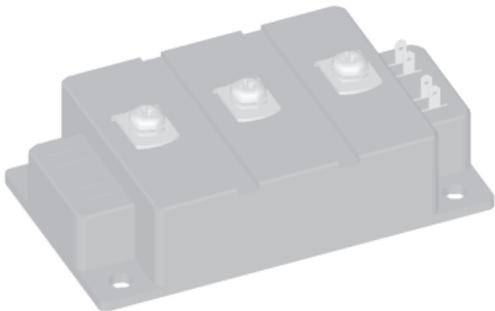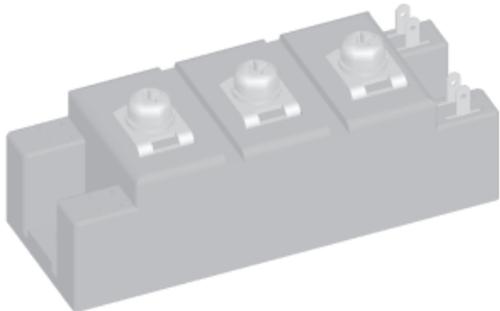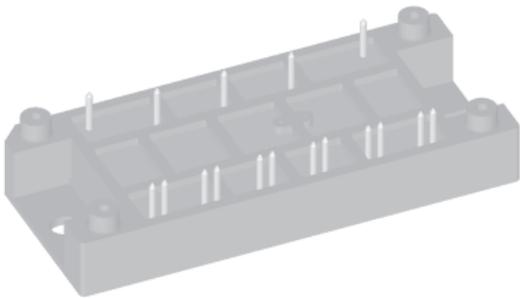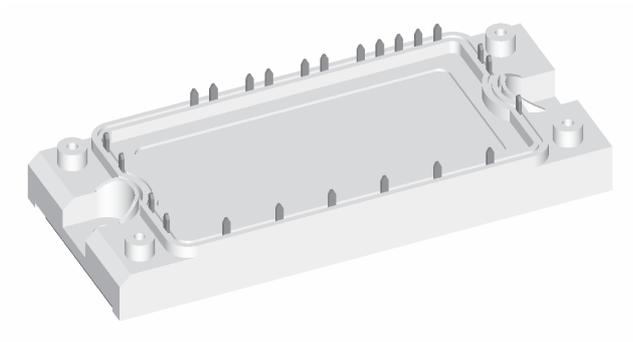Technical
Information

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Choosing the Appropriate
Component from
Data Sheet Ratings
and Characteristics

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This application note is intended to show how to choose the appropriate rating of a power semiconductor component for a known application using the specifications given in the data sheet. The explanations have been kept sufficiently general to be applicable to all common power circuits. However, for the sake of concreteness, they focus on IXYS IGBT modules and discretes respectively with or without diode. Proceeding as described in the following enables the designer to gain all necessary information from the data sheets for the most economic selection of power semiconductors.
For further details about data sheet specifications and ratings, please refer to the standards [1] for IGBTs, [2] for diodes and [3] for general remarks in their actual versions.

1   Power Losses

Power losses are important in several respects: Besides the efficiency of a converter, they determine heatsink and cooling method along with the rating of power semiconductors required. Power losses occur in several ways as explained in the following sections:

1.1 Conduction Losses

Conduction losses are caused by the forward voltage drop when the power semiconductor switch has been turned on by

$$P_C = V_{forward}(I) \bullet I \qquad (1)$$

where I is the current carried and $V_{forward}$ is the current dependant forward voltage drop given by table 1.

The given data should be used as follows:

- Using the numerical value is the most simple way to determine conduction losses. The numerical value can be applied if the current in the device is equal or close to the current it is specified for; data sheet numerical values are given for typical application currents.

- The graph most accurately deter-mines conduction losses. However data generation and calculation become rather laborious.

- A good compromise is to use the equation with the parameters given in the data sheet: For the sake of simplification, the exponential function of forward voltage drop has been linearized for the typical range of operating points.

- Please make sure the conditions the data used are given for correspond to the application. To estimate if a power semiconductor rating is appropriate, usually the values valid for elevated temperature, close to the maximum junction temperature T_{Jmax}, should be used to calculate power losses because this is commonly the operating point at nominal load - independent from temperature coefficient of the parameter being positive - such as saturation voltage of NPT IGBTs - or negative - such as forward voltage of fast diodes, at least at lower currents.

  This caveat should also be applied to the other types of losses as discussed below.

1.2 Blocking Losses

Blocking losses are generated by a low leakage current through the device while blocking a high voltage

$$P_B = V_{block}(I) \bullet I \qquad (2)$$

where I is the leakage current and V_{block} is the blocking voltage applied.

The data sheet indicates leakage current at certain blocking voltage and temperature. The dependence between leakage current and applied voltage typically is exponential; this means that using a data sheet value given for a blocking voltage higher than applied overestimates blocking losses. However in general, blocking losses are small and can often, but not always, be neglected.

1.3   Switching Losses

1.3.1   IGBT

IGBTs are designed for use in switching converters and not linear operation. This means switching time intervals are short compared to the pulse durations at typical switching frequencies, as can be seen from their switching times, such as fall time t_f and rise time t_r in the data sheets. Switching losses occur during these switching intervals.

For IGBTs they are specified as an amount of energy for a certain switching operation according to table 2.

Again the given data should be used as follows - see also section 1.1:

- Using the numerical value is the most simple way to determine switching losses. The numerical value can be applied if the switching operations are carried out at the same or similar conditions as indicated in the data sheet.

- The graphs permit the most accurate determination of switching losses, given the parameters of converter design - R_G - and converter current I_C.

	IGBT	Diode
numerical value	$V_{CE(sat)}$	V_F
graph	$I_C (V_{CE})$	$I_F (V_F)$
equation	$V_{CEsat} (I_C) = V_0 + R_0 \bullet I_C$	$V_F (I_F) = V_0 + R_0 \bullet I_F$
conditions	I_C: collector current V_{GE}: gate emitter voltage T_J: junction temperature	I_F: forward current T_J: junction temperature

Table 1: characterization of forward voltage drop

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Power Losses

	turn on	**turn off**
numerical values	E_{on}	E_{off}
graphs	$E_{on}(I_C)$, $E_{on}(R_G)$	$E_{off}(I_C)$, $E_{off}(R_G)$
conditions I_C: collector current... V_{CE}: collector emitter voltage... V_{GE}: gate emitter voltage... R_G: gate resistor T_J: junction temperature	...after turn on ...before turn on ...before and after turn on	...before turn off ...after turn off ...before and after turn off

Table 2: characterization of IGBT switching losses

- In some applications, collector emitter voltage V_{CE} in the blocking state slightly differs from the value as considered to be typical and indicated as a condition in the data sheet. In this case a linearization around the operating point according to

$$E_{on/off} = E_{on/off,\ ind.} \bullet \frac{V_{CE}}{V_{CE,\ ind.}} \quad (3)$$

may help to determine switching losses more accurately. $E_{on/off}$ and V_{CE} are the actual vaues in the application, while $E_{on/off,\ ind.}$ and $V_{CE,ind}$ are the vaues indicated in the data sheet.

- Please note that the specifications in the data sheet refer to typical operation in hard switching. However data for soft switching may be gained mainly using the graphs as listed in table 2 and by choosing the appropriate operating conditions defined by the snubber or resonant circuit:

  A properly designed snubber will reduce the switching losses the snubber is designed for - typically turn off losses, while the losses during the second switching operation - typically turn on - may also be influenced depending on the snubber circuit.

  Resonant switching can reduce switching losses in the power semiconductor close to zero depending on the circuit.

1.3.2 Diode

Diodes mainly experience turn off losses when used in a hard switching circuit with inductive load. In this case, the diode is carrying current, which commutates to a transistor being turned on, thus forcing the diode to turn off and take over blocking voltage, which is the case considered below. Applying voltage to a diode not carrying current - for example in resonant circuits or with an ohmic load - can eliminate diode turn off losses almost completely.

Diode turn off losses in a hard switching circuit with an inductive load are given by:

$$E_{off} = \left| \int_{t_o}^{t_o + t_{rr}} V_R \bullet I_F \bullet dt \right| \quad (4)$$

An idealized waveform of diode commutation is shown in figure 1; it helps to simplify equation 4 to an analytical expression as follows:

$$E_{off} = \frac{1}{8} \bullet I_{RM} \bullet V_R \bullet t_{rr} \quad (5)$$

With equations 4 or 5, diode switching losses can easily be estimated for the operating point in the application using the parameters given in the data sheet according to table 3.

Corresponding to section 1.3.1, the following use of data sheet values is recommended:

- Using the numerical values is the most simple way to determine switching losses. The numerical values can be applied if the switching operations are carried out at the same or similar conditions as considered to be typical and thus indicated as numerical values in the data sheet.

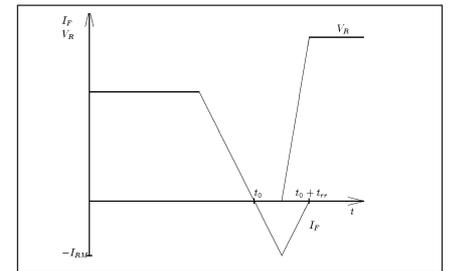- The graphs allow a more accurate determination of switching losses.

Figure 1 Idealized turn off waveform of a diode

numerical values	I_{RM}, t_{rr}
graph conditions	$I_{RM}(di/dt)$, $t_{rr}(di/dt)$ I_F: forward current before commutation di_F/dt: current fall rate during commutaiton V_R: reverse blocking voltage after turn off T_J: junction temperature

Table 3: Characterization of diode reverse recovery

- Please note again the specifications in the data sheet refer to the typical operation of hard switching. However data for soft switching may be gained mainly using the graphs as listed in table 3 and by choosing the appropriate operating conditions defined by the snubber or resonant circuit:

  A properly designed snubber will reduce the switching losses the snubber is designed for - typically turn off losses.

  Resonant switching is capable to reduce switching losses in the power semiconductor close to zero depending on the circuit.

Further Information on Fast Recovery Epitaxial Diodes FREDs is given in [4].

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2 Chip Temperature

Having calculated the power losses according to section 1, chip temperature can be computed for a certain component considering cooling conditions. Chip temperature must not exceed the maximum specified value $T_{J,max}$. Please be aware that all values of thermal resistance and impedance in the data sheets as explained in the following, refer to components that have been mounted according to the mounting instructions for the package.

There are two possibilities of calculating chip temperature: Average calculation which is more simple but often sufficient and dynamic calculation usually using a computer. The proceeding for both is described in the following sections.

2.1 Average Calculation

Average calculation can be advantageously used if switching frequency is sufficiently high in the kHz range and operating conditions of the device - which means mainly blocking voltage, forward current, switching frequency and duty cycle - are not time variant. This often is the case for DC-DC-converters. However the method may also be helpful for an initial estimation with typical values even if not all conditions are fulfilled.

Proceed as follows: Average power dissipation for one period of switching frequency is calculated using the values given by equations 1, 2, 4 or table 2 respectively along with equation 6:

$$\overline{P}_V = P_C \bullet d + P_B \bullet (1-d) + f_{sw} \bullet (E_{on} + E_{off}) \quad (6)$$

where f_{sw} is the switching frequency and d with $0 \leq d \leq 1$ is the duty cycle - the device is turned on for d/f_{sw}. Average junction temperature can then be calculated using

$$\overline{T}_J = \overline{P}_V \bullet R_{thJC} + T_C \quad (7)$$
$$\overline{T}_J = \overline{P}_V \bullet R_{thJH} + T_H \quad (8)$$

where T_C and T_H are constant case and heatsink temperatures and R_{thJC} and R_{thJH} are the values of thermal

resistance junction to case and heatsink respectively given in the data sheet. The calculation referring to heatsink is recommended if case temperature is unknown. To determine heatsink temperature the information required should be looked for in the data sheet of the heatsink; if it is measured, please make sure the temperature probe is fixed at least as close as possible to the module on the surface of the heatsink with a good thermal coupling.

Please note junction temperature will fluctuate around the average during one switching period; this amplitude however is rather low when the switching frequency is high enough, as mentioned as a condition above.

2.2 Dynamic Calculation

If an average calculation according to section 2.1 is considered to be not sufficiently accurate, a dynamic calculation can be used to determine time dependent junction temperature based on thermal impedance.

For this purpose, it is of course necessary to determine as a first step the electrical waveforms of current and voltage for each switch depending on supply, load and the pulse pattern generated by the control unit: Considering the different electrical and thermal shapes, durations and time constants, it usually will be most suitable to model the power semiconductors as ideal switches for this purpose. Based on these results in the next step time dependant power dissipations in the semiconductors - P_C, from equation 1, P_B from equation 2, E_{on} and E_{off} according to table 2 or equation 4 - are calculated. Depending on the variation of quantities calculated in the first step, the use of certain average values in the second step may however be possible to reduce computation effort to a minimum: For example, in an inverter with a switching frequency of several kHz and a 10 Hz sinusoidal output, the main variation of junction temperature is due to the 10Hz oscillation. The additional amplitude due to switching frequency may be neglected in many cases.

Dynamic calculation is based on a physical model of the power semiconductor component consisting of thermal resistances and thermal capacities together constituting a thermal network according to figure 2. The number of RC networks connected depends on the mechanical assembly of the component; however for practical reasons a reduction to the significant networks may be advantageous.
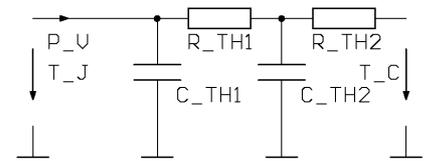

Figure 2 Equivalent circuit for a physical model of thermal impedance

There are several indications for thermal impedance in the data sheet, all of them referring to the component heat flow from junction to case:

- Z_{thJC} (t): Transient thermal impedance is shown graphically as a function of time. It is defined as

$$Z_{thJC}(t) = \frac{T_J(t) - T_{J0}}{P_V(t)} \quad (9)$$

with a constant power dissipation P_{V0} applied beginning at t = 0:

$$P_V(t) = \begin{cases} 0 & \text{for} \quad t < 0 \\ P_{V0} & \text{for} \quad t \geq 0 \end{cases} \quad (10)$$

Before, thermal equilibrium is assumed, so that:

$$T_J(t = 0) = T_{J0} \quad (11)$$

It thus describes the shape of junction temperature as the step response of the thermal network with the input being power dissipation and the output being junction temperature - in other words the transmittance $T_J(P_V)$ is characterized in the time domain. This transmittance can be used to determine junction temperature depending on a variety of input functions - see [5] and [6].

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The shape of this step response is characterized by the following limits:

$$\lim_{t \to 0} Z_{thJC}(t) = 0 \tag{12}$$

$$\lim_{t \to \infty} Z_{thJC}(t) = R_{thJC} \tag{13}$$

Case temperature is a disturbance variable to be determined by the knowledge of the thermal transition to the heatsink - basically characterized by R_{thJH}-R_{thJC}, the heatsink itself and the environmental conditions.

Thus Z_{thJC} describes the dynamic behaviour from the point of view of control.

- In case a simulation of the electrical circuit is performed, an equivalent electrical model is most advantageous to compute junction temperature. For this purpose the parameters R_{thi} and C_{thi} belonging to a circuit as shown in figure 2 may be indicated in the data sheet. This permits to directly integrate the thermal into the electrical simulation. This point of view of electrical circuitry is common to designers of electronics.

The impedance of the network in steady state again leads to the thermal resistance as explained in section 2.1:

$$R_{thJC} = \sum_{k=1}^{n} R_{thk} \tag{14}$$

with n being the number of R-C-networks.

Again the knowledge of case temperature T_C is essential because the calculation using Z_{thJC} only determines the difference between junction and case temperature - see above.

3 Conclusion

Several methods have been shown how to estimate power losses and junction temperature of a power semi-conductor component in an application. They are based on the knowledge of the application and the power semi-conductor data sheet; the latter is intended to contain all necessary information for this purpose. Accuracy partially depends on the computing effort - the simple methods permitting mental arithmetic may lead to a first rough estimation while accuracy increases using other methods of calculation and simulation described. The aim anyway has been to provide generally applicable procedures requiring only the necessary minimum of effort and being executable for each professional designer of power electronics.

It is recommended to make use of these means in the design phase of any converter to choose the most appropriately sized and cost effective power semiconductor components.

References
[1] IEC60747-9: Insulated Gate Bipolar Transistors (IGBTs)
[2] IEC60747-2: Rectifier Diodes
[3] IEC60747-1: General Remarks on Maximum Ratings and Characteristics, Test
[4] Rüdiger Bürkel, Thomas Schneider: Fast Recovery Epitaxial Diodes (FRED) - Characteristics, Applications, Examples; IXYS Semiconductor Data Book, Lampertheim, 1998
[5] O. Föllinger: Laplace- und Fourier-Transformation; AEG-Telefunken AG, 3. Auflage
[6] O. Föllinger: Regelungstechnik - Einführung in die Methoden und ihre Anwendung; Hüthig Buch Verlag, 6. Auflage

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