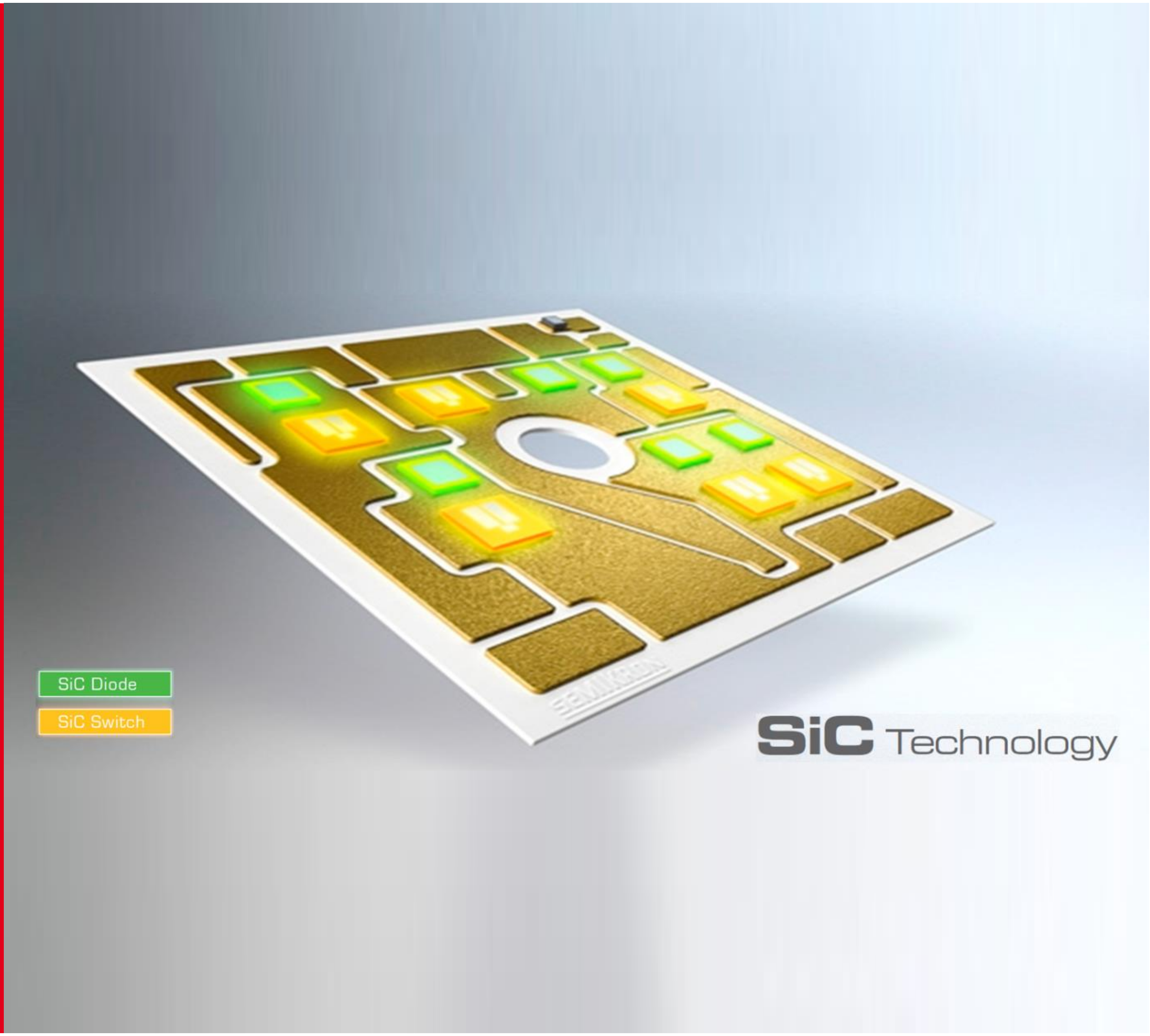
Silicon Carbide

Overview

Status

Activities



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Product Management

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Agenda

Content

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Why SiC? Opportunities…

Wide band-gap material:

– High blocking voltages are possible, e.g. 10kV

Unipolar devices, no minority charge carriers and therefore no “tail currents” or reverse recovery

– Schottky diodes:
  Recovery charge close to zero, can reduce IGBTs’ E_{on} drastically

– MOSFETs:
  very low switching losses, fast switching

– Higher carrier frequencies are possible with constant or even lower losses

– Drastically lower losses at same carrier frequency

Why SiC? Opportunities…

Very high thermal conductivity:

- Devices rated T_j = 175°C are standard (diodes), up to T_j = 225°C possible, in the future.
- Lower resulting R_{th}

Switching devices are MOSFETs generally,
IGBT will be feasible for high blocking voltages only (>10kV)

Linear forward characteristics of the MOSFET is beneficial in low load conditions.

No FWD required in certain topologies, MOSFET's body diode and reverse conduction capability can be utilized.

Small chip sizes lead to smaller power modules.

Applications

Renewable Energy Solar

- Increase switching frequency
- Reduce pasive filter components
- Increase efficiency

High Frequency Power Supplies Induction heating, Medical

Naturally high switching frequency

Motor Drives

- Reduce power losses
- Reduce cooling efforts
- Reduce size and weight

Traction Aux. power supplies (main drive)

- Increase switching frequency
- Reduce pasive filter components
- Reduce weight and size
- Reduce cooling efforts

Uninterruptable Power Supply (UPS)

- Increase switching frequency
- Reduce pasive filter components
- Increase efficiency

Diode Comparison

Comparison of following diodes:

Si (CAL HD) Diode:

standard SEMIKRON silicon freewheeling diode,
“Controlled Axial Lifetime High Density”.

Si Fast Diode:

ultra-fast silicon free wheeling diode.
Power Integrations Qspeed 600V, 8A diode (PFC diode)

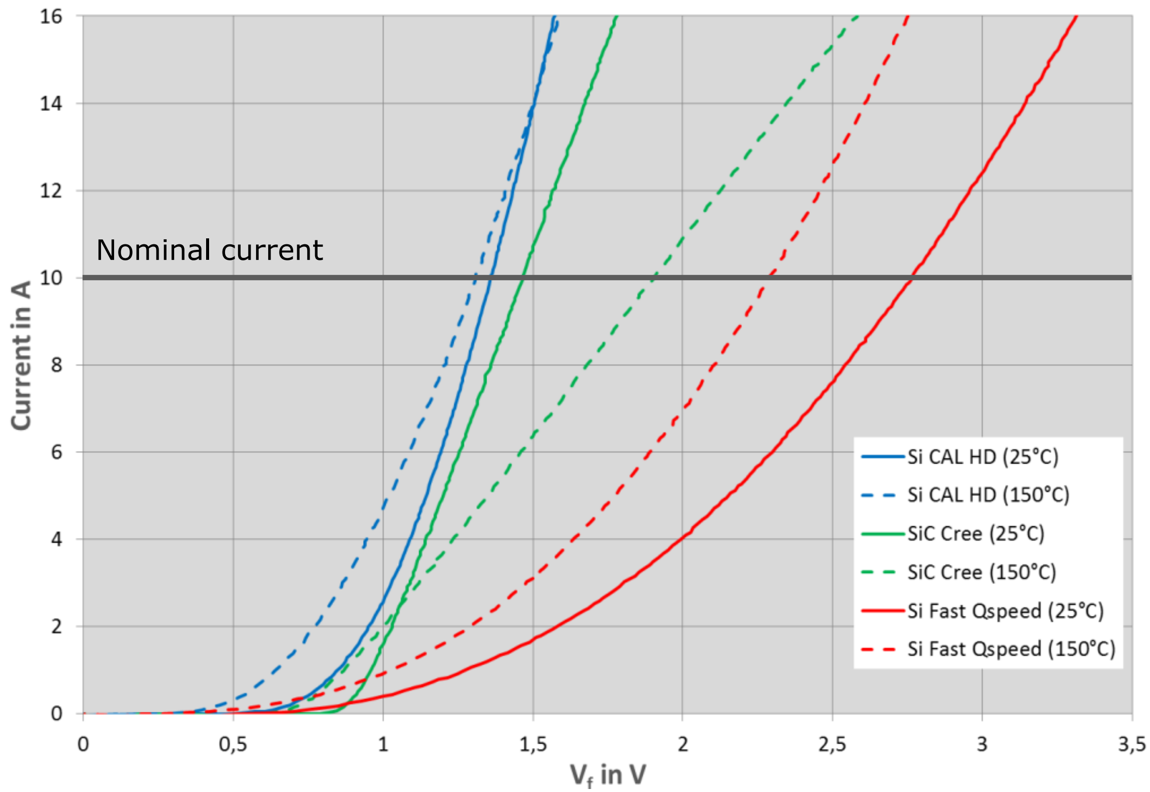
SiC Diode:

silicon carbide Schottky diode Cree
CPW2-1200-0010B

Mini SKiiP housing, 600V, 10A rated current,
switching in same operation point.

Diode Comparison – Static Losses

Higher static losses of SiC diode at nominal current compared to standard Si (CAL HD) diode, but lower than the Si Fast diode.



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Diode Comparison – Switching Losses

	Si (CAL HD)	SiC	Si Fast
	V_R = 300 V, I_F = 10 A, T_J = 150°C, R_{G_Off} = 51 Ω, $_{RG\_On}$ = 39 Ω		
di/dt	750 A/µs	700 A/µs	750 A/µs
I_{RRM}	14,9 A **Factor 3**	5,0 A	8,2 A
Q_C	1,36 µC **Factor 13**	0,098 µC	0,226 µC
E_{rr}	0,264 mJ **Factor 16**	0,016 mJ	0,024 mJ

Assuming the same point of operation:

– E_{rr} of the SiC diode is smaller by a factor of 16
– Q of the SiC diode is smaller by a factor of 13
– I_{RRM} of the SiC diode is smaller by a factor of 3

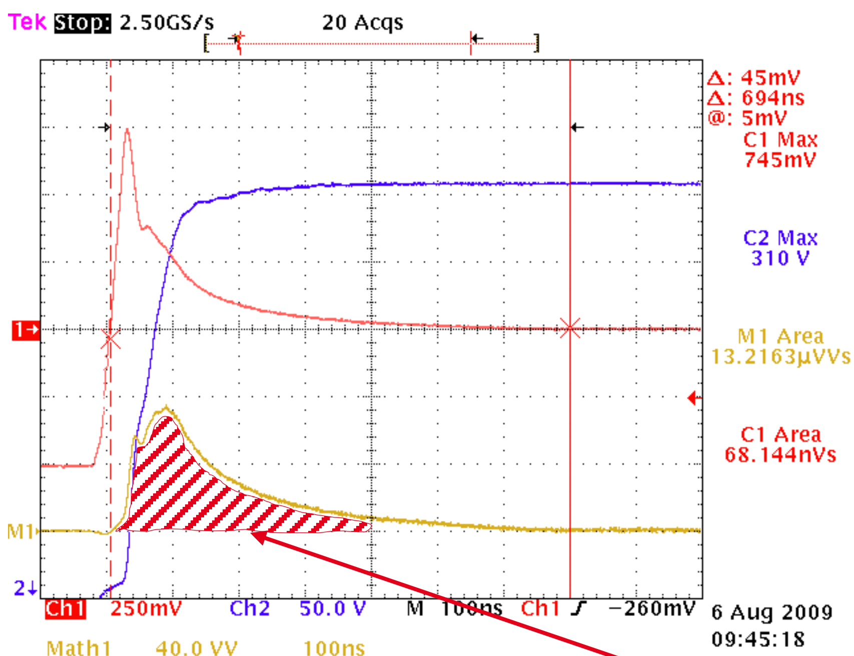
Compared to a standard Si (CAL HD) freewheeling diode

Note: as SiC Schottky diodes are unipolar devices a Qrr does not exist. The load measured in this case is only a capacitive load charge Q_c of parasitic capacitances.

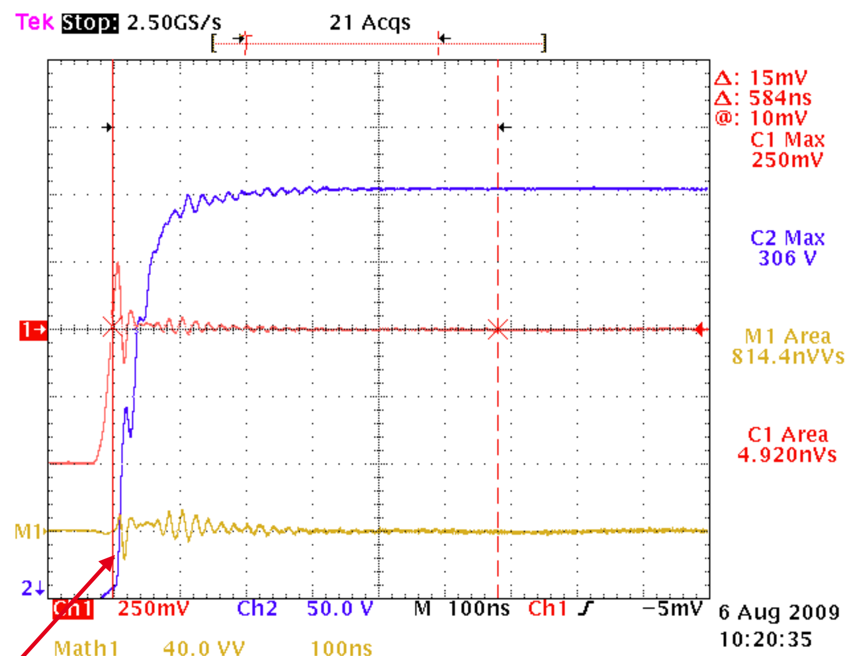
Diode Comparison – Static Losses

Switching Charts:

Si diode (CAL HD)



SiC diode



E_{rr}

With SiC diodes the E_{rr} is practically not measurable!

Si IGBT / SiC MOSFET Comparison

Comparison of following Si IGBTs and SiC MOSFETs:

– 650V SiC MOSFET, 120mOhm (15A)

– 600V Trench IGBT, 25A

and

– 1200V SiC MOSFET, 25mOhm (50A)

– 1200V IGBT 4, 50A

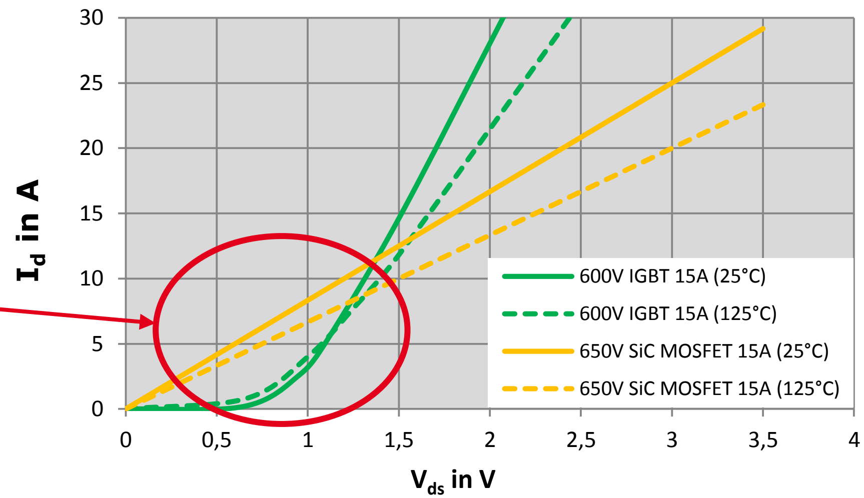
Either in MiniSKiiP housing or by data sheet value

Note:

It is generally difficult to give a SiC MOSFET current rating, the max. currents are mainly limited by thermal capabilities of the package design.

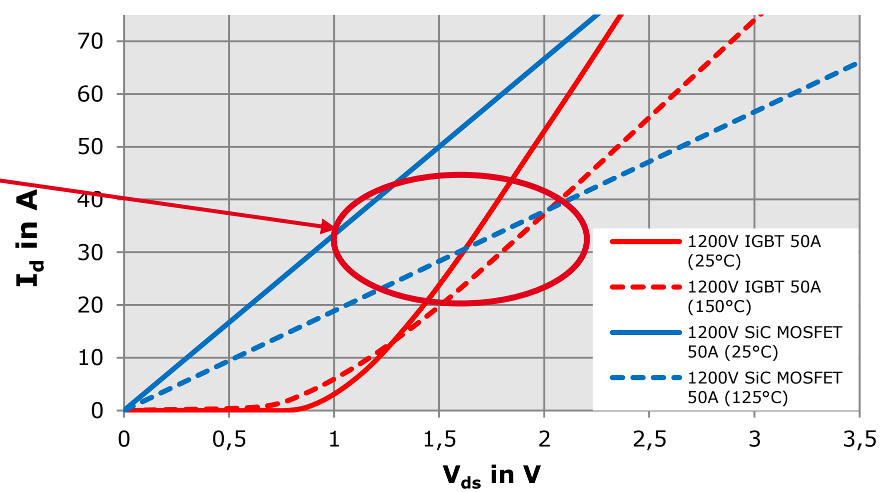
Si IGBT / SiC MOSFET comparison – Static Losses

Lower static losses of SiC MOSFETs compared to IGBTs thanks to linear output voltage:
Benefit in low load condition even at low switching frequency



Infineon IGBT 3 compared with ROHM SiC MOSFET

Strong temperature dependency of SiC MOSFET result in higher static losses at high load at $T_{j,op}$=125°C compared to IGBT.



Infineon low power IGBT 4 compared with CREE SiC MOSFET

SiC Modules

SiC Hybrid Modules: Si - IGBT + **SiC** Schottky Diode

Full SiC Modules: **SiC** MOSFET + **SiC** Schottky Diode
SiC MOSFET only

Hybrid SiC Modules: SKiM93

Example:

1200V, 300A SKiM93:

– Sintered chips

– Without baseblate

– Pressure contacted DBCs

Chipset of Hybrid SiC Module:

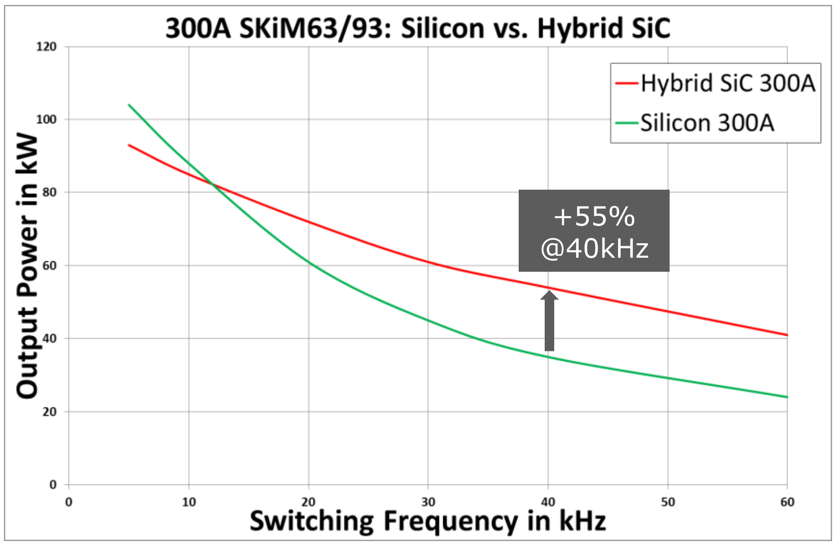
– Infineon Fast IGBT 2:
6 pcs. 50A dies per switch

– CREE SiC diode:
12 pcs. 10A diode per switch

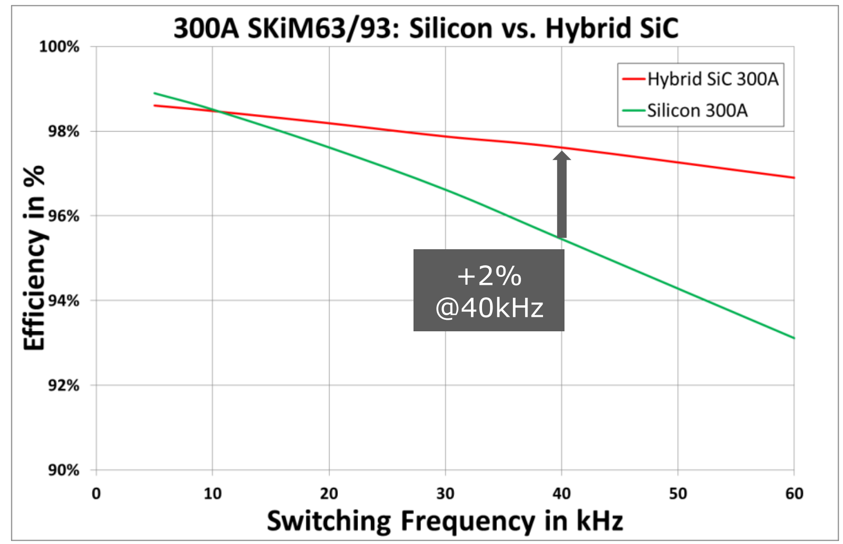
Hybrid SiC Modules: SKiM93

300A Hybrid SiC Power Module compared to a SKiM306GD12E4

+55% output current @ 40 kHz
by using SiC freewheeling diodes



+2 percentage points @ 40kHz
at the same time



Alternatively:
Keeping the currents constant reduces the absolute losses by 50% (1.6 kW to 0.8kW) and increases the efficiency by 2 percentage points.

Conditions: Vdc=560V, cosphi=0.85, simulated of overload condition of 200% OL for 0.5s.
Silicon, IGBT/Diode: $T_{j,op}$=150°C; Hybrid SiC: Si IGBT: $T_{j,op}$=125°C; SiC diode: $T_{j,op}$=150°C

Hybrid SiC Modules Summary

Static (diode) losses
+10…40% @ rated current

Dynamic losses
factor 10…20 lower E_{rr} -30% $E_{on,IGBT}$ (thanks to low I_{RRM})

Performance win:
up to 60% higher output power depending on f_{switch} and
similar power losses (with an efficiency increase of up to 3%)

Effienciency:
reduce power losses of inverters by 50% at the same output power

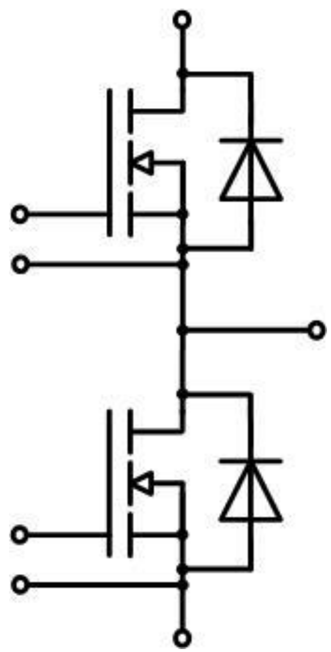
Full SiC Modules

Full SiC Modules can be built with or without freewheeling diode

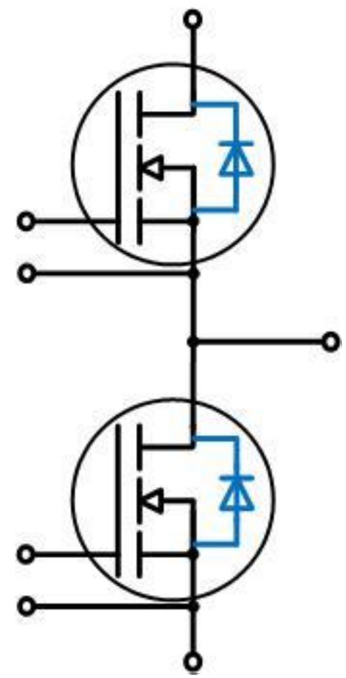
The MOSFET incorporates a diode (the body diode) with very high Vf

in the freewheeling period the MOSFET has to be switched on to avoid high conduction losses

switching losses increase slightly, conduction losses are lower



Full SiC halfbridge with freewheeling diodes



Full SiC halfbridge that uses the body diodes

Full SiC Modules

Example (Drive):

1200V, 20A inverter topology,
Mini 1 housing

– Without baseblate
– Spring contacts
– Easy mounting

Chipset:

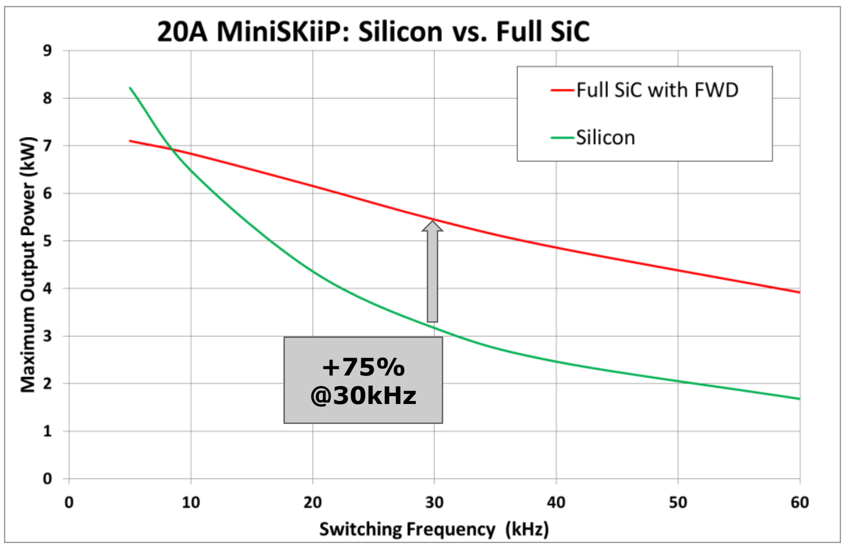
– Cree 1200V, 80mOhm SiC MOSFET
– Cree 10A SiC diode (optional)

Full SiC Modules (with freewheeling diode)

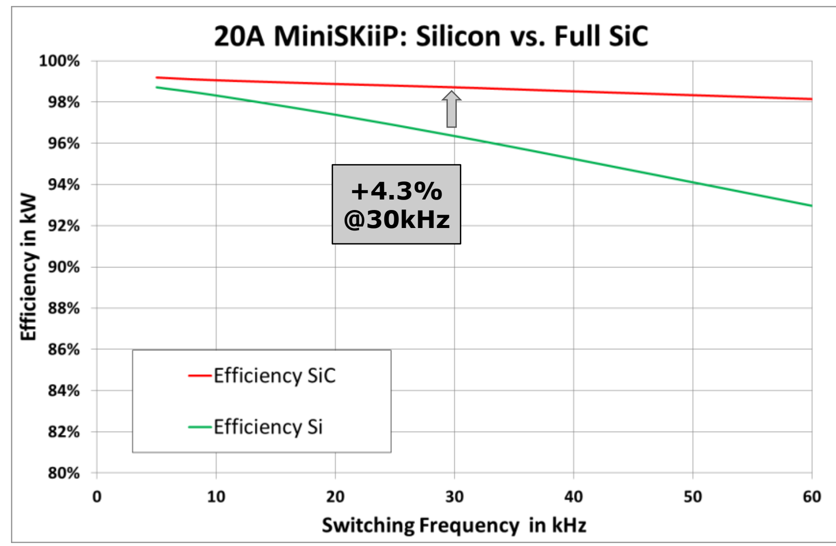
20A Full SiC Power Module compared to a 20A Silicon Module

Point of operation with maximum output power

Maximum Output Power



Efficiency



+75% output power @ 30kHz

➔ power density increase of 75%

+4.3% increase in efficiency @ 30kHz

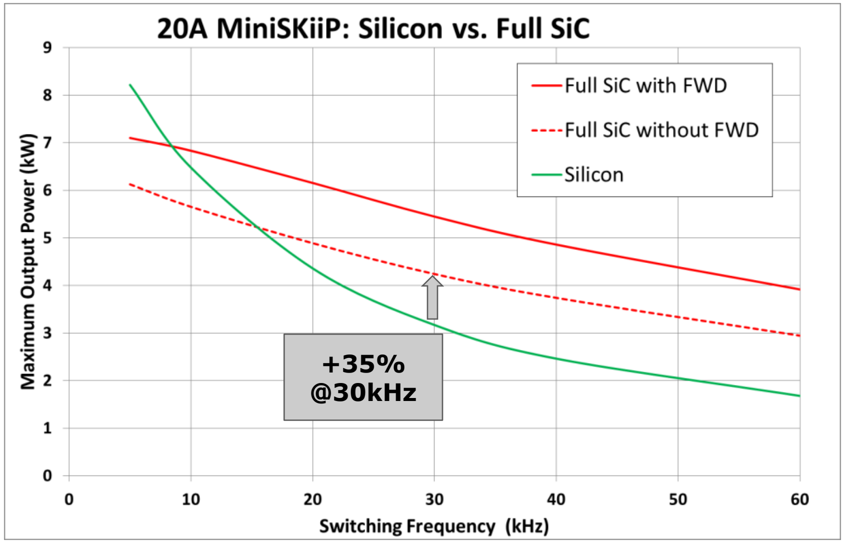
Conditions: Vdc=560V, cosphi=0.85, simulated of overload condition of 200% OL for 0.5s.
Silicon: Tj,op=150°C; SiC MOSFET: Tj,op=125°C; SiC diode: Tj,op=150°C

Full SiC Modules (without freewheeling diode)

20A Full SiC Power Module compared to a 20A Silicon Module

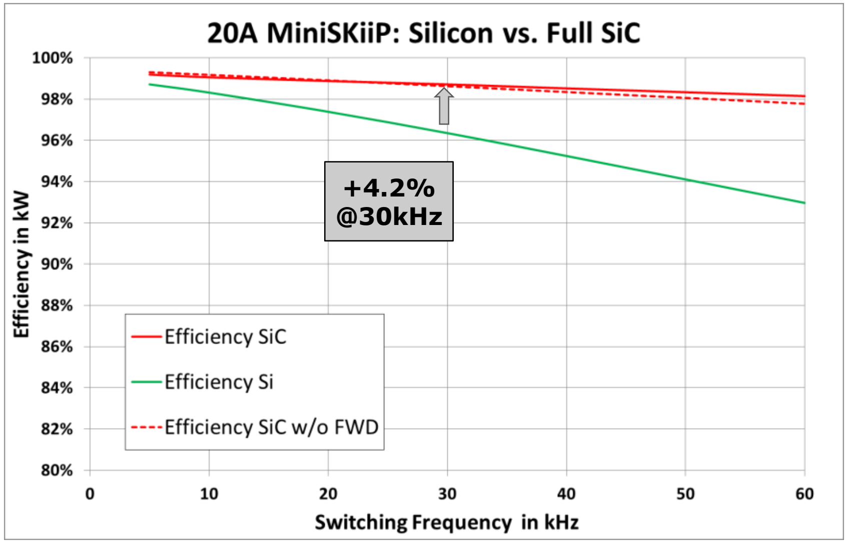
Point of operation with maximum output power

Maximum Output Power



+35% output power @ 30kHz

Efficiency



+4.2% increase in efficiency @ 30kHz

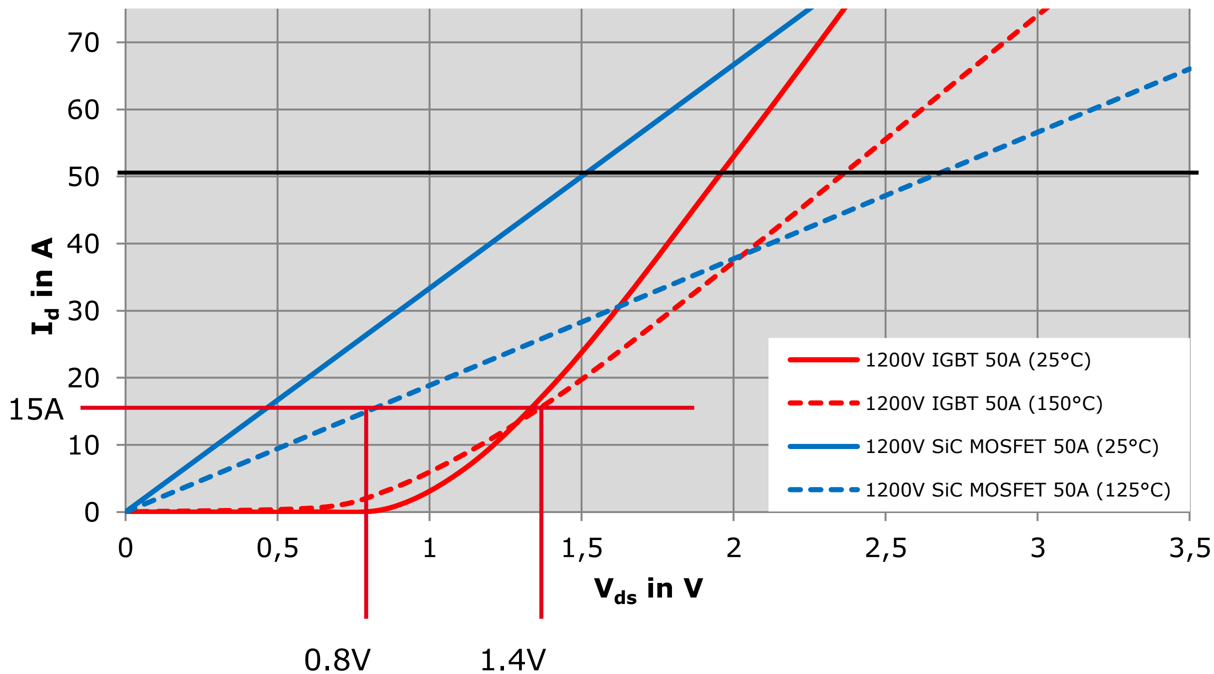
Conditions: Vdc=560V, cosphi=0.85, simulated of overload condition of 200% OL for 0.5s.
Silicon: Tj,op=150°C; SiC MOSFET: Tj,op=125°C; SiC diode: Tj,op=150°C

Full SiC Modules in low load

Thanks to the linear forward characteristic of MOSFETs conduction losses are lower than IGBT conduction losses in low load area.
At 15A:

IGBT voltage drop is about 1.4V (150°C) ➔ P_{cond} = 21 W

SiC MOSFET voltage drop is about 0.8V (125°C) ➔ P_{cond} = 12 W



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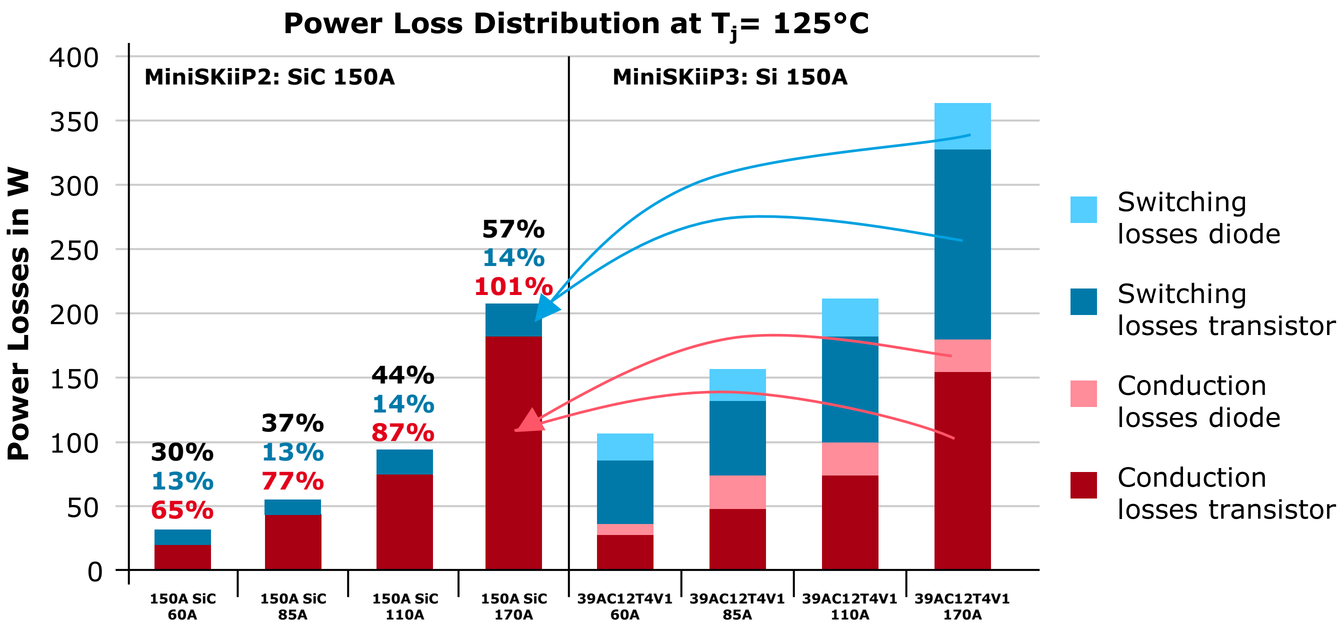
Full SiC Modules in low load

Comparison of:

- SKiiP39AC12T4V1, 1200V/150A, IGBT4 + CAL4F diode, MiniSKiiP 3
- Full SiC w/o FWD, 3pcs. 1200V/25mOhm / switch, MiniSKiiP 2



Conditions: $T_j = T_s$ = const. = 125°C, VDC=645V, 400Vout, cosphi=0.85, 4kHz

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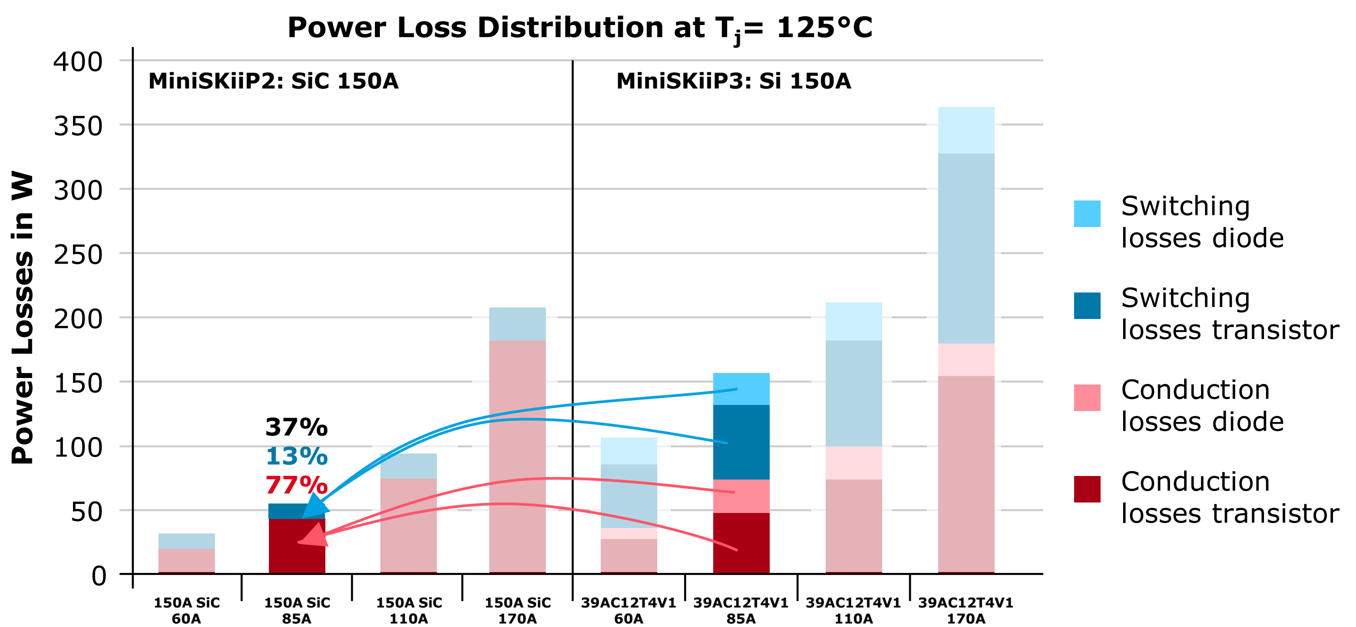
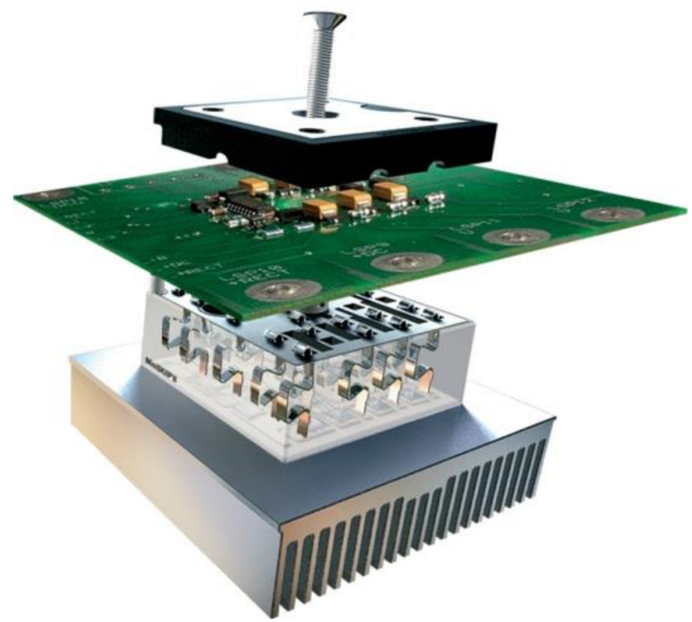
Full SiC Modules in low load



Full SiC Modules Summary

Benefits for Applications:

- Major increase of power density and output power (+75%) and efficiency (+4.3 percentage points) at the same time (@30kHz)
- Without diode freewheeling diode same efficiency increase (+4.2% percentage points) with medium power increase (+35%) (@30kHz)
- 50% lower power losses low load area easily possible!
- Higher switching frequency ➔ less current ripple ➔ less filtering
- Volume reduction on system level (module size, heatsink, fans…)



Challenges Using SiC Devices

Commercial:

High Cost:

- Currently cost is the main barrier for market introduction of SiC and is related to the material itself and chip production yield
  (chips with bigger area are more expensive than small chips).
- SiC cost will come down with increasing volume, prices for SiC devices in 650V/1200V have dropped about 30 to 50% since 2010
- SiC chips will always be more expensive than Si chips
  ➔ a system benefit has to ensure the payback
  (reduction of filter elements, heatsinks, cooling systems, general miniaturisation, etc.)
- A SiC module must be optimized for the application, a standard is difficult to define, even though it makes more sense in certain topologies
  (e.g. boosters)

Challenges Using SiC Devices

Commercial:

Market feedback:
In order to compensate the higher cost:

- Full SiC modules must not be more expensive than approx. 3 times of a standard silicon module
- Hybrid SiC modules must not be more expensive then approx. 1.5 time of a standard silicon module
- Today this can be possible already, but only for smaller current ratings. Estimation:
  - Hybrid SiC commercially feasible for current ratings up to approx. 100 to 150A
  - Full SiC commercially feasible for current ratings up to approx. 50A

In general: due to the high cost SiC modules should be optimized for the application!

Don’t use more SiC in the module than required…

Challenges Using SiC Devices

Technical:

- Only relatively small chips are available right now
  - Several chips have to be parallelized for higher current ratings
    ➔ oscillations during switching, but: better R_{th}
  - Small contact areas ➔ low (surge) currents

- Fast switching will lead to higher di/dt and dv/dt values and cause EMI and isolation issues.
- Gate driver needs to be changed coming from Si IGBTs to e.g. -4…+18V
- Can not replace IGBT solutions in current systems ➔ systems have to be optimized for increased switching speeds ➔ low inductance designs
- No field reliability data so far: thorough lab testing necessary, especially HV-H3TRB, power cycling and gate stress tests.

SiC Chip Availability

List covers chips available from ROHM and CREE

	SiC Diode	SiC MOSFET
600V	6 A 8 A 10 A	
650V	6 …20 A 30 A 50 A 100 A (samples)	15 A (120mΩ)
1200V	2, 5, 8, 10 A 15 A 20 A 50 A	3,5 A (450mΩ) 5 A (320mΩ) 10 A (160mΩ) 15 A (120mΩ) 20 A (80mΩ) 35 A (45mΩ) 50 A (25mΩ)
1700V	17 A 50 A	34A (100mΩ) 50A (40mΩ)

Note: Current ratings for SiC MOSFET are difficult to define and are only for reference.
They can not be regarded as a rating for IGBT replacement

SEMIKRON Status

- No standard topologies:
  SiC can make sense in many topologies:
  - 6-packs and half bridges for solar, drives, UPS…
  - Boosters (GAL) for solar, UPS, power supplies…
  - H-bridges (GH) for single phase applications, chargers, power supplies…
  - 3-level (MLI, TMLI) for UPS, solar…
  - Interleaved topologies
  - Etc…
- No standard package:
  many different packages on the market with SiC included, from baseplate-less to baseplate, DIP modules, different heights (12 to 31mm), etc…
- Package should have lowest inductance to utilize high switching speeds.
  All known packages are not perfect but many are good enough for SiC.
- Therefore we focus on customer specific modules, but offer SiC power modules for sampling:

New SEMITOP 3 SiC Power Modules

SK45MAHT12SCp:

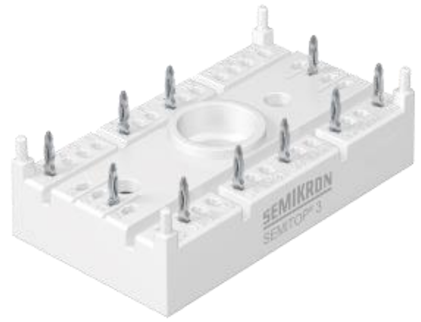
SEMITOP 3 housing with Press-fit pins

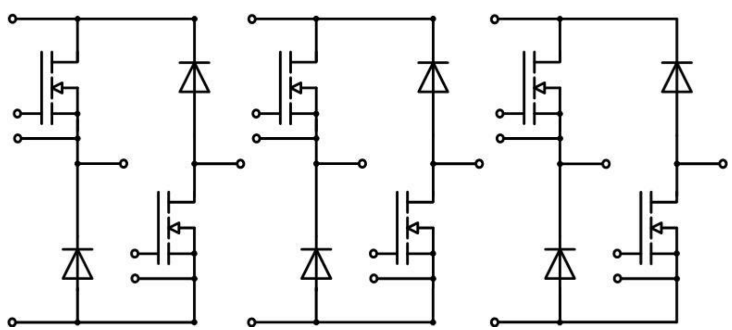
- Chipset:
  - 1 x S2307, 1200V/45mΩ ROHM SiC MOSFET per switch
  - 1 x S6305, 1200V/50A ROHM SiC Diode per switch
- 6-pack topology with split output: GD, GAL/GAR, GAH(GARL)
- 18 nH commutation inductance

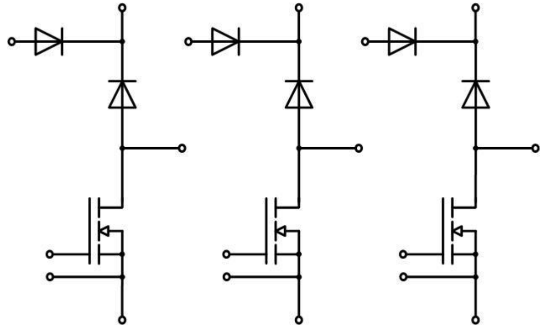
SK45MLT12SCp:

SEMITOP 3 housing with Press-fit pins

- Chipset:
  - 1 x S2307, 1200V/45mΩ ROHM SiC MOSFET per switch
  - 1 x S6305, 1200V/50A ROHM SiC Diode per switch
  - 1 x SKR 4.2Qu
- Triple boost topology with bypass diode
- 17 nH commutation inductance







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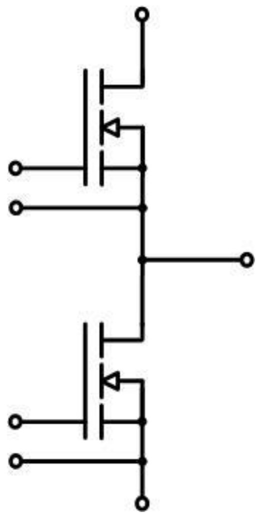
New SEMITRANS 3 SiC Power Module

SKM585MB120:

- SEMITRANS 3 housing
- Chipset:
  - 12 x S2307, 1200V/45mΩ ROHM SiC MOSFET per switch
- Half bridge topology
- 16 nH Commutation inductance

Flexible design ➔
module can be depopulated easily down to 6 chips per switch (approx. 300A)



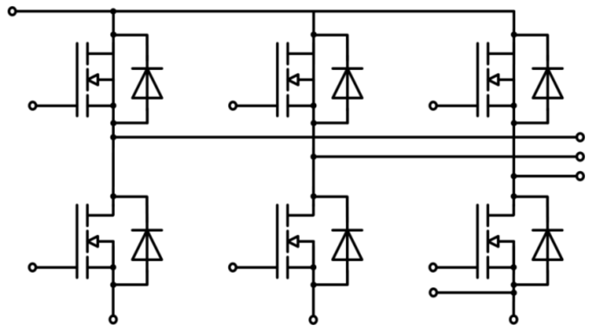
New SEMITOP 3 SiC Power Modules

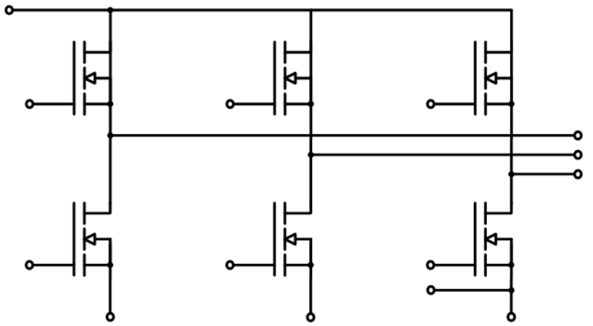
SKiiP13ACM12V15

- MiniSKiiP 1 housing
- Chipset:
  - 1 x CPM2-1200-0080B, 1200V/80mΩ CREE SiC MOSFET per switch
  - 1 x CPW2-1200-S010B 1200V/10A CREE SiC Diode per switch
- 6-pack topology

SKiiP13AC12V16

same SiC MOSFETs like SKiiP13ACM12V15 but without free-wheeling diodes





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SEMITRANS 3 / SKiM93 SiC Power Module

SKM200GB12T4SIC

- SEMITRANS 3 housing
- Chipset:
  - 2 x 1200V/100A IGBT 4 low power per switch
  - 16 x IDC08S120E, 1200V/8A Infineon SiC Diodes per switch

SKiM459GD12F4SIC

- SKiM93 housing
- Chipset:
  - 6 x1200V/75A Fast Trench IGBT per switch
  - 5 x CPW5-1200-Z050B 1200V/50A CREE SiC diode

Outlook and Support

New chip generations to come:

– CREE will introduce 3rd generation of MOSFET with very low specific $R_{ds,on}$

– ROHM will introduce Trench MOSFET and extend portfolio on current technology

Modules:

– SEMIKRON will have qualified SiC chips (CREE diode, ROHM diode) within the next weeks.

– SEMIKRON will also do additional reliability testing on SiC devices.

– SEMIKRON has investigated benefits of SiC in 3-level modules to generate additional portfolio.

SKD Support:

– We simulate your required SiC module in SEMISEL to make sure the customer gets what he needs

– Quick indication of MP price once the chipset is fixed

Outlook and Support

New chip generations to come:

Thank you for
your attention!