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Application Note

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Thermal Network Calculation for Level-3 Compact Models

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Introduction:

Compact level-3 PSPICE and SABER models are designed for the calculation of the electrical and thermal behaviour of electronic devices. To achieve correct simulation results it is mandatory to include the correct temperature dependencies in the electrical device equations of the model. It is further necessary to choose an adequate model of the thermal path between the electronic device and the ambient heat sink.

The system of electrical equations is coupled to the thermal equations as a feedback loop. The dissipated electrical power is fed to the thermal system and the resulting temperature rise is used to re-evaluate the electrical parameters (Figure 1).

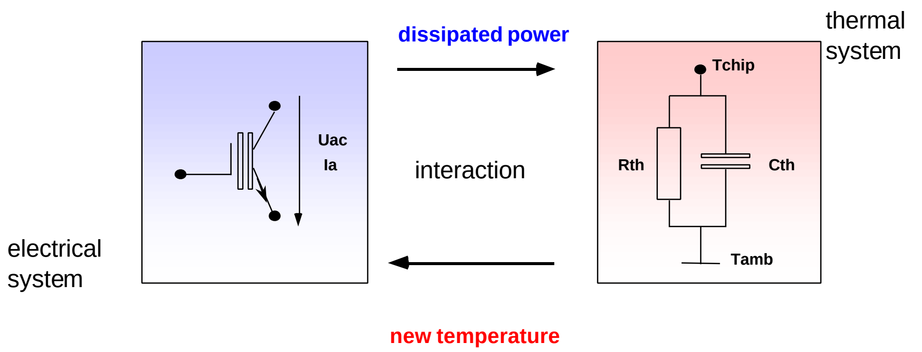

Figure 1: Interaction between the electrical and thermal sub-systems of a level-3 compact device model

This application note focuses solely on the thermal sub-system of the compact model. It describes how the appropriate thermal parameters are found.

Compact thermal models:

The parameters of the most common thermal model for electronic devices are directly extracted from measured device-cooling curves. Therefore, it is usually called the ‘practical thermal model’. As shown in Figure 2b, it consists of a chain connection of π-type thermal RC elements. The procedure of the thermal parameter extraction from measured cooling curves is widely described in literature.

The main drawback of this ‘practical model’ is, that, during the simulation of application circuits, it cannot be easily extended to include additional thermal devices such as new heat sinks.

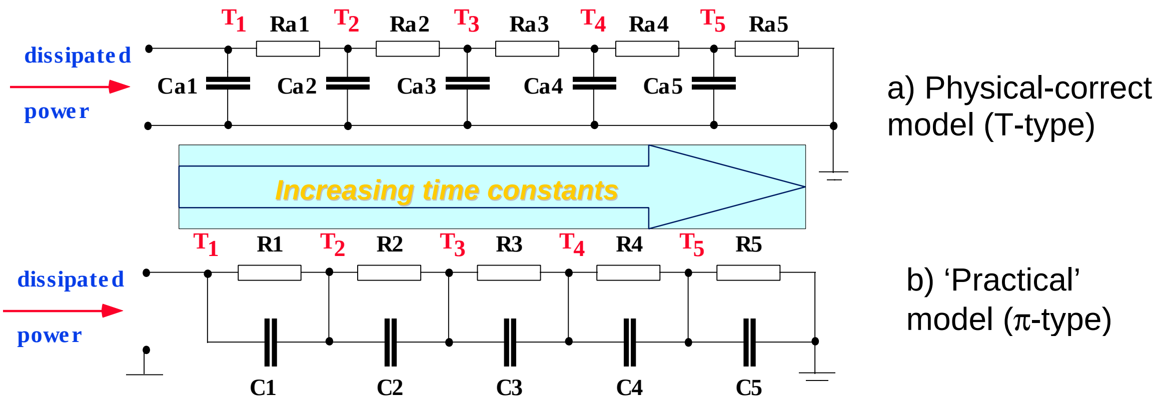

Figure 2: Thermal path models of electronic devices

Another type of model is the physical-correct model shown in Figure 2a. It consists of a chain connection of T-type RC elements and has the advantage that an extension with a heat sink model can be easily accomplished. The drawback of this type of model is that the parameters of this RC chain cannot be simply extracted from a cooling curve. The parameterization of this type of model requires a costly curve-fitting procedure or a detailed knowledge of the layer materials and layer sequence inside the device. It is very easy, however, to transform the parameters of the π-type thermal RC elements (Foster form according to circuit theory) into the appropriate T-type elements (Cauer form according to circuit theory).

The transformation procedure:

The transformation of the parameters of the 'practical model' into the parameters of the physical correct model is described in detail in [1]. It is based on the frequency-dependent representation of the RC chains.

In MATHCAD, the 'practical' thermal impedance function can be written as

$$\mathrm{Zth\_m}(s) := \sum_{\nu=0}^{n-1} \frac{\mathrm{Rth}_\nu}{1 + s \cdot \mathrm{Rth}_\nu \cdot \mathrm{Cth}_\nu}$$

where s = jω and n = Number of RC-cells of the chain connection.

The 'physical correct' thermal impedance function is by the equation:

$$\mathrm{Zth\_p}(s, \mathrm{Cth\_p0}, \mathrm{Rth\_p0}, \mathrm{Cth\_p1}, \mathrm{Rth\_p1}, \mathrm{Cth\_p2}, \mathrm{Rth\_p2}, \mathrm{Cth\_p3}, \mathrm{Rth\_p3}) := \cfrac{1}{s \cdot \mathrm{Cth\_p0} + \cfrac{1}{\mathrm{Rth\_p0} + \cfrac{1}{s \cdot \mathrm{Cth\_p1} + \cfrac{1}{\mathrm{Rth\_p1} + \cfrac{1}{s \cdot \mathrm{Cth\_p2} + \cfrac{1}{\mathrm{Rth\_p2} + \cfrac{1}{s \cdot \mathrm{Cth\_p3} + \cfrac{1}{\mathrm{Rth\_p3}}}}}}}}}$$

Furthermore, the following three assumptions apply:

1) The number of RC cells is identical in both chains.
2) The reciprocal value of the first chain capacitance in the physical-correct model is identical to the reciprocal sum of the capacitance values of the ‘practical model’.
3) The sum of the resistance values is identical in both models

Starting with the extracted ‘practical’ RC values and applying a ‘least-mean-square procedure’ to the physical-correct impedance function results in the fast and efficient transformation procedure.

Example:

As an example, the data-sheet values of the ‘practical’ thermal model of the DUOPACK IGBT SKW25N120 are used. The resulting impedance curve is displayed in Figure 3. The transformation, i.e. the least-mean-square procedure, is carried out by means of a MATHCAD document using the MATHCAD functions ‘MINFEHL’ (German version) or ‘MINERROR’ (English version). The resulting thermal impedance curve versus the complex frequency $s = j\omega$ is shown in Figure 3. The difference between the original and the transformed impedance curve is negligible.

In Table 1, the extracted RC parameters of the practical thermal model and the related transformed parameters are summarized.

Device: SKW25N120			
Parameters extracted from Zth curve (p)		*Transformed parameters (T – physical correct)*	
Rth in Ohms	Cth in Farad	Rth in Ohms	Cth in Farad
0.037	0.01	0.058	0.0081
0.081	0.041	0.078	0.038
0.209	0.43	0.216	0.391
0.074	6.728	0.049	9.696

Table 1: Parameter sets of alternative junction-case thermal models (DUOPACK IGBT SKW25N120)

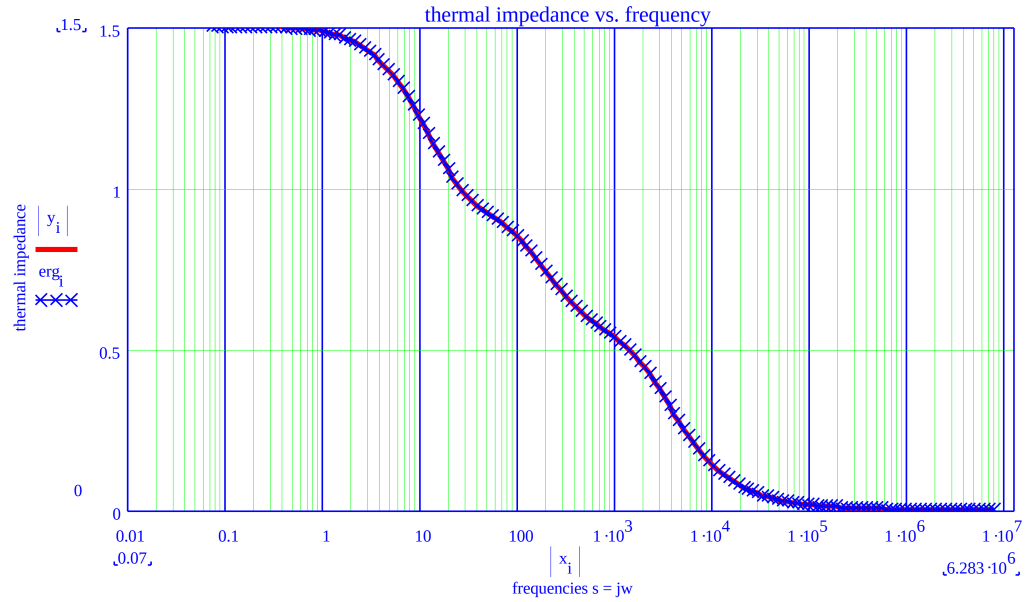

Figure 3: Comparison of thermal impedance curves (red: extracted parameters; blue: transformed parameters)

Summary:

The transformation procedure of ‘practical’ thermal to physical-correct model parameters can be easily implemented in a MATHCAD spreadsheet. The resulting physical correct parameter sets can be included in level-3 device models to simulate the device’s temperature behavior during operation. Furthermore, the physical-correct thermal model can be easily extended to include the influence of additional heat sinks.

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Bibliography:

[1] H. Müller, *Beziehungen zwischen dem praktisch verwendeten und dem physikalisch sinnvollen Wärmeersatzschaltbild von Dioden und Thyristoren,* Archiv für Elektrotechnik 54, p. 170 ff (1971)

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