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

Cauer model has been chosen allowing customers to extend the thermal model to their system by including interface material and heat sinks

RC thermal models of GaN Systems devices are found on GaN Systems product pages
Contents

- RC network definition
- GaN\textsuperscript{PX} RC model structure
- How to use GaN\textsuperscript{PX} RC model during SPICE simulation
- SPICE simulation examples
**Thermal network**

- Thermal resistance ($R_\theta$)
- Thermal capacitance ($C_\theta$)
- Time dependent temperature distribution

### Equations for calculating $R_\theta$ and $C_\theta$:

1. $R_\theta = \frac{L}{k \cdot A}$  
2. $R_\theta = \frac{L}{k \cdot A_{\text{active}}}$  
3. $R_\theta = \frac{\Delta T}{P}$  
4. $C_\theta = C_p \cdot \rho \cdot L \cdot A$  
5. $C_\theta = C_p \cdot \rho \cdot L \cdot A_{\text{active}}$

where:
- $L$ – layer thickness (m)
- $k$ – thermal conductivity (W/m·K)
- $A$ – layer area (m$^2$)
- $A_{\text{active}}$ – device active area (m$^2$)
- $\Delta T$ – temperature rise (°C)
- $C_p$ – pressure specific heat capacity (W·s/kg·K)
- $\rho$ – density (kg/m$^3$)

### Analogy between Electrical and Thermal Parameters

<table>
<thead>
<tr>
<th>Electrical Parameters</th>
<th>Thermal Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage $V$ (V)</td>
<td>Temperature difference $\Delta T$ (°C)</td>
</tr>
<tr>
<td>Current $I$ (A)</td>
<td>Power $P$ (W)</td>
</tr>
<tr>
<td>Resistance $R$ (Ω)</td>
<td>Thermal resistance $R_\theta$ (°C/W)</td>
</tr>
<tr>
<td>Capacitance $C$ (F)</td>
<td>Thermal capacitance $C_\theta$ (W·s/°C)</td>
</tr>
</tbody>
</table>

**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 layers of the package

**Pros:**
- Cauer RC model reflects the real, physical setup of the device
- Allows to add extra $R_\theta$ and $C_\theta$ to simulate the Thermal Interface Material (TIM) or Heatsink

**Cons:**
- Detailed thermal analysis using FEA
- Challenge to extract the thermal capacitance

**Foster Model**
- Foster thermal model is not based on the physical property and packaging structure
- $R_\theta$ and $C_\theta$ are curve-fitting parameters

**Pros:**
- Can be extracted from the transient respond curve from the datasheets
- Can be extracted from a measured heating or cooling curves

**Cons:**
- Valid only for measured conditions
- Adding extra resistance and capacitance requires new curve fitting
Contents

- RC network definition
- GaNPx RC model structure
- How to use GaNPx RC model during SPICE simulation
- SPICE simulation examples
**GaN$\text{PX}$ 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

<table>
<thead>
<tr>
<th>GaN$\text{PX}$</th>
<th>$R_{\text{BJC}}$ ($^\circ\text{C/W}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS66502B</td>
<td>2.0</td>
</tr>
<tr>
<td>GS66504B</td>
<td>1.0</td>
</tr>
<tr>
<td>GS66508B</td>
<td>0.5</td>
</tr>
<tr>
<td>GS66508P</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Cauer model was chosen for all GaN Systems transistors

GaN\textsubscript{Px} consists of 4 layers:

- Layer thermal resistance was derived from the thermal simulation and calculated using the equation (3):
  \[ R_{\theta 1} = \frac{\Delta T}{P} = \frac{T_J - T_1}{P} \]

- Layer thermal capacitance was calculated using the active area of the device (equation (5)):
  \[ C_{\theta 1} = C_{P1} \cdot \rho_1 \cdot L_1 \cdot A_{\text{active}} \]
GS66508P: Comparison with SPICE simulation

Boundary Condition:
- Power $P = 80$ W
- Case temperature at 25 °C

Good agreement between Cauer model from thermal and SPICE simulations has been achieved.
Contents

- RC network definition
- GaNPX RC model structure
- How to use GaNPX RC model during SPICE simulation
- SPICE simulation examples
How to use GaN\textsubscript{PX} RC model during SPICE simulation

**SPICE Netlist in .lib File:**

- \( R_{th\_1} \) T11 TJ \{0.011\}
- \( C_{th\_1} \) 0 TJ \{4.25e-5\}
- \( R_{th\_2} \) T22 T11 \{0.231\}
- \( C_{th\_2} \) 0 T11 \{2.96e-3\}
- \( R_{th\_3} \) T33 T22 \{0.237\}
- \( C_{th\_3} \) 0 T22 \{6.65e-4\}
- \( R_{th\_4} \) TC T33 \{0.021\}
- \( C_{th\_4} \) 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
- RC network definition
- GaN PX RC model structure
- How to use GaN PX RC model during SPICE simulation
- SPICE simulation examples
SPICE simulation examples

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

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


3. EPC2031 SPICE Thermal Model: http://epc-co.com/epc/Products/eGaNFETsandICs/EP2031.aspx


