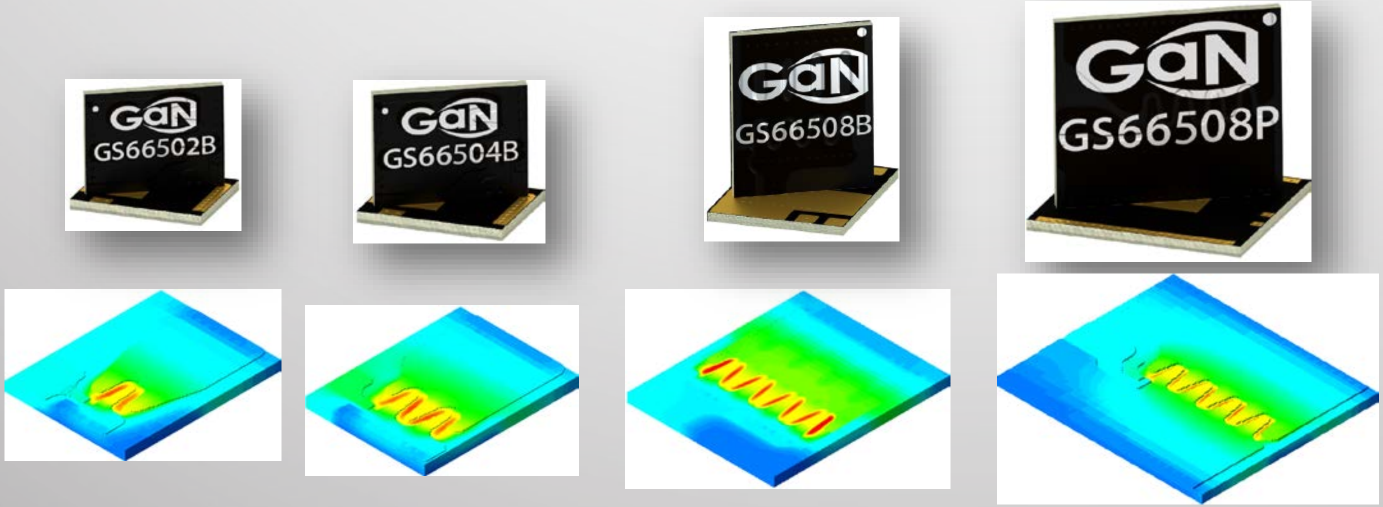
Contents

GaN*PX*® package Junction-to-Case thermal resistance

- The detailed steady state and transient thermal analysis were conducted using a 3D heat transfer software with Computational Fluid Dynamics (CFD) capabilities: ElectroFlo and ANSYS Icepack

- During the steady state analysis the device junction-to-case thermal resistance was obtained

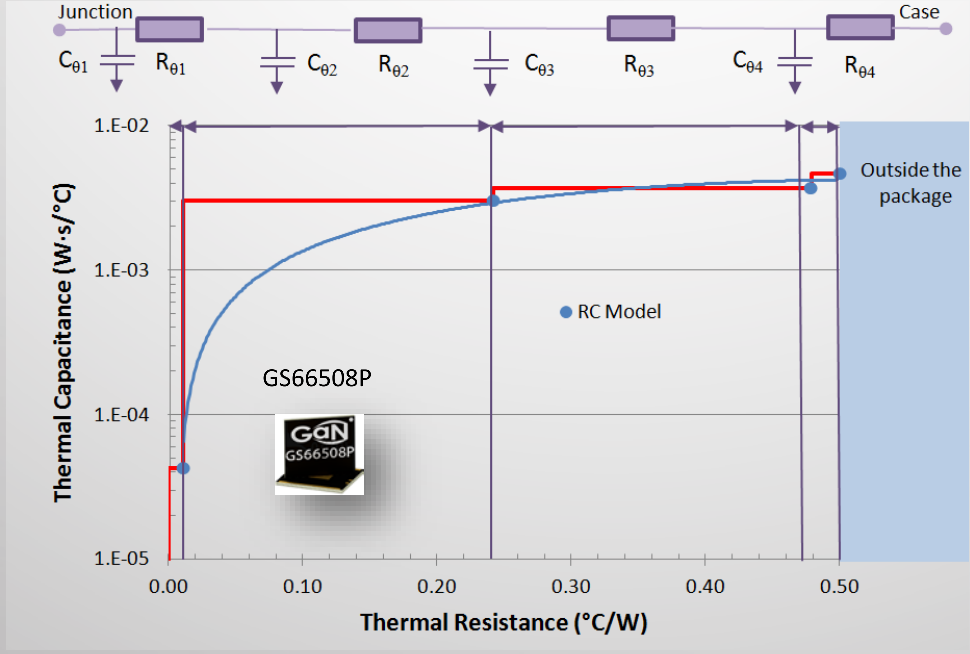
650 V Devices



MPN	$R_{\theta JC}$ (°C/W)
GS66502B	2.0
GS66504B	1.0
GS66508B	0.5
GS66508P	0.5

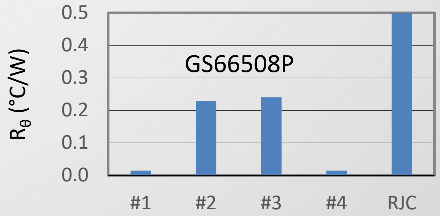
GaN*PX*® package RC model structure

The Cauer model was chosen for all GaN Systems transistors



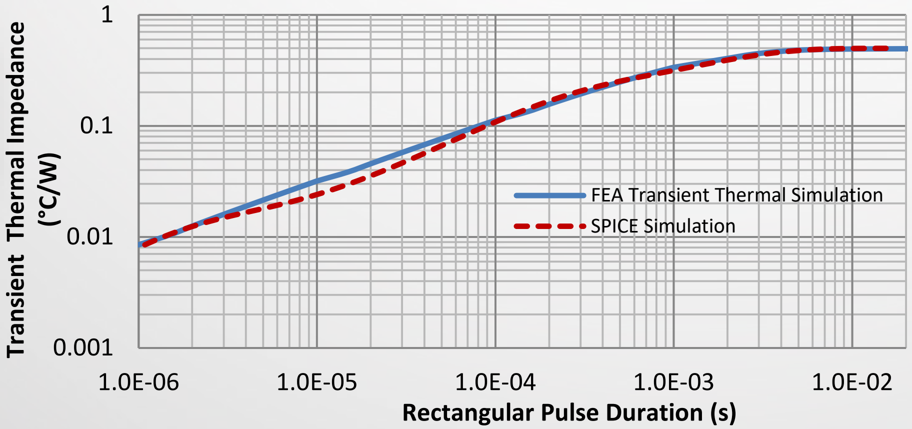
The GaN*PX*® package consists of 4 layers:

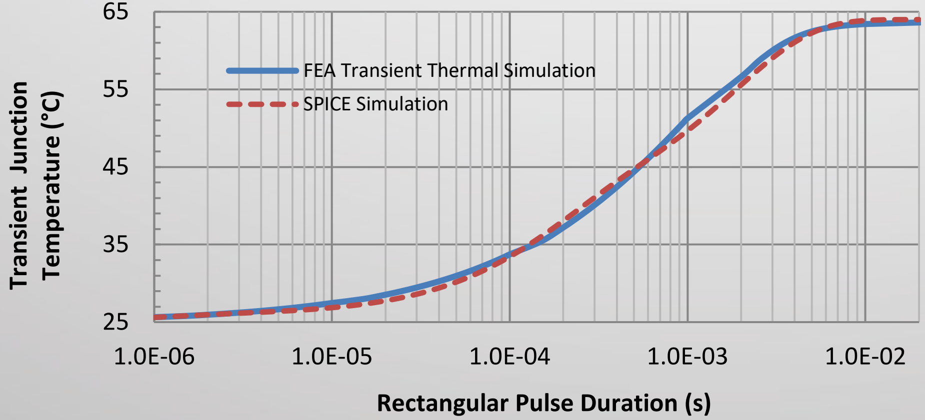
#1	GaN
#2	Si
#3	Attachment
#4	Cu Base



- Layer thermal resistance was derived from the thermal simulation and calculated using the equation (3):
  - $R_{\theta 1} = \Delta T/P = (T_J - T_1)/P$
- Layer thermal capacitance was calculated using the active area of the device (equation (5)):
  - $C_{\theta 1} = C_{P1} \cdot \rho_1 \cdot L_1 \cdot A_{active}$

Thermal and SPICE simulation comparison



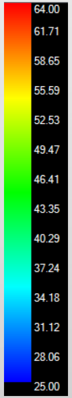


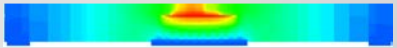
GS66508P Cauer RC model

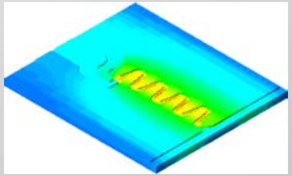
	R_θ (°C/W)	C_θ (W·s/°C)
#1	0.015	8.0E-05
#2	0.23	7.4E-04
#3	0.24	6.5E-03
#4	0.015	2.0E-03

Boundary Condition:

- Power P = 78 W
- T_{case} = 25 °C







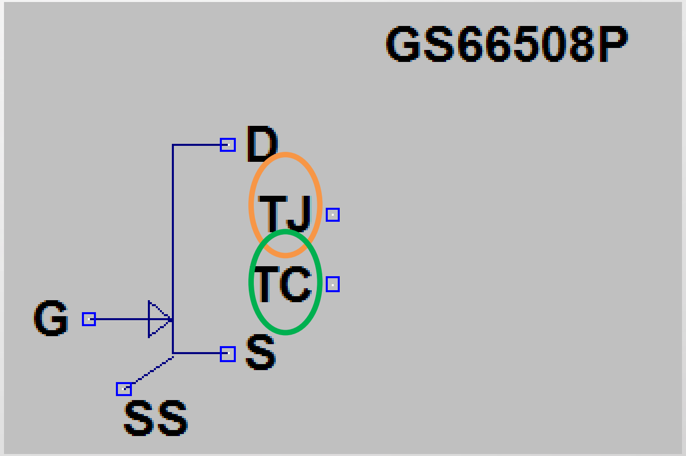
Good agreement between transient thermal simulation and SPICE simulation has been achieved

Contents

SPICE Netlist in .lib File :

```
Rth_1 T11 TJ {0.011}
Cth_1 0 TJ {4.25e-5}
Rth_2 T22 T11 {0.231}
Cth_2 0 T11  {2.96e-3}
Rth_3 T33 T22 {0.237}
Cth_3 0 T22 {6.65e-4}
Rth_4 TC T33 {0.021}
Cth_4 0 T33 {1.01e-3}
```

SPICE Symbol:



In the SPICE Schematics:

- Connect T_C to a voltage equal to the case temperature
- Read $V(T_J)$ to measure the junction temperature

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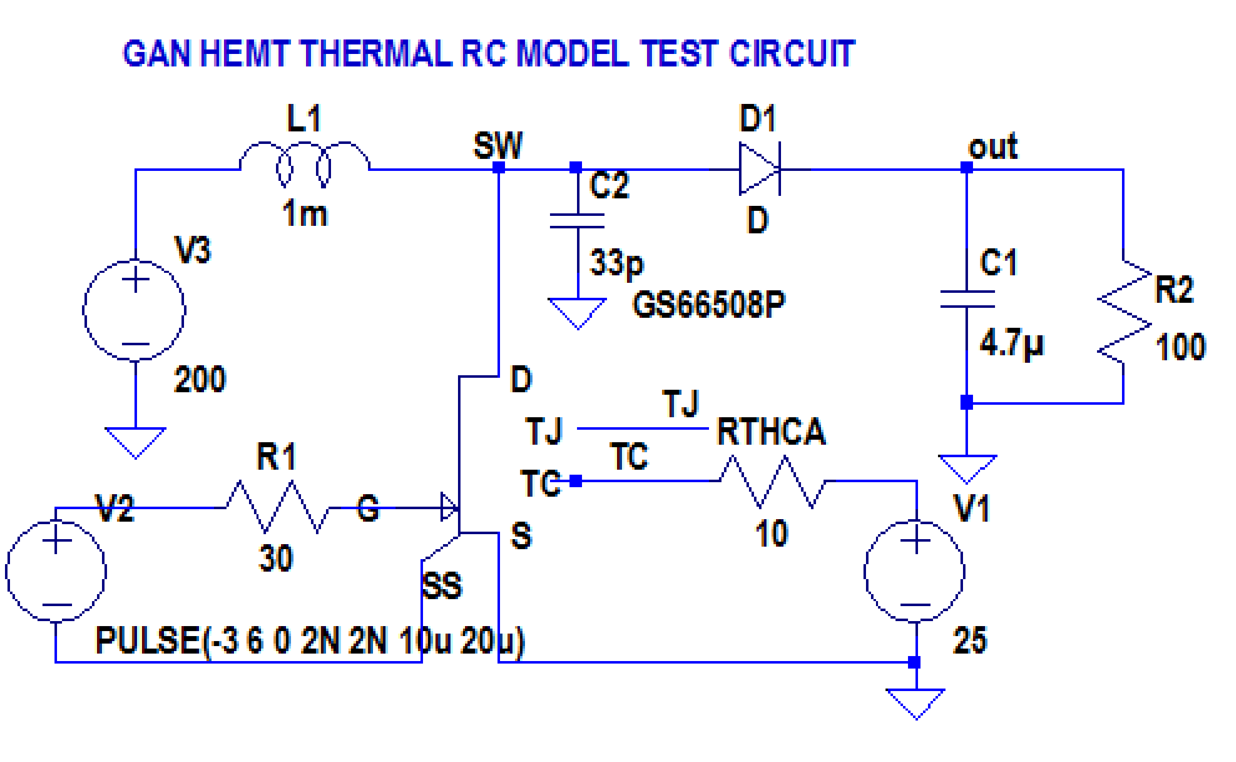
SPICE simulation examples

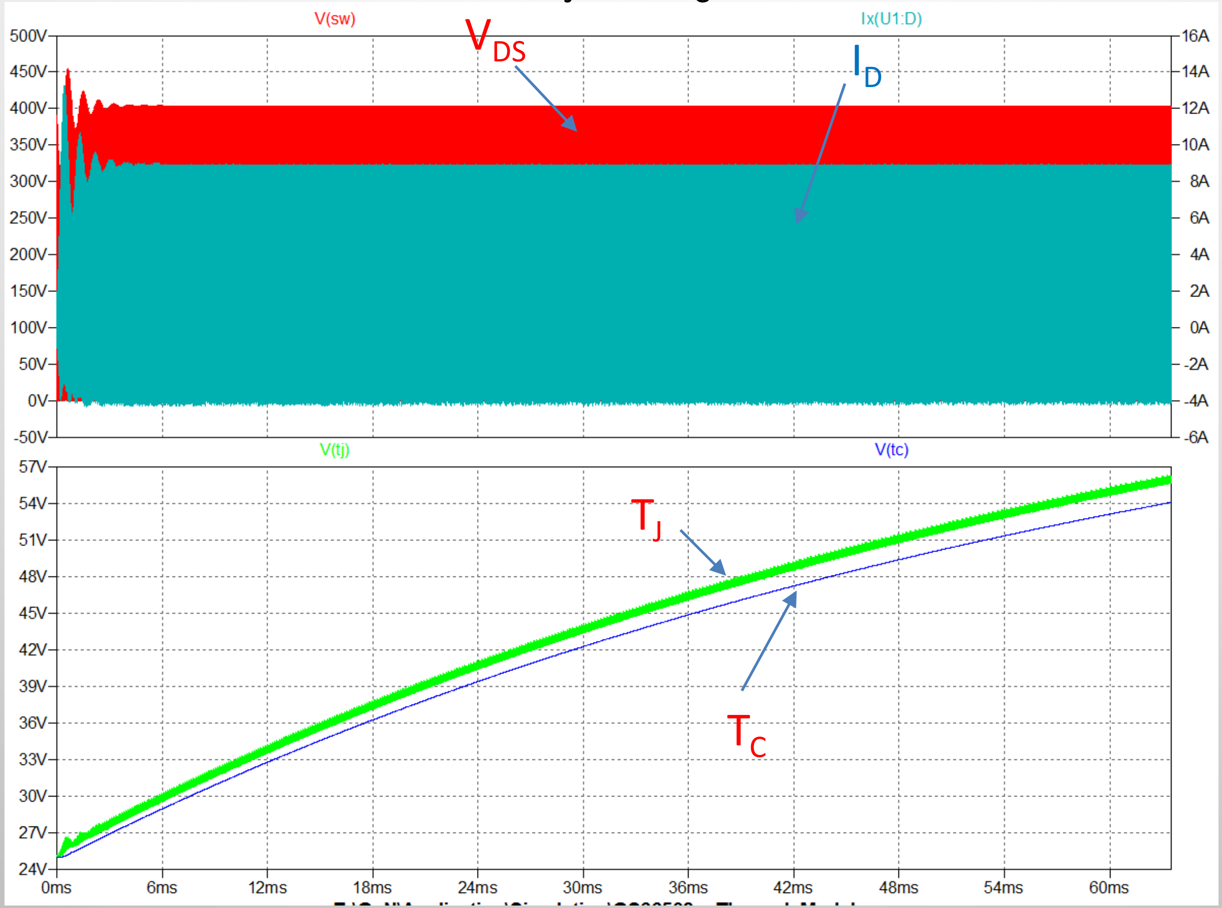
A simple boost converter circuit was used to verify the functionality of RC thermal model

- 200 - 400 V, I_{out} = 4 A
- D = 0.5, F_{sw} = 50 kHz
- T_A = 25 °C
- R_{THCA} = 10 °C/W
- Monitor T_J, T_C



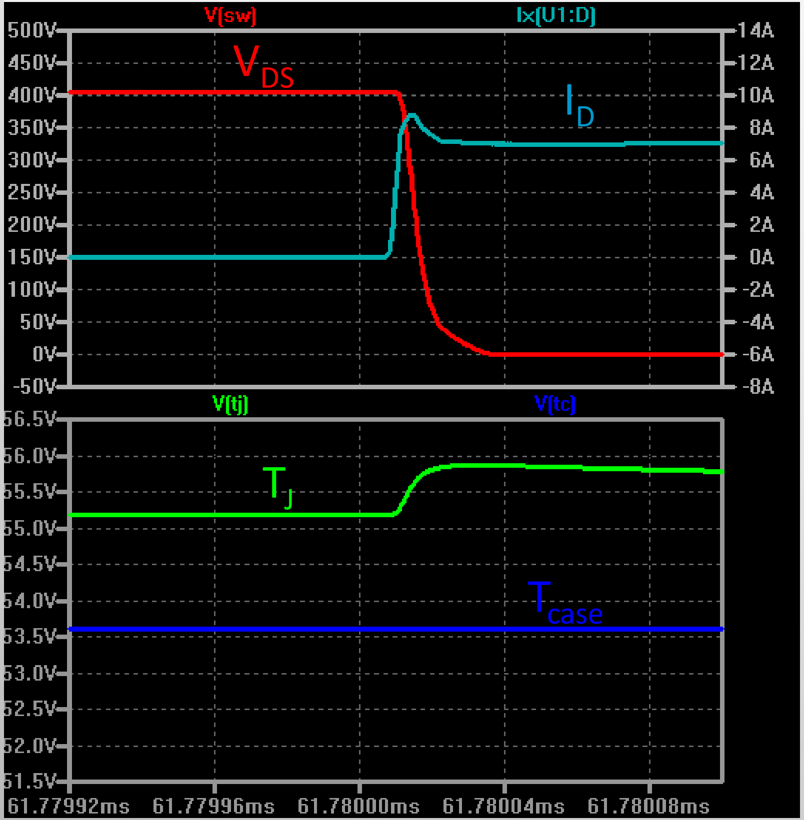
SPICE simulation examples - waveforms

Transient thermal simulation showing T_J and T_C time constant for first 70ms

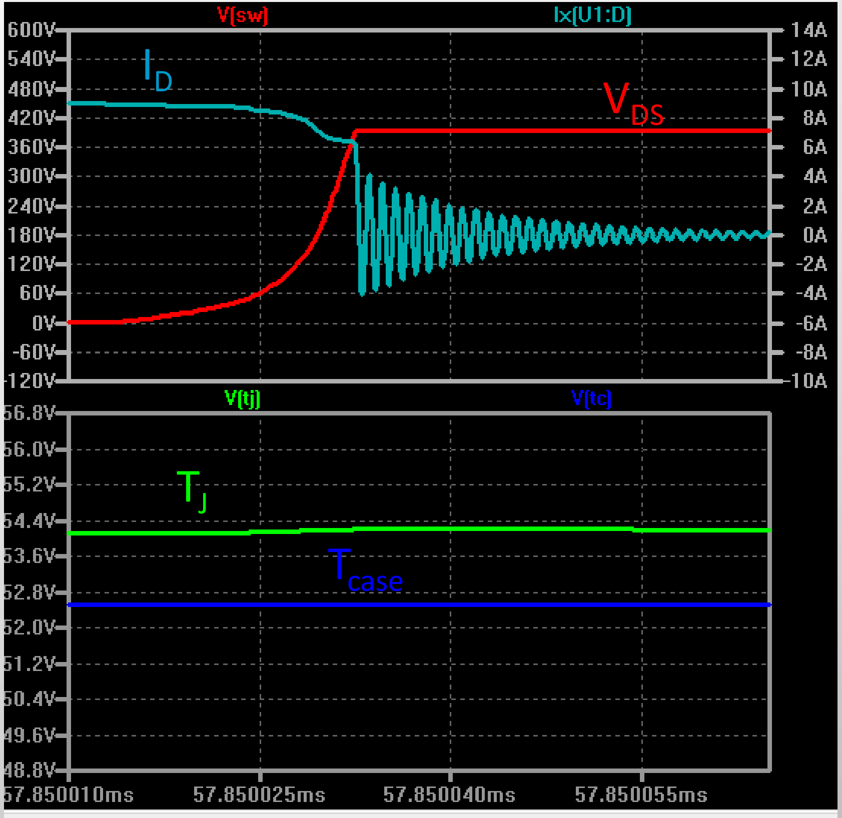


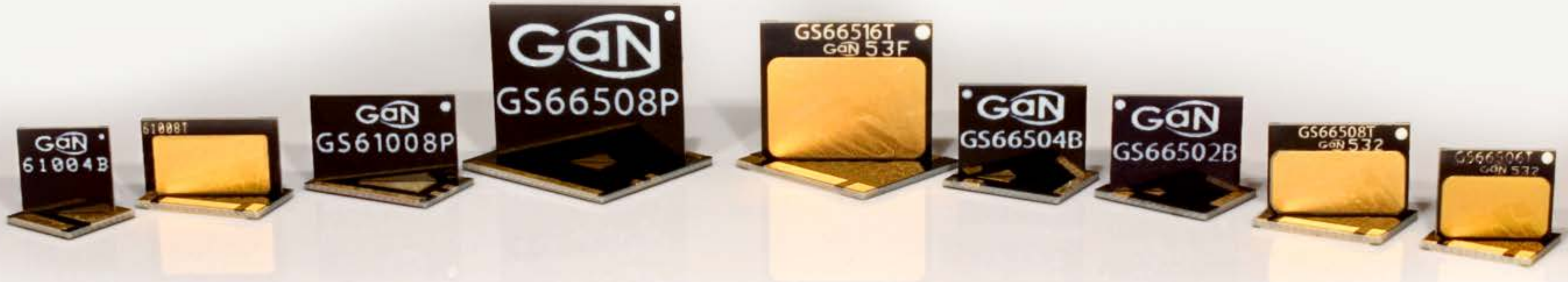
SPICE simulation examples – Switching transient

Thermal simulation – Turn-on



Thermal simulation – Turn-off





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