Application Note
AN 26-001

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Prepared by:	Daniel Prindle
Approved by:	Andreas Giessmann

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CAL3 to CAL4 Transition in the SKiiP3

1. CAL3 Diode Obsolescence

The CAL3 diode used in the SKiiP3 has reached the end of its lifetime. Several pieces of critical equipment used in the production of this diode have gone obsolete by their supplier and is no longer supported. This means that the CAL3 diode production cannot be reliably maintained into the distant future. For this reason, the CAL3 diode inside the SKiiP3 must be replaced. Note that only the diode is being replaced, the IGBT and gate driver will not be changed. The following part numbers will be affected by this change:

Table 1: Affected part numbers

3-Bay Sixpacks	2-Bay Half Bridges	3-Bay Half Bridges	4-Bay Half Bridges
SKiiP 513 GD172-3D SKiiP 603 GD172-3D	SKiiP 1013 GB172-2D SKiiP 1203 GB172-2D	SKiiP 1513 GB172-3D SKiiP 1803 GB172-3D	SKiiP 2013 GB172-3D SKiiP 2403 GB172-4D

All variants of these parts will be affected, including IPMs (**I**ntelligent **P**ower **M**odules) with any additional suffix. This includes parts with additional features, such as:
U DC link voltage measurement
F Fiber optic interface

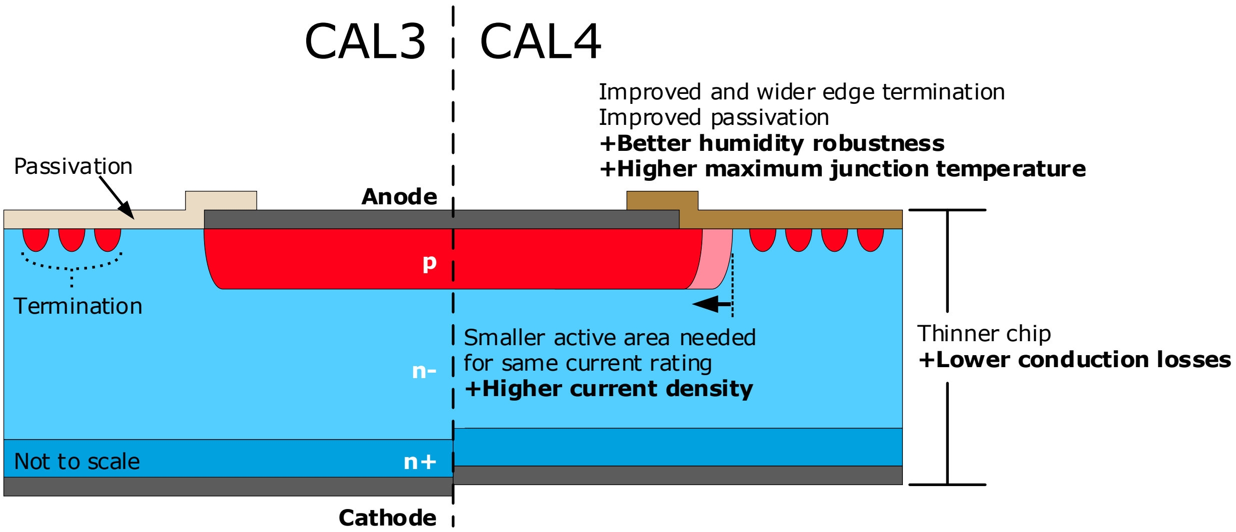
Along with all heatsink types:
L Air
W Water
HP High performance liquid cooler
K Custom cooler, typically followed by 3 or 4 digits, such as K123 or K1234

2. CAL4 Introduction

The CAL4 diode has a long history of use within a variety of Semikron Danfoss products, such as the SKiiP4. A detailed overview of the CAL diode can be found in the CAL Diode Technical Explanation [3].

The CAL4 diode utilizes same core CAL diode technology as the CAL3. However, CAL4 also has several improvements over its older counterpart. This newer generation of diode does feature lower conduction losses for the same chip area. Most notably, the humidity robustness has been significantly improved thanks to an improved termination and passivation layer. The CAL4 diode is tested using with the more difficult HV-H3TRB test. See Chapter 4.2 for more information on these tests.

Figure 1: Improvements with new generation



3. Performance Comparison

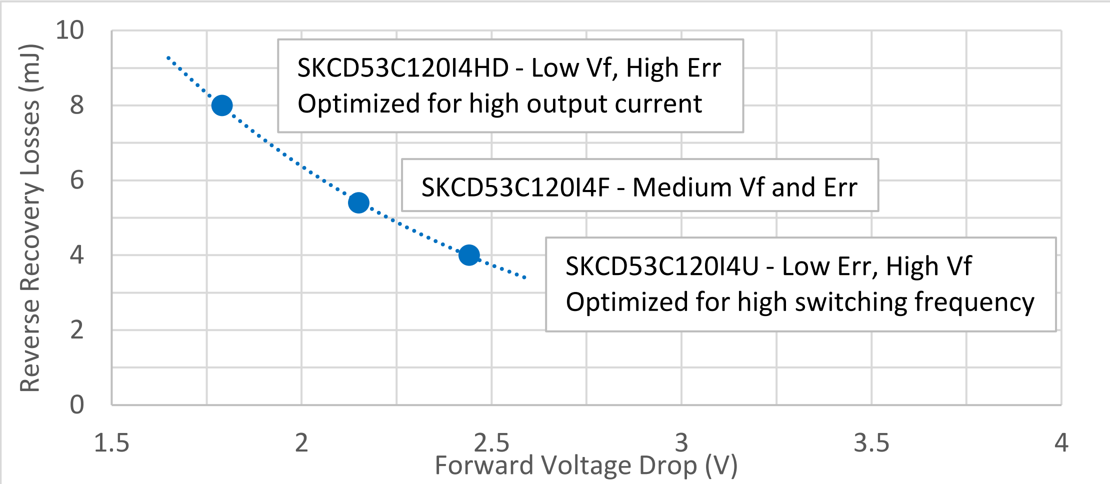
The table below shows the main parameters of the two diodes taken from two SKiiP 2013 GB172 datasheets, one with a CAL3 and one with a CAL4. Within the scope of the multiple changes made, the CAL4 diode matches the performance of the CAL3 rather well. An explanation of the differences in E_{rr} and I_{FSM} can be found in Chapters 3.2 and 3.3 respectively.

Table 2: Datasheet parameter comparison

	CAL3	CAL4		Conditions
V_f	1.84	1.62	V	T_j = 25°C, chip level
E_{rr}	144	173	mJ	T_j = 125°C, 900V, 1200A
I_{FSM}	13500	11500	A	T_j = 150°C, t_p = 10ms
I^2t	911	661	A^2s	T_j = 150°C, t_p = 10ms
$R_{th(j-s)}$	0.029	0.029	K/W	

The largest difference in terms of normal operation is the decrease in forward voltage drop (V_f) and increase in reverse recovery losses (E_{rr}). This is because the CAL4 diode lays along a slightly different point on the technology curve, a tradeoff curve where a decrease in V_f results in a corresponding increase in E_{rr}, or vice versa, with respect to designs using the same technological generation. The CAL4 diode used in the SKiiP3 is shifted slightly to the left on the technology curve relative to an equivalent CAL3. An example technology curve with the chip part numbers and behaviors is shown below.

Figure 2: Example CAL4 diode technology curve

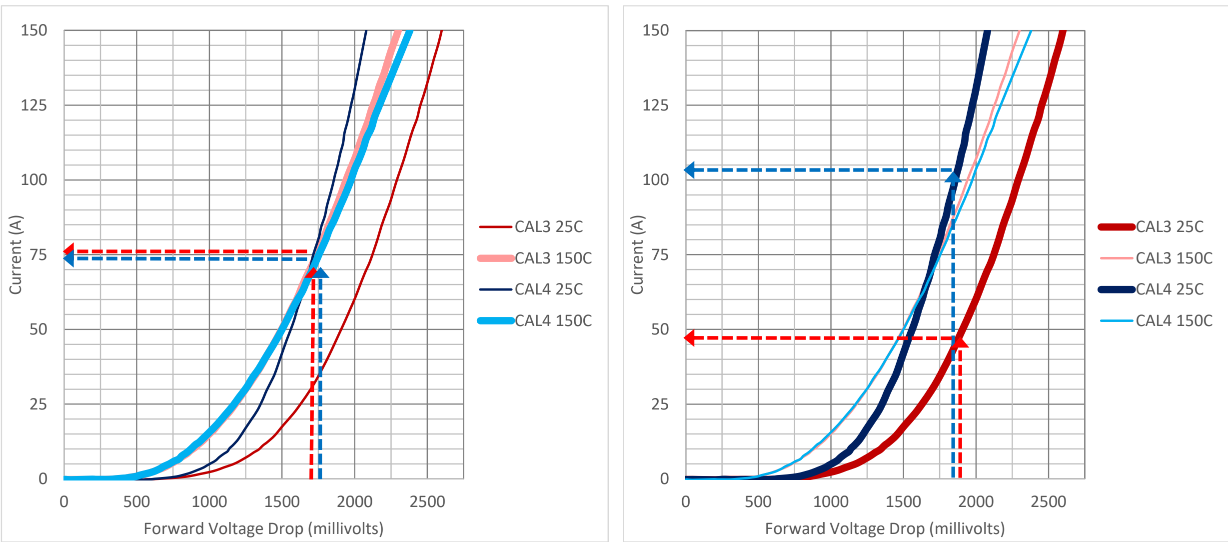


3.1 Static performance

The CAL4 diode has been tuned to match at 150°C, however the CAL4 voltage drop is lower at low temperatures. When a 75A-rated CAL3 and a 75A-rated CAL4 chip are connected in parallel, they will have the same voltage drop and the current will be shared according to their respective V_f vs. I_f curves.

With 150A applied and a junction temperature of 150°C, both chips would carry roughly 75A. However, at 25°C, the CAL4 would take roughly 103A and the CAL3 only 47A. This is approximately a 68% to 32% current sharing ratio. This will cause an imbalance in losses and may cause overheating. The practical implications of this current imbalance are discussed further in Section 5.1.

Figure 3: Static current sharing of 75A-rated chip (25°C left, 150°C right)

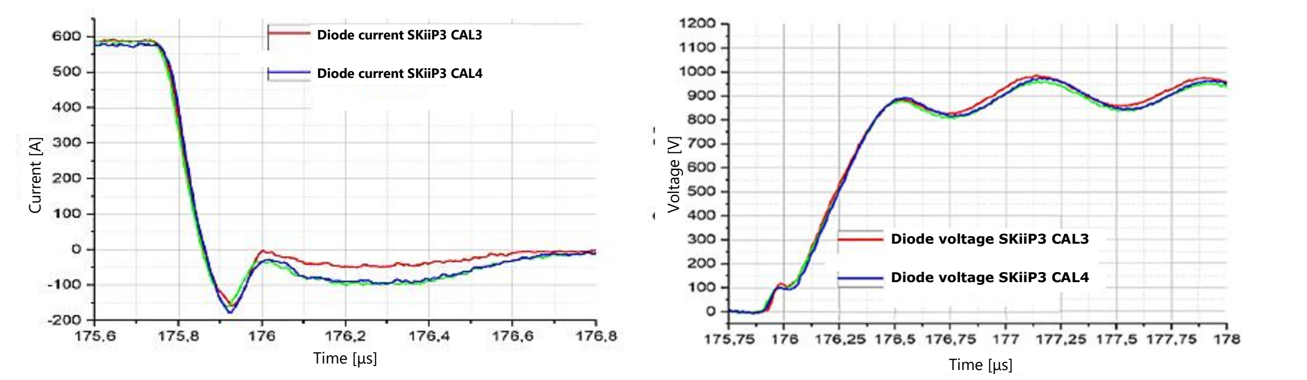


3.2 Dynamic performance

The following waveforms show the result of double pulse tests using a SKiiP 2403 GB 172 IPM, one with the reference (CAL3) and one with new (CAL4) chips inside. The same gate driver, capacitor bank, and measurement setup were used in all tests.

The switching profiles are extremely well matched. The didt, dvdt, and peak overvoltage peaks are all very similar. The slightly larger tail current of the CAL4 results in a higher E_{rr}.

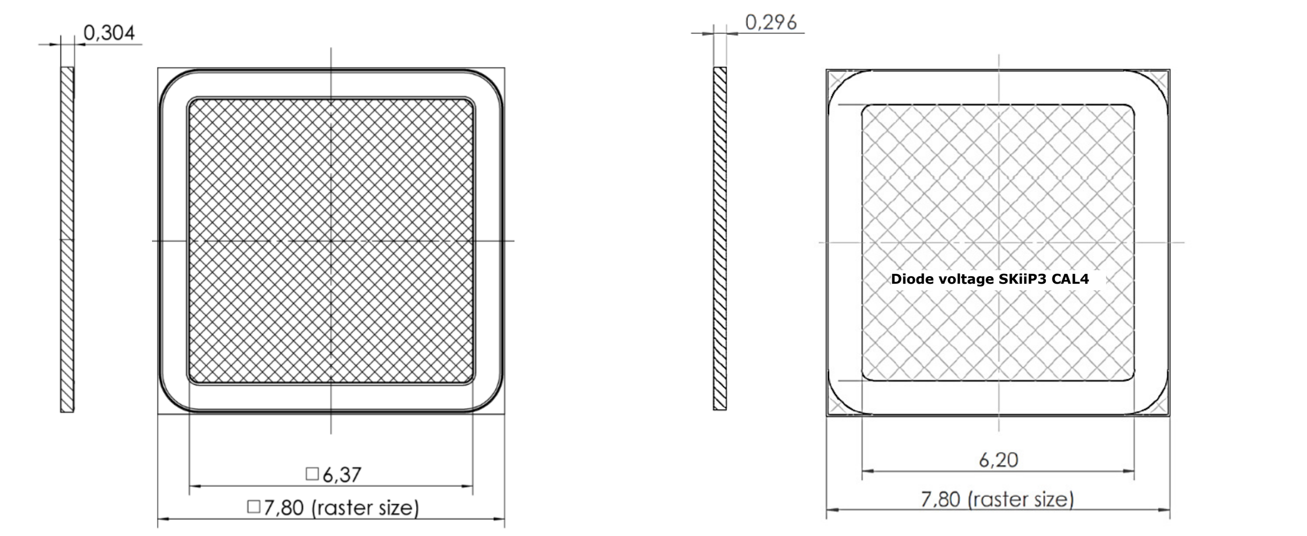
Figure 4: Reverse recovery waveforms (current left, voltage right)



3.3 Surge current (I_{FSM})

Surge current performance is highly correlated to the thermal mass of the diode being tested. The CAL4 diode is thinner (0.294mm instead of 0.304mm). The active area of the CAL4, the checkered area below, is also smaller. This results in noticeably lower surge current (I_{FSM})and i^2t rating for the CAL4 diode. This must be taken into consideration when replacing a CAL3 SKiiP3 with a CAL4 SKiiP3.

Figure 5: CAL3 (left) and CAL4 (right) chip size comparison (in mm)



4. Qualification Tests

4.1 Standard qualification tests

The CAL4 SKiiP3 has been subjected to the following standard qualification tests.

Table 3: Qualification tests for CAL4 SKiiP3 requalification		
Test	**Test Conditions**	**Standard**
High Temperature Reverse Bias (HTRB)	1000h, V_{GE} = 0V, 95% RH, V_{CEmax}, T_{sink}=T_{jmax}-10°C	IEC 60747-9
High Voltage, High Humidity, High Temperature, Reverse Bias (HV-H3TRB)	504h, 85°C, 85% RH, V_{GE}=0V, V_{CETest}=80% V_{CEMax}	IEC 60068 Part 2-67
High Temperature Storage	1000h, T_{amb} = +125°C	IEC 60068 Part 2-2
Low Temperature Storage	1000h, T_{amb} = -40°C	IEC 60068 Part 2-1
Thermal Cycling	100 cycles, -40°C/ +125°C	IEC 60068 Part 2-14
Power Cycling (EOL-Test)	20k load cycles @ ΔT_j = 110K	IEC 60747-9

4.2 Enhanced humidity testing

The H3TRB test has historically been used to confirm that chip and module designs are robust when used in humid environments. In this test, voltage is applied, collector to emitter, and the device is stored in a high humidity and high temperature environment for an extended period of time. Devices are checked for signs of degradation, including corrosion of the surface of the edge termination and a change in the electrical characteristics.

In recent years, however, as chip technology has improved and the demands on chips have increased, the H3TRB test has been overtaken by HV-H3TRB test. The collector-emitter voltage has been increased from 80V, regardless of the rating of the device, to 80% of the maximum blocking voltage. For example, a 1700V rated diode was previously tested at only 80V but now is tested at 1360V. This increase in voltage significantly increases the stress on the device and demonstrates its enhanced capabilities.

Table 4: Humidity qualification tests	
H3TRB Test	85°C, 85% RH, V_{GE}=0V, V_{CETest} = 80V regardless of chip rating
HV-H3TRB Test	85°C, 85% RH, V_{GE}=0V, V_{CETest} = 80% V_{CEMax}

5. Application Specific Considerations

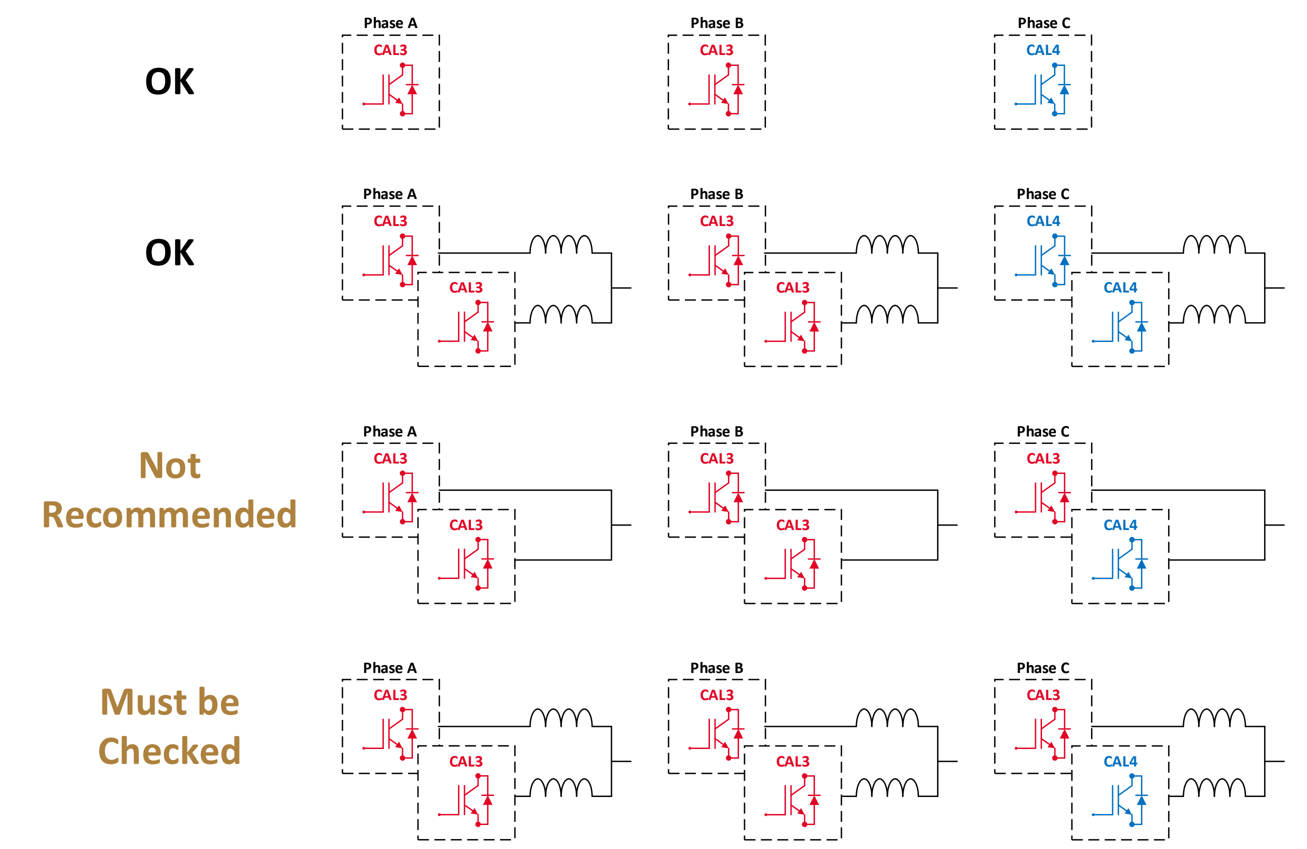
5.1 Using SKiiP3 with CAL4 diode as a service part

When replacing an older CAL3 SKiiP3 IPM with a newer IPM that has a CAL4 diode, some factors must be considered. The forward voltage drops of both types are not well matched at low temperatures. Consequently, good current sharing will likely not occur if SKiiPs are connected in hard parallel, i.e. with minimal inductance between them.

It is recommended to avoid hard-paralleling SKiiP3 IPMs with CAL3 and CAL4 diodes, i.e. connecting them in parallel minimal inductance between them. The poor current sharing at low temperatures will result in considerably higher static and dynamic losses in the CAL4 IPMs. This may result in overheating and damage to the unit.

If a current-sharing inductor is used, the user must confirm that both SKiiPs remain in their safe operating area under all load conditions prior to installing 'mixed' systems in the field. See the SKiiP3 Technical Explanation [4] Section 7.9 for more information on this topic.

Figure 6: Replacement configurations



Symbols and Terms

Letter Symbol	Term
CAL	Controlled Axial Lifetime
didt, dvdt	Rate of change in current (i) or voltage (v) in time
RH	Relative Humidity
I^2t	Amps squared seconds, the amount of current and time that can be applied to a semiconductor before it is damaged
I_{FSM}	Surge Current
IPM	Intelligent Power Module
$R_{th(j-c)}$	Thermal Resistance, junction to case
T_{amb}	Ambient Temperature
T_j	Junction Temperature
V_{CEMax}	Maximum Collector Emitter Voltage, used to describe the blocking voltage of a power module, occasionally used informally for a MOSFET module with Drain-Source terminals or diode module with Anode-Cathode terminals
V_f	Forward Voltage Drop

A detailed explanation of the terms and symbols can be found in the "Application Manual Power Semiconductors"

References

[1] www.semikron-danfoss.com
[2] A. Wintrich et al., “Application Manual Power Semiconductors”, 3rd ed., Semikron Danfoss International GmbH, www.semikron-danfoss.com
[3] J. Fajer et al., “Technical Explanation CAL Freewheeling Diodes”, Semikron Danfoss International GmbH, 3 Feb. 2025, www.semikron-danfoss.com
[4] A. Schiller, “Technical Explanation SKiiP3”, Semikron Danfoss International GmbH 2017, www.semikron-danfoss.com

IMPORTANT INFORMATION AND WARNINGS

Semikron Danfoss International GmbH
Sigmundstrasse 200, 90431 Nuremberg, Germany
Tel: +49 911 65596663
sales@semikron-danfoss.com, www.semikron-danfoss.com