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Application Note

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Short-Circuit Simulation with Level-3 Compact Models

Author: Peter Türkes

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www.infineon.com/simulate

Support: simulate@infineon.com

Power Management & Supply

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PSPICE Device Models:

The following 1200V S-IGBT/EMCON-fast DuoPack devices are covered by this note:

- SKP(B)02N120
- SKW07N120
- SKW15N120
- SKW25N120

Their PSPICE models are provided in a level-3 version which takes into account the dynamic temperature behavior. The PSPICE files comprise a library file (duo_p_120_L3.lib) and a 5-pin schematic (duo_p_120_L3.slb). The temperature-dependent-model parameters have been validated by dc measurements for temperatures up to 150°C.

Three of the five pins of the PSPICE model schematic correspond to the device's electrical connections (gate, anode, and cathode). The remaining two pins are thermal pins. As shown in Figure 1, they are labeled as **tc** (case temperature) and **tamb** (ambient or reference temperature). The thermal pins can be used to attach a user-defined heat-sink model that is represented by a physical-correct T-type thermal network. The thermal impedances of chip and package are included in the model's physical-correct description. The reference temperature of each device can be set by a local model parameter. In case no external heat-sink model is used, the pins **tc** and **tamb** need to be shorted.

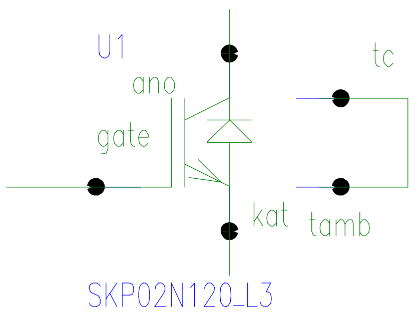


Figure 1: Example for a level-3 DuoPack PSPICE schematic (thermal pins are shorted – only the internal thermal model is used)

Short-Circuit Simulation with 1200V-DuoPack Models:

Influence of Thermal Path

Standard short-circuit tests for power devices are of major interest. They are applied in order to evaluate a device's reliability and operating limits. The short-circuit current of a device is measured within the limits of the data sheet constraints (for 1200V-

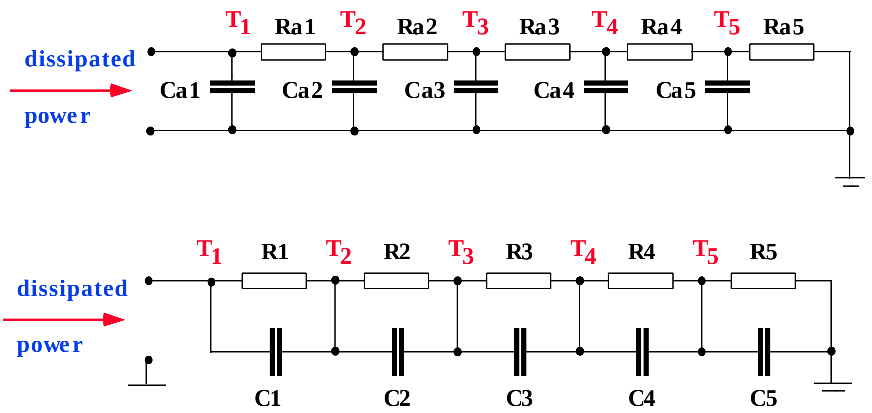
DuoPack devices: V_{ge} = 15V, 100V < V_{ce} < 1200V and T_j < 150°C). The junction temperature limit is only valid at the beginning of the short-circuit pulse. In order to provide the user with reliable PSPICE models, it is of high importance to cover this mode of operation.

Thermal Path Models

The simulation of the short-circuit behavior of a power device requires the knowledge of the parameters of the thermal path. The thermal path of a power device is characterized by standard transient-thermal impedance measurements that result in a cooling curve. The cooling curve represents the temperature difference **Tj(t) – Tcase** of the device as a function of time after the device is heated in steady state with well-defined power **Q.** The transient-thermal impedance **Zth(t)** is then defined as the ratio (**Tj(t) – Tcase)/Q.**

For the device's data sheet, a set of Rth and Cth values is extracted from the measured Zth(t) curve. As shown in Figure 2b, the thermal parameters are analogous to the resistance and capacitance values of an electrical π-type network. This type of network, however, is not suitable for simulation purposes. A higher flexibility in simulation applications can be accomplished when the physical-correct T-representation of the thermal network is used instead (Figure 2a). This representation permits a simple extension of the RC-ladder network to include additional thermal elements such as heat sinks [1,2].

Both types of thermal models exhibit the same step-response behavior.



a) T-model

b) Π-model

Figure 2: Thermal models for PSPICE simulation of dynamic temperature behavior

The transformation of the parameters extracted from the Zth measurements (Figure 2b) into the physical-correct parameters (Figure 2a) can be accomplished by a leastmean-square-fit procedure [1,2]. Here, this procedure is carried out using the mathematical software MATHCAD. The results are shown in Figure 3.

The response characteristics for both thermal-path representations are identical. The RC parameters of the two network types are listed in Table 1.

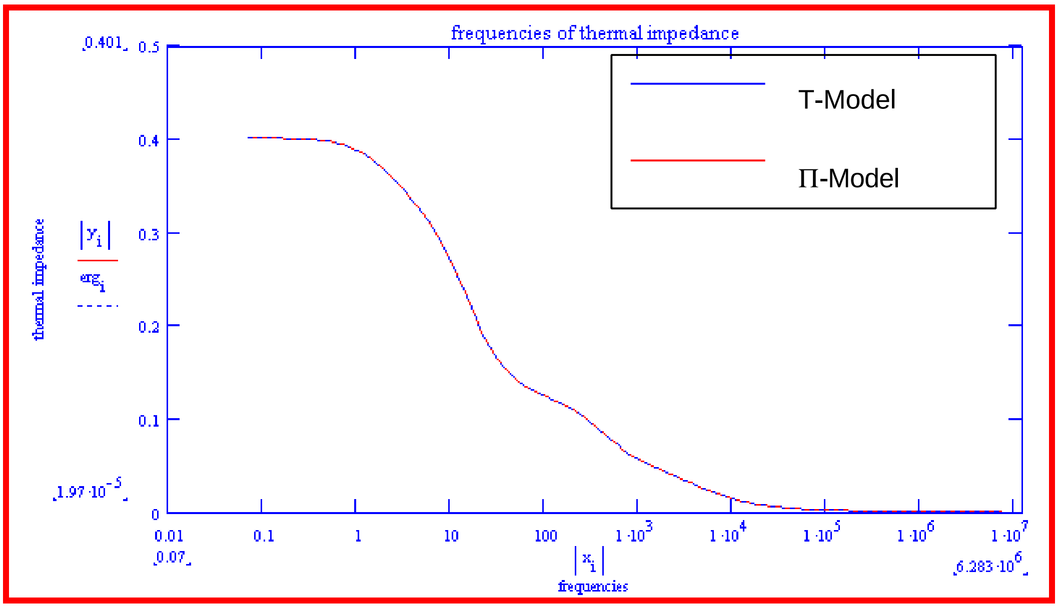


Figure 3: Frequency-dependent response characteristics for IGBT SKW25N120

Device: SKW25N120			
Π-Model (parameters extractred from Zth curve)		*T-Model (transformed, physical-correct parameters)*	
Rth in Ohms	Cth in Farad	Rth in Ohms	Cth in Farad
0.037	0.01	0.058	0.0081
0.081	0.041	0.078	0.038
0.209	0.43	0.216	0.391
0.074	6.728	0.049	9.696

Table 1: Parameter sets for junction-case thermal networks for IGBT SKW25N120

For all the aforementioned PSPICE device models, the physical-correct T-representation of the thermal model has been implemented.

It should be noted that level-3 transient-temperature models results require a longer simulation time than lower-level models.

Configuration of Measurement and Simulation Circuit

In order to compare simulation and measurement results, the PSPICE simulation is set up according to the measurement configuration (see Figure 4). The values of the parasitic stray inductance and the parasitic serial resistance are extracted from the measurements: the inductance value is calculated from the voltage drop and the current slope during turn-on, the resistance value from the voltage drop during on-state.

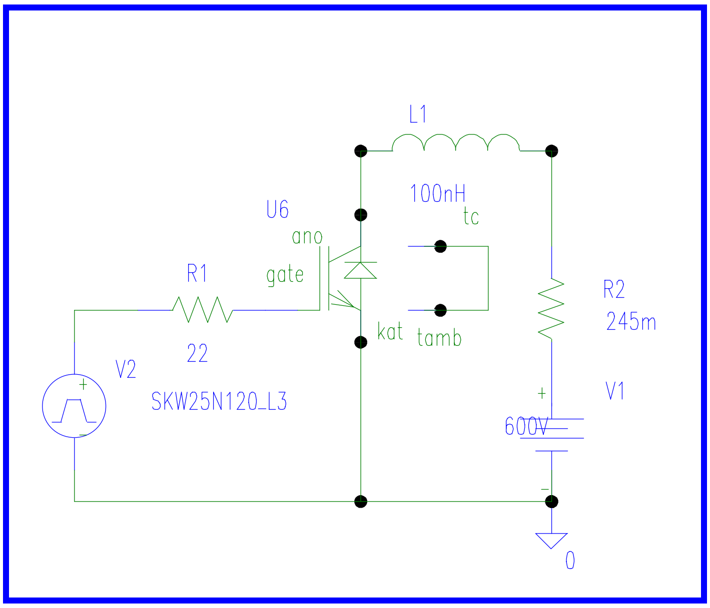


Figure 4: PSPICE simulation schematic for short circuit test of SKW25N120

Simulation Results

The simulation and measurement traces for the short-circuit behavior of the devices SKW25N120 and SKP02N120 are shown in Figures 5 and 6, respectively. For both devices, a significant deviation between simulation and measurement results can be observed.

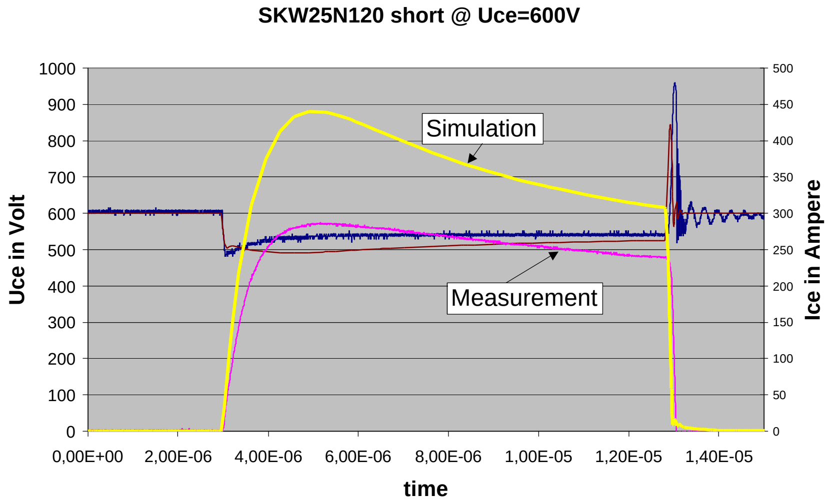


Figure 5: Simulated and measured short-circuit traces for SKW25N120

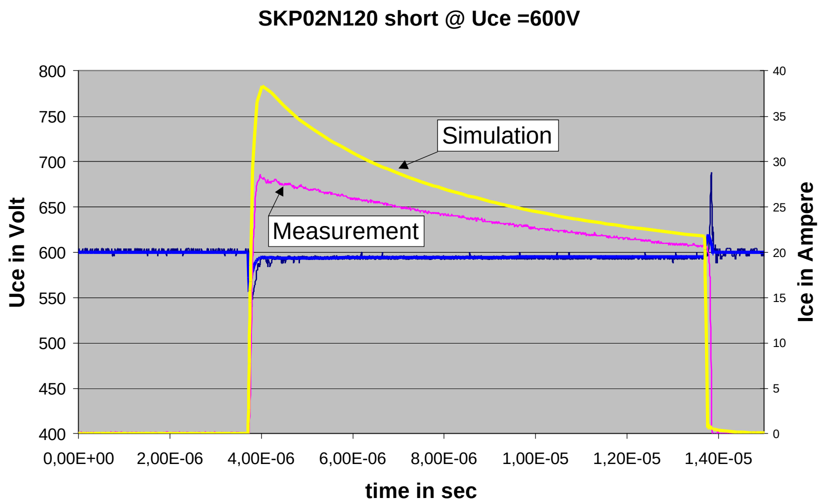


Figure 6: Simulated and measured short-circuit traces for SKB02N120

The simulated currents are much higher than the measured ones. This is expected since the smallest time constant in the thermal model extracted from the cooling curve is much higher than the short-circuit time of 10µsec. The calculated transient temperature is therefore too low.

In order to improve the simulation accuracy, an additional thermal RC element is needed that takes into account the thermal behavior of the chip. The values of this element are calculated from the chip geometry. Thereby, it is assumed that the main part of the short-circuit power is generated in the vicinity of the IGBT-MOS channel and the adjacent high-field region. Adding the new RC element to the input terminal of the physical-correct thermal model (Figure 7) does not change the overall transient-thermal impedance curve (Figure 8).

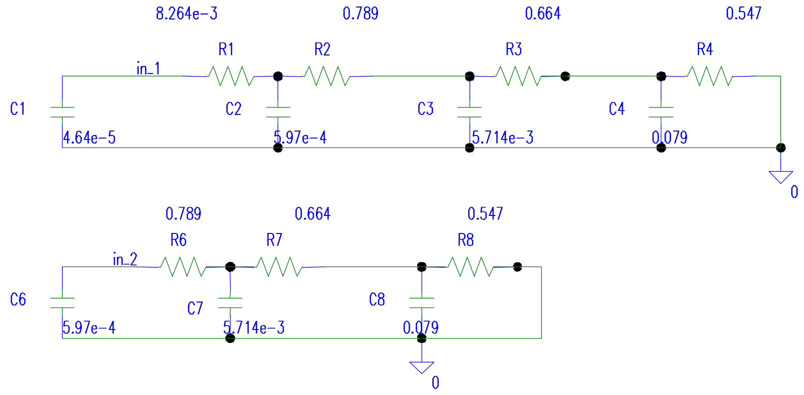


Figure 7: Standard thermal model (lower schematic) and extended thermal model (upper schematic) for SKB02N120

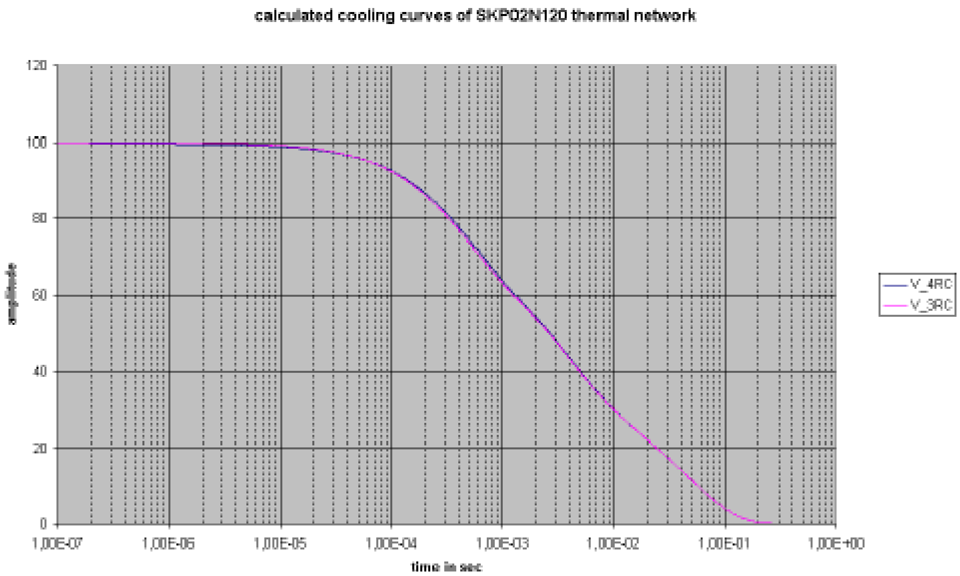


Figure 8: Transient thermal impedance curves for standard and extended thermal model for SKB02N120

Accounting for the transient-thermal behavior of the chip, however, significantly improves the transient simulation results as shown in Figures 9 and 10. The temperature rise for the thermal model with additional chip time constant is far steeper than the one for the original simulation. As a consequence, a far higher temperature of over 300°C is reached at the end of the short circuit. (Caution: In this case, the data-sheet limitation applies: the number of short-circuit events shall not exceed 1000 !)

short circuit SKP25N120 @ Uce = 600V

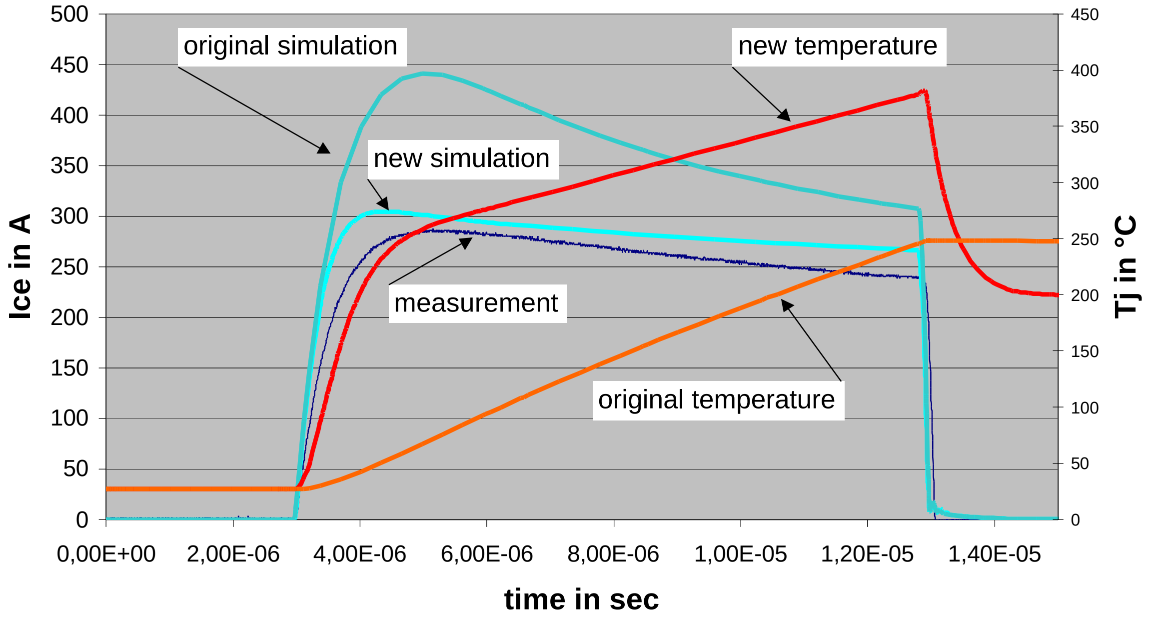


Figure 9: Measured and simulated short-circuit transient currents and temperatures with and without thermal chip time constant (SKW25N120).

SKP02N120 short circuit @Uce = 600V

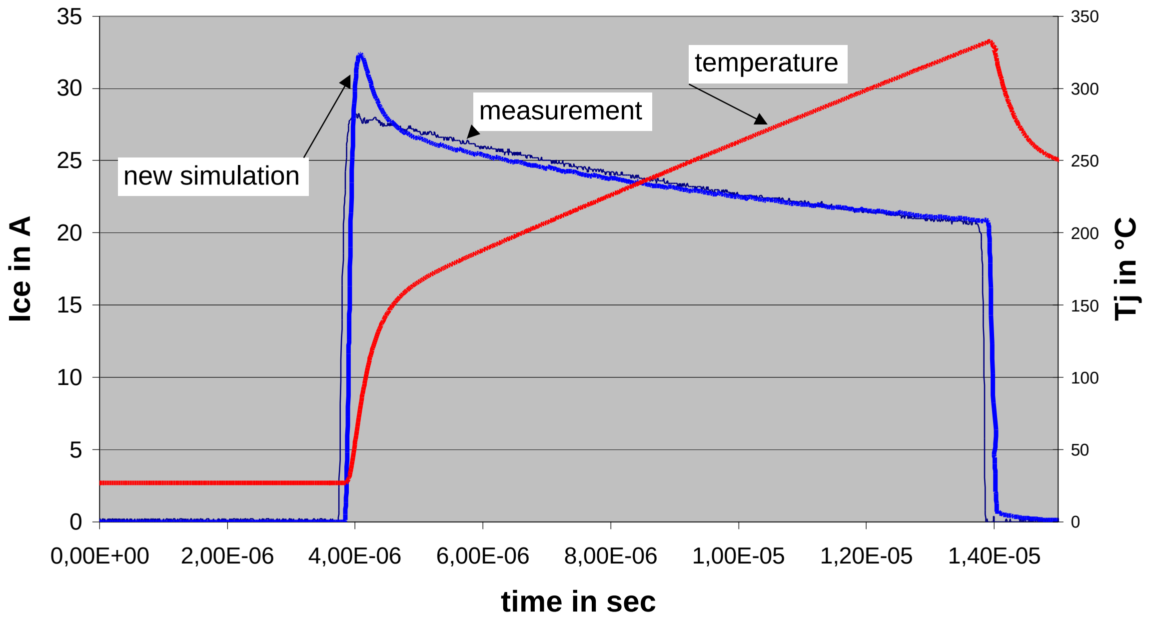


Figure 10: Measured and simulated short-circuit transient currents and temperatures with and without thermal chip time constant (SKP02N120).

Summary:

It has been shown that the use of level-3 DuoPack models allows for realistic simulations of the DuoPack short-circuit behavior. The validity of the simulation results has been demonstrated by comparing slope and absolute value of the measured and simulated short-circuit currents. In order to carry out correct short-circuit simulations, it is necessary to perform a detailed analysis of the thermal path of the device and to extract the related RC parameters.

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Bibliography:

[1] H. Müller, *Beziehungen zwischen dem praktisch verwendeten und dem physikalisch sinnvollen Wärmeersatzschaltbild von Dioden und Thyristoren,* Archiv für Elektrotechnik 54, p. 170 ff (1971)

[2] P. Türkes, *Thermal Network Calculation for Level-3 Compact Models*, Infineon Application Note, AN-PSM-12 (2001)

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CH
Siemens Schweiz AG
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T (+41)1-4 953065
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D
Infineon Technologies AG
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T (+49)2 11-3 99 29 30
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Infineon Technologies AG
Werner-von-Siemens-Platz 1
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Infineon Technologies
Siemens House
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T (+44)13 44-39 66 18
Fax (+44)13 44-39 66 32

H
Simacomp Kft.
Lajos u.103
H-1036 Budapest
T (+36)1-4 57 16 90
Fax (+36)1-4 57 16 92

HK
Infineon Technologies
Hong Kong Ltd.
Suite 302,Level 3,
Festival Walk,
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T (+8 52)28 32 05 00
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I
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Via Piero e Alberto Pirelli,10
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T (+81)3-54 49 64 11
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MAL
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Siemens Components Scandinavia
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Fax (+46)8-7 03 35 01
Email:
scs@components.siemens.se

RC
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Fax (+65)7 42 62 39

USA
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Beijing Office
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Vantone New World Plaza
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Jie
100037 Beijing
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Infineon Technologies
Hong Kong Ltd.
Chengdu Office
Room14J1,Jinyang Mansion
58 Tidu Street
Chengdu,
Sichuan Province 610 016
T (+86)28-6 61 54 46 /79 51
Fax (+86)28 -6 61 01 59

Infineon Technologies
Hong Kong Ltd.
Shanghai Office
Room1101,Lucky Target Square
No.500 Chengdu Road North
Shanghai 200003
T (+86)21-63 6126 18 /19
Fax (+86)21-63 61 11 67

Infineon Technologies
Hong Kong Ltd.
Shenzhen Office
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