USER GUIDE PRD-09611

WOLFSPEED PLECS MODELS USER GUIDE

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This document introduces PLECS models provided by Wolfspeed and how to quickly get started simulating in PLECS. The PLECS simulation tool is briefly introduced, followed by an explanation of the data provided in Wolfspeed's PLECS models. Finally, guidelines to get started with system simulations are provided along with best practices for accurate results.

To install Wolfspeed's PLECS thermal models, see the instructions in Section 2 More information can be found here: Thermal Library

CONTENTS

1. INTRODUCTION TO PLECS

PLECS is a simulation tool optimized for switched-mode power electronic systems. By using idealized switching dynamics instead of simulating the nuance of semiconductor transients, it can simulate power electronic systems much faster than simulation environments where the power semiconductors are modelled in detail.

PLECS also includes a thermal model of the power semiconductors. This feature is key to correctly selecting Wolfspeed's products for a target application and determining their performance. By using the models provided by Wolfspeed, designers can quickly import the conduction losses, switching losses, and thermal behavior described in a specific product's datasheet and evaluate its performance in their target application.

See Plexim's website to download the latest version of the PLECS software, the PLECS User Manual, and review various tutorials covering the basics of using PLECS.

2. WOLFSPEED'S PLECS MODELS

Wolfspeed offers two versions of its MOSFET models, the legacy model (Separate MOSFET and Diode thermal descriptions) and the MOSFET with Diode model (User Manual Description). Both can be found at https://www.wolfspeed.com/tools-and-support/power/ltspice-and-plecs-models/:

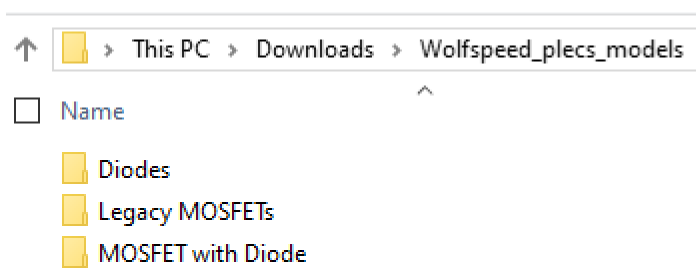


Figure 1: Contents of Wolfspeed_plecs_models.zip

After extracting the folder containing the PLECS models, you can add them directly to PLECS's Thermal description search path. This can be accessed via File → PLECS Preferences. The legacy models are compatible with the separate MOSFET and diode model blocks, while the combined MOSFET and Diode model work with the integrated block built into PLECS, facilitating easier integration into new circuits. For legacy models, a distinct MOSFET model and its corresponding body diode model file (named as *mosfet_bodydiode.XML*) must be used together to accurately assess semiconductor losses. In contrast, for the MOSFET with Diode models, only one thermal description file is required to model semiconductor losses for both the MOSFET and its body diode.

For Schottky Diodes, Wolfspeed provides a single version which are same as the Legacy body-diode models. These diodes can be easily integrated into PLECS in the same manner as the MOSFET models. For a detailed explanation of how the diode models function, please refer to Section 2.2. More information can be found here: Diode.

2.1 Overview of Wolfspeed MOSFET PLECS models

2.1.1 Model Parameters

a) Legacy models:

MOSFET/Module Parameters

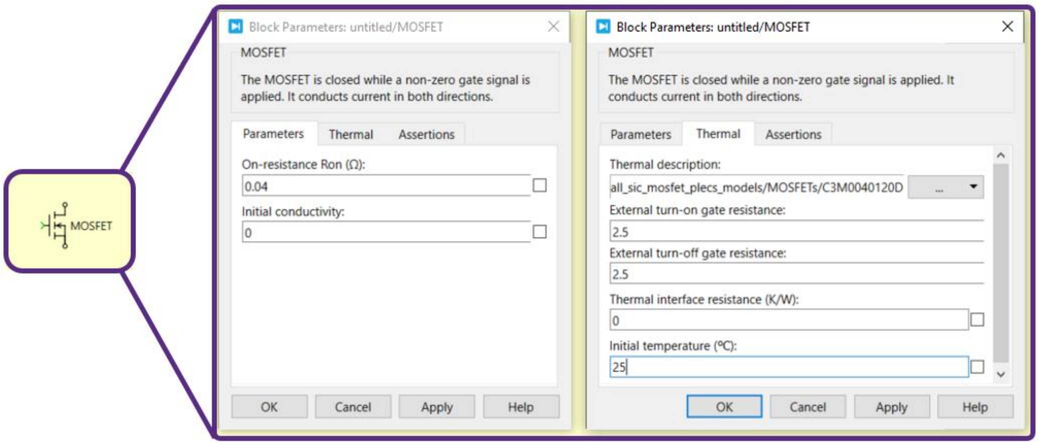


Figure 2: MOSFET/Module parameters as seen in PLECS

Parameters	Tab	Details
On-Resistance Ron	Parameters	MOSFET channel resistance at operating conditions
Initial conductivity	Parameters	Initial conduction state of the MOSFET
Thermal description	Thermal	Selects thermal description for the model
External Turn-on gate resistance	Thermal	Set turn-on Gate Resistor value
External Turn-off gate resistance	Thermal	Set turn-off Gate Resistor value
Thermal interface resistance (K/W)	Thermal	Thermal resistance between case and heatsink
Initial temperature (°C)	Thermal	Initial junction temperature at the start of simulation

Body-Diode Parameters

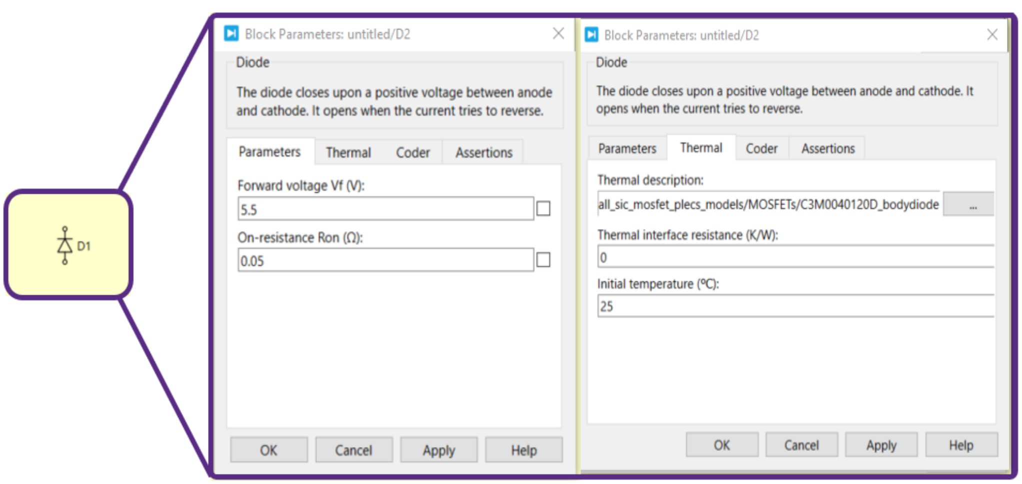


Figure 3: Body-diode Parameters as seen in PLECS

Parameters	Tab	Details
Forward voltage Vf (V)	Parameters	Forward voltage drop of body-diode at operating conditions
On-Resistance Ron (Ω)	Parameters	The resistance R_{on} of the conducting diode
Thermal description	Thermal	Selects thermal description model of the body-diode
Thermal interface resistance (K/W)	Thermal	Thermal resistance between case and heatsink
Initial temperature (°C)	Thermal	Initial junction temperature at the start of simulation

b) MOSFET with Diode models:

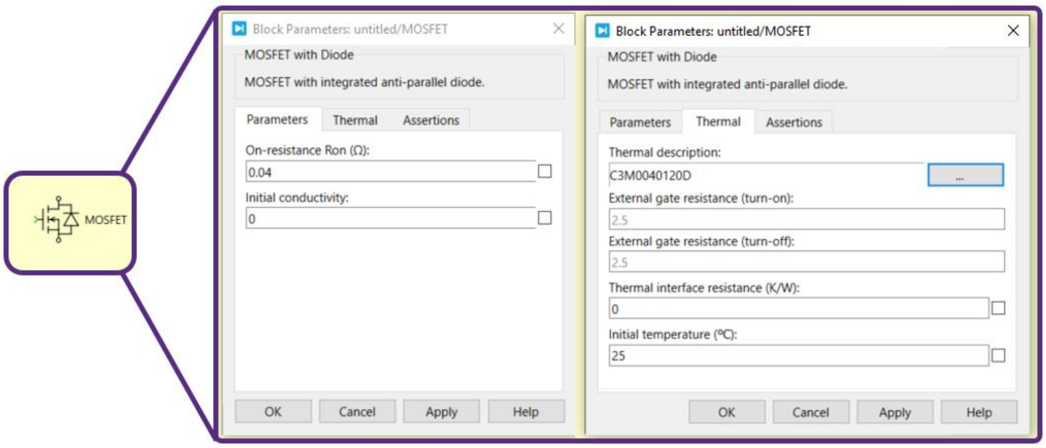


Figure 4: MOSFET with Diode model parameters as seen in PLECS

Variable	Tab	Details
On-Resistance Ron	Parameters	MOSFET channel resistance at operating conditions
Initial conductivity	Parameters	Initial conduction state of the MOSFET
Thermal description	Thermal	Selects thermal description model of the MOSFET/Module
External Turn-on gate resistance	Thermal	Set turn-on Gate Resistor value
External Turn-off gate resistance	Thermal	Set turn-off Gate Resistor value
Thermal interface resistance (K/W)	Thermal	Thermal resistance between case and heatsink
Initial temperature (°C)	Thermal	Initial junction temperature at the start of simulation

2.1.2 Switching Losses

The switching losses presented in the PLECS models are derived from empirical measurements and are organized as a look-up table, incorporating temperature, blocking voltage, and drain current as input variables. Utilizing these values, along with linear interpolation and extrapolation between the points in the table, PLECS generates instantaneous energy during hard-switched turn-on and turn-off events. Both turn-on and turn-off losses are modeled in a similar manner, featuring distinct look-up tables. These losses are measured at the datasheet recommended operational gate-on and gate-off voltages.

Wolfspeed has two different approaches for modeling the dependence of switching losses on gate resistance. The first is to scale the result of the 3D lookup table, E_{SW} vs I_{DS}, V_{DS}, and T_J, based on the gate resistance parameter, using an equation of R_G vs E_{SW} at a nominal value, as shown in Figure 5.

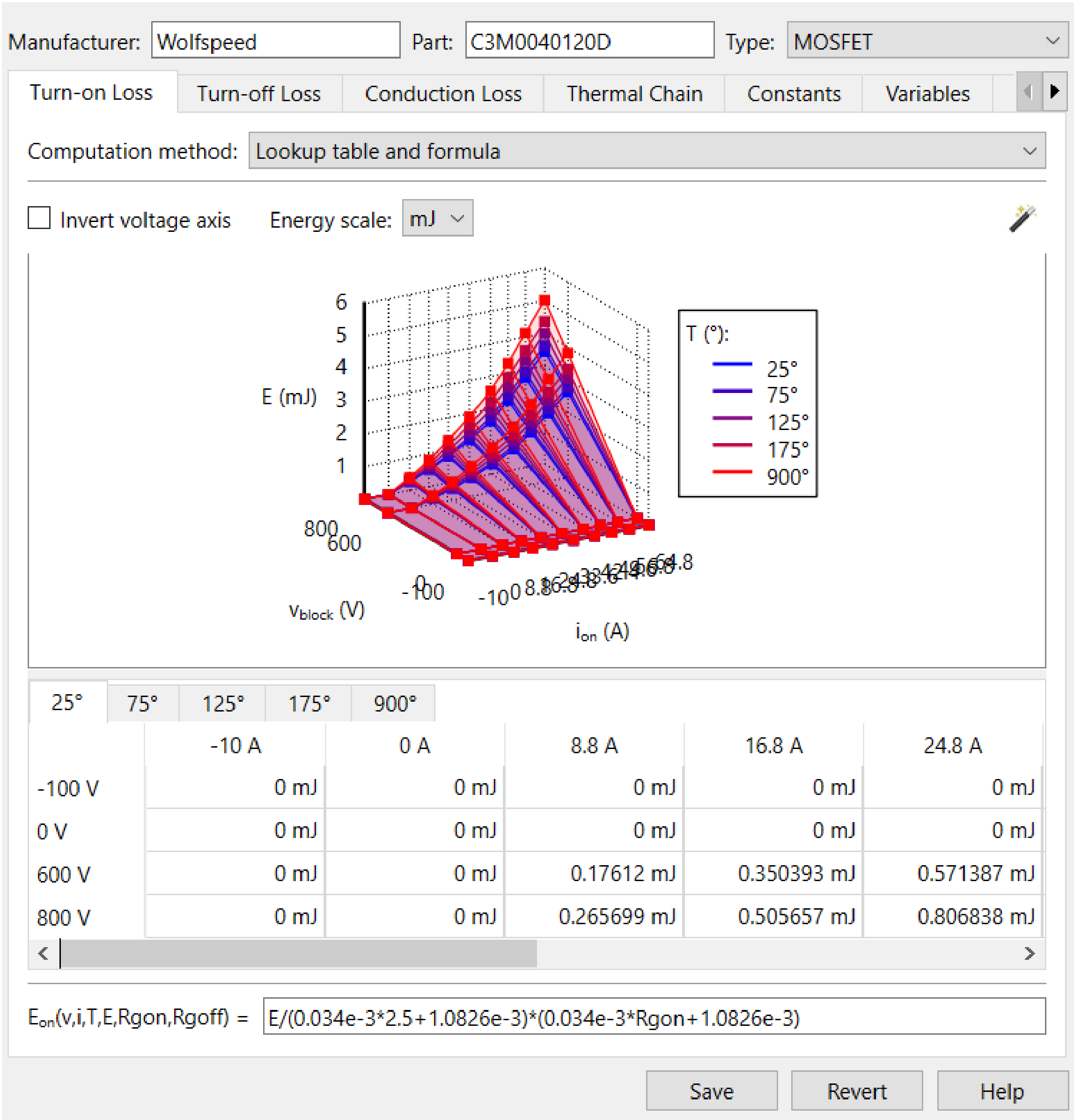


Figure 5: Example table of turn-on losses in C3M0040120D

The more accurate approach, used in some of the latest Wolfspeed models, is to define a custom four-dimensional table which defines E_{SW} in terms of I_{DS}, V_{DS}, T_J, and R_G. Figure 6 shows the example of a four-dimensional custom-table, while Figure 7 shows the equation the PLECS model uses to reference this custom table. Please note that the four-dimensional Custom tables are only supported in PLECS version 4.8 and higher.

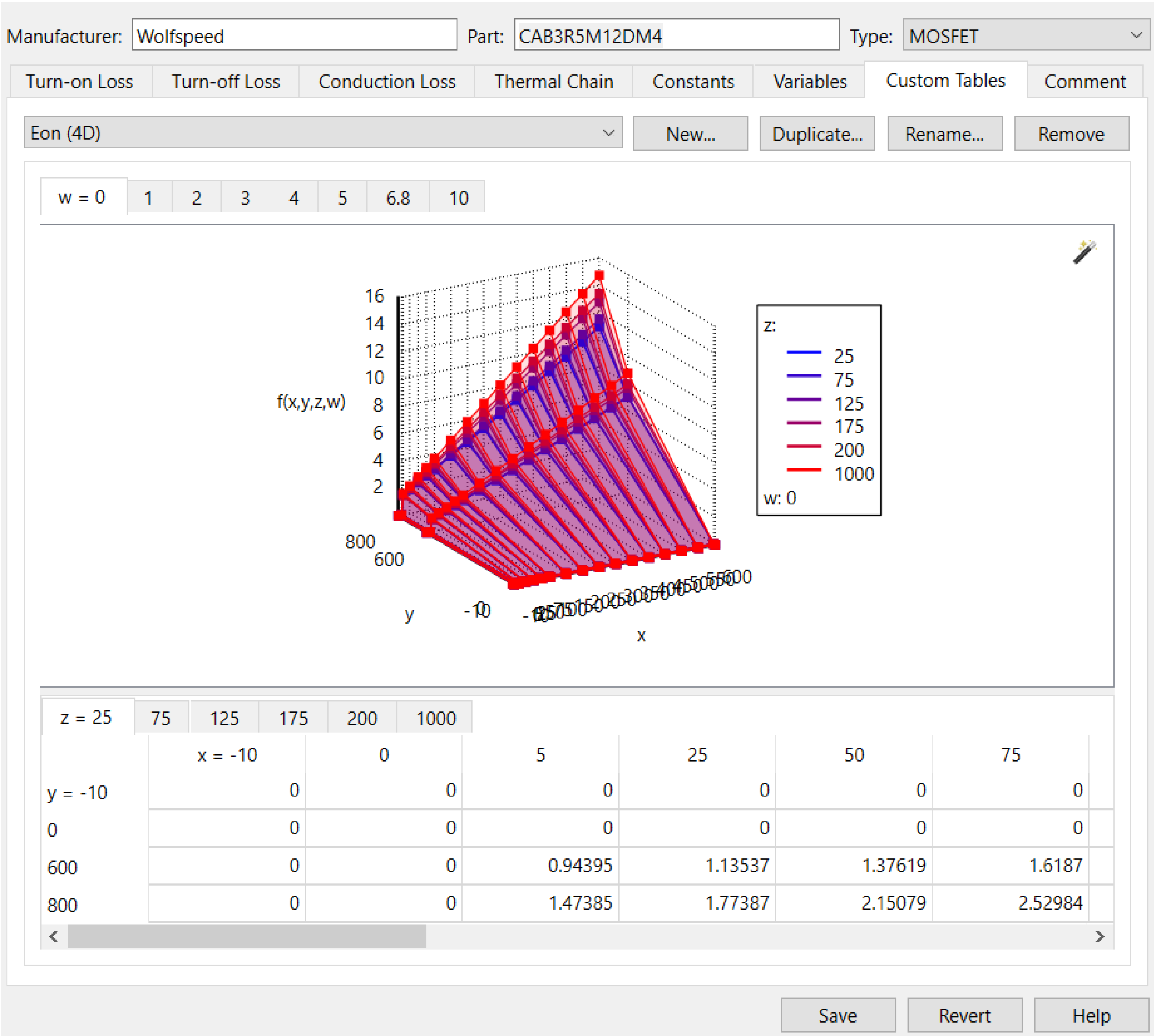


Figure 6: Custom 4D table defining E_{ON} losses in CAB3R5M12DM4 Legacy model

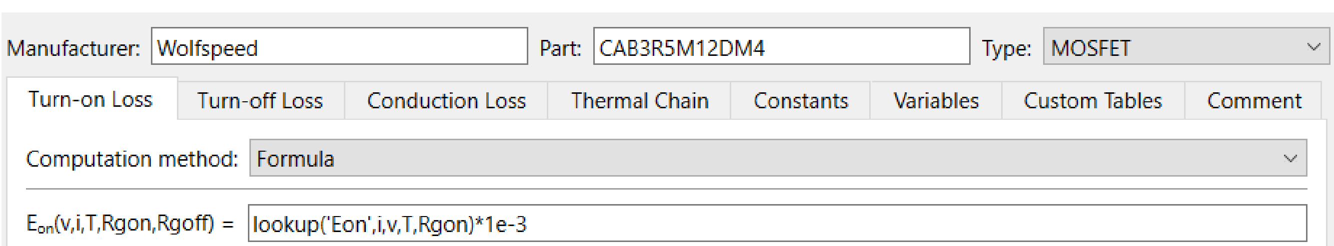


Figure 7: Function referencing custom table for E_{ON} losses

Both the legacy PLECS models and the MOSFET with Diode models are designed to handle switching losses using the same strategy. More information about the Switching loss can be found here: Switching Losses.

Note: Switching losses may vary due to factors such as board layouts and gate drivers and can differ in individual applications.

2.1.3 Channel Conduction Losses

The next element of the model is a conduction loss map based on the measured static characteristics of the product at different temperatures and currents, using the datasheet recommended operational gate-on voltage. It provides a voltage value at a given current and junction temperature. PLECS will linearly interpolate/extrapolate from these values. Whenever the MOSFET conducts current, continuous power is dissipated in the thermal domain based on the drain current, temperature, and corresponding voltage drop in the MOSFET. Whenever the device is operating in third quadrant with an ON signal, this will be the applied loss.

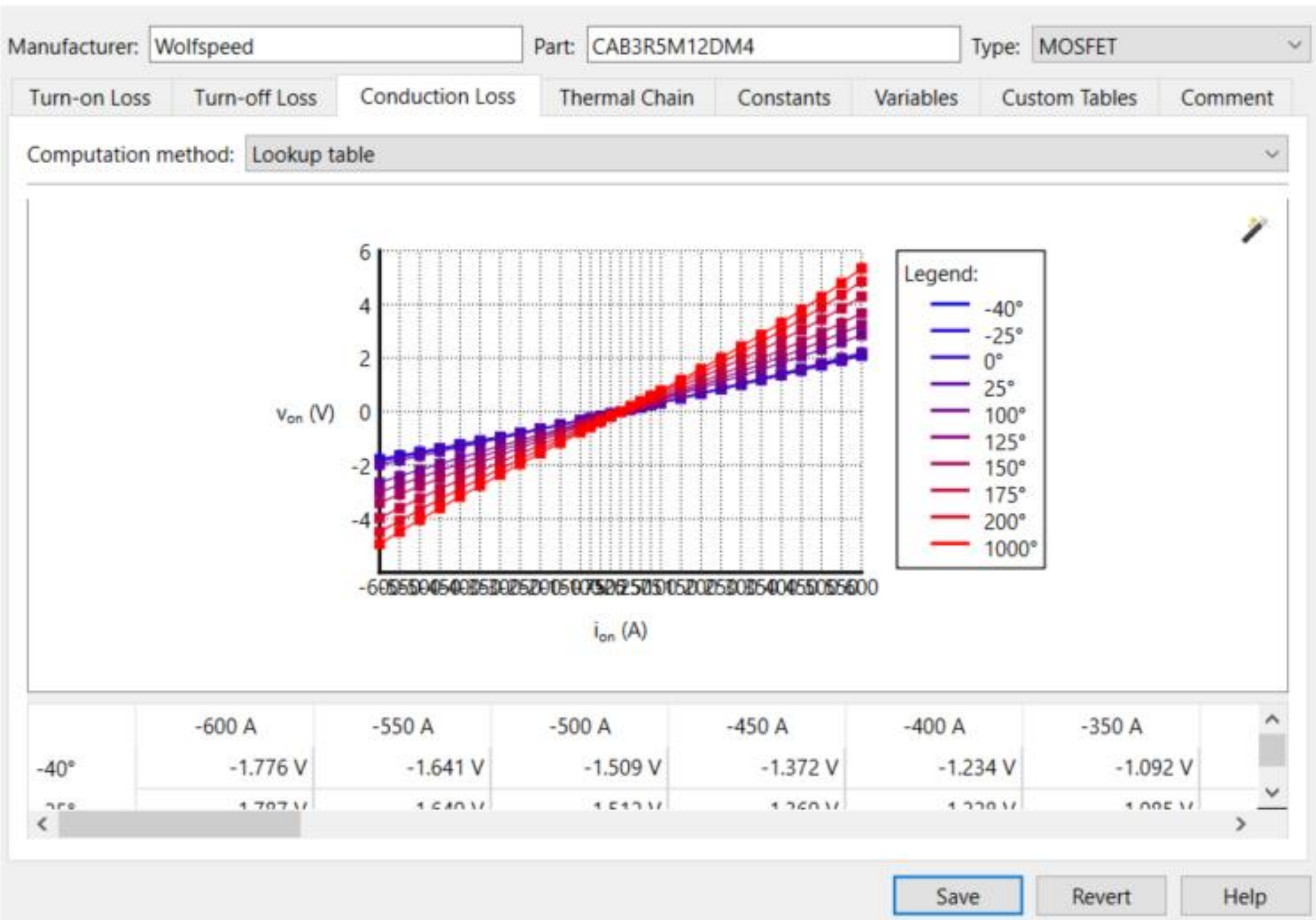


Figure 8: Example table of conduction losses in Legacy models

The conduction loss model is the same across all versions of Wolfspeed models. For Legacy models, the conduction loss data is found in the 'Conduction Loss' tab. In the MOSFET with Diode models, this data is located in the 'Cond. Loss (Gate On)' tabs within their thermal descriptions. More information about the conduction loss can be found here: Conduction Losses.

2.1.4 Body Diode Conduction Losses

The model also includes reverse conduction losses for when the channel is gated off and the body diode is conducting. These are based on the measured static characteristics of the body diode at different temperatures, under the datasheet suggested operational gate-off voltage. Whenever the body diode is conducting instead of the MOSFET channel (e.g. under negative gate bias) the respective conduction losses will come from the body diode conduction loss table.

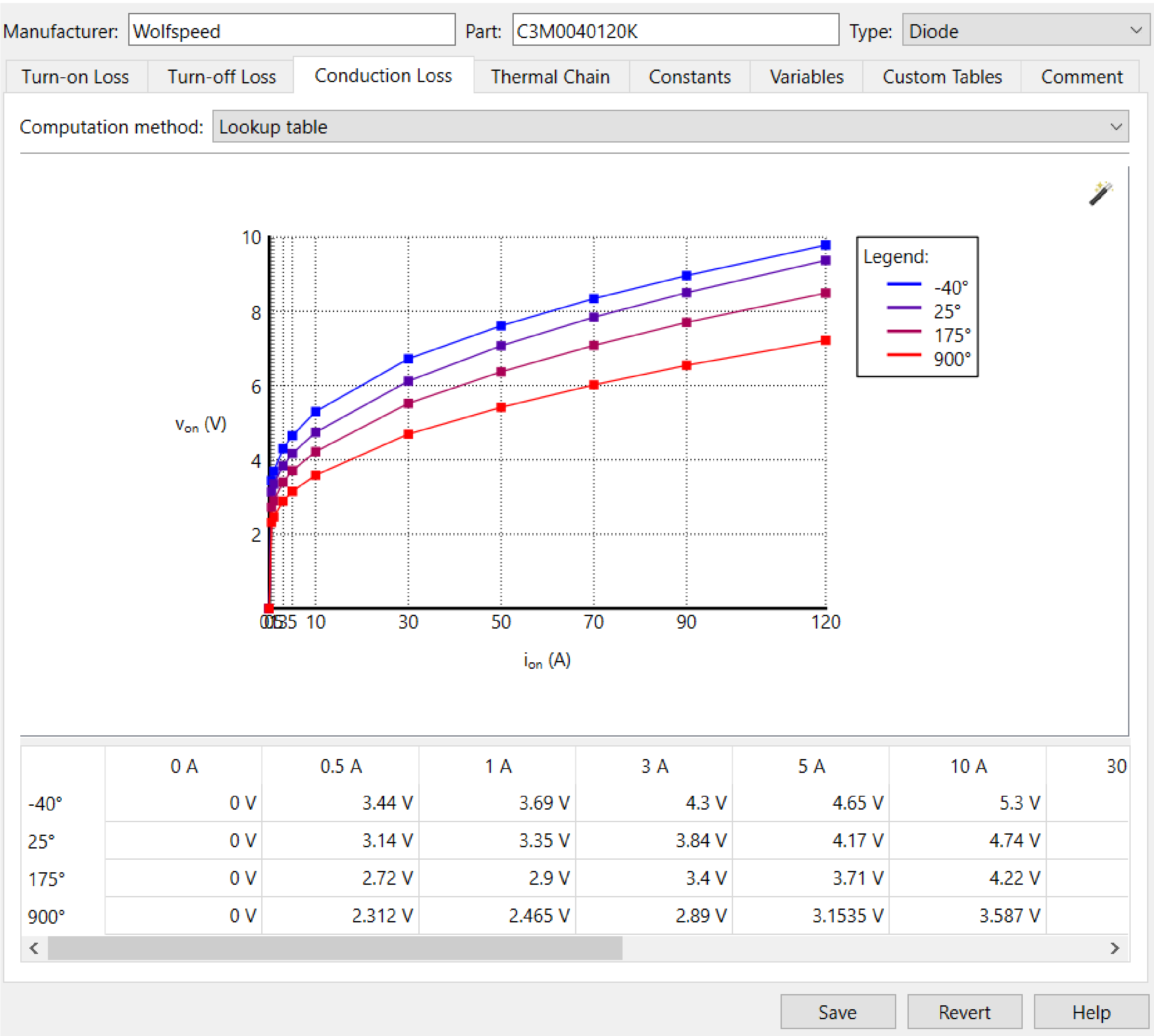
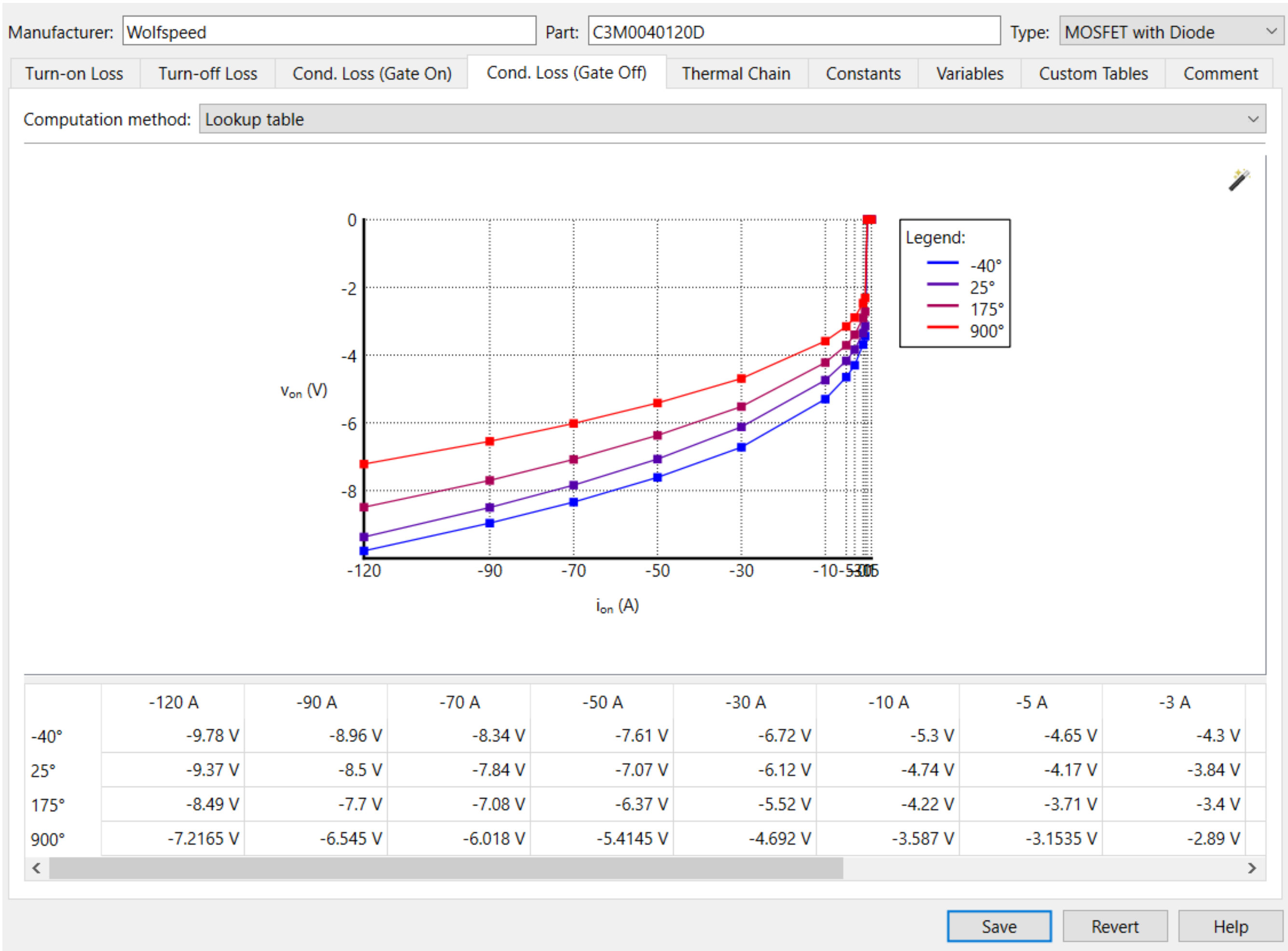


Figure 9: Body diode conduction loss look-up table (Legacy model).



	-120 A	-90 A	-70 A	-50 A	-30 A	-10 A	-5 A	-3 A
-40°	-9.78 V	-8.96 V	-8.34 V	-7.61 V	-6.72 V	-5.3 V	-4.65 V	-4.3 V
25°	-9.37 V	-8.5 V	-7.84 V	-7.07 V	-6.12 V	-4.74 V	-4.17 V	-3.84 V
175°	-8.49 V	-7.7 V	-7.08 V	-6.37 V	-5.52 V	-4.22 V	-3.71 V	-3.4 V
900°	-7.2165 V	-6.545 V	-6.018 V	-5.4145 V	-4.692 V	-3.587 V	-3.1535 V	-2.89 V

Figure 10: Body diode conduction loss look-up table (MOSFET with Diode model).

The body diode conduction loss model is the same across all versions of Wolfspeed models. For Legacy models, the body diode conduction loss data is found in the 'Conduction Loss' tab of their corresponding *mosfet_bodydiode.XML* thermal description. In the MOSFET with Diode models, this data is located in the 'Cond. Loss (Gate Off)' tabs within their thermal descriptions. More information about the conduction loss can be found here: Conduction Losses.

2.1.5 Thermal Network

A transient thermal impedance model is provided inside the MOSFET model for junction-to-case. An external thermal network can be added to model the heat management system's thermal performance (see Section 3.2, Modeling Thermal Management System for additional details). The thermal network is identical for both the Legacy and MOSFET with Diode models. More information about Thermal network model can be found here: Editing the Thermal Equivalent Circuit.

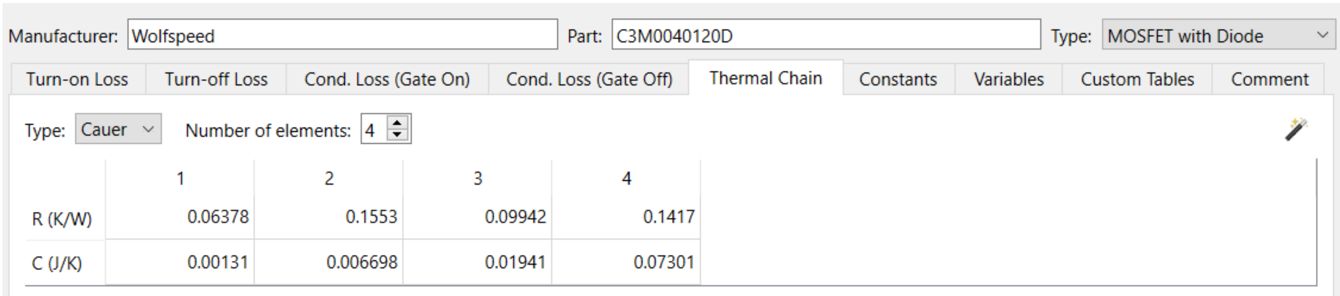


Figure 11: Example transient thermal model based on 4th order Cauer network

Note: For CAS modules, only Legacy models are available. In these modules, one switch position has a MOSFET and an external Schottky diode connected in parallel. These two devices have different junction-to-case thermal impedance networks, so they require separate thermal descriptions—one for the MOSFET and another for the Schottky diode.

2.2 Overview of Wolfspeed Diode PLECS models

2.2.1 Model Parameters

Schottky-Diode Parameters

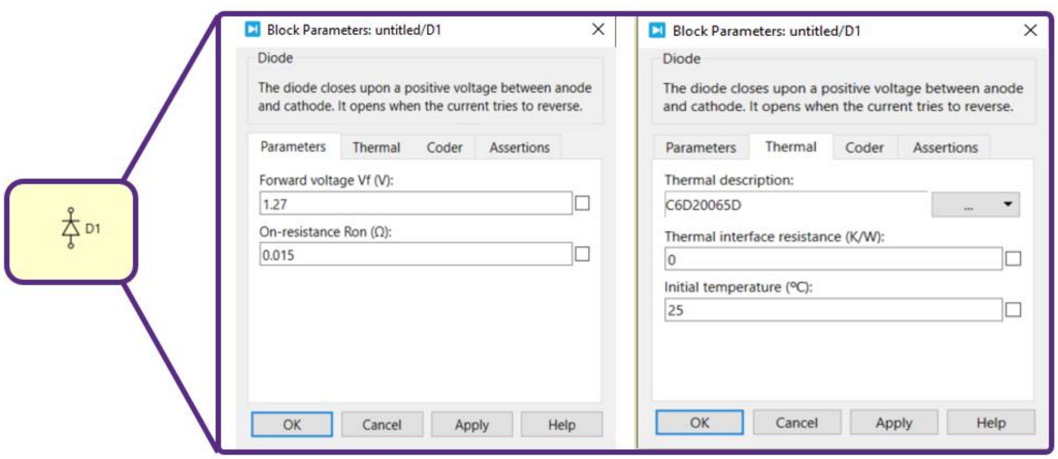


Figure 12: Schottky diode models parameters as seen in PLECS

Parameters	Tab	Details
Forward voltage Vf (V)	Parameters	Forward voltage drop of diode at operating conditions
On-Resistance Ron (Ω)	Parameters	The resistance R_{on} of the conducting diode
Thermal description	Thermal	Selects thermal description model of the diode
Thermal interface resistance (K/W)	Thermal	Thermal resistance between case and heatsink
Initial temperature (°C)	Thermal	Initial junction temperature at the start of simulation

2.2.2 Diode Conduction Losses

The conduction loss is modeled as voltage drop across the model and is a function of junction temperature and current flowing through the device, PLECS then internally calculated the conduction loss by taking the product of current flowing through the device and the voltage drop across it taken from the conduction loss look up table. PLECS will linearly interpolate/extrapolate from these values. Whenever the Diode conducts current, continuous power is dissipated in the thermal domain based on the drain current, temperature, and corresponding voltage drop in the diode as mentioned above. More information about the conduction loss can be found here: Conduction Losses.

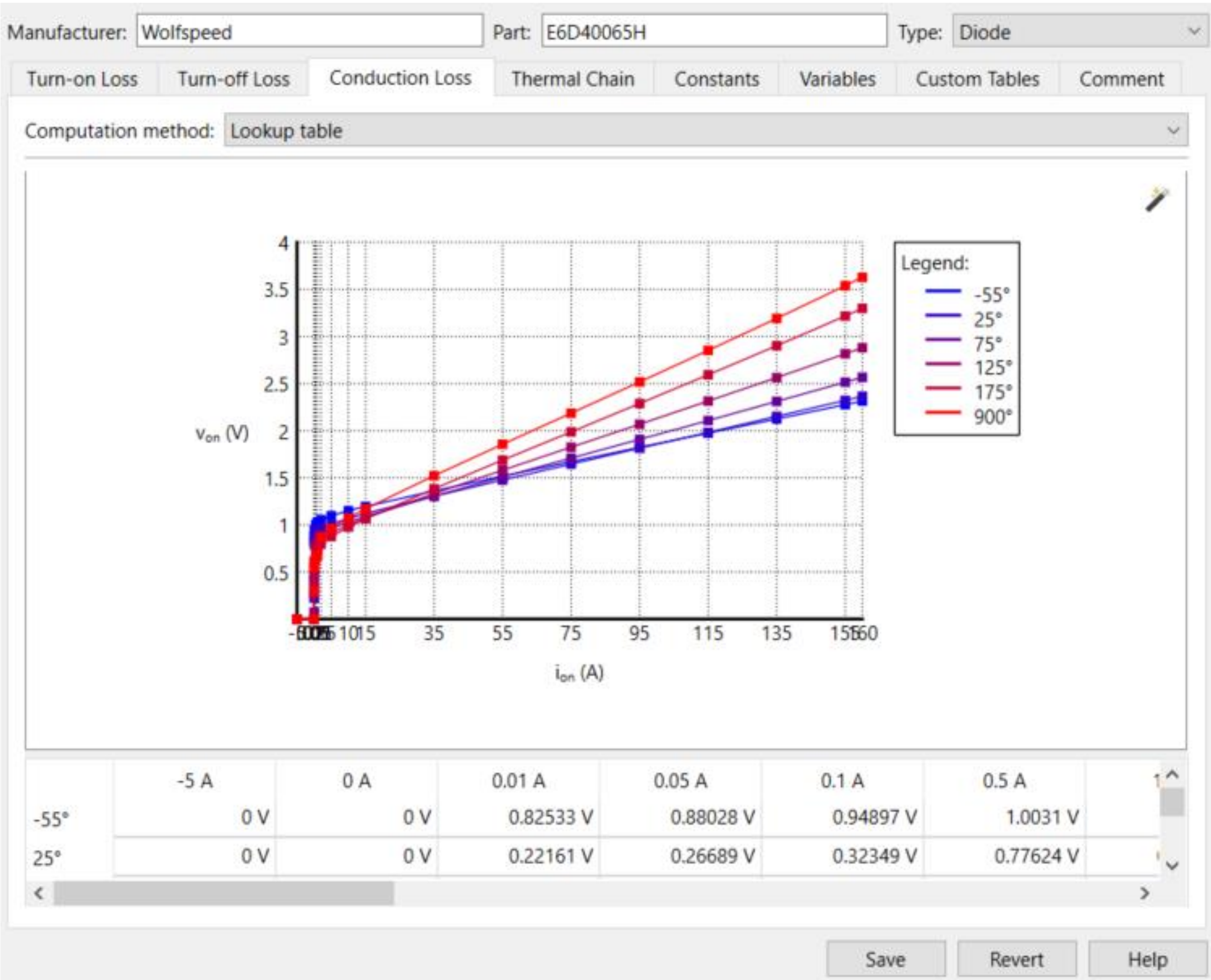


Figure 13: Diode conduction loss look-up table.

2.2.3 Thermal Network

A transient thermal impedance model is provided inside the Diode model for junction-to-case which is identical to the MOSFET thermal network model. An external thermal network can be added to model the heat management system's thermal performance (see Section 3.2, Modeling Thermal Management System for additional details). More information about Thermal network model can be found here: Editing the Thermal Equivalent Circuit.

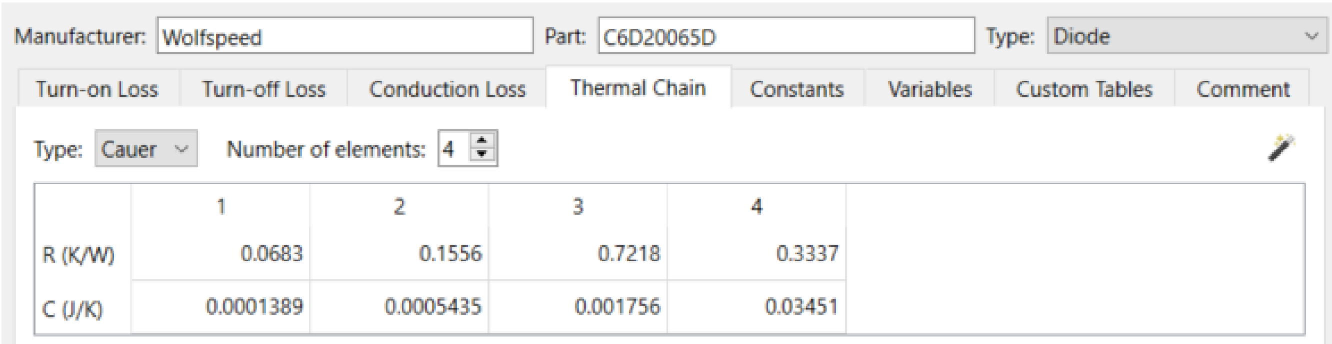


Figure 14: Example transient thermal model based on 4th order Cauer network

3. ADDITIONAL GUIDANCE AND BEST PRACTICE

3.1 Model Usage Tips

By following the steps in Section 2, the Wolfspeed thermal library will be added to a global path, i.e. any new simulation will be able to access them. The user can also include models in a local path, where the scope of use is only for a simulation file in the same folder. This is useful when modifications want to be made to the model, or if the user wants to keep version control of the thermal descriptions used in their simulation.

Local Path: To do this, in the directory where the simulation file is located, the user can create a folder with the same name as the *.plecs* file, with the suffix *_plecs*. These models will only be available for the specific simulation in that folder and will be the prioritized models by PLECS. As an example, if a simulation named *example_model.plecs* is created, then a folder named *example_model_plecs* containing the .xml files can be placed in the same directory. This is illustrated in Figure 15. Note that PLECS will add thermal files when started, so it will need to be restarted if the files are added while PLECS is already open (or the thermal library can be refreshed).

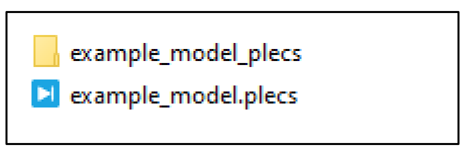


Figure 15: Example of local folder containing thermal models

The losses and temperatures are calculated from the electrical domain as turn-on, turn-off, and conduction losses. Therefore, the first step is for the user to set up an electrical system simulation. Once the electrical domain is working as intended, the Power semiconductor component (MOSFET, Module or Schottky diode) can be linked manually to a thermal model as shown in Figure 16. Alternatively, the model can be selected by a reference variable as shown in Figure 17.

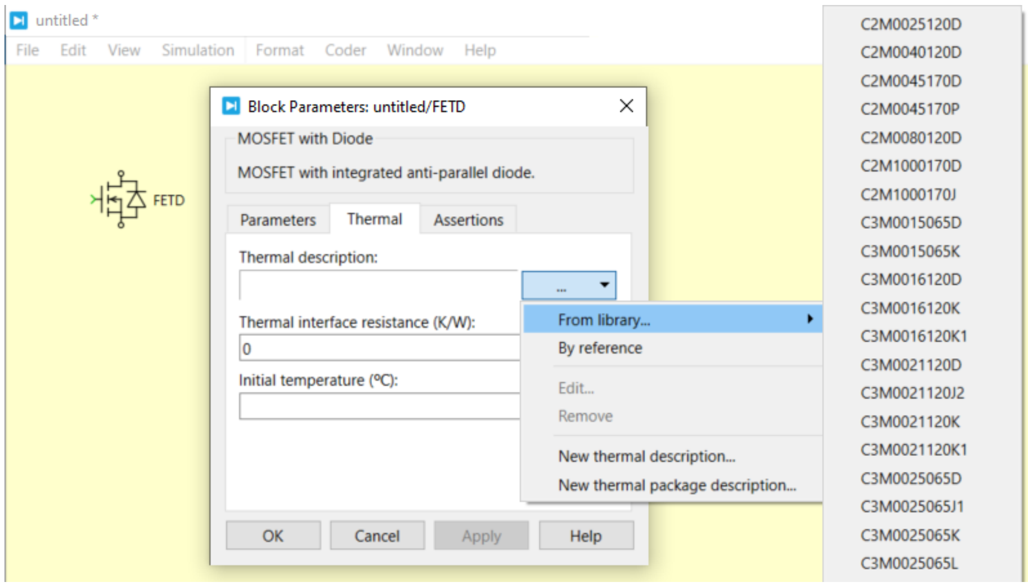


Figure 16: Example of selecting MOSFET thermal models (MOSFET with Diode model)

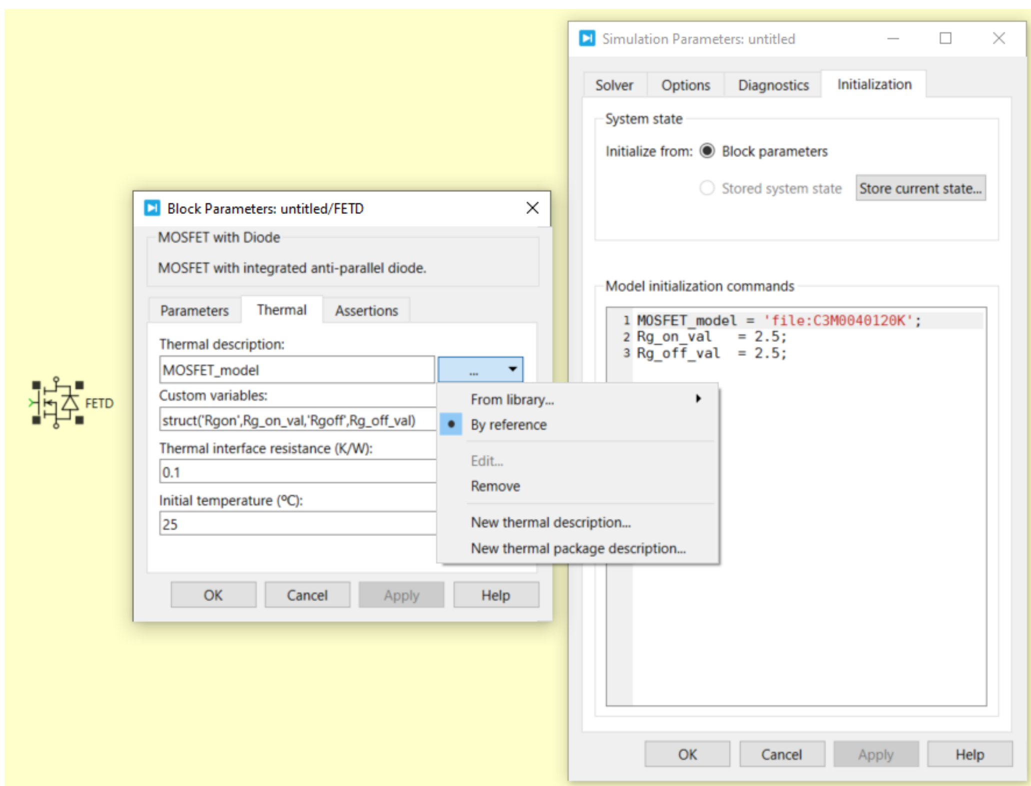


Figure 17: Example of selecting model using a variable

This can be advantageous as it allows easy switching between models or even control of the model selection from a simulation script (*Simulation → Simulation Scripts*).

3.2 Modeling Thermal Management System

When implementing a PLECS model, the model itself contains in the loss tables and internal thermal characteristics of the device. This, however, is not the complete system required in order to properly predict the junction temperature and losses (since temperature is an input to losses). As such, any MOSFET in PLECS which has a model file applied but no heatsink will generate the error shown in Figure 18.

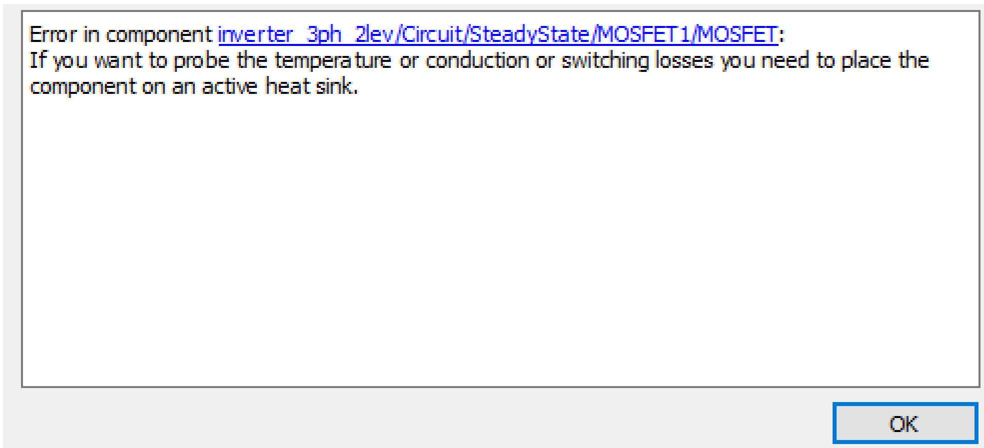


Figure 18: Error generated when a model is applied to a MOSFET with no heatsink

Instead, a heatsink must be placed under each device as shown in Figure 19.

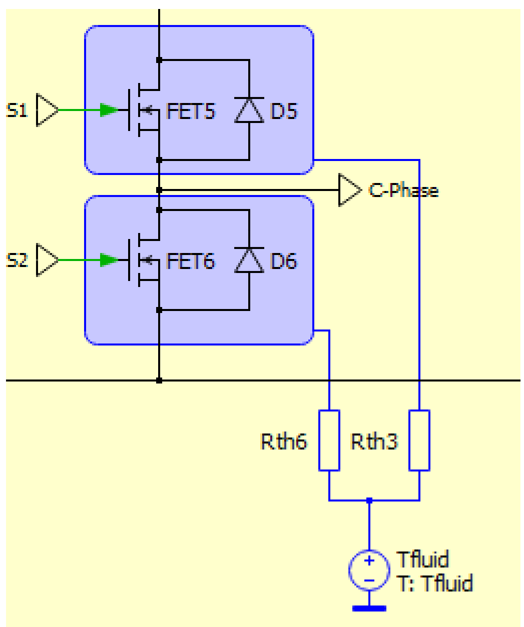


Figure 19: Example of MOSFET and diode with heatsinks for each switch position

The typical arrangement is to define a R_{TH} from case to ambient (or fluid) for each device (or switch position, in the case of a power module). This R_{TH} value can include both the contribution of the thermal interface and heatsink to ambient, or those elements can be divided into separate thermal equivalent resistances. Additionally, for more accurate transient temperature prediction, the capacitance of the heatsink can be estimated and included in the heatsink model. If the $R_{TH,ext}$ is not included, this capacitance will be ignored, and the case temperature will be locked to the external temperature applied. For modules with integrated pin-fins (e.g. ECB2R1M12YM3), the module already includes a thermal model representing $R_{TH,JF}$, and an external R_{TH} is unnecessary (although one can be used to approximate the module performance at lower flow rates).

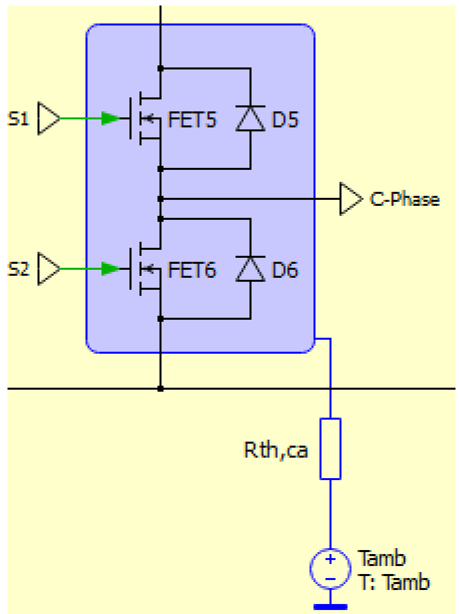


Figure 20: Alternate heatsink configuration for half-bridge power modules

For power modules, when the thermal capacitance is known, it is more accurate to use a single heatsink for all switch positions (two in the case of a half bridge). In general, more complex thermal models are possible, such as including a current source into the heatsink to represent the dissipation of a component not modeled in the electrical simulation (e.g. inductor losses).

4. FAQS

4.1 What gate voltage values were used for the loss tables in the model?

The models always use the recommended gate voltage, which is specified in the key parameters section of the device's datasheet, see "Operational Gate-Source Voltage". An example is shown in figure 21 from the [C3M0040120K](C3M0040120K) datasheet. Always refer to the latest datasheets.

Key Parameters

Parameter	Symbol	Min.	Typ.	Max	Unit	Conditions	Note
Drain - Source Voltage	V_{DS}			1200	V	$T_C = 25°C$	
Maximum Gate - Source Voltage	$V_{GS(max)}$	-8		+19		Transient	
Operational Gate-Source Voltage	$V_{GS\ op}$		-4/15			Static	Note 1

Figure 21: Example datasheet key parameters table

4.2 How is a module represented by the MOSFET symbol in PLECS? How do I implement a half-bridge model?

The model represents one switch position inside the module, and accounts for the parallel die in the module. Modeling the half-bridge CAB525F12XM3 requires two MOSFET symbols, as shown in the Figure 22.

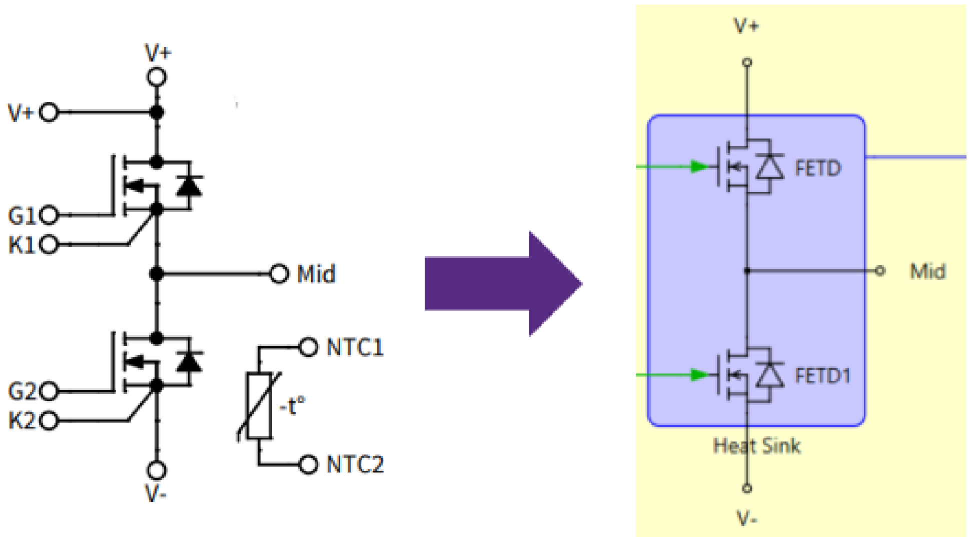


Figure 22: Example half-bridge implementation

4.3 Why is it necessary to select electrical parameters even if the thermal description is chosen?

The electrical parameters of the semiconductor (e.g. on resistance or forward voltage) are not linked by default to the thermal description. In general, PLECS separates the thermal and electrical domains to avoid logical loops which would reduce simulator performance. Additionally, semiconductor parasitics typically play a much smaller role in the macro behavior of the converter (for example, the drain current will be set by the inductors impedance in most situations). One particularly important caveat is that when using a MOSFET and diode in parallel (to simulate an external Schottky, for example), if both Ron and Vf are left as zero, PLECS will simulate equal current sharing between the devices, which can lead to incorrect loss calculations.

4.4 Why do I see spikes when I plot switching losses of a MOSFET?

While the conduction loss table of the MOSFET is stored as a voltage vs current curve, the switching loss table in the MOSFET model is stored in terms of energy. When a switching event occurs, a discrete impulse of energy loss is injected into the thermal system. To create a readable graph, these discrete loss events should be averaged into power loss. It can also be helpful to average conduction losses to see trends more clearly. There are two separate averaging blocks required for conduction and switching losses: the Periodic Averaging block and the Periodic Impulse Average block.

- **Periodic Average Block:** This block periodically averages a continuous input signal and is used to compute the average conduction loss over a specified averaging period.

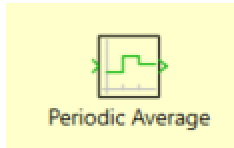


Figure 23: Periodic average block

- **Periodic Impulse Average Block:** Similar to the Periodic Averaging block, this block is designed to periodically average input signal consisting of Dirac impulses and are therefore suitable to calculate average switching losses of the device.

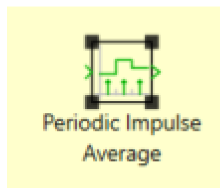


Figure 24: Impulse average block

Both the conduction losses and switching losses can be accessed using PLECS probe block as shown in Figure 25. The probe captures the relevant signals, which can then be directed to the averaging blocks to determine the conduction and switching power losses of the device.

Note: The above losses are only defined when the device is placed on a heat sink.

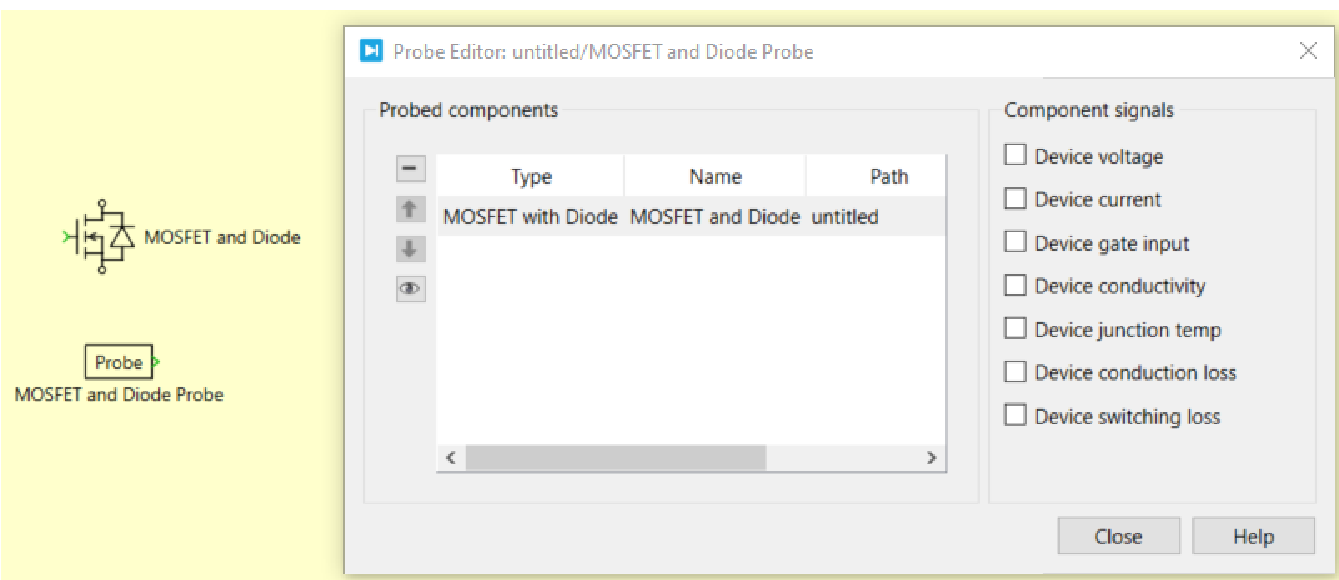


Figure 25: Example of a probe block

Revision History

Date	Revision	Changes
October 2025	1	Initial Release