PSIM

TUTORIAL

Loss Calculation and Transient Analysis of SiC and GaN Devices

July 2018

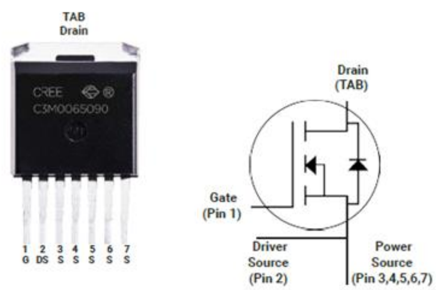
Wide band gap devices, such as SiC and GaN devices, are increasingly used in power electronics applications for their characteristics of high frequency switching and low losses. This tutorial shows how losses and transient behaviour of these devices can be analysed and simulated in PSIM using PSIM's Thermal Module and SPICE Module.

To illustrate the process, Cree's SiC device C3M0065090J (900V, 35A) and GaN Systems' GaN HEMT GS66508 (900V, 35A) are used in the examples. Results of power losses from the Thermal Module are compared with the results from the SPICE simulation.

1. Loss Calculation of SiC Devices

The first step for loss calculation is to add the device into the device database. In PSIM, go to the **Utilities** menu, and select **Device Database Editor**. In the Device Database Editor window, select one device database file to add the device into (for example, "MOSFET_SiC.dev", or select **File** >> **New Device File** to create a new device file. To add a SiC device, select **Device** >> **New MOSFET (Eon)**.

Cree's SiC C3M0065090J is a 900-V 35-A device, as shown below.



To add Cree SiC C3M0065090J, with the manufacturer datasheet in hand, complete the information required, and enter the curves of the transistor and diode characteristics in the Device Database Editor.

Since device curves are often provided under different values of the gate-source voltage V_{GS}, one needs to define the gate-source voltage that will be used in the circuit first. For this example, we assume that the gate-source voltage V_{GS} is from -4V to +15V. Curves from the datasheet are captured following the procedure described in Section 4.10.7 of the PSIM User Manual or in the document "Tutorial – IGBT loss calculation in the Thermal Module.pdf". The following curves are captured from figures in the C3M0065090J datasheet:

VDS vs. IDS:	Fig. 1, 2, and 3 of the datasheet for V_{GS}=15V
VDS vs. IDS (3rd):	Fig. 13, 14, and 15 of the datasheet for V_{GS}=15V. These curves are for 3rd-quadrant operation where the transistor gating signal is present and the current IDS is negative.
Eon vs. IDS:	Fig. 24 and 26. Fig. 24 gives the Eon vs. IDS curve for 25 ^{o}C. We will use Fig. 26 to derive the curves at other junction temperatures. For example, from Fig. 26, we can read Eon at 25, 100, 150 ^{o}C for IDS of

20A. We will then assume that Eon is scaled in the same way under different values of IDS, and use the same ratio to derive the Eon vs. IDS curves at 100 ^oC and 150 ^oC.

To read values from Fig. 26, one can use the **Curve Capture Tool** from the **Utilities** menu.

Eoff vs. IDS: Fig. 24 and 26. The process is the same as for Eon vs. IDS above.

Eon vs. RG: Fig. 25.

Eoff vs. RG: Fig. 25.

Eon vs. VDS @ IDS1: Fig. 23 and 24. This curve shows how Eon changes versus the voltage at one current value IDS1. We will choose IDS1=20A. We will read Eon from both Fig. 23 and Fig. 24 at 20A.

Eoff vs. VDS @ IDS1: Fig. 23 and 24. This curve shows how Eoff changes versus the voltage at the current value IDS1 of 20A. We will read Eoff from both Fig. 23 and Fig. 24 at 20A.

Eon vs. VDS @ IDS2: Fig. 23 and 24. This curve shows how Eon changes versus the voltage at another current value IDS2. We will choose IDS2=30A. We will read Eon from both Fig. 23 and Fig. 24 at 30A.

Eoff vs. VDS @ IDS2: Fig. 23 and 24. This curve shows how Eoff changes versus the voltage at the current value IDS2 of 30A. We will read Eoff from both Fig. 23 and Fig. 24 at 30A.

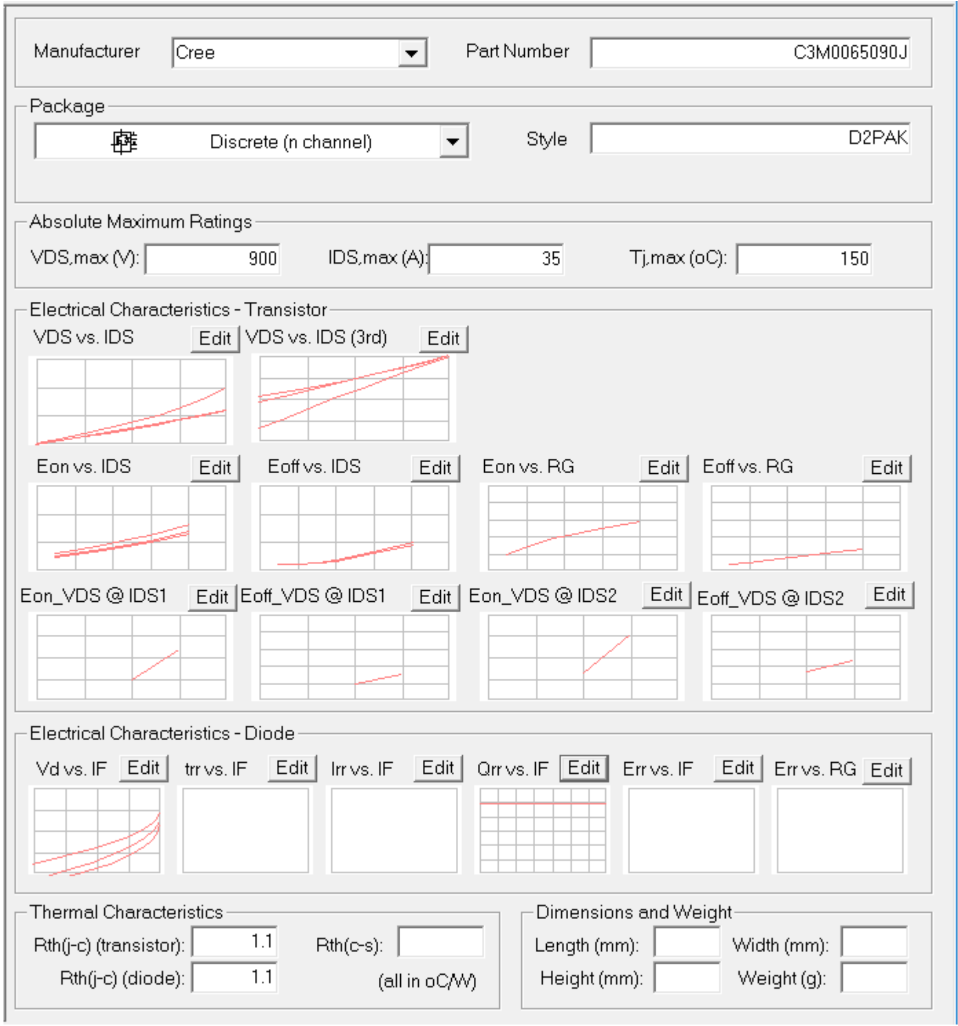
Vd vs. IF: Fig. 8, 9, and 10 for V_{GS}=-4V. These are the conduction characteristics for the body diode.

Qrr vs. IF: No curves are gives for the reverse diode characteristics. There is only one point given for Qrr=245 nC at ISD=20A and Tj=150. ^oC. This point is entered in the Qrr vs. IF curve.

After the entry is completed, the device C3M0065090J is shown in the Device Database Editor as below.

Note that when the transistor gating signal is present and the current flows from source to drain (i.e. IDS < 0), the device operates in the 3rd quadrant. The device conduction loss is calculated as follows:

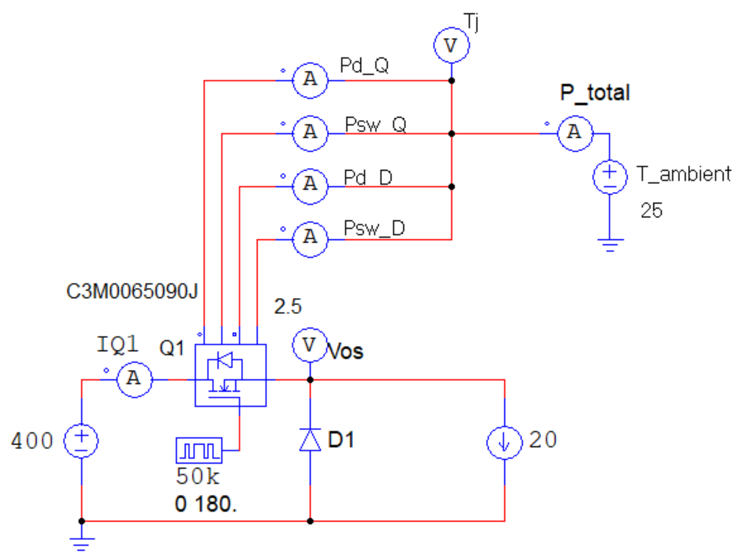
- If the graph "VDS vs. IDS (3rd)" is not provided, the current is assumed to flow through both the transistor and the diode. The current split will be calculated automatically by PSIM. The curve "VDS vs. IDS" is used to calculate the transistor conduction loss, and the curve "VD vs. IF" is used to calculation the body diode conduction loss.
- If the graph "VDS vs. IDS (3rd)" is provided, it is assumed that all the current flows through the transistor, not the body diode, and the graph "VDS vs. IDS (3rd)" is used to calculate the conduction loss. In reality, the current does flow through both the transistor and the diode. But we assume that majority of the current flows through the transistor, and the diode conduction is ignored.



Once the device is in the database, it can be used in PSIM for loss calculation. In PSIM, go to **Elements** >> **Power** >> **Thermal Module**, and select **MOSFET (Eon) (database)**, and place the element on the schematic. Double click on the element, and click on the browse button next to the Device input field to browse and select the device C3M0065090J.

The circuit below shows a buck converter circuit with the device C3M0065090J. The circuit operating conditions are:

Input:	400 V
Load:	20 A
Switching frequency:	50 kHz
Duty cycle:	0.5
Tj:	25 ^{o}C
V_{GS}:	-4V/+15V
Rg(ext):	2.5 Ohm



There are four nodes on the side of the SiC. The currents from these nodes represent the transistor conduction loss Pd_Q, transistor switching loss Psw_Q, body diode conduction loss Pd_D, and body diode switching loss Psw_D. The voltage at these nodes represent the junction temperature.

Transistor losses from the simulation are:

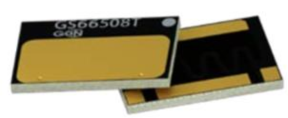
Conduction loss Pd_Q = 12.6 W
Switching loss Psw_Q = 3.3 W

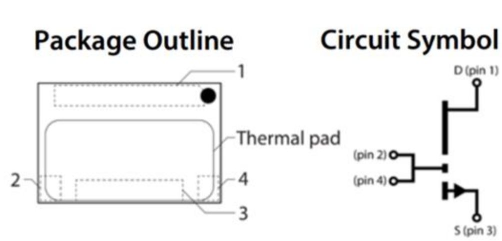
The body diode does not conduct in this case.

2. Loss Calculation of GaN Devices

To add a GaN device in the Device Database Editor, select **Device** >> **New MOSFET (Eon)**.

GaN Systems' GaN HEMT GS66508T is a 650-V 30-A device, as shown below.





To add GaN GS66508, with the manufacturer datasheet in hand, complete the information required, and enter the curves of the transistor characteristics in the Device Database Editor.

In this example, we assume that the gate-source voltage V_{GS} is from -3V to +6V. The following curves are captured from figures in the GS66508T datasheet:

VDS vs. IDS: Fig. 15 of the datasheet for V_{GS}=6V. Note that when capturing this curve, one cannot capture the entire graph as it is. This is because, for this graph, the current range is different for different temperatures. For example, for 25ºC, the current ranges from 0 to around 86A, but for 100ºC, the current ranges from 0 to around 45A. In order to perform interpolation, the database in PSIM requires that for different temperatures, currents must have the same range. In this example, we will choose a range of 0 to 30A, as indicated in the red line in the graph below.

GS66508T I_{DS} vs. V_{DS} , T_J dependence

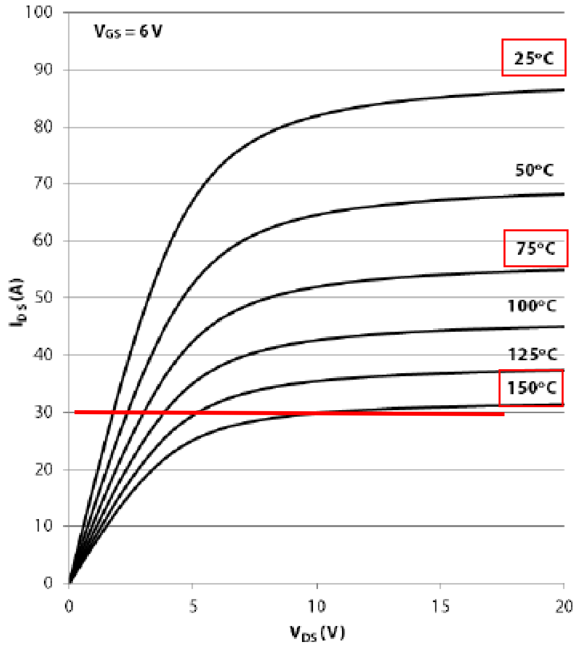


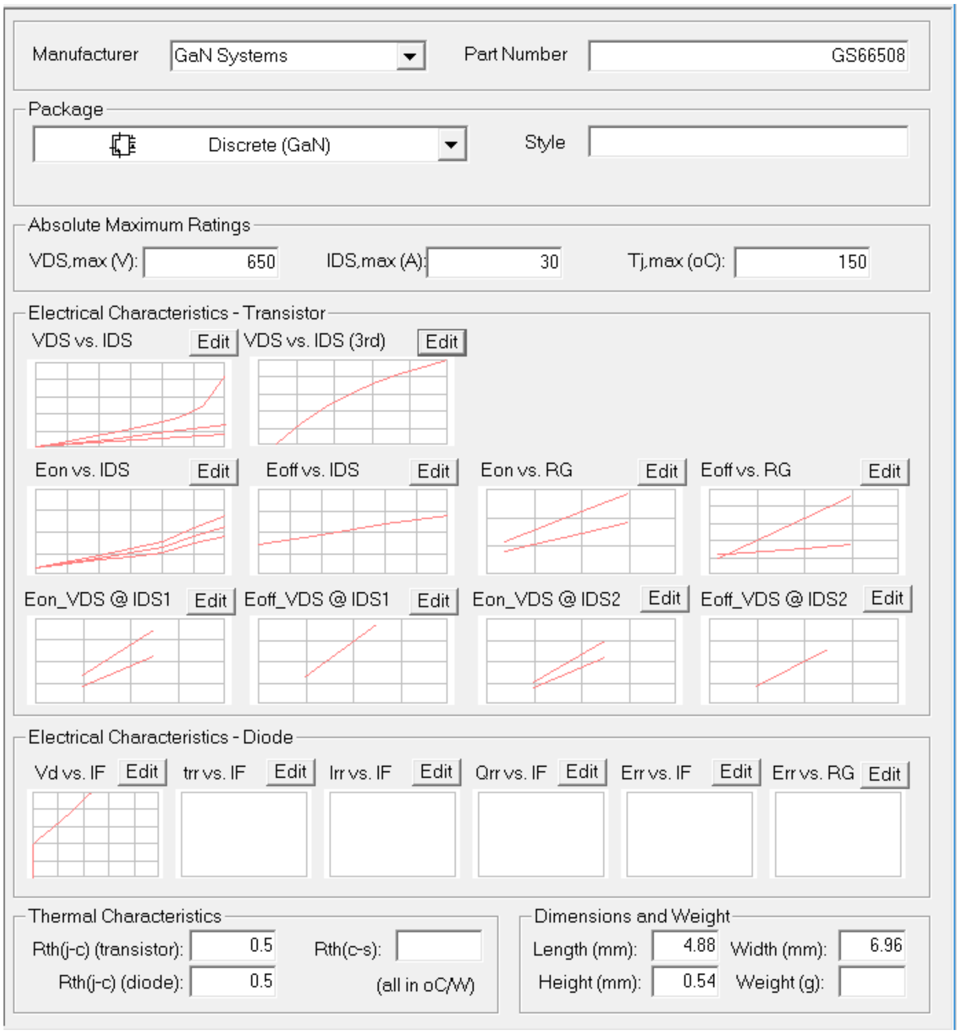
Figure 5 : Typical I_{DS} vs. V_{DS} @ V_{GS} = 6 V

Curves for 25ºC , 75ºC , and 155ºC are captured.

VDS vs. IDS (3rd): Fig. 9 for V_{GS}=6V. This curve is for 3rd-quadrant operation where the transistor gating signal is present and the current IDS is negative.

Vd vs. IF: Fig. 9 for V_{GS}=-2V. The GaN HEMT device does not have a body diode. This curve is used to represent the operation where the transistor gating signal is low and the current IDS is negative.

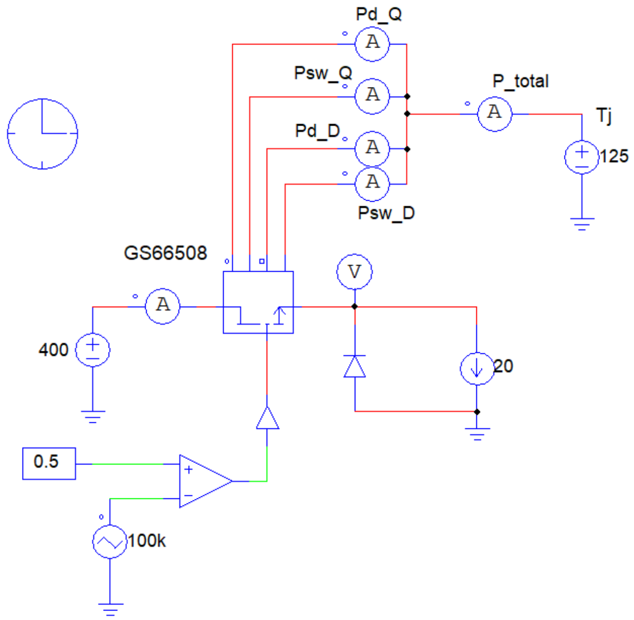
Data of other curves are not available on the datasheet but were supplied by the manufacturer. After the entry is completed, the device GS66508 is shown in the Device Database Editor as below.



Once the device is in the database, it can be used in PSIM for loss calculation. In PSIM, go to **Elements** >> **Power** >> **Thermal Module**, and select **MOSFET (Eon) (database)**, and place the element on the schematic. Double click on the element, and click on the browse button next to the Device input field to browse and select the device GS66508.

The circuit below shows a buck converter circuit with the GS66508. The circuit operating conditions are:

Input:	400 V
Load:	20 A
Switching frequency:	100 kHz
Duty cycle:	0.5
Tj:	125 °C
V_{GS}:	-3V/+6V
Rg_on:	10 Ohm
Rg_off:	2 Ohm



There are four nodes on the side of the GaN device. The currents from these nodes represent the transistor conduction loss Pd_Q, transistor switching loss Psw_Q, body diode conduction loss Pd_D, and body diode switching loss Psw_D. The voltage at these nodes represent the junction temperature.

Transistor losses from the simulation are:

Conduction loss Pd_Q = 25.3 W
Switching loss Psw_Q = 8.32 W

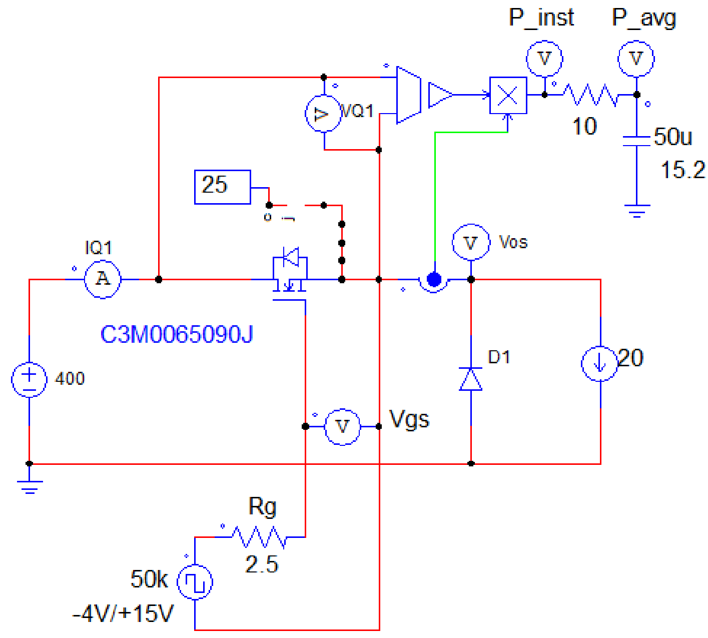
3. Transient Analysis in SPICE

With PSIM's SPICE Module, the switching transients of SiC and GaN devices using SPICE models can be studied conveniently in the PSIM environment using either the built-in SPICE engine in PSIM or LTspice[1].

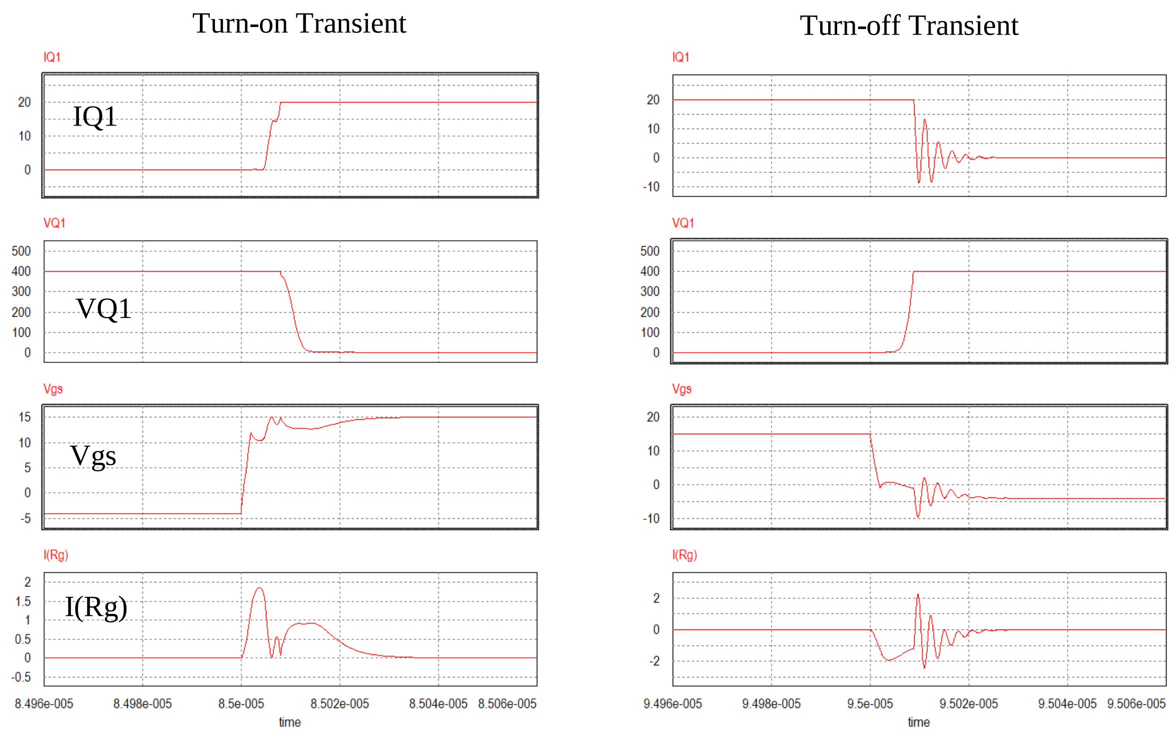
For both the SiC device C3M0065090J and the GaN device GS66508, SPICE models for LTspice are available from manufacturers. These models are used in the simulation below.

The equivalent SPICE circuit of the same buck converter circuit in Section 1 for C3M0065090J is shown below.

[1] LTspice is copyright by Linear Technology Co., 1998-2018

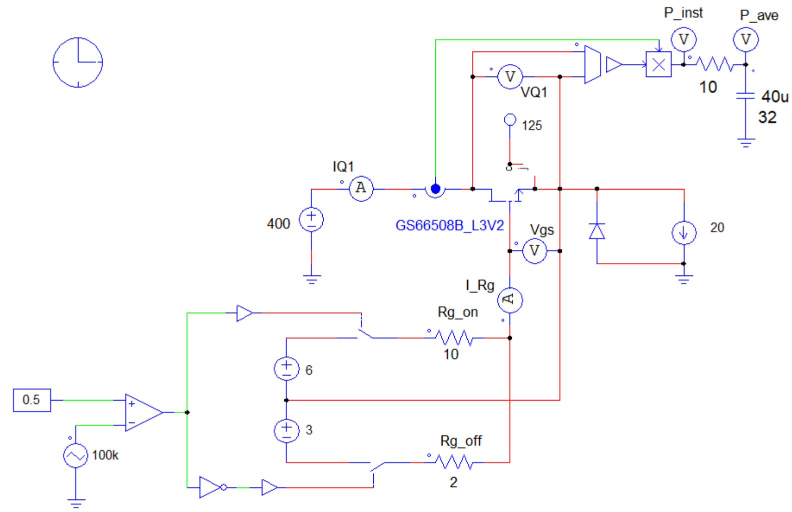


Waveforms of the transistor turn-on and turn-off transients are shown below:

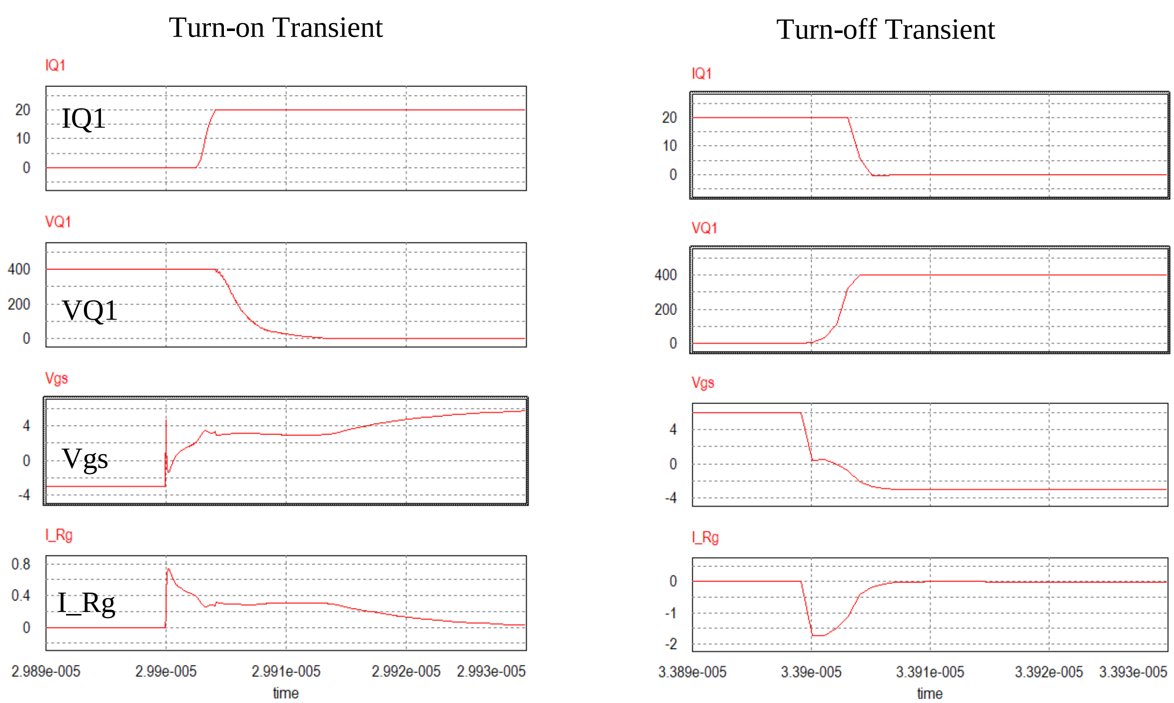


The waveforms show the transistor voltage, current, gate voltage, and gate current during the turn-on and turn-off process.

A GaN device can be studied in a similar way. The equivalent SPICE circuit of the same buck converter circuit in Section 2 for GS66508 is shown below.



Waveforms of the transistor turn-on and turn-off transients are shown below:



The waveforms show the transistor voltage, current, gate voltage, and gate current during the turn-on and turn-off process.

4. Loss Result Comparison between Thermal Module and SPICE

Losses can also be calculated from SPICE simulation by multiplying the transistor voltage and current and taking the average. The comparison between loss results from the Thermal Module and SPICE is given below.

For the buck converter with the Cree SiC C3M0065090j:

Transistor Loss (W)	Thermal Module	SPICE
P_total	15.9	15.1
P_conduction	12.6	12.4
P_switching	3.3	2.7
Simulation time (study time: 2ms)	< 1 sec	9 sec

The loss results are very close.

For the buck converter with the GaN GS66508:

For Tj = 25 ^{o}C:

Transistor Loss (W)	Thermal Module	SPICE
P_total	16.8	13.8
P_conduction	10.5	10.4
P_switching	6.3	3.4
Simulation time (study time: 60us)	< 1 sec	38 sec

For Tj = 125 ^{o}C:

Transistor Loss (W)	Thermal Module	SPICE
P_total	32.6	31.8
P_conduction	25.3	25.4
P_switching	8.3	6.4
Simulation time (study time: 60us)	< 1 sec	1 min 30 sec

The loss results are also very close.

For the buck converter with the GaN GS66508, if the dc input voltage is changed from 400V to 200V, the SPICE simulation would hang up at around 160 us.

4. Conclusions

From the two examples above, it shows that:

- Losses of SiC and GaN can be calculated easily in PSIM based on information from manufacturer datasheets or from manufacturers.
- Losses calculated from the Thermal Module are very close to the results from SPICE simulation. However, simulation with the Thermal Module is much faster, and does not have any convergence issue.
- Detailed transient analysis of SiC and GaN devices based on SPICE models can also be carried out in PSIM. SPICE simulation does provide valuable insight on device switching transient, and can help designers study voltage/current overshoot and stress, and design gate drive circuits.

With the capability to perform both detailed device-level analysis and behaviour-level and control analysis, PSIM provides the complete simulation and design environment for all your power electronics needs.