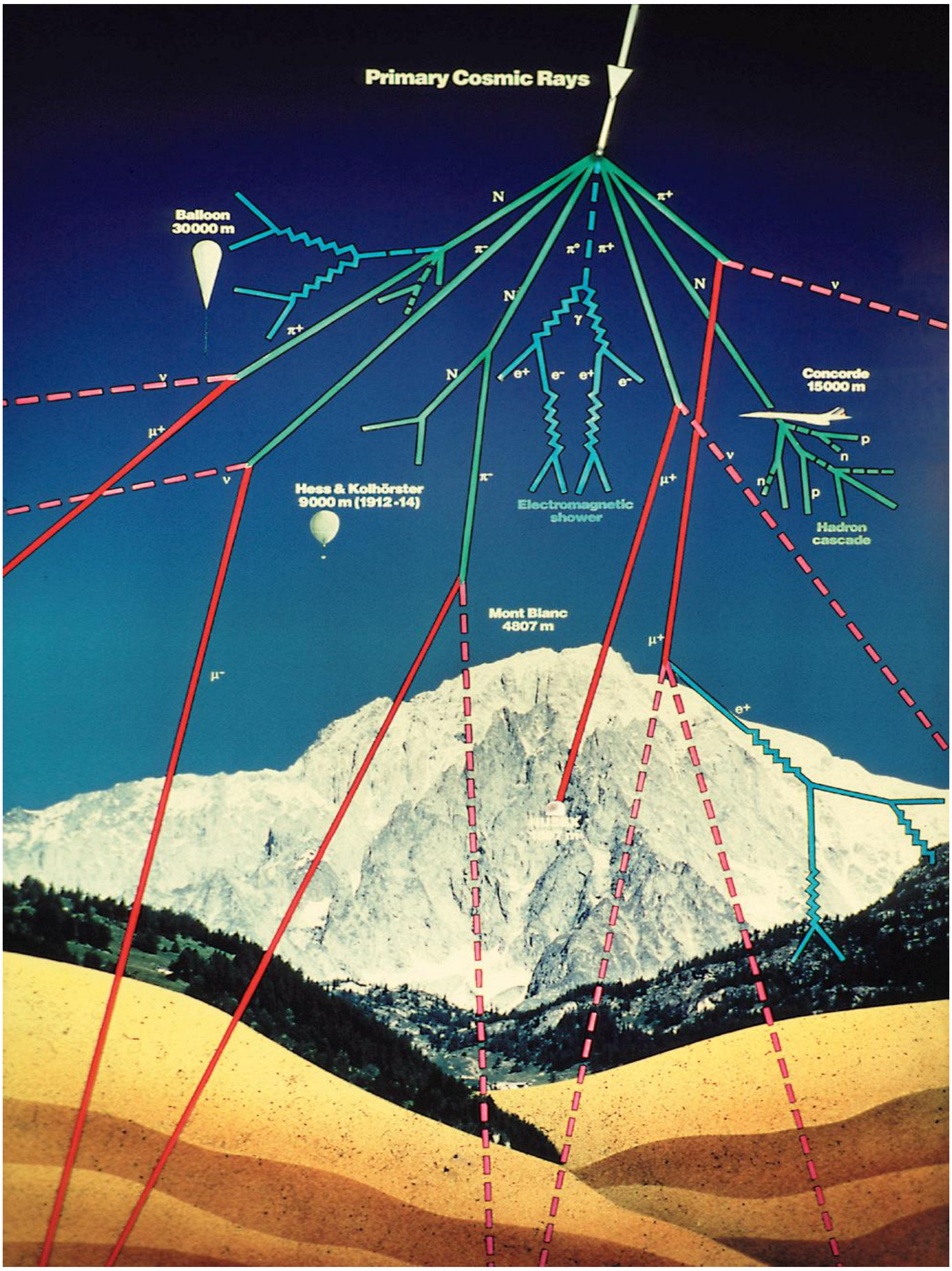
Failure Rates of HiPak Modules Due to Cosmic Rays



Failure Rates of HiPak Modules Due to Cosmic Rays

Application Note 5SYA 2042-02

Nando Kaminski

ABB Switzerland Ltd, Semiconductors

November 2004

Table of Contents:

1 Introduction

In the early 1990's a new failure mode for high current, high voltage semiconductor devices was discovered. The failure mode was of considerable practical significance and caused a series of equipment malfunctions in the field.
This failure mode affects all kind of devices like diodes, thyristors, GTOs, IGCTs, IGBTs, etc. It consists of a localised breakdown in the bulk of the devices and is not related to junction termination instabilities. The location of the breakdown spot on the wafer is random. The onset of the breakdown occurs without a precursor within a few nanoseconds and there is no sign of early failures or wear out. The failure rate is, thus, constant in time but strongly dependent on the applied voltage and shows a small dependence on temperature.
Experiments in a German salt mine 140m below ground did not show any of these failures, while experiments on the Jungfraujoch (3480m above sea level) in the Swiss Alps yielded a much higher failure rate than in laboratories close to sea level. Furthermore, irradiation with heavy energetic particles creates the same failure patterns. All together it was concluded that "cosmic rays" are the root cause of this kind of failure and this conclusion is now supported by a huge number of experiments done all around the world.

Primary cosmic rays are high-energy particles, mostly protons, that are found in space and that penetrate our atmosphere. They come from all directions and have a wide energy range of incident particles. Most of these cosmic rays originate from supernovae. Originally the Austrian physicist Viktor Hess (Nobel Prize 1936) discovered cosmic rays because of the ionization they produce in our atmosphere. In fact, a primary cosmic ray particle usually does not reach the surface of the earth directly but collides with an atmospheric particle (see front page). There it generates a variety of other energy-rich particles, which later collide with other atmospheric particles. The process of a cosmic ray particle colliding with atmospheric particles and disintegrating into smaller pions, muons, neutrons, and the like, is called a cosmic-ray shower. Most of the generated particles are harmless for semiconductor devices but some, mostly neutrons, may be lethal. Occasionally cosmic ray related events are observed, which do not lead to any perceivable damage but in general, the device is doomed even if fast fuses are used.

Today ABB's high current, high voltage semiconductors are designed such that the failure rate due to cosmic rays is reduced to an "acceptable" level. Nevertheless, cosmic-ray induced failures have to be taken into account for every power electronic circuit. In particular, semiconductors for applications with a high utilisation of the device's blocking capability and for equipment operating at high altitudes have to be assessed carefully. This application note is intended to provide a basis on which the power electronics designer can estimate failure rates, adjust parameters such as DC-link voltages or simply select the right semiconductor device for a particular application.

2 Modelling the Failure Rates

In order to provide the user with a simple failure rate calculation tool, a mathematical model was developed that covers the three most important influences: blocking voltage, junction temperature, and altitude. The failure rate model consists of three multiplicands:

- • the dependence on the DC-voltage (V_{DC} in volts, $V_{DC} > C_1$) at nominal conditions, i.e. 25°C and sea level
- , the dependence on the temperature (T_{vj} in degrees Celsius), term equals unity if T_{vj} equals 25°C
- ƒ the dependence on the altitude (h in meters above sea level), term equals unity if h equals 0, i.e. sea level.

Altogether the formula reads:

$$l(V_{DC},T_{vj},h) = \underbrace{C_3 \cdot \exp\left(\frac{C_2}{C_1 - V_{DC}}\right)}_{\bullet} \cdot \underbrace{\exp\left(\frac{25 - T_{vj}}{47.6}\right)}_{,} \cdot \underset{f}{\exp\left(\frac{1-\left(1-\frac{h}{44300}\right)^{5.26}}{0.143}\right)}$$

The multiplicands , and ƒ equal unity at nominal conditions (25°C and sea level, respectively). Thus, the formula can be simplified for certain cases. If e.g. a converter operates only at sea level multiplicand ƒ can be neglected.

NB:
- The model delivers failure rates in FIT, i.e. number of failures within 10^9 element hours.
- The formula is only valid if the DC-link voltage V_{DC} is larger than the parameter C_1 because the formula has a pole at C_1. For V_{DC} values below C_1 the failure rate is regarded as zero.
- The failure rate model describes only failures that are due to cosmic rays. The model does not cover failures due to other root causes.

2.1 Voltage Dependence

The formula for the voltage dependence (multiplicand •) is a pure fit to measured data. The formula has no physical background but fits the data almost perfectly as can be seen in the graphs shown in section 3. The model's parameters C_1, C_2, and C_3 are, therefore, characteristic values of the individual devices and can be looked up in the table in section 3. The parameters have also no physical meaning.

2.2 Temperature Dependence

The formula for the temperature dependence (multiplicand ‚) is again a fit to measured data. However, experiments indicate that the failure rates decrease exponentially with temperature and that this dependence is practically independent of the device type. Therefore, the formula does not require any device specific parameters.

2.3 Altitude Dependence

The formula for the altitude dependence (multiplicand ƒ) assumes a screening of cosmic rays by the atmosphere and is, thus, based on the barometric formula. This implies that all devices are affected the same way, so again the formula does not contain any device specific parameters.

3 Failure Rates of the Individual HiPak Types

The following table gives the device-specific parameters for the individual HiPak types. The cosmic ray measurements were done on chip-level. The model parameters were afterwards fitted to the measured failure rates scaled to the number of chips in the respective HiPak. All values are typical values and may vary considerably.

Product	C_1 [V]	C_2 [V]	C_3 [FIT]
5SNA 1800E170100	983	914	$3.41 \cdot 10^6$
5SNA 2400E170100	983	914	$4.55 \cdot 10^6$
5SNA 1200E250100	1200	750	$4.44 \cdot 10^5$
5SNA 1200E330100 5SNA 1200G330100	1784	2211	$1.41 \cdot 10^6$
5SNA 0600G650100	2866	12100	$2.72 \cdot 10^7$

Section 3.1 gives two examples of how to calculate the failure rate by using the formula and sections 3.2 to 3.6 show some selected graphs for each product listed above together with the underlying measurements.

3.1 Calculation Examples

Assume a 1700V-1800A-HiPak (5SNA 1800E170100) operated at a DC-link voltage of 1250V, a temperature of 125°C and at sea level. Because the altitude is at its nominal value the last multiplicand can be ignored. Together with the parameters from the table above, the failure rate formula now reads:

$$l(1250V, 125°C, 0m) \;=\; 3.41 \cdot 10^6\, FIT \cdot \exp\left(\frac{914}{983 - 1250}\right) \;\cdot\; \exp\left(\frac{25 - 125}{47.6}\right) \;\approx\; 13600\, FIT$$

13600 FIT means 13600 failures within 10^9 element hours or an MTTF of 1/λ = 73500 h, i.e. 8.4 y. Assuming a converter output stage with six HiPak modules, the MTTF reduces to 1.4 y and this is usually not regarded as sufficient reliability. Obviously, the targeted DC-link voltage is too high.

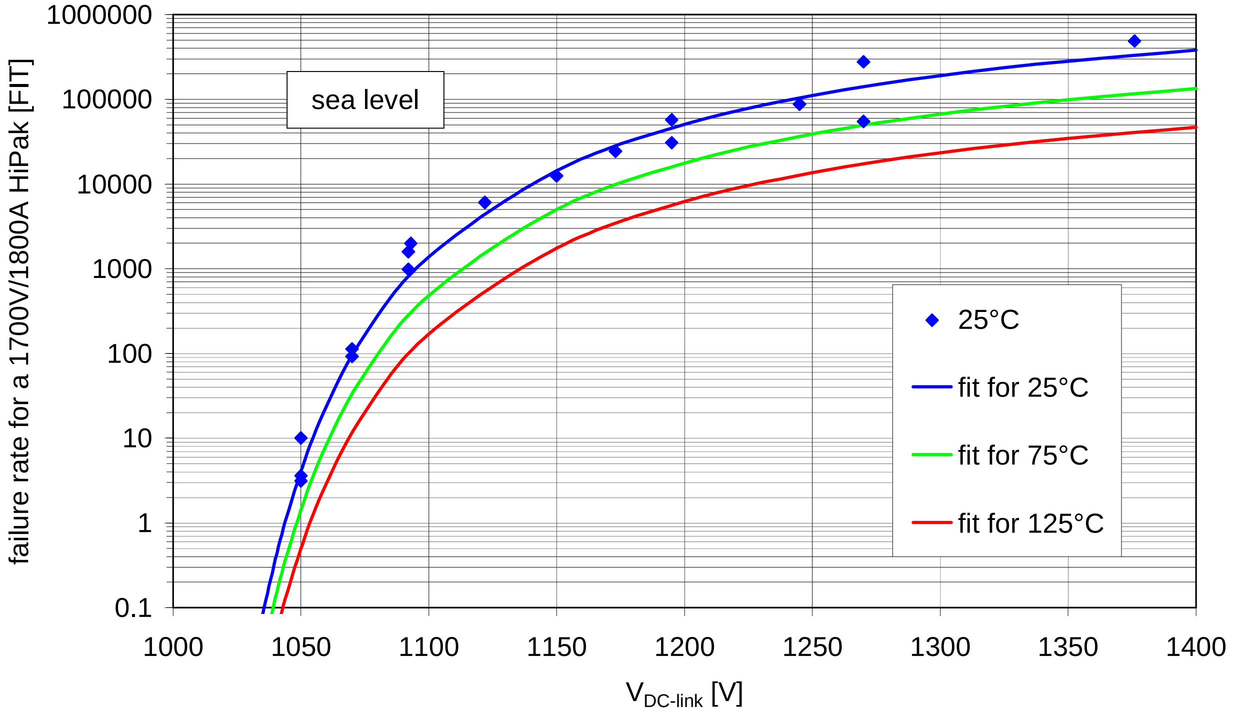
Assume now a 2500V-1200A-HiPak (5SNA 1200E250100) that is operated at a DC-link voltage of 1250V, a temperature of 25°C and at an altitude of 6000m. Because the temperature is at its nominal condition the multiplicand ‚ can be ignored. Together with the parameters from the table above the failure rate formula now reads:

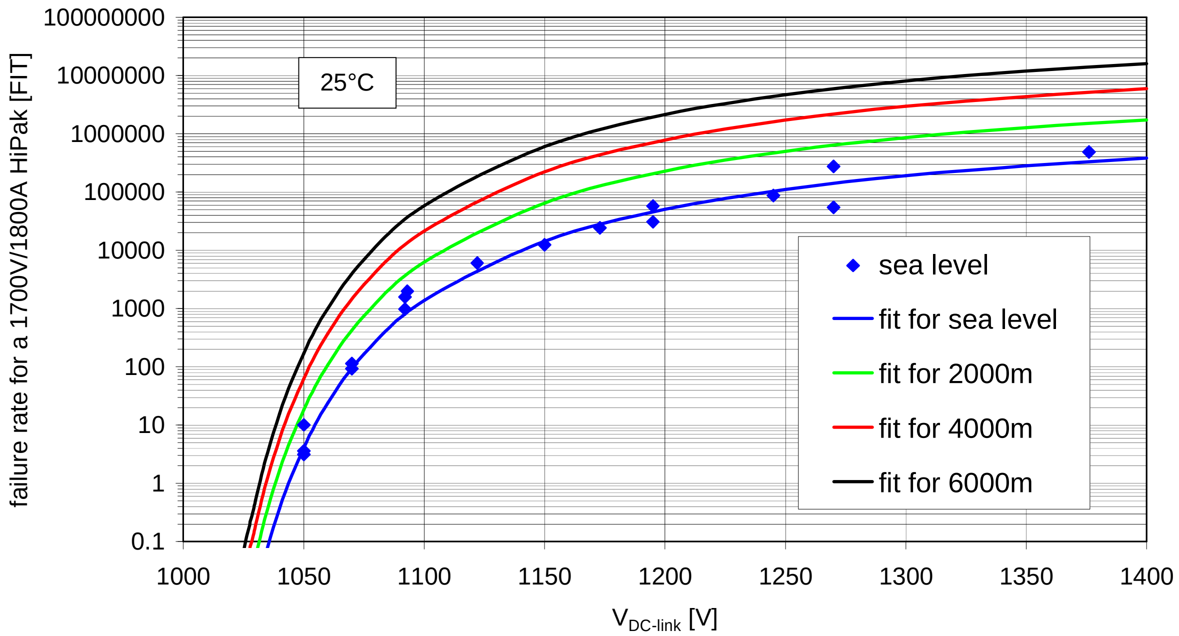
$$l(1250V, 25°C, 6000m) \;=\; 4.44 \cdot 10^5\, FIT \cdot \exp\left(\frac{750}{1200 - 1250}\right) \;\cdot\; \exp\left(\frac{1 - \left(1 - \frac{6000}{44300}\right)^{5.26}}{0.143}\right) \;\approx\; 5.7 FIT$$

In this example the MTTF is $1.8 \cdot 10^8$ h or 20000 y. Even if the circuit contains a number of devices the overall reliability will not be affected by cosmic ray induced failures. Nevertheless, due to the statistical nature of the effect there might be cosmic ray failures in the field.

3.2 Graphs for 5SNA 1800E170100

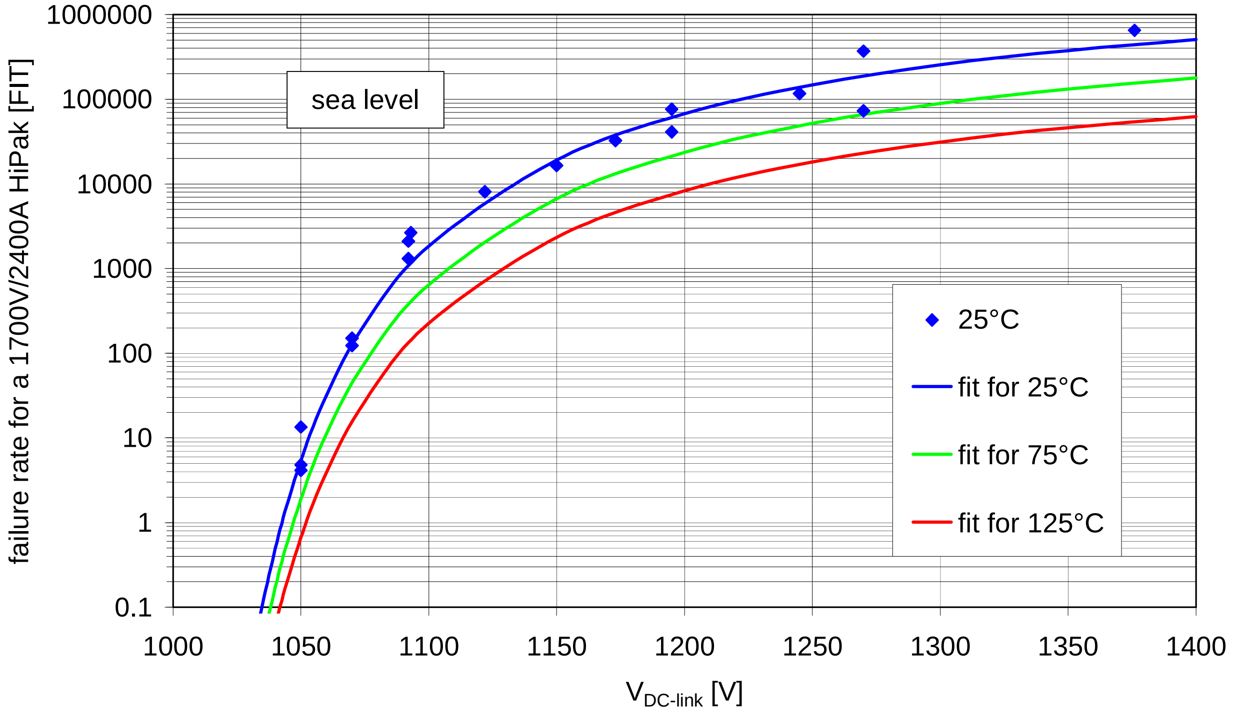
Relevant test reports: LB ATSQ 03-003 (alias LB PTS 03-003) for the IGBT and LB IGBT 01-081 for the diode.

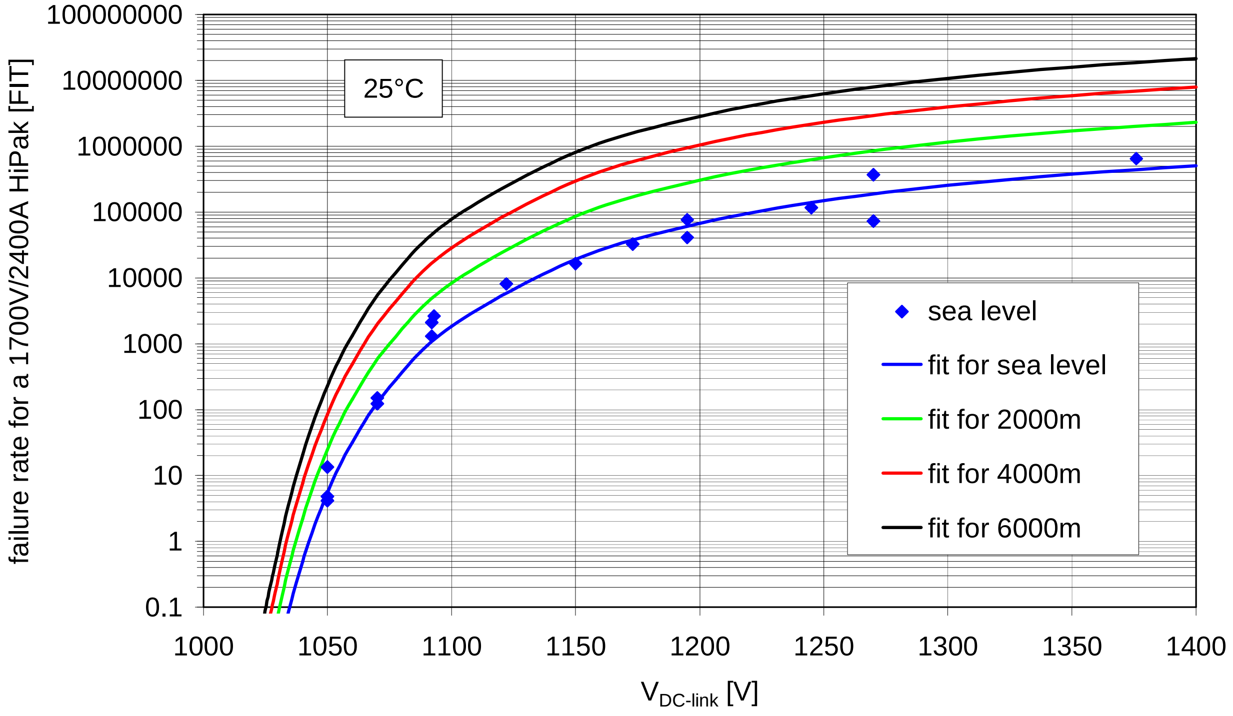




3.3 Graphs for 5SNA 2400E170100

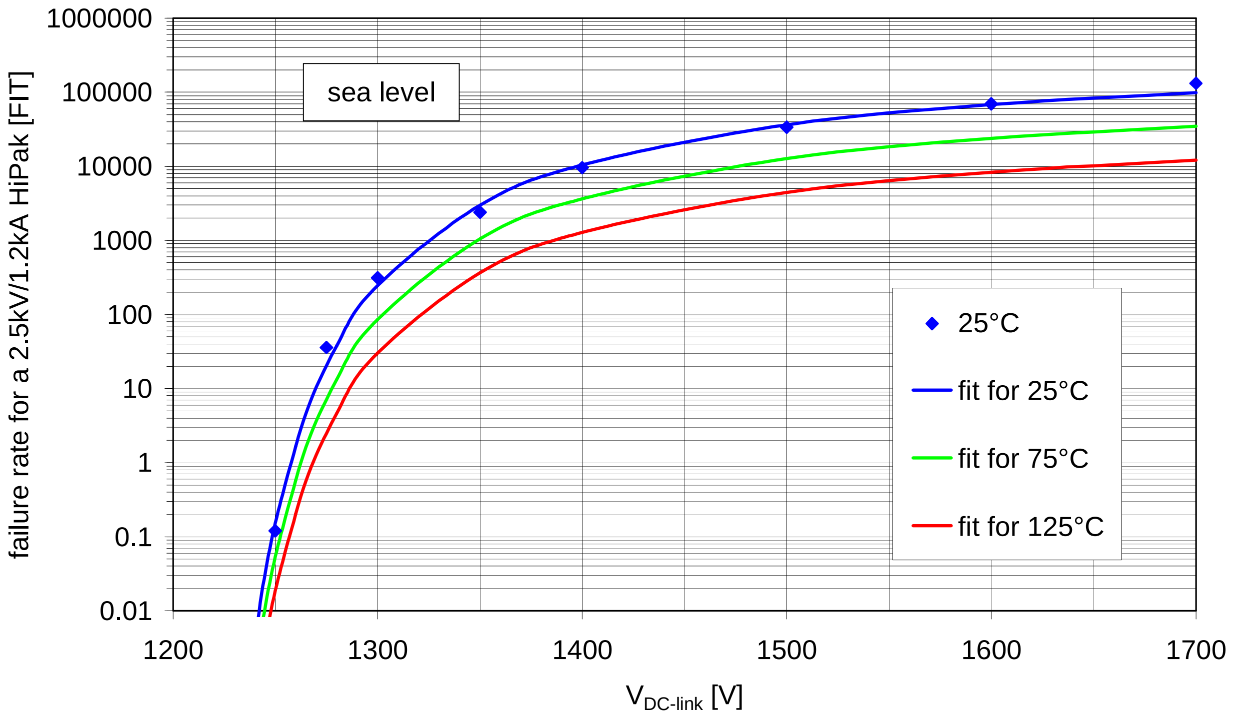
Relevant test reports: LB ATSQ 03-003 (alias LB PTS 03-003) for the IGBT and LB IGBT 01-081 for the diode.

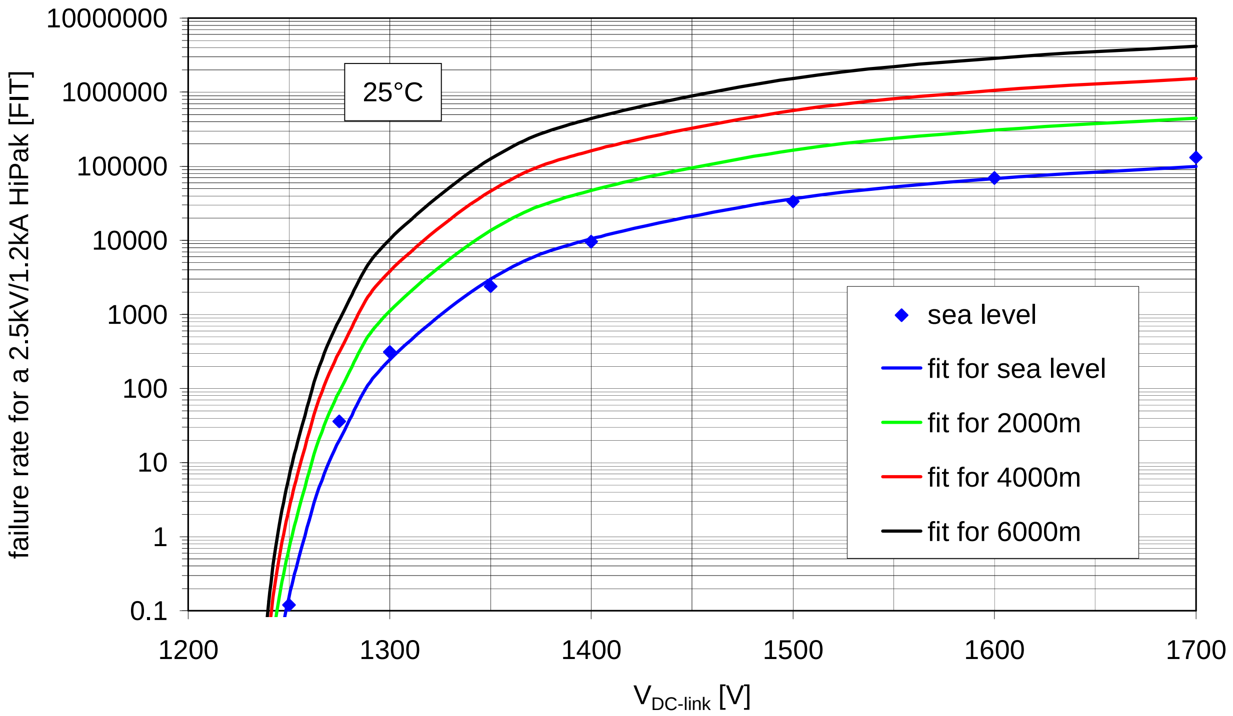




3.4 Graphs for 5SNA 1200E250100

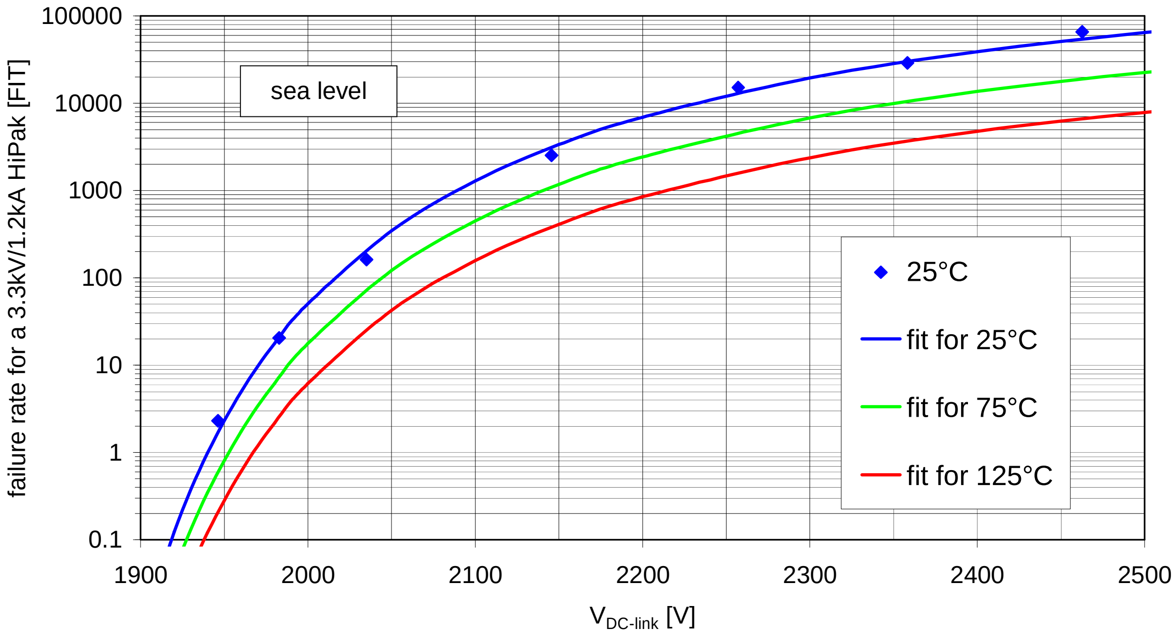
Relevant test reports: LB IGBT 01-086 for the IGBT and LB ATSQ 02-015 for the diode.

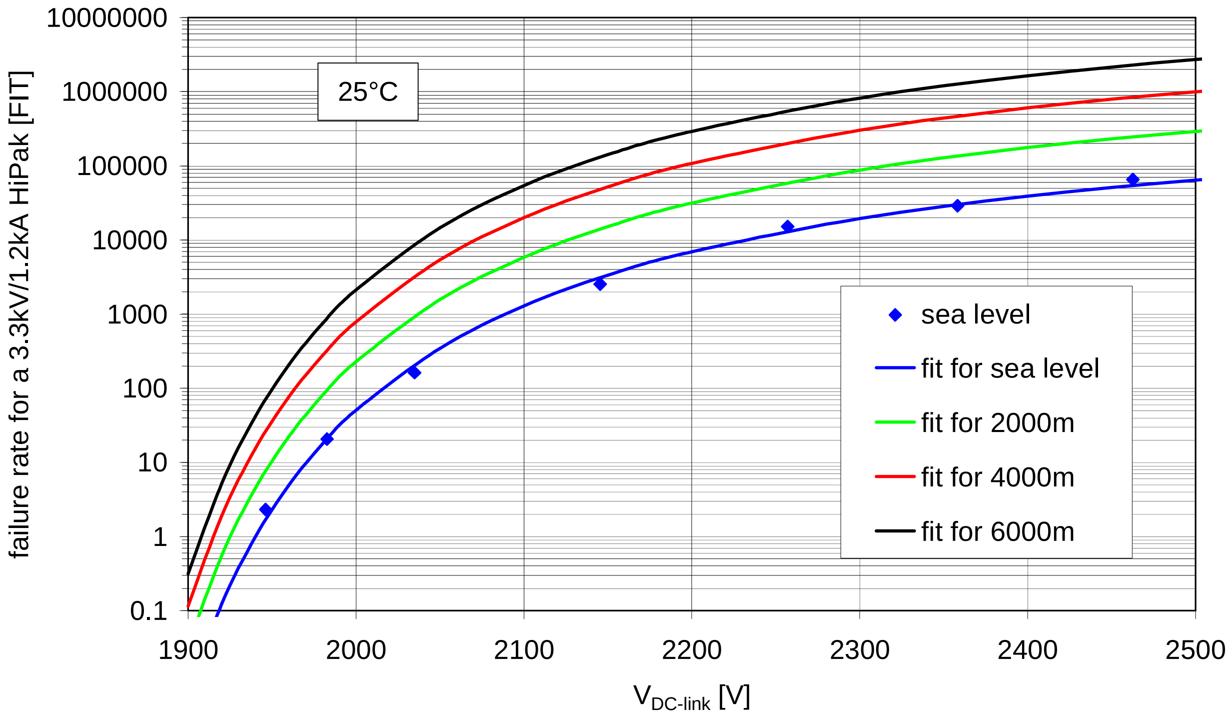




3.5 Graphs for 5SNA 1200E330100 and 5SNA 1200G330100

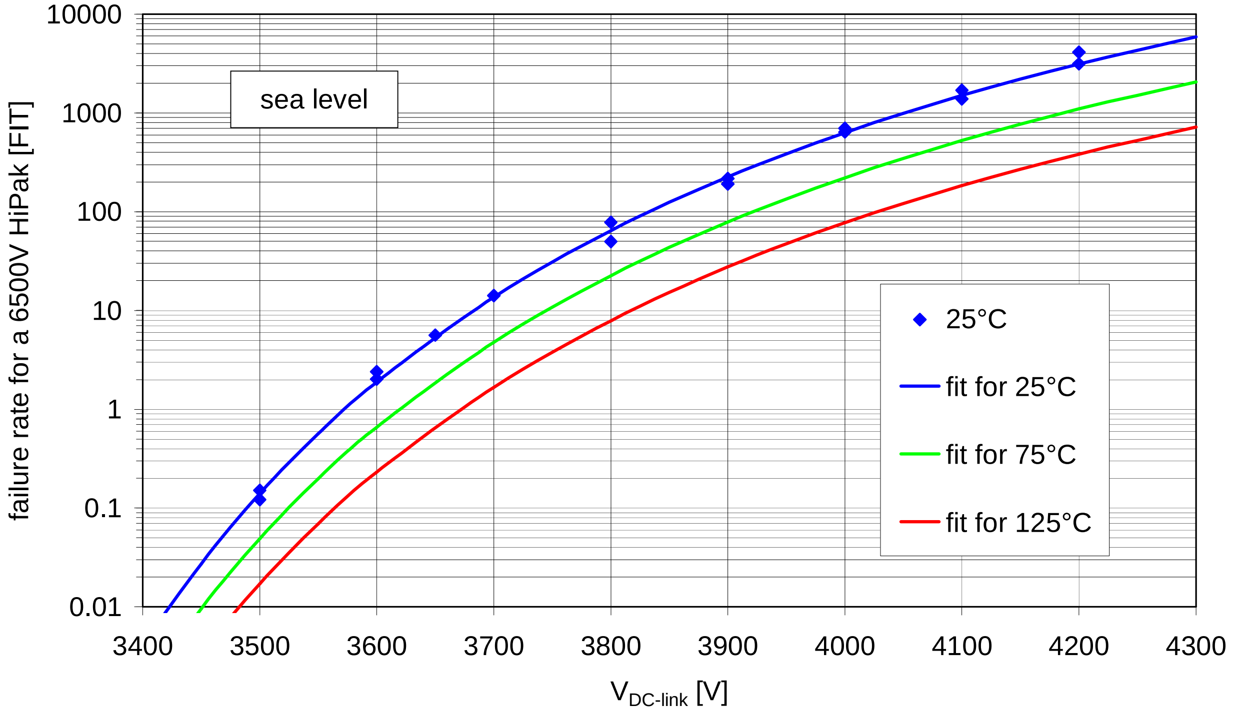
Relevant test reports: LB PTS 04-012 for the IGBT and LB PTS 04-011 for the diode.

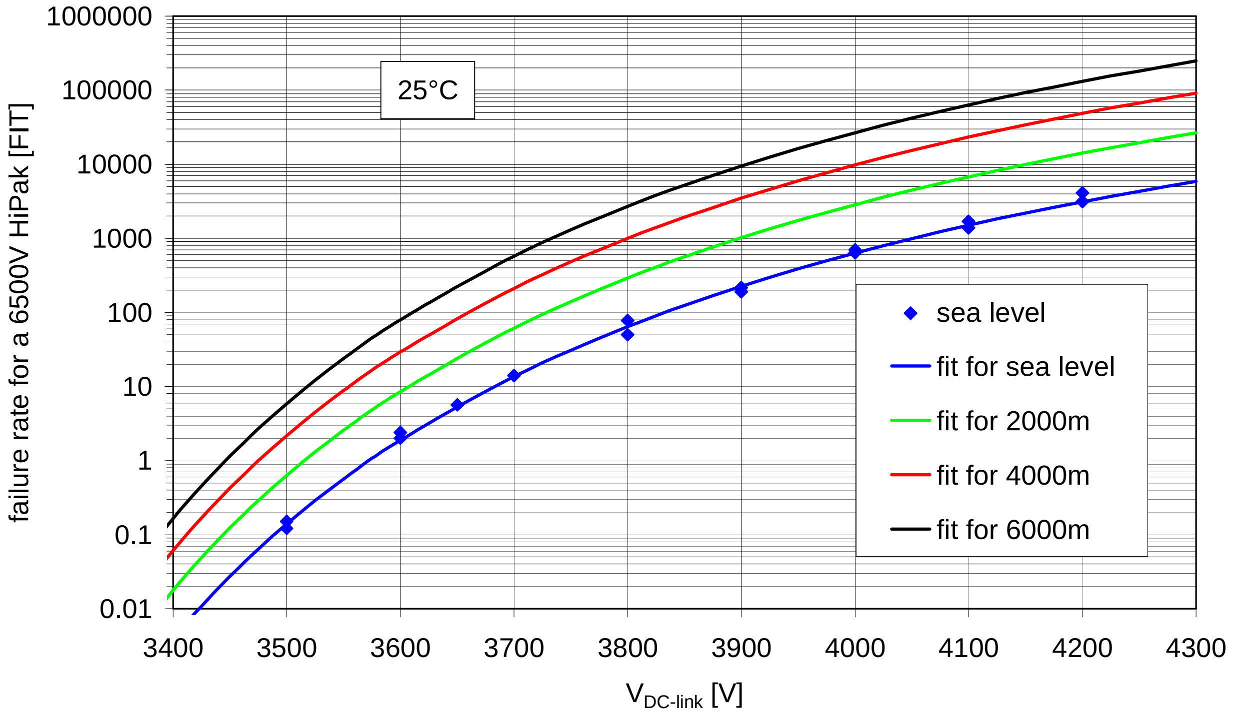




3.6 Graphs for 5SNA 0600G650100

Relevant test reports: LB PTS 04-036 for the IGBT and LB PTS 04-038 for the diode.





4 Additional notes

4.1 Varying voltages

The model assumes a DC-voltage. However, sometimes the applied voltage is not constant at all or the DC-voltage changes at least slightly with the operation mode. In such cases a more sophisticated approach would be necessary. In fact, the correct value would be obtained by integrating the failure rate over the voltage distribution. Of course, this could be done numerically using the failure rate formula. However, due to the exponential voltage dependence of the failure rate it is usually sufficient to consider only the highest voltages and the voltages to which it is mainly exposed. Assume for example a converter that is 98% of the time operated at a DC-link voltage of 1050V and 2% of the time at 1100V (e.g. due to breaking operation). The converter is equipped with 1700V-2400A-HiPaks (5SNA 2400E170100) and operates at 25°C and sea level. If one of the modules conducts 50% of the time (during conduction cosmic ray failures are impossible due to the very low voltage) the formula for this module reads:

$$49\% \cdot l(1050V) + 1\% \cdot l(1100V) \approx 49\% \cdot 5.4FIT + 1\% \cdot 1840FIT \approx 2.7FIT + 18.4FIT \approx 21FIT$$

4.2 Application support

For further information please contact:

Product Management
Eric Carroll
Phone +41 58 586 12 86
Fax +41 58 586 13 06
E-Mail eric.carroll@ch.abb.com

Reliability Engineering
Nando Kaminski
Phone +41 58 586 15 30
Fax +41 58 586 13 09
E-Mail nando.kaminski@ch.abb.com

ABB Switzerland Ltd
Semiconductors
Fabrikstrasse 3
CH-5600 Lenzburg, Switzerland

Phone +41 58 586 14 19
Fax +41 58 586 13 06
E-Mail abbsem@ch.abb.com
Internet www.abb.com/semiconductors

Data sheets of the devices and your nearest sales office can be found at the ABB Switzerland Ltd, Semiconductors internet web site:
http:// www.abb.com/semiconductors