Semiconductor component thermal model taking into account non-linearity and multipathing of the cooling system

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Outline

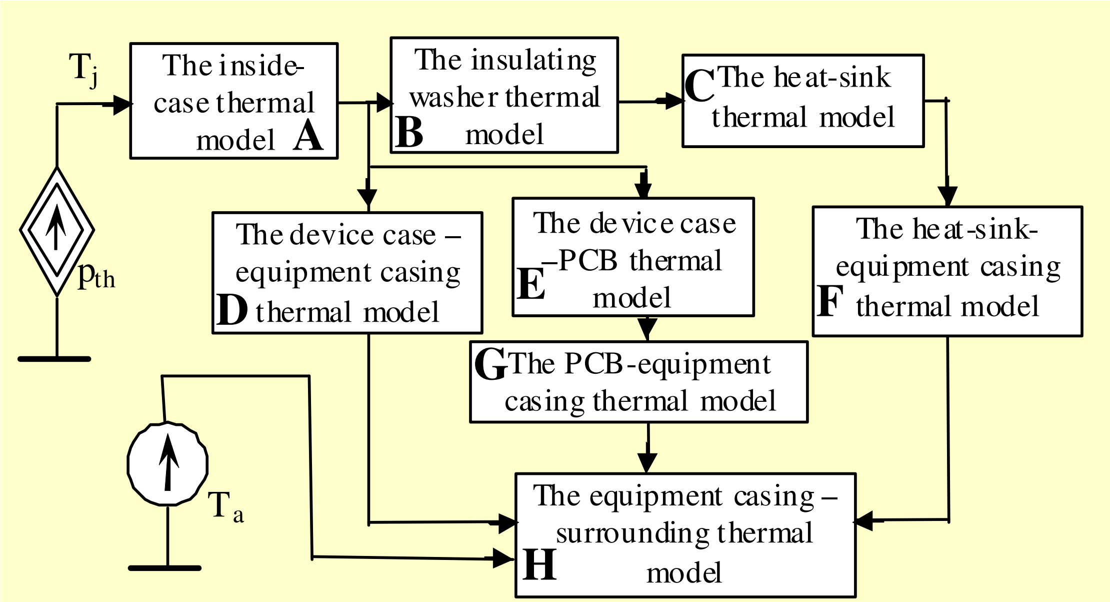
- Introduction
- The measuring set
- The model form
- Results
- Conclusions

Introduction (1)

- Ensuring effective cooling of electronic components is one of the most important challenges the designers and constructors of electronic and power electronics devices are facing.
- The designer usually has information about the estimated value of the power dissipated in the discrete electronic components and imposed restrictions concern, e.g. a permissible value of input power from the power source and the maximum size and shape of the system casing.
- Under these conditions, the cooling system components are often intuitively chosen.
- Selection of the components of the heat flow path is complicated and difficult due to the multipath heat transport from the die to the surroundings.
- In order to determine the thermal properties of the electronic components, their thermal models are formulated.

Introduction (2)

- The structure of the thermal model, taking into account the multipathing heat transport



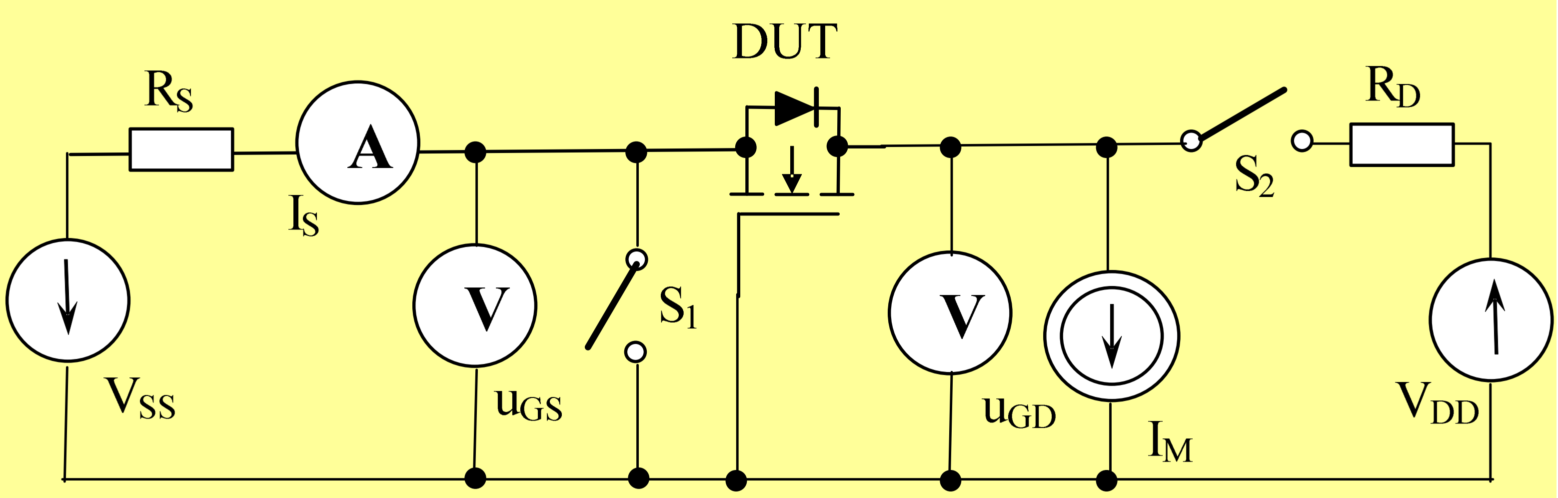
- As you can see, the heat can flow in various ways, using three mechanisms of its transfer: conduction, convection and radiation.

Introduction (3)

- The practical verification of the design of the cooling system typically is made experimentally by constructing a prototype.
- This often results in long time designing and oversizing cooling system components, leading to increase in the cost of the device.
- The commonly used thermal models have a form of the RC network of the Cauer or Foster structure.
- Due to the dependence of the parameters describing the heat stream through each elements of the path of the heat flow on temperature, the thermal model is generally non-linear.
- In the literature, only empirical dependencies describing the device transient thermal impedance on the dissipated power for the one chosen cooling condition of the device are described.
- In this paper the thermal properties of the circuit consisting of the power transistor mounted on aluminium heat sink with insulating washers and the Peltier module are analyzed.

Measuring set (1)

- The results of measurements of the transient thermal impedance are obtained by means of the electric method using the cooling curve.
- The voltage on the forward biased body diode is used as a thermally-sensitive parameter.
- The block diagram of this measuring set



Measuring set (2)

- On the basis of the measured runs of $u_{GD}(t)$, the thermometric characteristics $u_{GD}(T)$ and the value of the power P_H at the end of the second stage of the measurement, the course of the transient thermal impedance $Z_{th}(t)$ is calculated using the following formula

$$Z_{th}(t) = \frac{u_{GD}(t) - u_{GD}(T_a)}{P_H \cdot F}$$

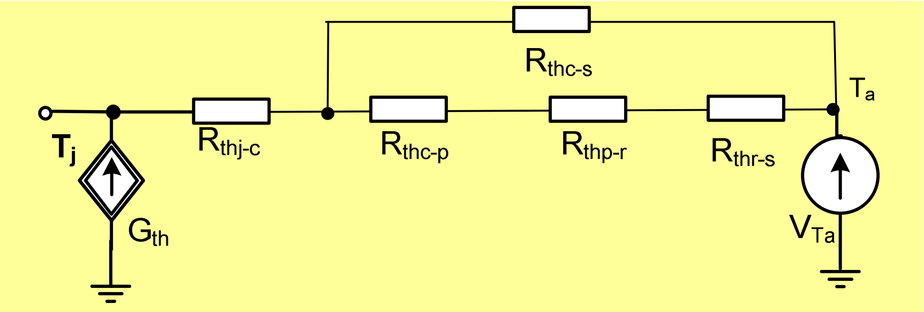
T_a - the ambient temperature

F - the slope of the thermometric characteristic $u_{GD}(T)$.

- The thermal resistance R_{th} is equal to the value of $Z_{th}(t)$ at the steady state.

Form of the thermal model (1)

- The cooling system of the power MOS transistor contains a heat-sink and a Peltier module.
- The formulated dc thermal model of the considered system



- The thermal resistance R_{thj-c} is equal to the value given by the producer in the catalogue card.
- The values of the thermal resistance between the case and the surroundings R_{thc-s} is estimated from the measurements of R_{thj-a} of the transistor operating without any heat-sink as the difference between R_{thj-a} and R_{thj-c}.
- The thermal resistance of the isolating washer can be given on the basis of the values of the thermal conductance and geometrical dimensions of the element case given by the producer.

Form of the thermal model (2)

- The thermal resistance between the heat-sink and the surroundings $R_{thr\text{-}s}$ can be obtained from the catalogue dependences of the thermal resistance of the heat-sink on its length.
- If such dependence is not accessible, the value $R_{thr\text{-}s}$ can be obtained on the basis of the measurement of the thermal resistance $R_{thj\text{-}a}$ of the transistor installed on the heat-sink and it can be calculated from the dependence:

$$R_{thr-s} = R_{thj-a} - R_{thj-c} - R_{thc-p} - R_{thp-r}$$

- It should be taken into account that the value of $R_{thr\text{-}s}$ depends on the spatial orientation of the heat-sink and the values of this parameter at different orientations of the heat-sink can differ from one other of even about 20%.
- The value of the thermal resistance between the Peltier module and the heat-sink

$$R_{thp-r} = R_{th3} - R_{th4}$$

- R_{th3} - the value of $R_{thj\text{-}a}$ of the transistor with the heat-sink and the Peltier module
  R_{th4} - the value of $R_{thj\text{-}a}$ of the transistor with the heat-sink without the Peltier module
- The value $R_{thp\text{-}r}$ is a decreasing function of both the power p_{th} dissipated in the examined transistor and the power p_p supplying the module.

Results (1)

- The correctness of the worked out thermal model was verified for the power MOS transistor IRF530 operating at different cooling conditions
  - For the transistor situated on the heat-sink without the additional isolating washer the thermal resistance between the heat-sink and surroundings $R_{thr\text{-}s}$ is non-linear - its value depends on the power p_{th} dissipated in the transistor

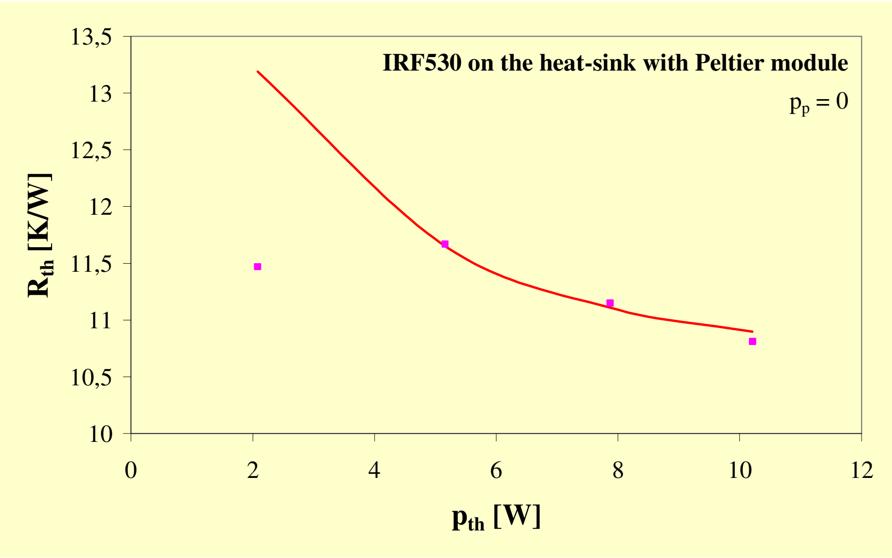
$$R_{thr-s} = R_0 + R_1 \cdot \exp\left(-\left(p_{th} - p_0\right)/a\right)$$

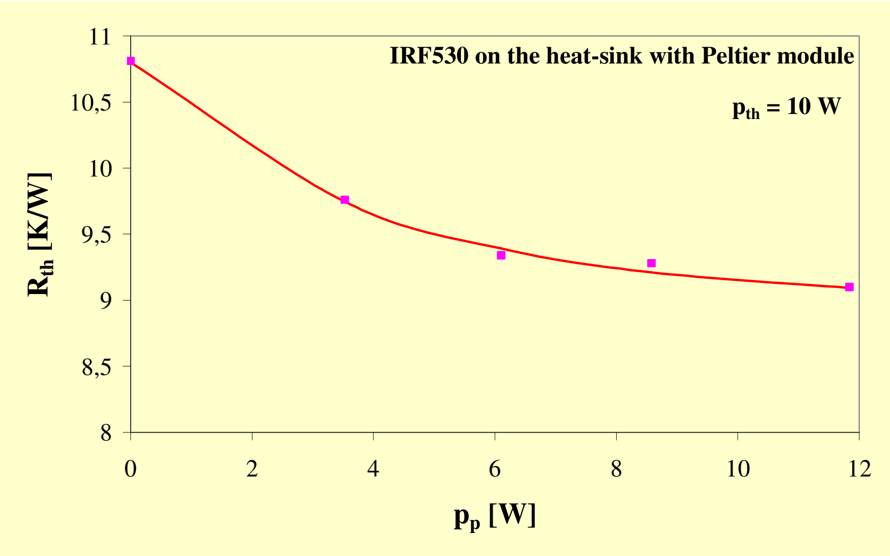
  - For the considered cooling system R_0 = 1.9 K/W, R_1 = 1.5 K/W, p_0 = 12 W, a = 8 W.
- The operation of the transistor IRF530 separated from the same heat-sink through the Peltier module is also considered.
- The thermal resistance of the connection between the case of the device and the module is 0.5 K/W.
- The thermal resistance of the Peltier module depends both on the temperature difference between both its sides, and hence on the power p_{th} dissipated in the examined device, and on the power p_p supplying the Peltier module. The thermal resistance $R_{thp\text{-}r}$ is described by the formula

$$R_{thp-r} = R_2 + R_3 \cdot \exp\left(-p_p/b\right) + R_4 \cdot \exp\left(-\left(p_{th} - p_1\right)/c\right)$$

- For the considered transistor, the values of parameters in the equation are as follows: R_2 = 4.7 K/W, R_3 = 1.8 K/W, R_4 = 1 K/W, p_1 = 5 W, b = 4 W, c = 3.2 W.

Results (2)





points – results of measurements
lines – results of calcualtions

Conclusions

- In the paper the thermal model of power semiconductor devices taking into account the multipath and nonlinearity of phenomena describing the heat transport is proposed.
- The results of calculations and measurement shown in the paper prove the correctness of the worked out model.
- The parameters of this model are estimated on the basis of the catalogue data or from the simple measurement, which can be performed by the user.
- The obtained results of the verification of the model both at free and forced cooling testify to the generality of the worked out model.
- Currently the authors are conducting works the aim of which is to take into account in the presented model: the thermal inertia, sizes and the shape of the heat-sink or printed circuit boards and the influence of the case of the device on efficiency of heat dissipation in the examined transistor.