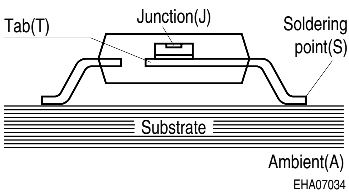
Thermal Resistance calculation

1 Thermal Resistance

The heat caused by the power loss P_{tot} in the active semiconductor region during operation results in an increased temperature of the component. The heat is dissipated from its source (junction J or channel Ch) via the chip, the case and the substrate (pc board) to the heat sink (ambient A). The junction temperature T_J at an ambient temperature T_A is determined by the thermal resistance R_{thJA} and the power dissipation P_{tot}:

$$T_J = T_A + P_{tot} \times R_{thJA}$$

(with R_{thJA} in K/W or °C/W)



2 RF and AF Transistors and Diodes in SMD Packages

In SMD packages the heat is primarily dissipated via the pins. The total thermal resistance in this case is made up of the following components:

$$R_{thJA} = R_{thJT} + R_{thTS} + R_{thSA}$$
$$R_{thJS} = R_{thJT} + R_{thTS}$$

R_{thJA} thermal resistance between junction and ambient (total thermal resistance)

R_{thJS} thermal resistance between junction and soldering point

R_{thJT} thermal resistance between junction and chip base (chip thermal resistance)

R_{thTS} thermal resistance between chip base and soldering point (package/alloy layer)

R_{thSA} thermal resistance between soldering point and ambient (substrate thermal resistance)

R_{thJS} contains all type-dependent quantities. For a given power dissipation P_{tot} it is possible to use it to precisely determine the component temperature if the temperature T_S of the warmest soldering point is measured (for bipolar transistors typically the collector, for FETs the source lead).

$$T_J = T_S + P_{tot} \times R_{thJS}$$

The temperature of the soldering point T_S is determined by the application, i.e. by the substrate, heat produced by external components and the ambient temperature T_A. These components combine to form the substrate thermal resistance R_{thSA} that is circuit-dependent and can be influenced by heat dissipation measures.

$$T_S = T_A + P_{tot} \times R_{thSA}$$

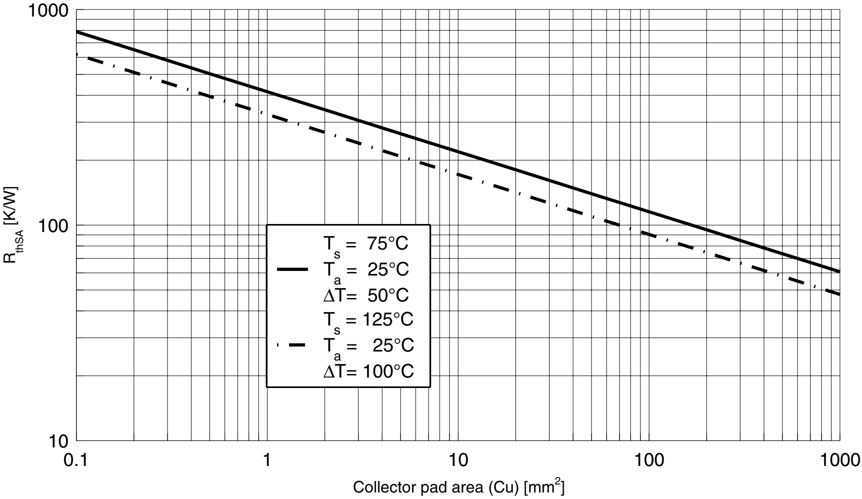
If measurement of the temperature of the soldering point T_S is not possible, or if estimation of the junction temperature is sufficient, R_{thSA} can be read from diagrams below. Here we give an approximate value of the thermal resistance R_{thSA} between the soldering point on an epoxy or ceramic substrate and still air as a function of the area of the collector mounting or ceramic. The parameter is the dissipated power, i. e. the heat $T_S - T_A$ of the pc board. So in this case for the operating temperature:

$$T_J = T_A + P_{tot} \times (R_{thJS} + R_{thSA})$$

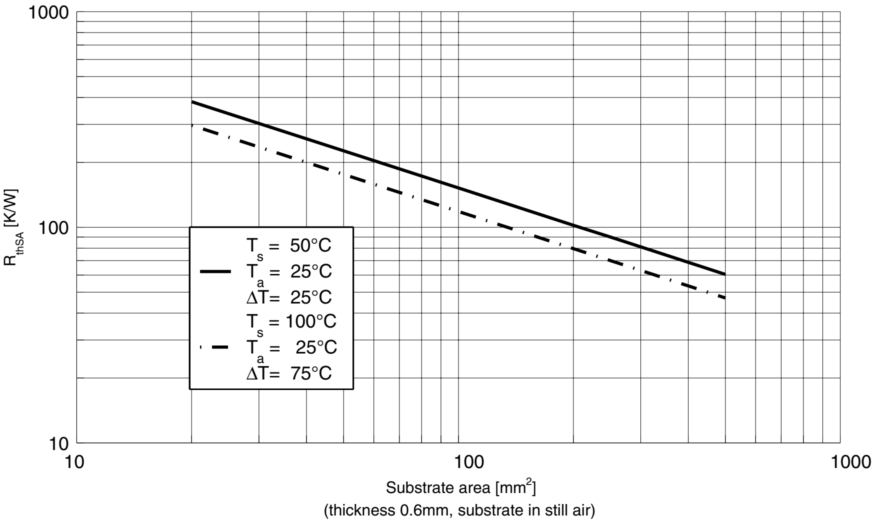
In the data sheets R_{thJS} is stated as a thermal reference quantity of the heat dissipation. The total thermal resistance R_{thJA} is stated for comparison purposes. Depending on the typical component application, substrates of the following kinds are used for reference:

- AF applications epoxy circuit board: collector mounting area in cm^2 Cu (see **data sheets**), thickness 35 µm Cu.
- RF applications ceramic substrate: 15 mm × 16.7 mm × 0.7 mm (alumina) or epoxy circuit board with collector mounting area corresponding to 80 K/W.

The two diagrams below show, to an approximation, the thermal resistance as a function of the substrate area, assuming that the test device is located in the center of a virtually square substrate.



Heat Dissipation from PC Board to Ambient Air
(mounting pad Cu 35 µm/ substrate: epoxy 1.5 mm)



Heat Dissipation from Al_2O_3-Substrate to Ambient Air
(substrate in still air, vertical 0.6 mm thick)

2.1 Temperature Measuring of Components Leads

Measuring with temperature indicators (e. g. thermopaper)

Temperature indicators do not cause heat dissipation and thus allow an almost exact determination of temperature. A certain degree of deviations can only result from rough-grade indication of the temperature indicators. This method is quite easy and provides sufficient accuracy. It is particularly suitable for measurement on pc boards.

Measuring with thermocouple elements

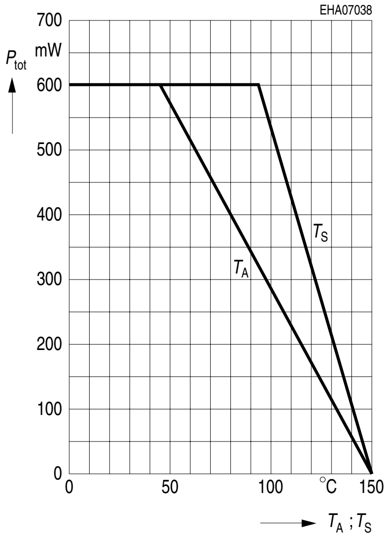
Measurement with thermocouple elements is not advisable because the functioning of the circuit can be influenced by the electrical conduction and the heat dissipation by the soldering point. This corrupts the results of the measurement, unless measurement is carried out with appropriate effort.

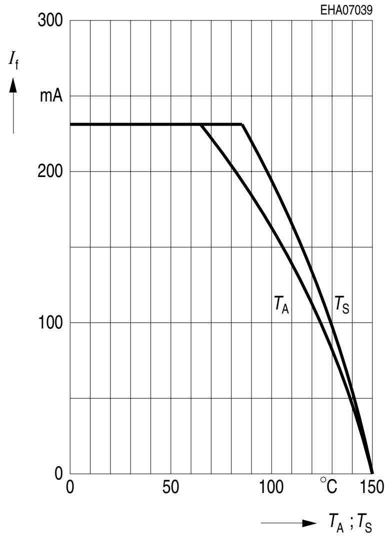
2.2 Permissible Total Power Dissipation in DC Operation

The total power dissipation P_{tot} defines the maximum thermal gradient in the component. As a result of the heating of components, the maximum total power dissipation $P_{tot\,max}$ stated in the data sheets is only permissible up to limits of $T_{S\,max}$ or $T_{A\,max}$. These critical temperatures describe the point at which the maximum permissible junction temperature $T_{J\,max}$ is reached. The maximum permissible ambient or soldering-point temperature is calculated as follows:

$$T_{S\,max} = T_{J\,max} - P_{tot\,max} \times R_{thJS}$$
$$T_{A\,max} = T_{J\,max} - P_{tot\,max} \times R_{thJA}$$

In diodes the power dissipation is for the most part caused by internal resistance. So the diagram has to be translated into the form $I_F = f\,(T_S;\,T_A)$, resulting in the bent shape of the curve. For R_{thJA} the appropriate standard substrate was taken in each case. The diagrams shown here are intended as examples. For the application the curve given in the data sheet is to be taken. Exceeding the thermal max. ratings is not permissible because this could mean lasting degradation of the component's characteristics or even its destruction.





Total Power Dissipation
$P_{tot} = f\,(T_S;\ T_A{}^{1)})$

Forward Current
$I_F = f\,(T_S;\ T_A{}^{1)})$

1) Al_2O_3-Substrat 15 mm × 16,7 mm × 0,7 mm / Package mounted on alumina 15 mm × 16.7 mm × 0.7 mm

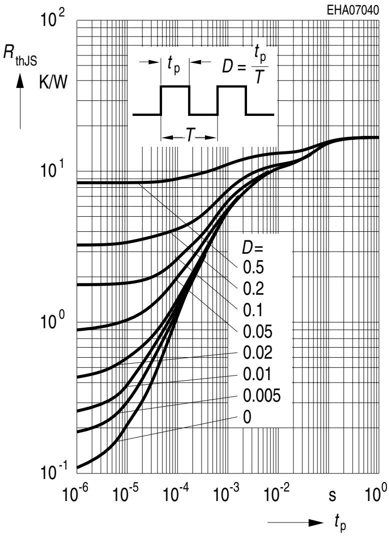
2.3 Permissible Total Power Dissipation in Pulse Operation

In pulse operation, under certain circumstances, higher total power dissipation than in DC operation can be permitted. This will be the case when the pulse duration t_p, i. e. the length of time that power is applied, is small compared to the thermal time constant of the system. This time constant, i. e. the time until the final temperature is reached, depends on the thermal capacitances and resistances of the components chip, case and substrate. The thermal capacitance utilized in the component is a function of the pulse duration.

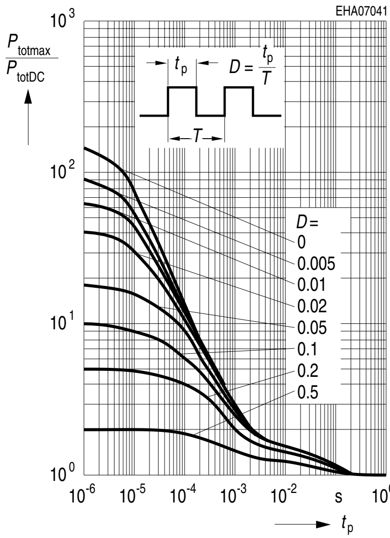
Here we describe this through the transient thermal resistance. The pulse-load thermal resistance, or the permissible increase in P_{tot} that can be derived from it, is shown by way of examples in the following curves. For the application the particular data sheet should be taken.

$$P_{tot\ max} / P_{tot\ DC} = f\,(t_p)$$

The duty factor t_p/T is given as a parameter for periodic pulse load with a period of T. For long pulse durations the factor $P_{tot\ max} / P_{tot\ DC}$ approaches a value of 1, i. e. P_{tot} in pulsed operation can be equated with the DC value. At extremely short pulse widths, on the other hand, the increase in temperature as a result of the pulse (residual ripple) becomes negligible and a mean temperature is created in the system that corresponds to DC operation with average pulse power.



Permissible Pulse Load
$R_{thJS} = f(t_p)$



Permissible Pulse Load
$P_{tot\ max}/P_{tot\ DC} = f(t_p)$