



PLECS

*DEMO MODEL*

## Buck Converter with Thermal Model

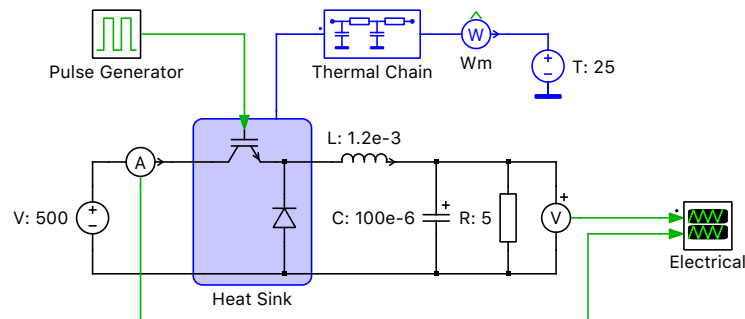
Last updated in PLECS 4.7.1

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# 1 Overview

This demonstration shows a simple unregulated buck converter including a basic thermal model. It serves as an example for using thermal descriptions, the heat sink and the thermal chain.



**Figure 1: Buck converter**

## 2 Model

### 2.1 Electrical Model

This schematic shows a simple buck converter using an IGBT. The circuit is clocked with a fixed frequency of 10 kHz.

### 2.2 Thermal Model

An example thermal description is assigned to both the IGBT and the free wheeling diode. These descriptions can be viewed and edited by double-clicking on the component and selecting **Edit...** from the drop-down menu of the **Thermal description** parameter. The thermal parameters were obtained from measurements of commonly available semiconductors.

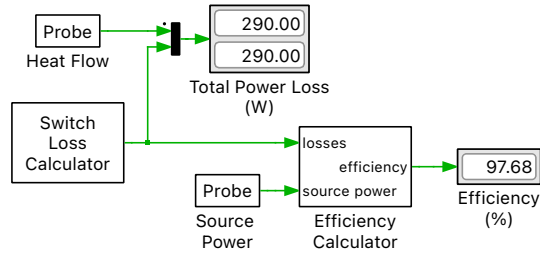
The two semiconductors can be considered to be packaged together as a chopper module. In this example the heat sink represents not the actual heat sink in the circuit, but a common surface that the two devices are connected to, and should be considered as the case of the chopper module. A Thermal Chain component is used to model the thermal transitions of the case of the semiconductors to the actual heat sink and from the heat sink to the ambient temperature of the environment. Note that hierarchical modeling for additional thermal layers, such as to include not only the case, but also the heat sink, is possible in PLECS. An example of this concept is shown in the demo model “Boost Converter with PFC and Thermal Model”.

The thermal descriptions for the IGBT and diode are stored in a private thermal library in the directory `/buck_converter_with_thermal_model_plecs`.

The average switching, conduction and total losses of the semiconductor devices can be calculated easily using the “Switch Loss Calculator” component. Select the switch components of interest in the schematic editor and drag them onto the probed components list of the “Switch Loss Calculator” block. For more details, browse the **Help** section of this block.

The Switch Loss Calculator block’s **Averaging time** parameter should be selected based on the specific circuit. For example, this typically should relate to the fixed switching frequency for DC-DC conversion systems ( $1/10e3$  for a 10 kHz switching frequency), though for AC systems the AC or line frequency is more appropriate ( $1/60$  for a 60 Hz line frequency). Note that for calculating losses in non-periodic systems, such as resonant converters, longer averaging intervals should be used to filter out variations in the conduction intervals.

The “Efficiency Calculator” subsystem calculates the converter efficiency using the source power and total switch losses.



**Figure 2: Thermal losses**

### 3 Simulation

The first Scope shows the output voltage and the source current. The second Scope shows the temperatures of the semiconductor junctions and case of the combined chopper package. The electrical values reach equilibrium very early on in the simulation while the temperature takes much longer to approach steady-state conditions.

#### 3.1 Steady-state Operation

The steady-state operating temperatures can be calculated with the Steady-State Analysis that is pre-configured in the model. For PLECS Standalone or Blockset (in Simulink) execute the following steps:

- *Standalone:* From the **Simulation** menu choose **Analysis tools...**. This opens a dialog, in which the analysis has already been pre-configured. To start the analysis, click on the **Start analysis** button. You can display the progress of the analysis by clicking on the **Show log** button.
- *Blockset:* Double-click on the Steady-State Analysis block to open the dialog and click on the **Start analysis** button. The progress of the analysis is displayed in the MATLAB Command Window.

When the analysis has finished a simulation of five steady-state cycles is displayed for all waveforms preconfigured in the Scope.

#### 3.2 Loss and Efficiency Calculation

The total average losses of the diode and IGBT are calculated and compared with the heat flow in the thermal circuit. Note that it takes several seconds for the heat sink to warm up, while the loss probes are connected directly to the source components. In this case the converter efficiency is calculated using the source power and total switch losses, but the heat sink can also capture ohmic losses from resistors.

The efficiency equation is derived as:

$$\frac{P_{\text{input}} - P_{\text{switches}}}{P_{\text{input}}} = 1 - \frac{P_{\text{sw}}}{P_{\text{in}}}$$

Note that this formula is the official instruction in PLECS since the thermal losses are not automatically fed back into the electrical network, and therefore any measurement of the power at the load will differ from the theoretical value and should not be used in determining the system efficiency.

## 4 Conclusion

This model uses blocks from the PLECS thermal domain to calculate the switching and conduction losses of an IGBT and a diode as well as model the thermal impedance network between device junction and ambient temperature. Control domain blocks are used to extract the same loss information without the use of the thermal domain, and to calculate the circuit efficiency.

## Revision History:

PLECS 4.3.1	First release
PLECS 4.7.1	Updated the model with the Switch Loss Calculator

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