High-voltage: 3.3kV & 6.5kV IGBT3 Modules

Never stop thinking

Chip generations of 3300V IGBT modules

K: IHM A
H: IHM B

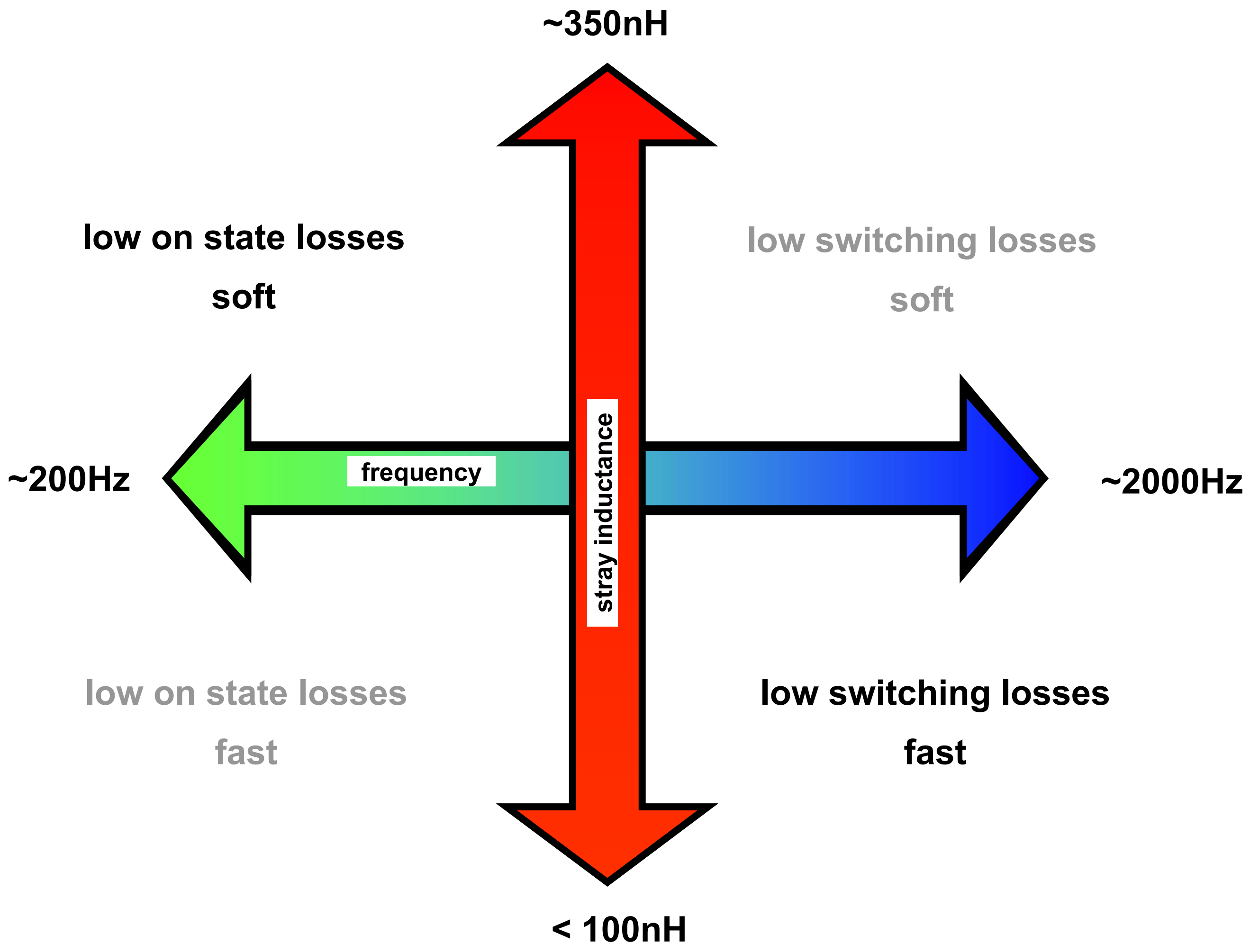
		standard 2nd gen. **KF2C**	low loss 2nd gen. **KL2C**	Trench+FS 3rd gen. **HL3**	Trench+FS 3rd gen. **HE3**
IGBT optimized regarding -->		NPT low switching losses	NPT with field stop low saturation voltage high DC stability	NPT Trench with field stop low saturation voltage high DC stability	NPT Trench with field stop low switching losses high DC stability
V_{cesat}(V)	25°C	3.4	3.0	2.15	2.7
	125°C	4.3	3.7	2.5	2.95
E_{on}(mJ) 125°C		2200	3150	2550	2200
E_{off}(mJ) 125°C		1550	1900	2200	1550
Diode		Emcon	Emcon with field stop	Emcon 3 field stop	Emcon 3 field stop
V_f(V)	25°C	2.8	2.6	2.05	2.5
	125°C	2.8	2.55	2.0	2.5
E_{rec}(mJ) 125°C		1550	1650	2650	1350
switching frequency		... 1000Hz	... 500Hz	... 500Hz	... 2000Hz
housing insulation		IHM A 6kV	IHM A 6kV	IHM B 6kV	IHM B 6kV
DC stability 100fit @		1800V	2150V	2100V	2100V
Tvjmax		125°C	125°C	150°C	150°C

for better comparability all Vcesat, Vf and switching energies are rated @ 1200A

Benefits of new IGBT3 chip generation

- optimization regarding two fields of applications:
  - → „fast“ version with low E_{on} + E_{off}
    high switching frequencies up to 2 kHz, $L_s < 100nH$ required
  - → „soft“ version with low V_{cesat} and V_f
    low switching frequencies, high stray inductances up to 350nH
- cosmic radiation robustness
  - → $V_{CE\,D}$ (T_{vj} = 25° C, 100 fit) = 2100V
- higher current rating; enlarged diode area for lower R_{thjc}

Diversity of requirements: two optimized versions of 3.3kV chips for different fields of applications



low on state losses

soft

low switching losses

soft

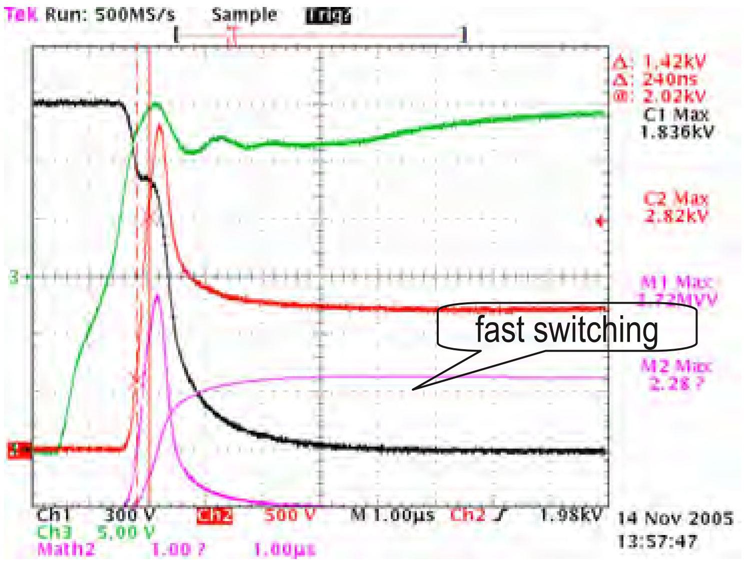
low on state losses

fast

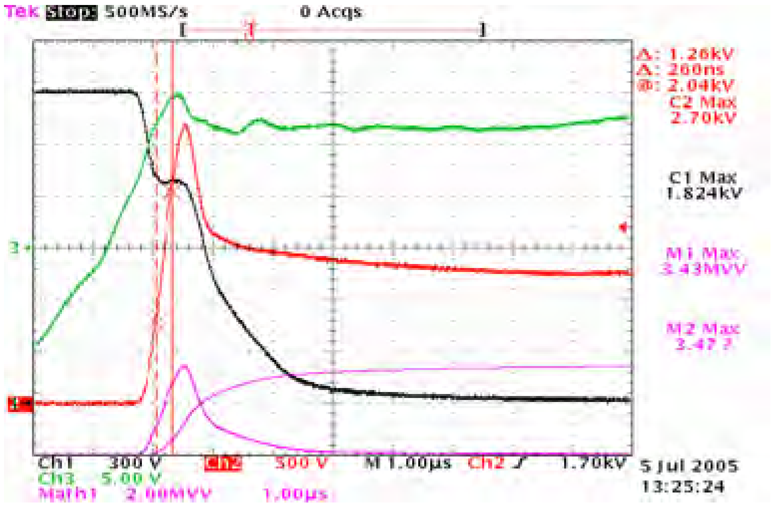
low switching losses

fast

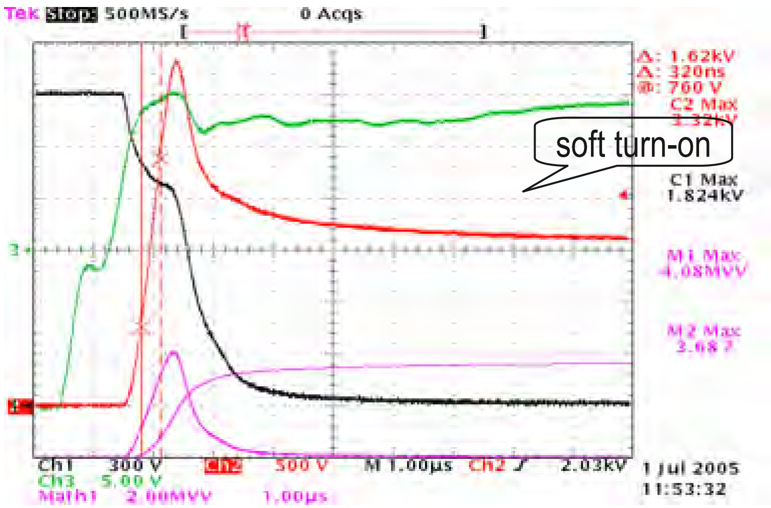
Comparison turn-on behavior KF2C-KL2C-HL3-HE3



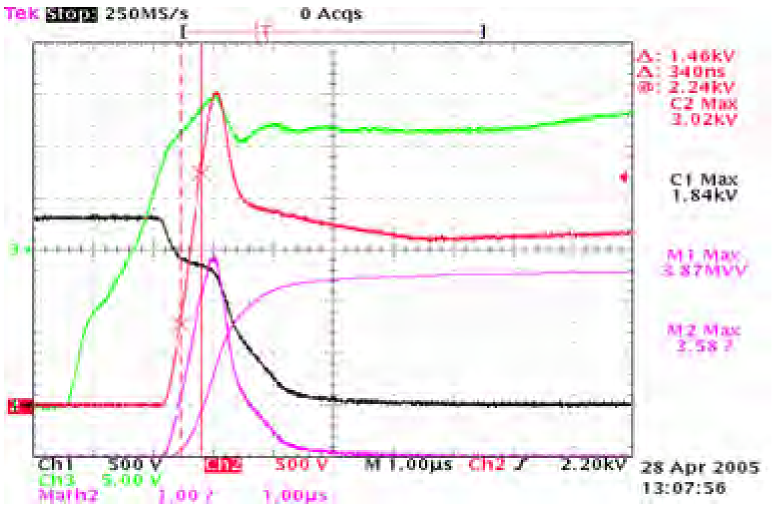
fast switching



left: KF2C
right: KL2C
@1800V / 1200A

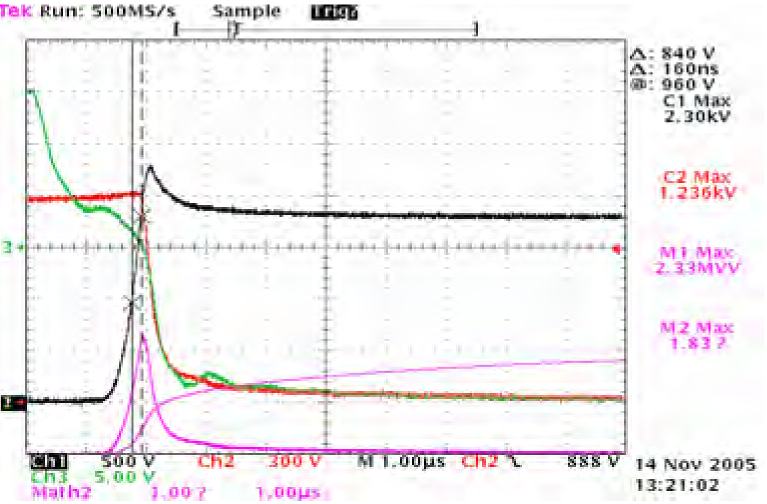


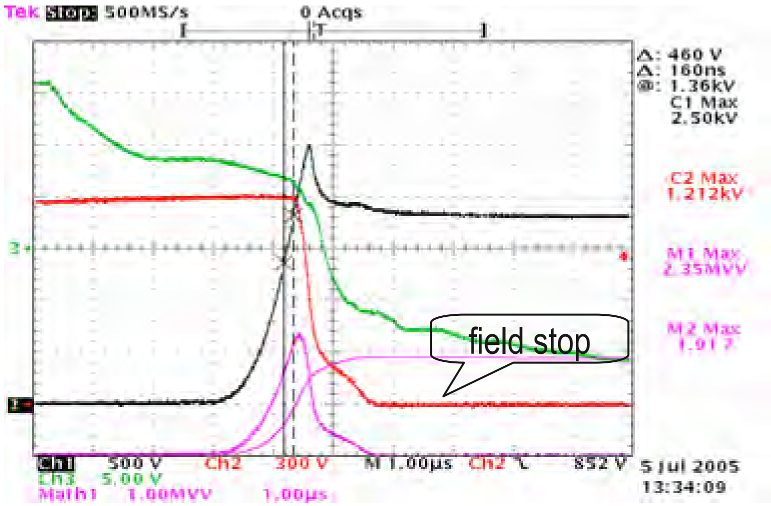
soft turn-on



left: HL3
right: HE3
@1800V / 1500A

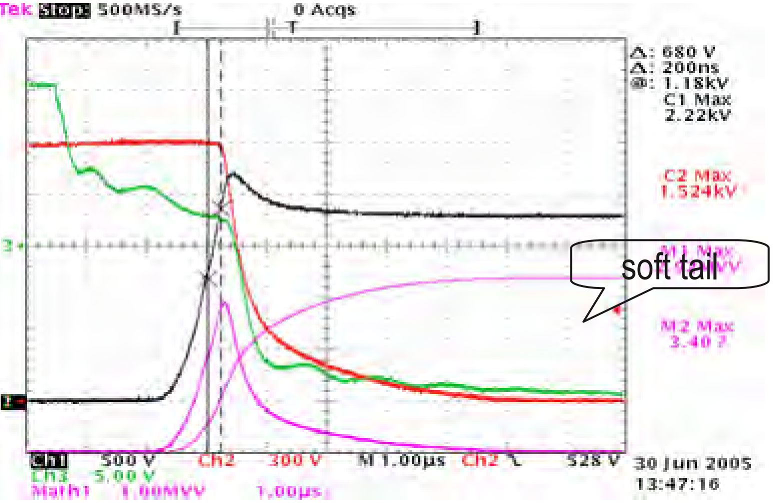
Comparison turn-off behavior KF2C-KL2C-HL3-HE3



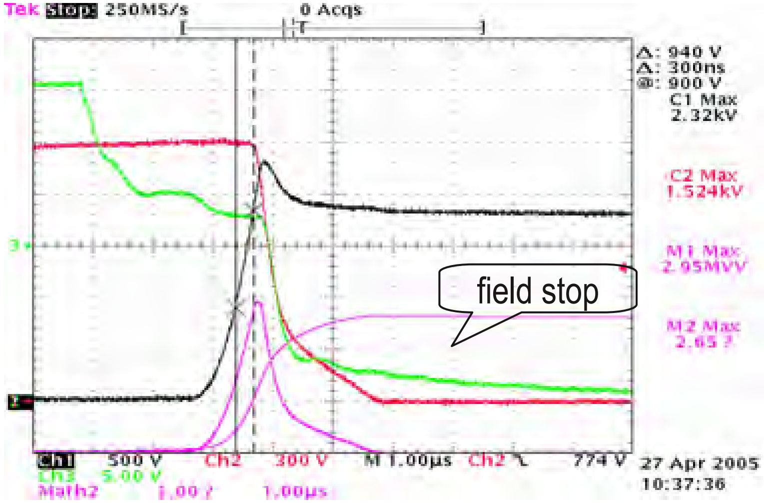


field stop

left: KF2C
right: KL2C
@1800V / 1200A



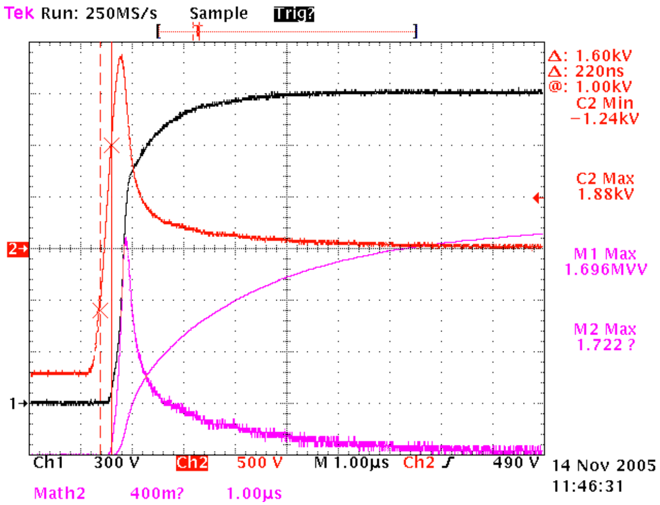
soft tail

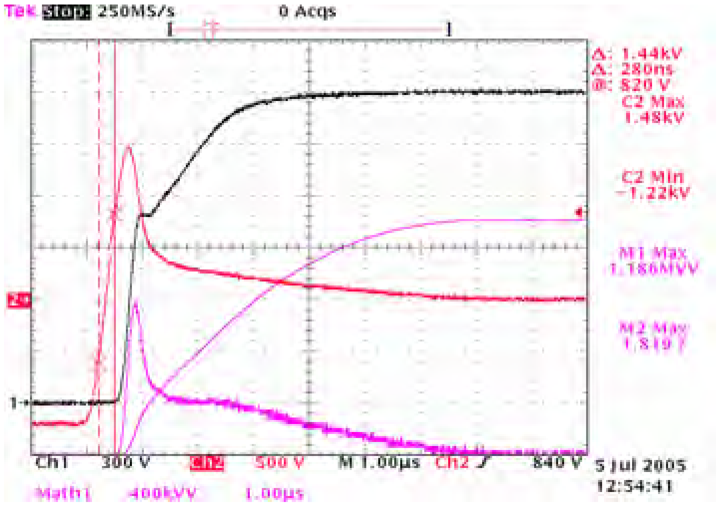


field stop

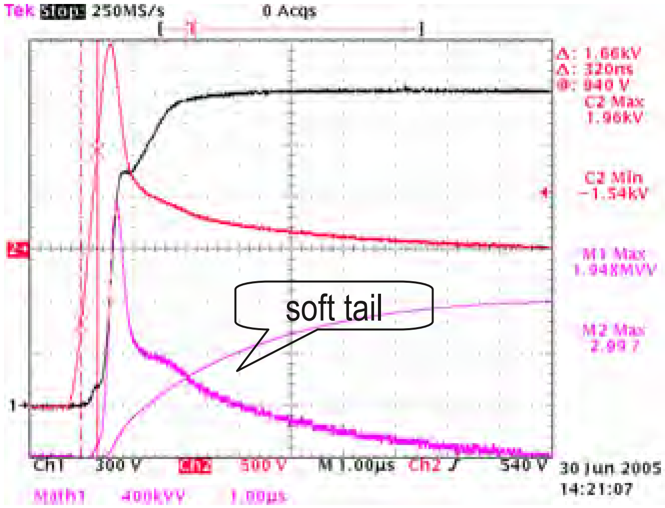
left: HL3
right: HE3
@1800V / 1500A

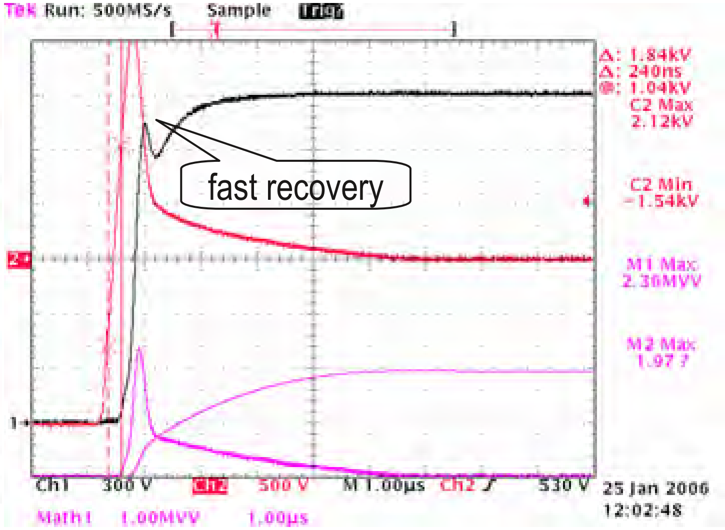
Comparison recovery behavior KF2C-KL2C-HL3-HE3





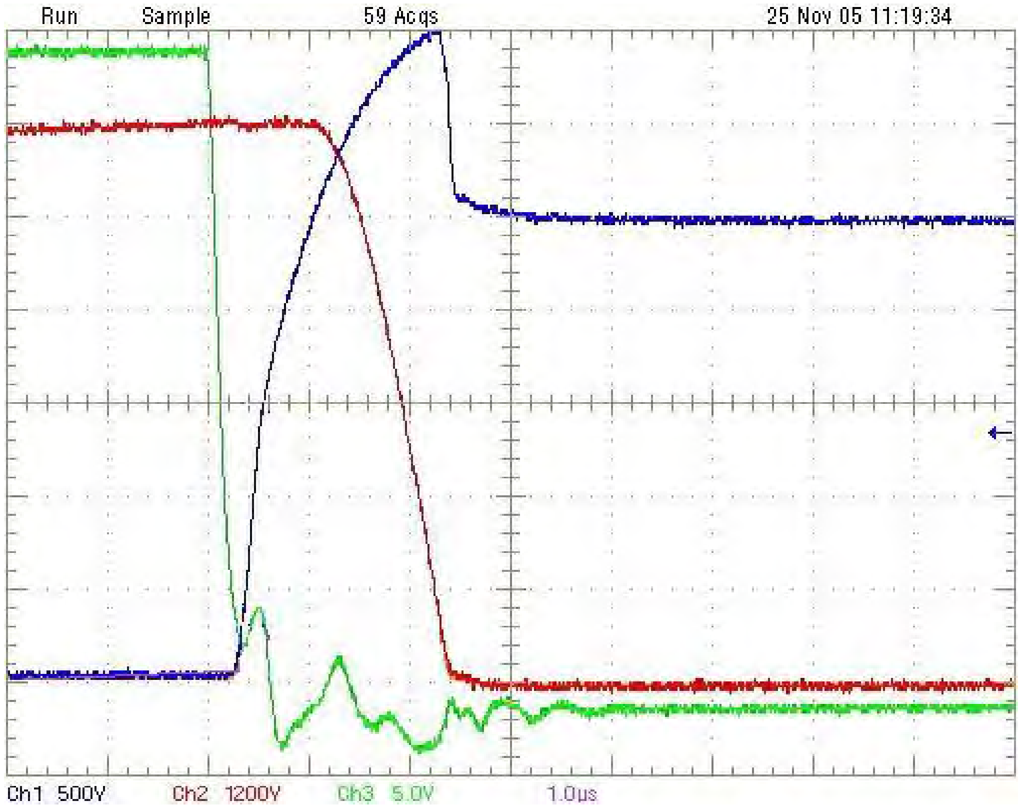
left: KF2C
right: KL2C
@1800V / 1200A





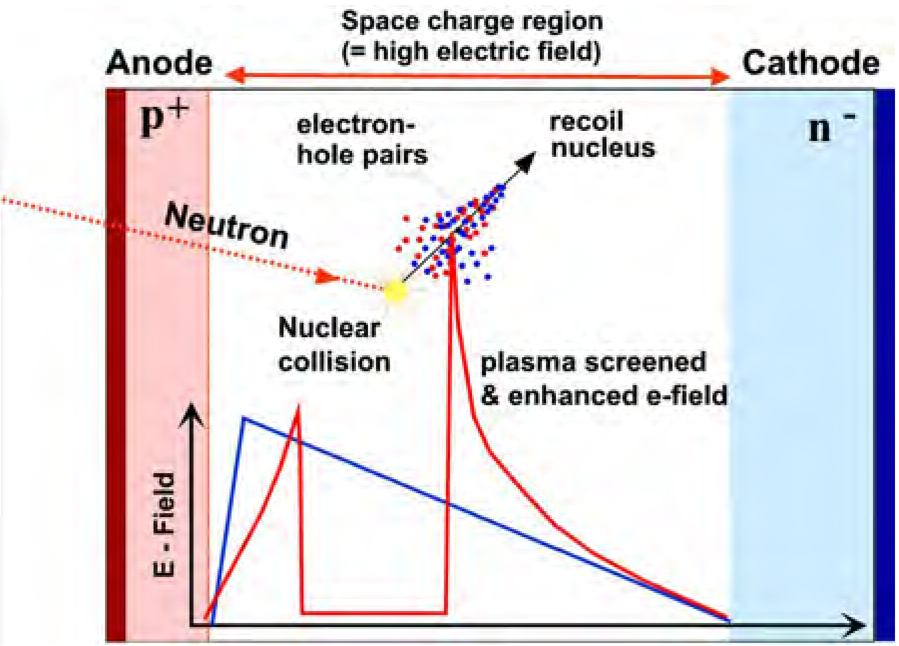
left: HL3
right: HE3
@1800V / 1500A

150° C SC operation



Overcurrent turn-off at 5xI$_{nom}$, T$_{vj}$=150°C and V$_{DC}$=2500V (V$_{GE}$: 5V/div, V$_{CE}$: 500V/div, I$_{C}$: 1200A/div)

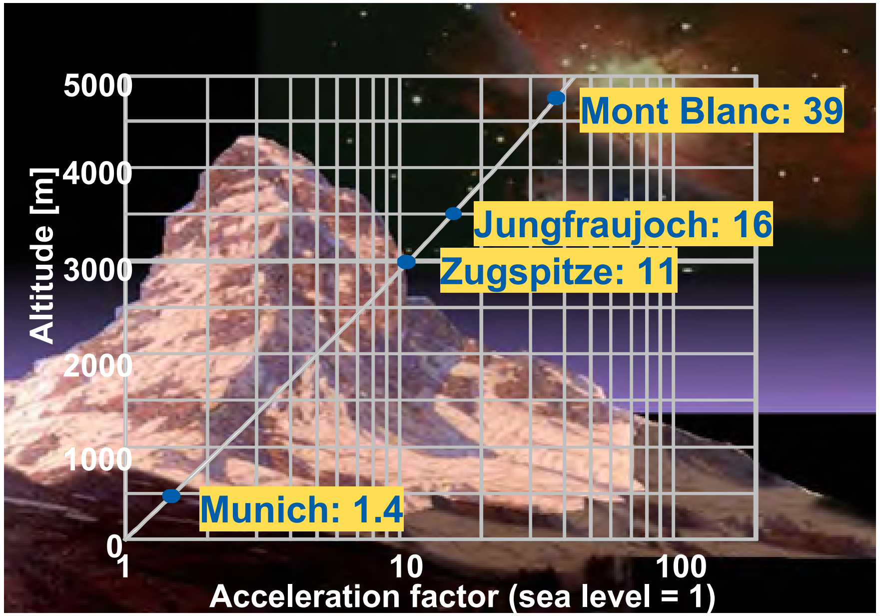
Cosmic radiation



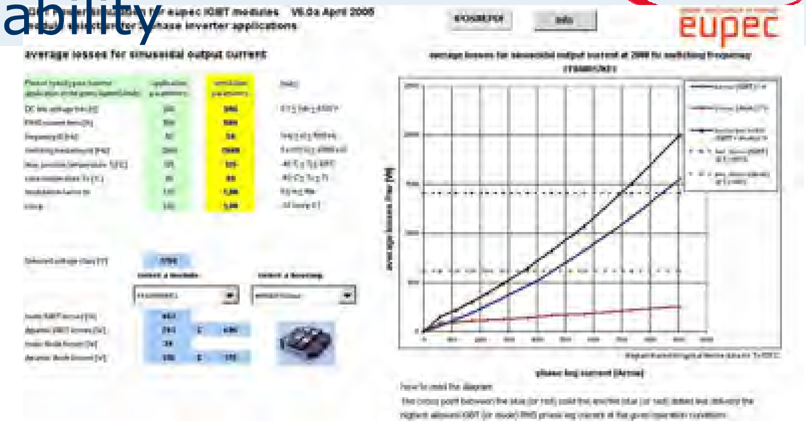
Neutrons at high energy levels generated by cosmic radiation could produce highly localized charged plasmas which in turn could trigger a destructive discharge in the semiconductor due to a massive charge multiplication.

The DC voltage to achieve a neglectable failure rate of 100 fit has been raised from 1800V for the 1200A 2nd gen. device to 2100V for the 1500A 3rd gen. device.

Altitude dependent acceleration factors →



IPOSIM comparison of current carrying capability

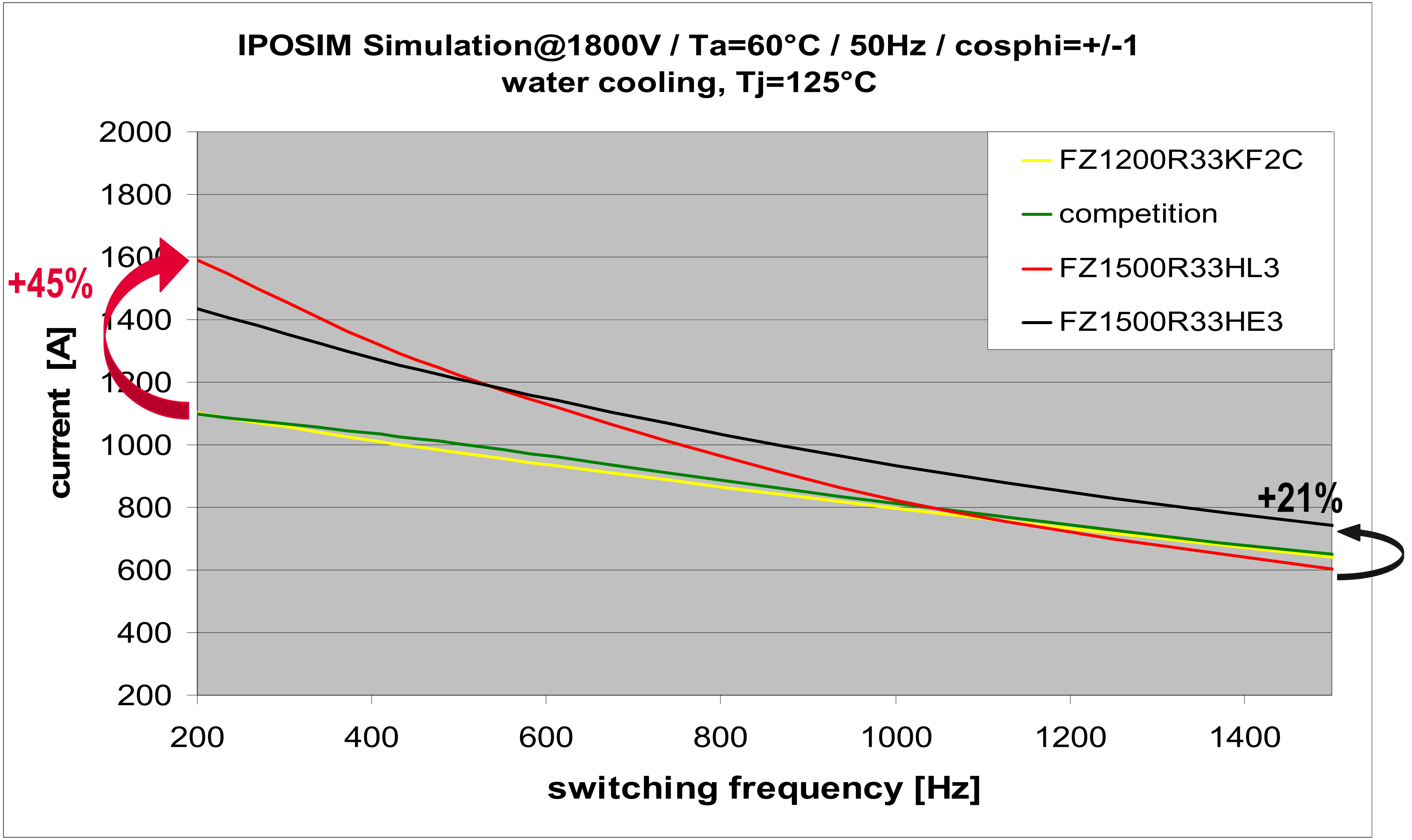


Compared devices:

- FZ1200R33KF2C (2nd gen. NPT)
- FZ1500R33HL3 (3rd gen. field stop plus trench in IHM-B housing, soft)
- FZ1500R33HE3 (3rd gen. field stop plus trench in IHM-B housing, fast)

Alle simulations are done with comparable operation conditions:
1800V / 50Hz / m=1 / f_{sw}=200...1500Hz / T_{jmax}=125° C /
cosphi=1 (IGBT) or cosphi=-1 (Diode)
with water cooling: T_a = 60° C / R_{thhs} = 6 K/kW
The max reachable currents for T_{vjmax}=125° C are calculated in the following

IPOSIM simulation results for T_{vjmax}=125° C



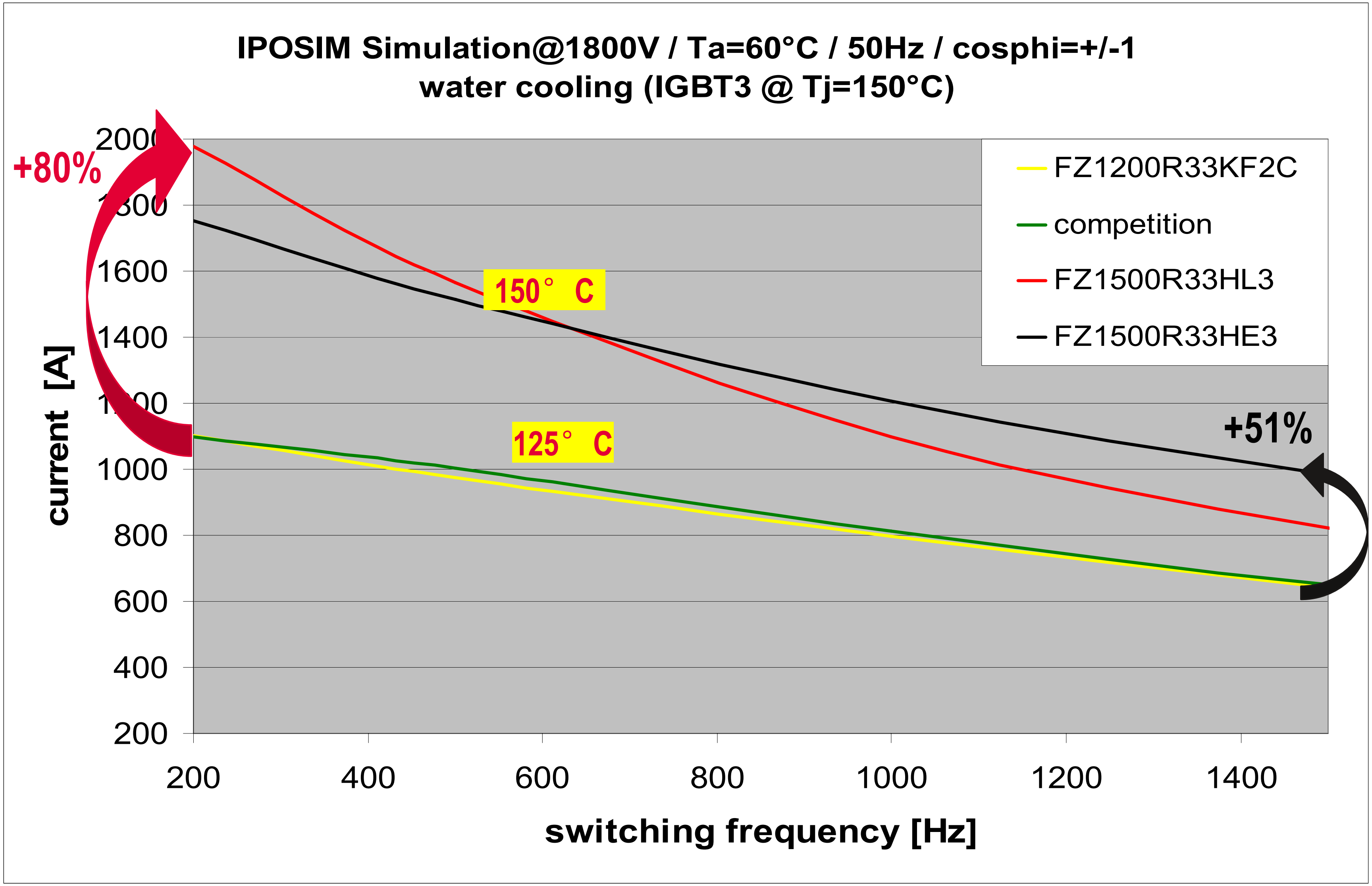
IPOSIM simulation results for T_{vjmax}=125°C

FZ1500R33HL3:
Field of application: up to 500Hz even with high stray inductances.
Clearly superior to all other devices in this frequency range.
Improvement in the range 200...500Hz: +22...45%

FZ1500R33HE3:
Field of application: above 500Hz.
Clearly superior to all other devices in this frequency range.
Improvement in the range 500...1500Hz: +15...21%

An extensive increase of current yield can be achieved by use of the new IGBT3 technology !

IPOSIM simulation with T_{vjmax}=150°C for IGBT3



IPOSIM simulation with T_{vjmax}=150°C for IGBT3

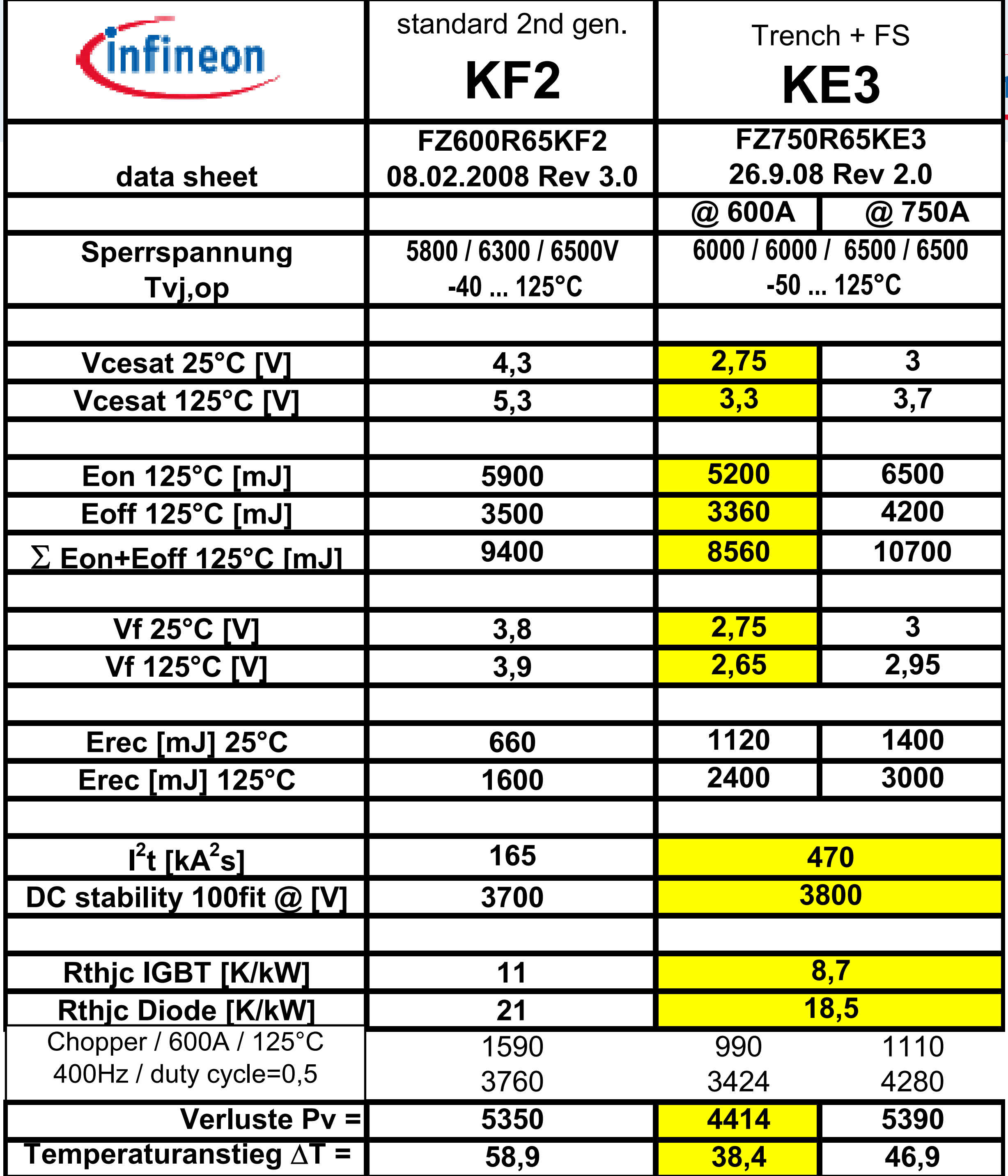
FZ1500R33HL3:
overall improvement (due to chip technology and increased max. junction temperature) in the range 200...500Hz: +56...80%

FZ1500R33HE3:
overall improvement (due to chip technology and increased max. junction temperature) in the range 500...1500Hz: +51...52%

Raising the allowed operation temperature from 125°C to 150°C for IHM B housings will bring an additional enormous increase of dissipateable power !

Overview 6500V chip generations

KF1 →



	standard 2nd gen. **KF2**	Trench + FS **KE3**	
data sheet	**FZ600R65KF2 08.02.2008 Rev 3.0**	**FZ750R65KE3 26.9.08 Rev 2.0**	
		@ 600A	**@ 750A**
Sperrspannung Tvj,op	**5800 / 6300 / 6500V -40 ... 125°C**	**6000 / 6000 / 6500 / 6500 -50 ... 125°C**	
Vcesat 25°C [V]	**4,3**	**2,75**	**3**
Vcesat 125°C [V]	**5,3**	**3,3**	**3,7**
Eon 125°C [mJ]	**5900**	**5200**	**6500**
Eoff 125°C [mJ]	**3500**	**3360**	**4200**
∑ Eon+Eoff 125°C [mJ]	**9400**	**8560**	**10700**
Vf 25°C [V]	**3,8**	**2,75**	**3**
Vf 125°C [V]	**3,9**	**2,65**	**2,95**
Erec [mJ] 25°C	**660**	**1120**	**1400**
Erec [mJ] 125°C	**1600**	**2400**	**3000**
I^2t [kA^2s]	**165**	**470**	
DC stability 100fit @ [V]	**3700**	**3800**	
Rthjc IGBT [K/kW]	**11**	**8,7**	
Rthjc Diode [K/kW]	**21**	**18,5**	
Chopper / 600A / 125°C 400Hz / duty cycle=0,5	1590 3760	990 3424	1110 4280
Verluste Pv =	**5350**	**4414**	**5390**
Temperaturanstieg ΔT =	**58,9**	**38,4**	**46,9**

Improvement in robustness of 6.5kV KF2 type

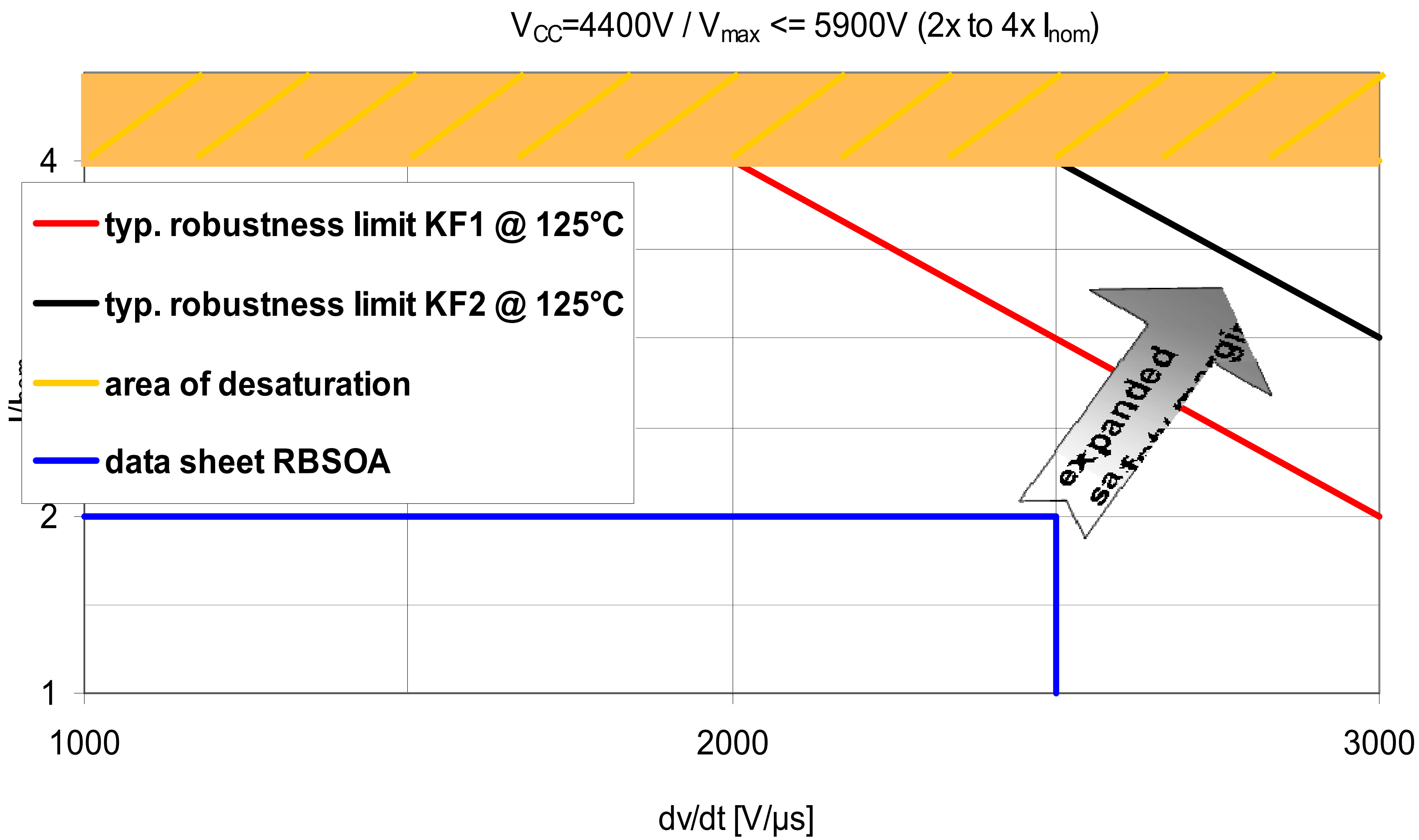
The KF1 chip generation is now in the market and in mass production for more than four years. Since the customers are increasingly confident in the robustness of the corresponding devices, we see a tendency to boost the current and voltage utilization in new high power application designs. As a consequence,

Infineon decided to apply latest technical expertises and expand the overall robustness of the IGBT device by a chip modification named “KF2”.

Robustness in this context is expressed by the distance between points of destruction and test or operation conditions. It can be visualized by a so called robustness map shown in the following diagram.

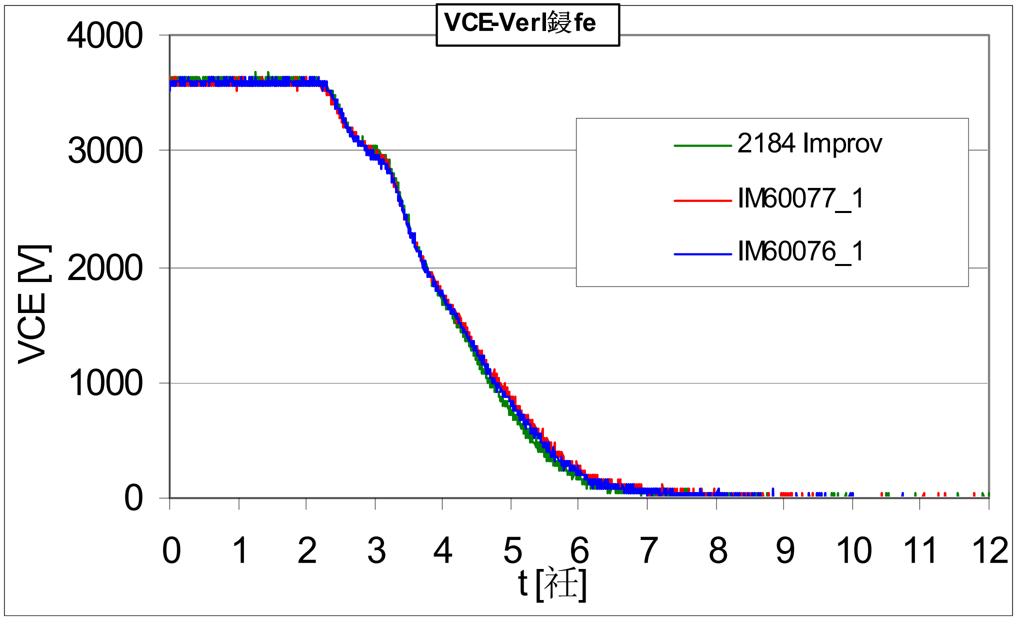
For improving the safety margins KF2 should be used for new designs.

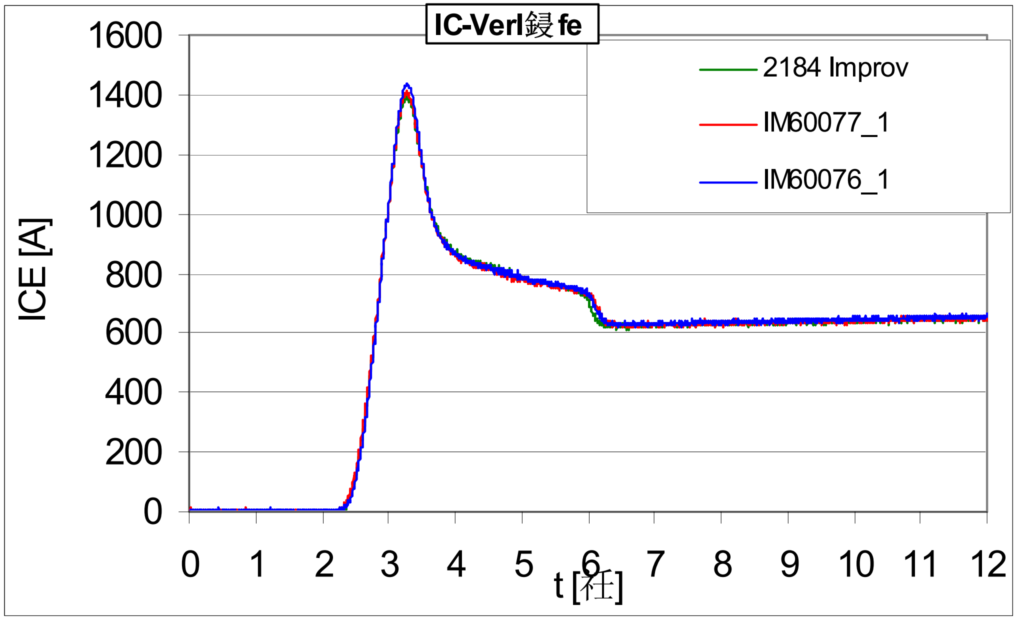
Improvement in robustness of 6.5kV KF2 type



Robustness map KF1 and KF2

Turn-on comparison KF1 vs. KF2



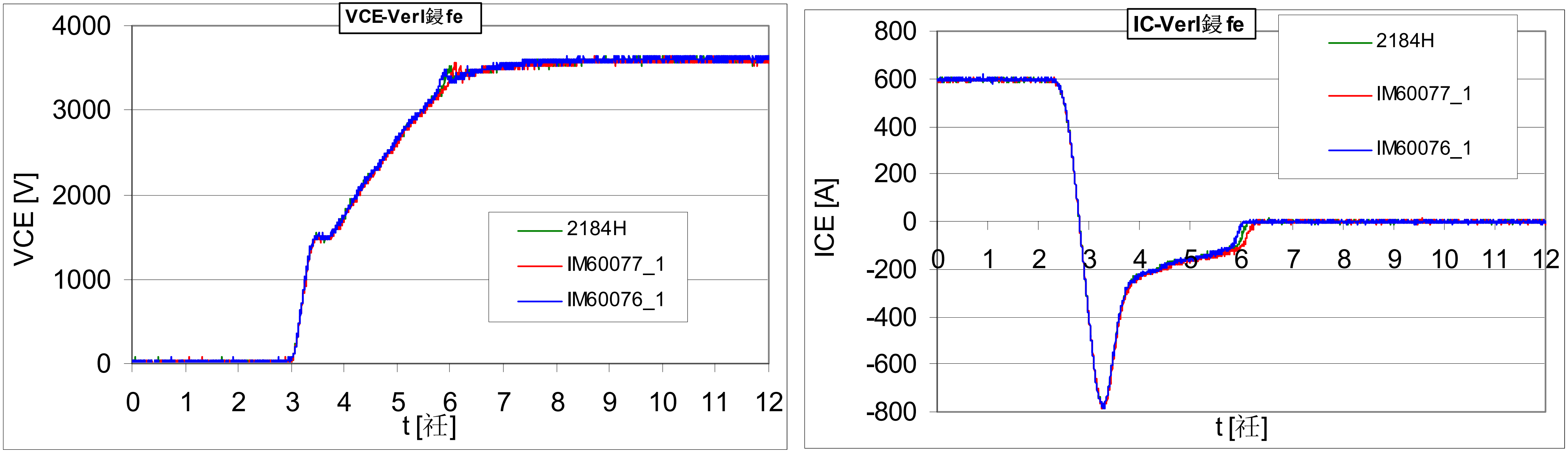


Turn-on comparison at Inom and 125°C

Improved device (KF2): “2184 Improv”

standard device (KF1): “IM60077_1” and “IM60076_1”

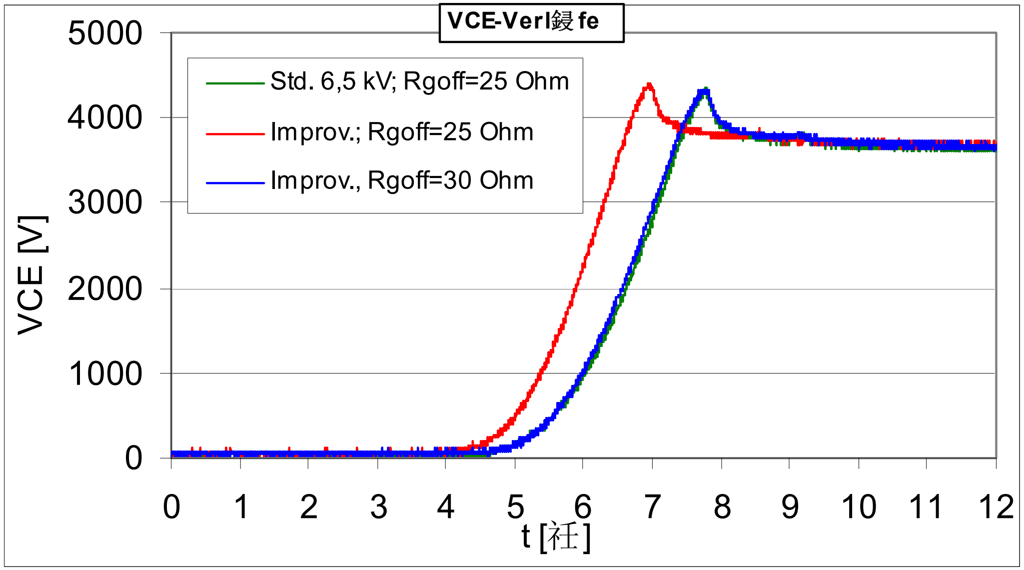
Diode recovery comparison KF1 vs. KF2

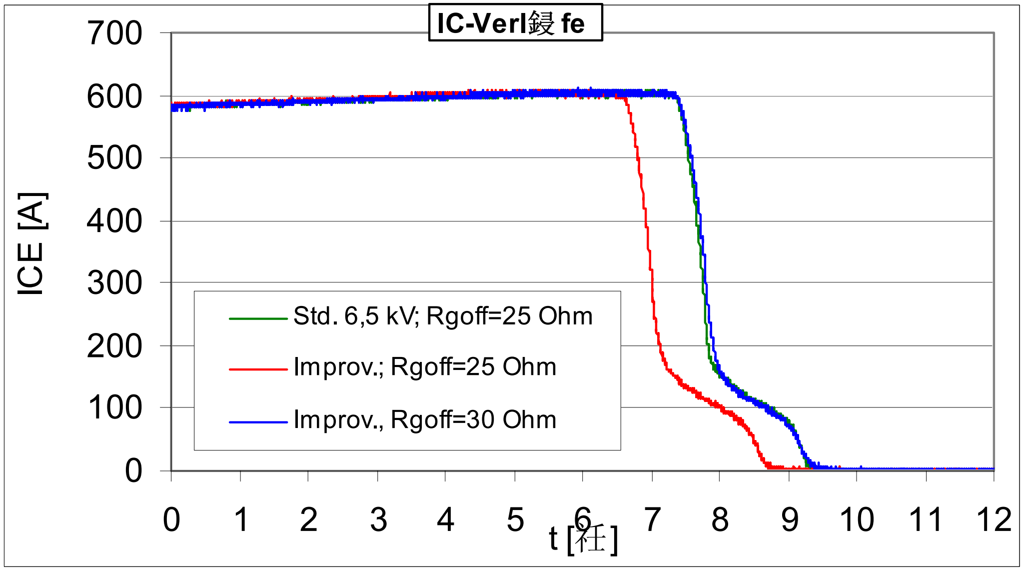


Diode recovery comparison at Inom and 125°C

Improved modules KF2 and standard device KF1 show no significant differences in their turn-on and recovery behavior at identical Rgon.

Turn-off comparison KF1 vs. KF2





Turn-off comparison at Inom and 125°C

green: standard device (KF1) at nominal Rgoff = 25Ω

red: improved device (KF2) at Rgoff = 25Ω

blue: improved device (KF2) at new nominal Rgoff = 30Ω

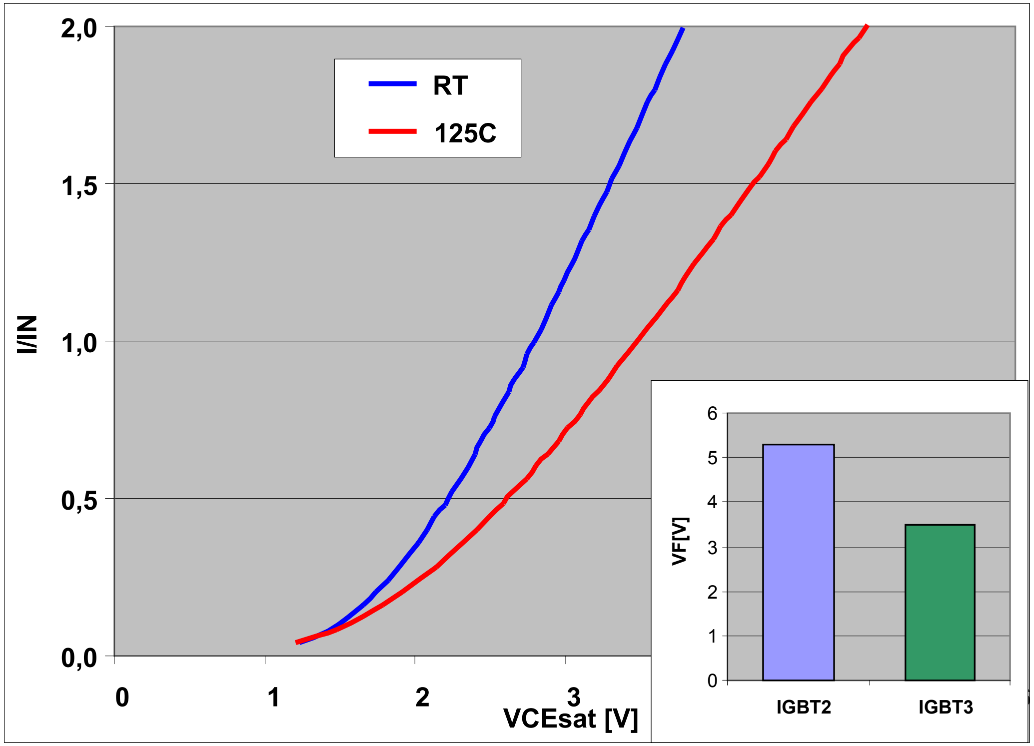
By increasing the Rgoff from 25Ω to 30Ω the turn-off behavior of the KF2 device can be fully adapted to the behavior of the standard KF1 device.

Benefits of new IGBT^3 chip generation compared to IGBT^2

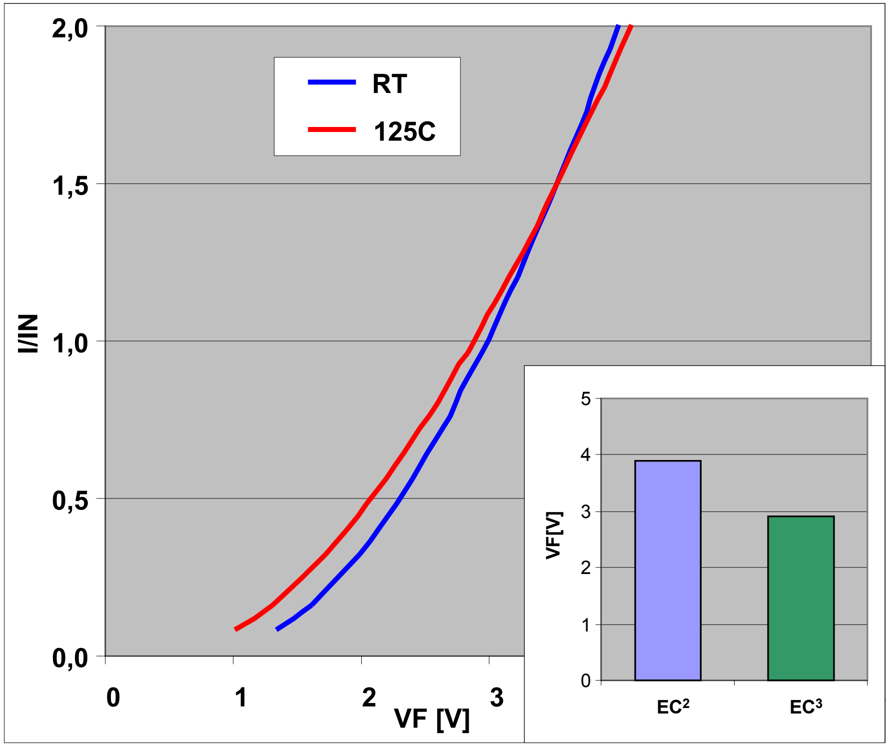
- Storage temperature extended from -40° C down to -55° C
- Cosmic radiation robustness $V_{CE\,D}$(T_{vj} = 25° C, 100 fit) raised from 3700V to 3800V
- Nominal current rating raised from 600A to 750A
- Drastical reduction of V_{cesat} and V_f due to Trench and field-stop technology
- Drastical increase of i^2t-capability from 165 to 470kA^{2}s
- enlarged diode area for lower R_{thjc}; well suited for the needs of regenerative operation in traction applications

6.5kV IGBT^3 V_{cesat} and V_f

V_{CEsat}



V_f



Significant reduction of conduction losses by

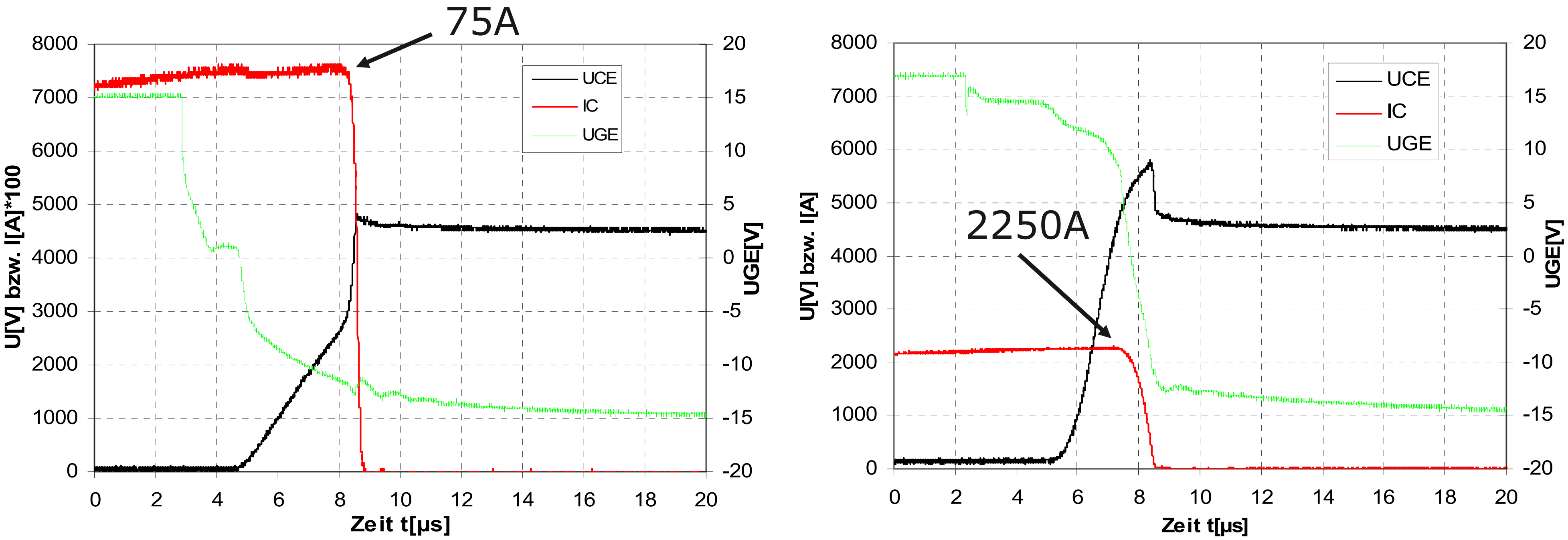
- increase of active area (optimization of edge structure)
- optimization of charge carrier distribution

> 30% V_{CESat} reduction of IGBT^3 against IGBT^2

> 20% V_F reduction of EC^3 diode against 2nd gen.

6.5kV IGBT³ switching behavior

Turn-off behavior of 750A module at L_s=280nH, V_{DC}=4.5kV

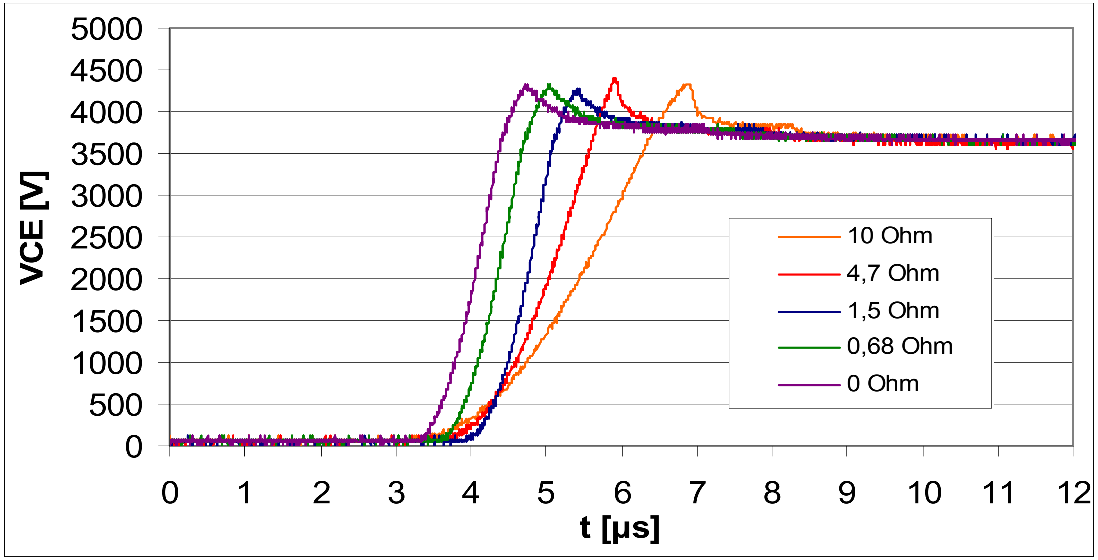


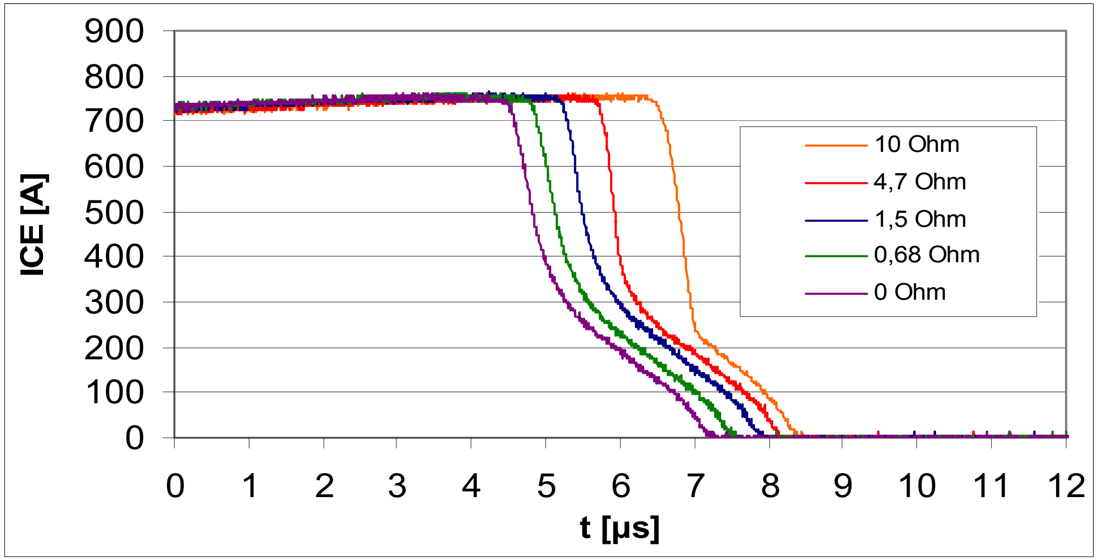
T_{vj}=25°C; I_C=1/10xI_n

T_{vj}=125°C; I_C=3xI_n

- Softness and robustness verified under worst-case conditions

6.5kV IGBT^3 switching behavior





Turn-off behavior 750A module at L_s=280nH, V_{DC}=4,5kV, I_C=750A; T_{vj}=125°C

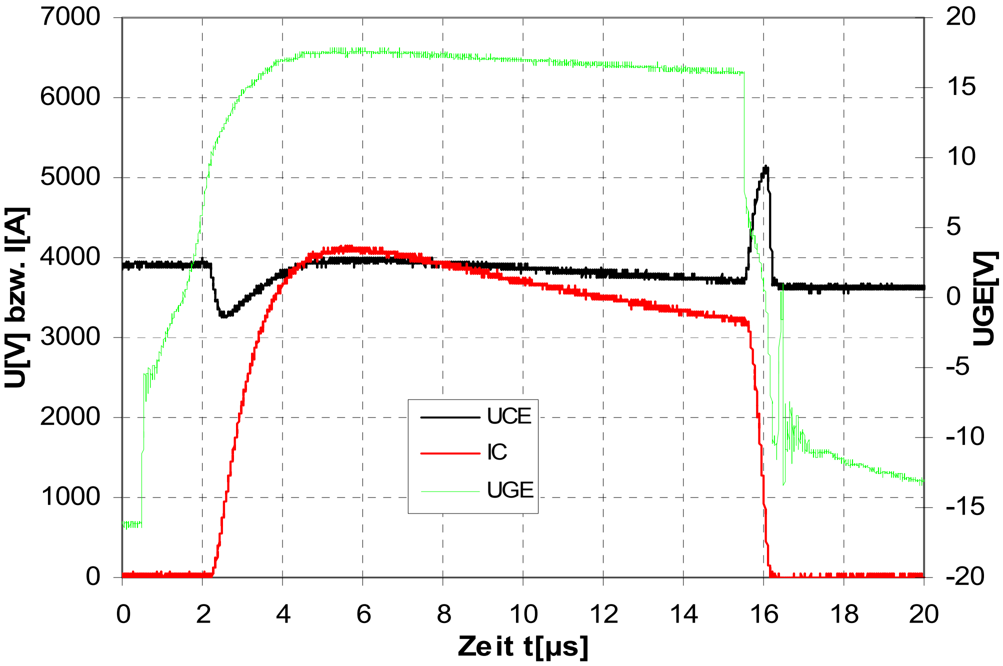
- dv/dt saturates at 4.5kV/µs
- soft turn-off
- comparable turn-off losses IGBT^3 vs. IGBT^2 despite an increase of I_n by 25%

6.5kV IGBT^3 short circuit behavior

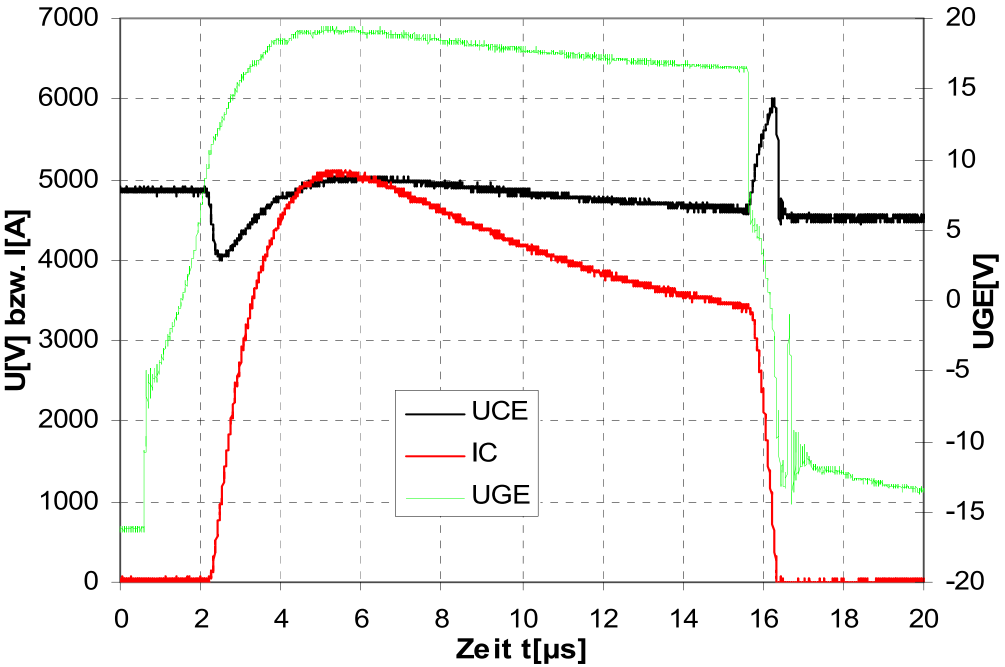
T_{vj}=125° C, t=14µs

V_{GE}=15V with 17V clamping

V_{CC}=3600V

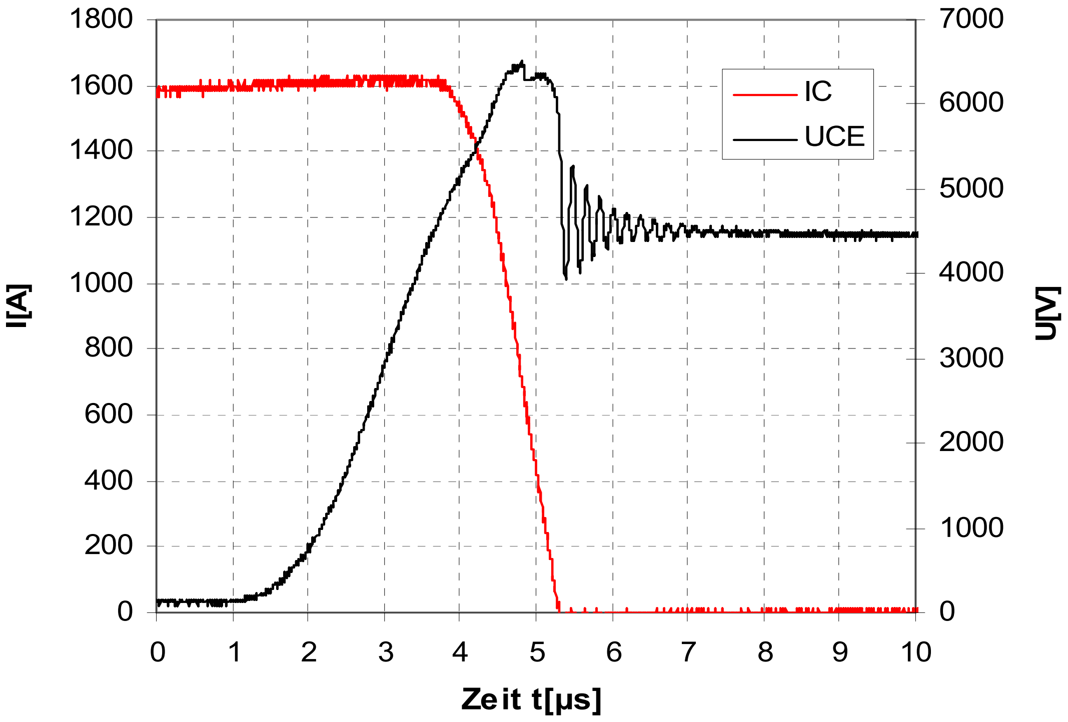


V_{CC}=4500V



- very good short circuit behavior for -40° to +125° C temperature range
- free of any oscillations above V_{CE} = 800V
- ≥ 40% margin for SC time against data sheet value

6.5kV IGBT³ clamping of over-current

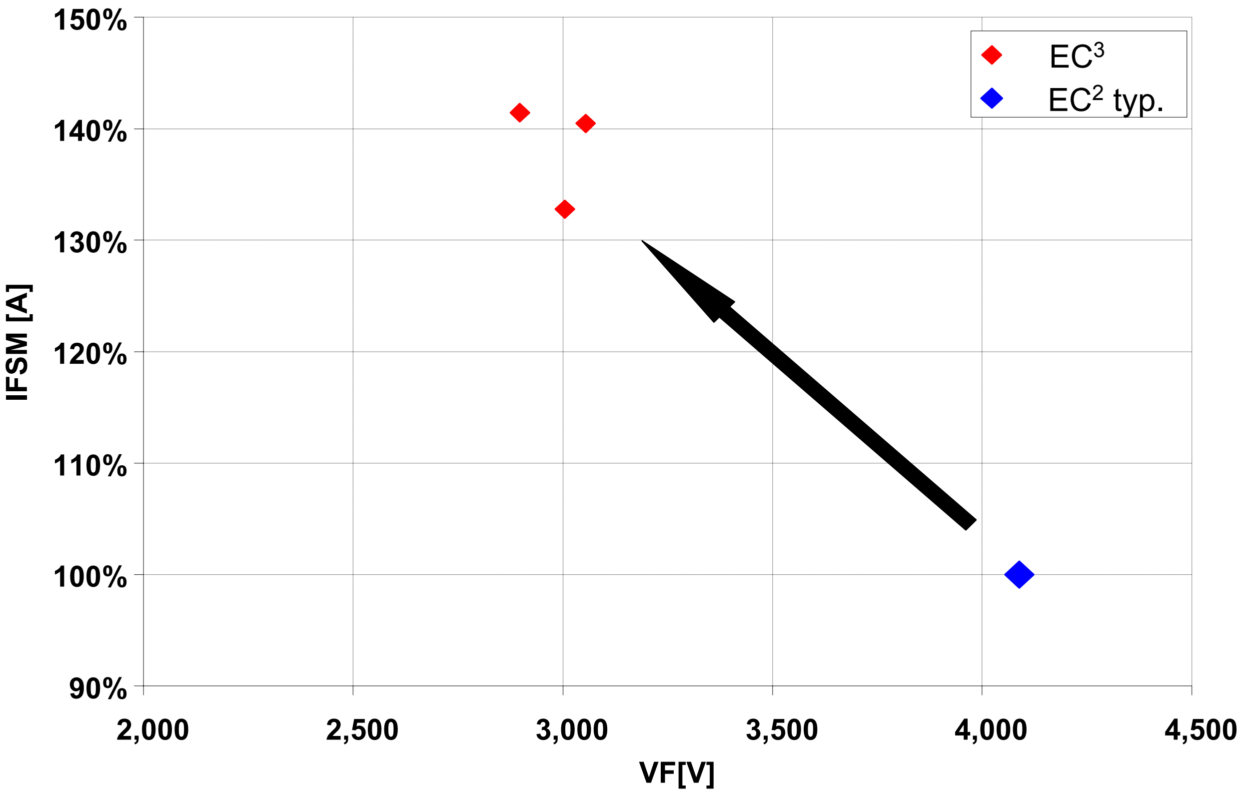


- repetitive overcurrent turn-off with self-clamping
- turn-off current 1600A *) for 500A module (>3xI_N)
- T_{vj}=125° C
- even with high stray inductance L_s of 800nH

*) for regular operation:
max. 2xI_n allowed

6.5kV EC^3 diode I^2t

Comparison I_{FSM} measurements 3rd vs. 2nd gen. diode

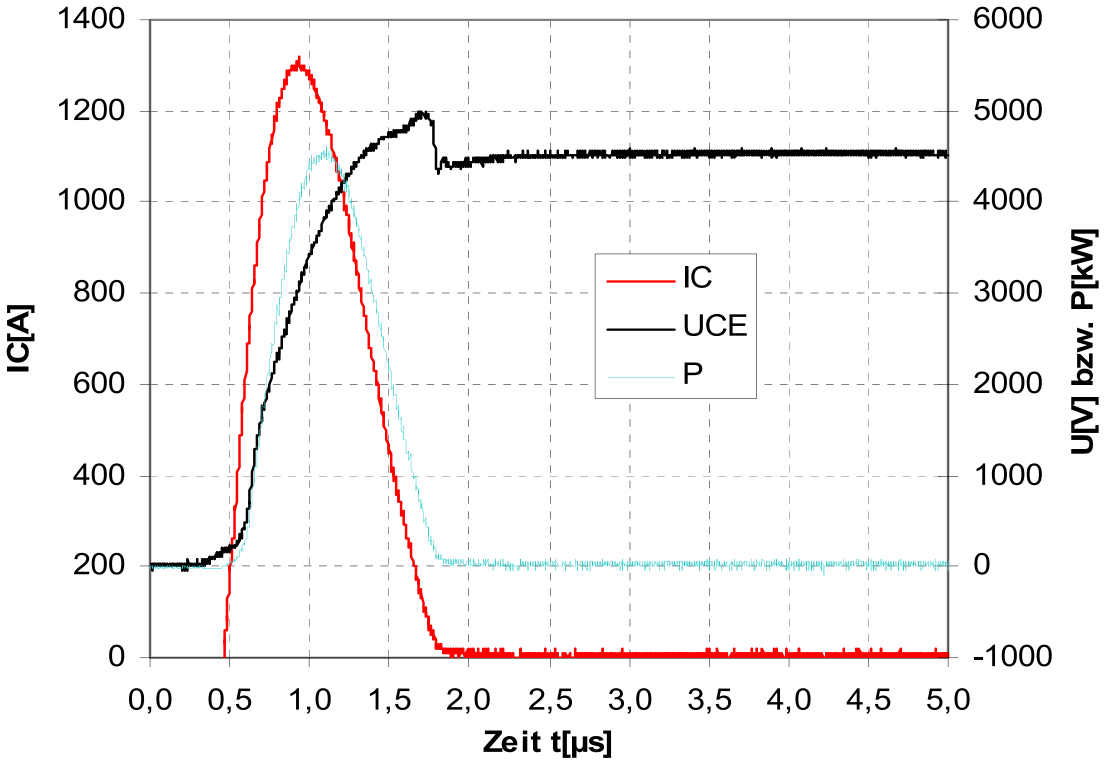


Considerable increase in surge current capability for new 6.5 kV EC^3 diode by

- larger active chip area
- lower conduction losses

6.5kV EC³ diode robustness

Diode turn-off 250A (1 of 3 systems)



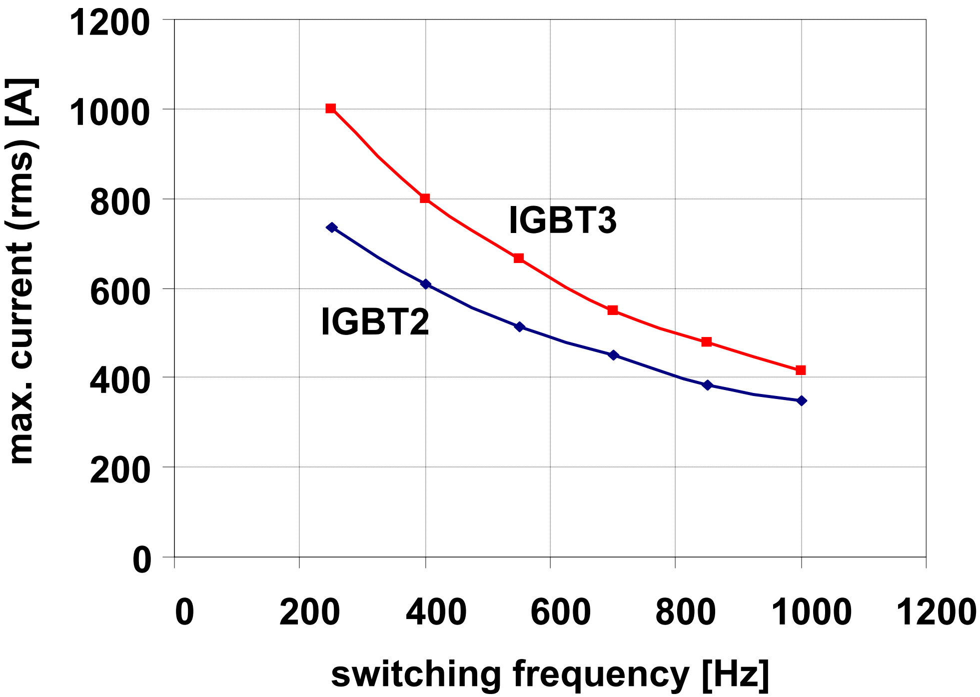
T_{vj}=125° C

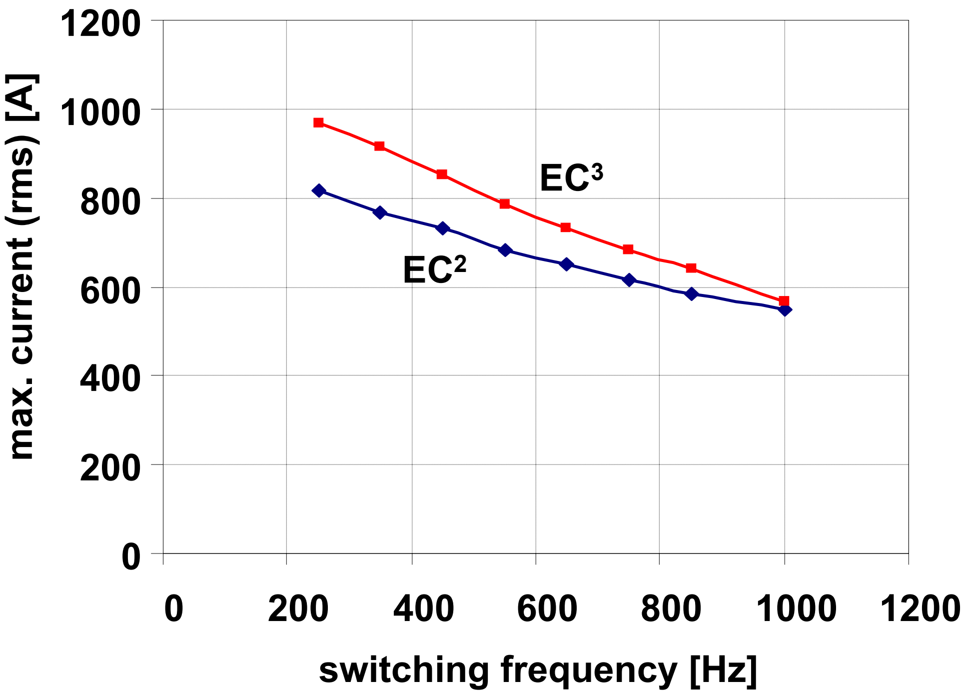
dI/dt=4kA/µs

- single pulse
  - P_{max} 4.5 MW for a 250A system reached
  - P_{max} of clearly above 10 MW for 750A module expected
- continuous operation
  - considerable expansion of specified SOA possible

Simulation of achievable inverter currents

simulated max. inverter currents for a 6.5 kV 190x140 base plate module

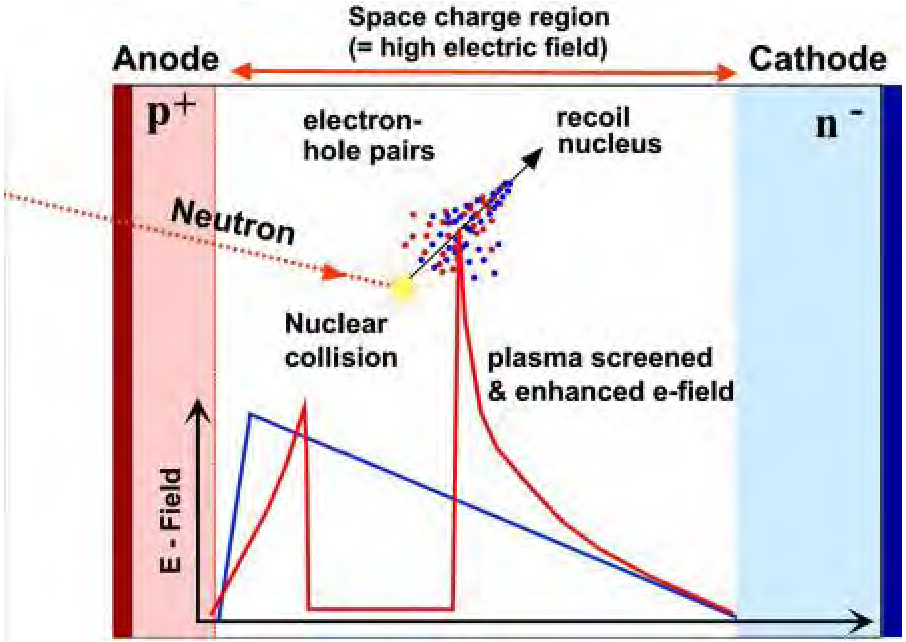




T_a = 40 °C
V_{CE} = 3.6 kV
m = 1
f_0 = 50 Hz
$R_{th(H-A)}$ = 6 K/kW

- up to 30 % higher current yield for $IGBT^3$ in the relevant frequency range of 250 Hz to 500 Hz

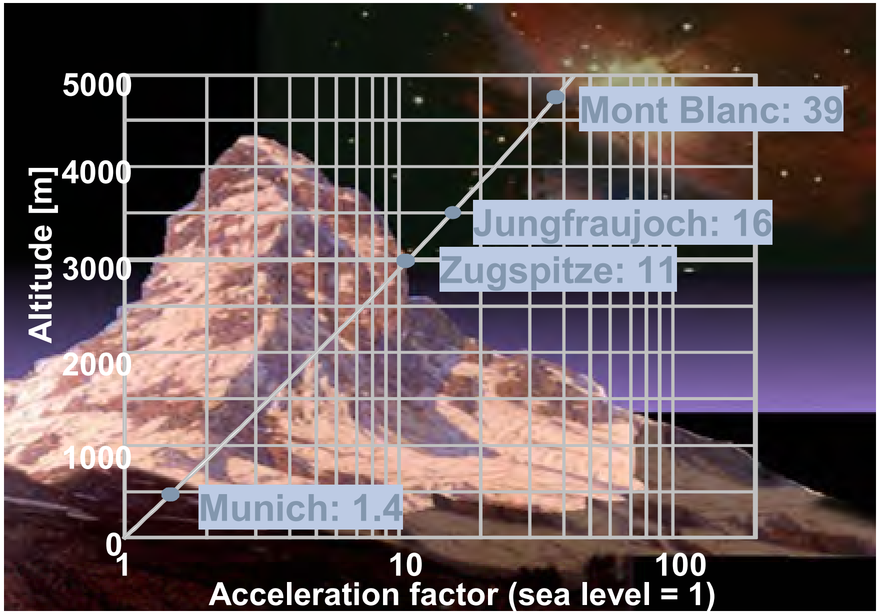
Cosmic radiation



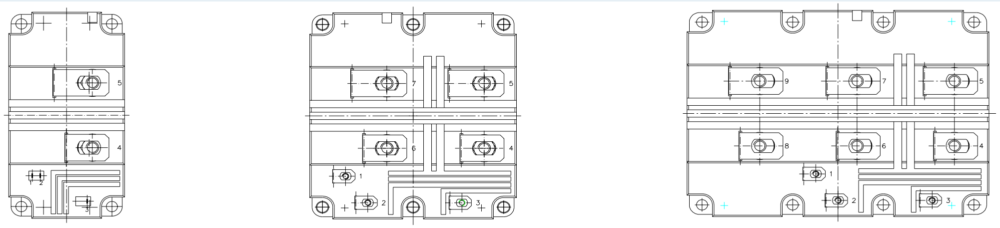
Neutrons at high energy levels generated by cosmic radiation could produce highly localized charged plasmas which in turn could trigger a destructive discharge in the semiconductor due to a massive charge multiplication.

The DC voltage to achieve a neglectable failure rate of 100 fit has been raised from 3700V for the 600A 2nd generation device to 3800V for the 750A 3rd generation device.

Altitude dependent acceleration factors →



6.5kV IHV IGBT-Modules KF2

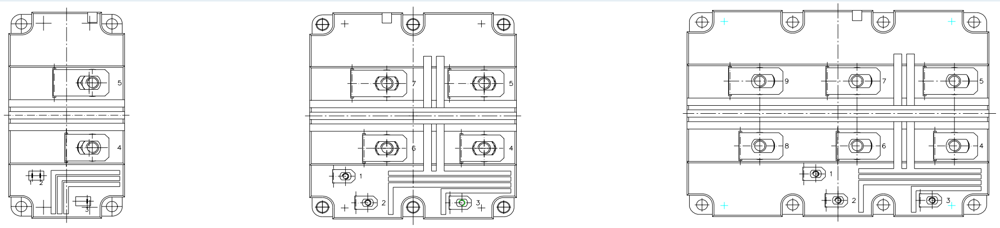


I_C [A]	Single Switch		
	140x73mm	140x130mm	140x190mm
200	FZ200R65KF2*		
400		FZ400R65KF2	
600			FZ600R65KF2

I_C [A]	Chopper-module		Diode-module
	140x130mm	140x190mm	140x130mm
200	FD200R65KF2-K*		DD200S65K2*
400		FD400R65KF2-K*	DD400S65K2*

* Time Schedule not fixed yet!

6.5kV IHV IGBT-Modules KF2 with -55°C / -50°C

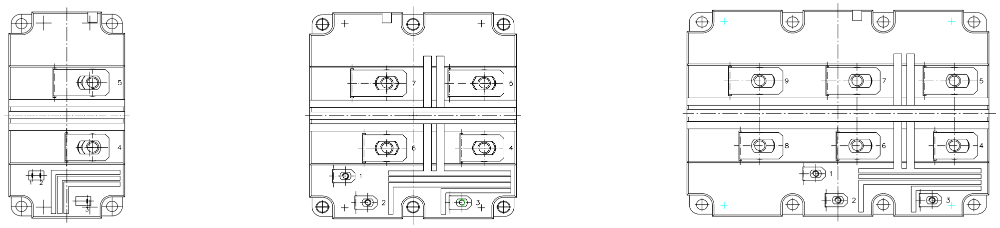


I_C [A]	Single Switch		
	140x73mm	140x130mm	140x190mm
200	FZ200R65KF2T*		
400		FZ400R65KF2T	
600			FZ600R65KF2T

I_C [A]	Chopper-module		Diode-module
	140x130mm	140x190mm	140x130mm
200	FD200R65KF2-KT*		DD200S65K2T*
400		FD400R65KF2-KT*	DD400S65K2T*

* Time Schedule not fixed yet!

6.5kV IHV IGBT-Modules with $IGBT^3$: KE3

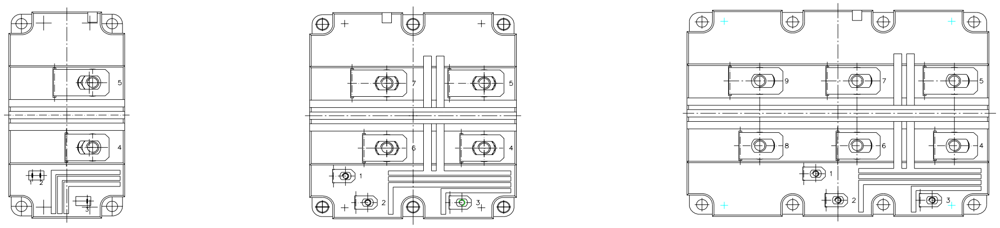


I_C [A]	Single Switch		
	140x73mm	140x130mm	140x190mm
250	FZ250R65KE3*		
500		FZ500R65KE3*	
750			FZ750R65KE3

* Time Schedule not fixed yet!

* Time schedule not fixed yet!

6.5kV IHV IGBT-Modules with IGBT³: KE3 with -50°C / -55°C



I_C [A]	Single Switch		
	140x73mm	140x130mm	140x190mm
250	FZ250R65KE3T*		
500		FZ500R65KE3T*	
750			FZ750R65KE3T

* Time Schedule not fixed yet!

* Time schedule not fixed yet!

6.5kV IGBT^3 plus EC^3 summary

- static losses reduced by 30-40% (@ 600A)
- Thermal resistance reduced from 11→8.7K/kW and 21→18.5K/kW (IGBT/Diode) → new edge concept increases available active area
- Nominal current raised from 600 to 750A → simplifies circuit in case of paralleling
- Robustness improvement IGBT:

  final test with 3*Inom far above RBSOA possible
- Robustness improvement Diode:

  P_{max} raised from 1,8 to 3MW, i^2t increased from 165 to 435A^2s
- cosmic radiation robustness 100 fit value raised from 3700V to 3800V
- minimum operation temperature T_{vjop} lowered to -50°C
- minimum storage temperature T_{stg} lowered to -55°C
- design support given by IPOSIM dimensioning program
- no C_{GE} needed