Green Power Solutions

Semiconductors for the most difficult applications

Virgiliu Botan – Hitachi Energy Semiconductors

GPS Tech Seminar 2023

PUBLIC

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Hitachi Energy Semiconductors

Semiconductors for the most difficult Applications

Virgiliu Botan - Product Manager

2023-11-02

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Power semiconductors history

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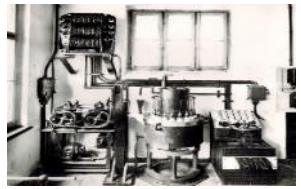
Pioneering technology over a century – A long-term partner

Hitachi Energy is a leading supplier of power semiconductors with more than 100 years experience in power electronics



1913
Start of development and production of mercury-arc rectifiers

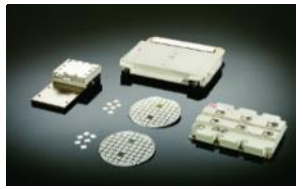
1981
Development of high-power semiconductor factory in Lenzburg, Switzerland

1996
Beginning of production of IGCT in Lenzburg, Switzerland

2010
Expansion of production facilities in Lenzburg, Switzerland

2014
Inauguration of new state of the art research laboratory in Dättwil, Switzerland

1939
First HVDC transmission line in Wettingen, Switzerland



1998
Inauguration of production facilities for IGBT in Lenzburg, Switzerland

2010
Acquisition of Polovodice in Prague, Czech Republic

2012
Successful design and development of hybrid HVDC breaker

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Hitachi Energy Semiconductor Footprint

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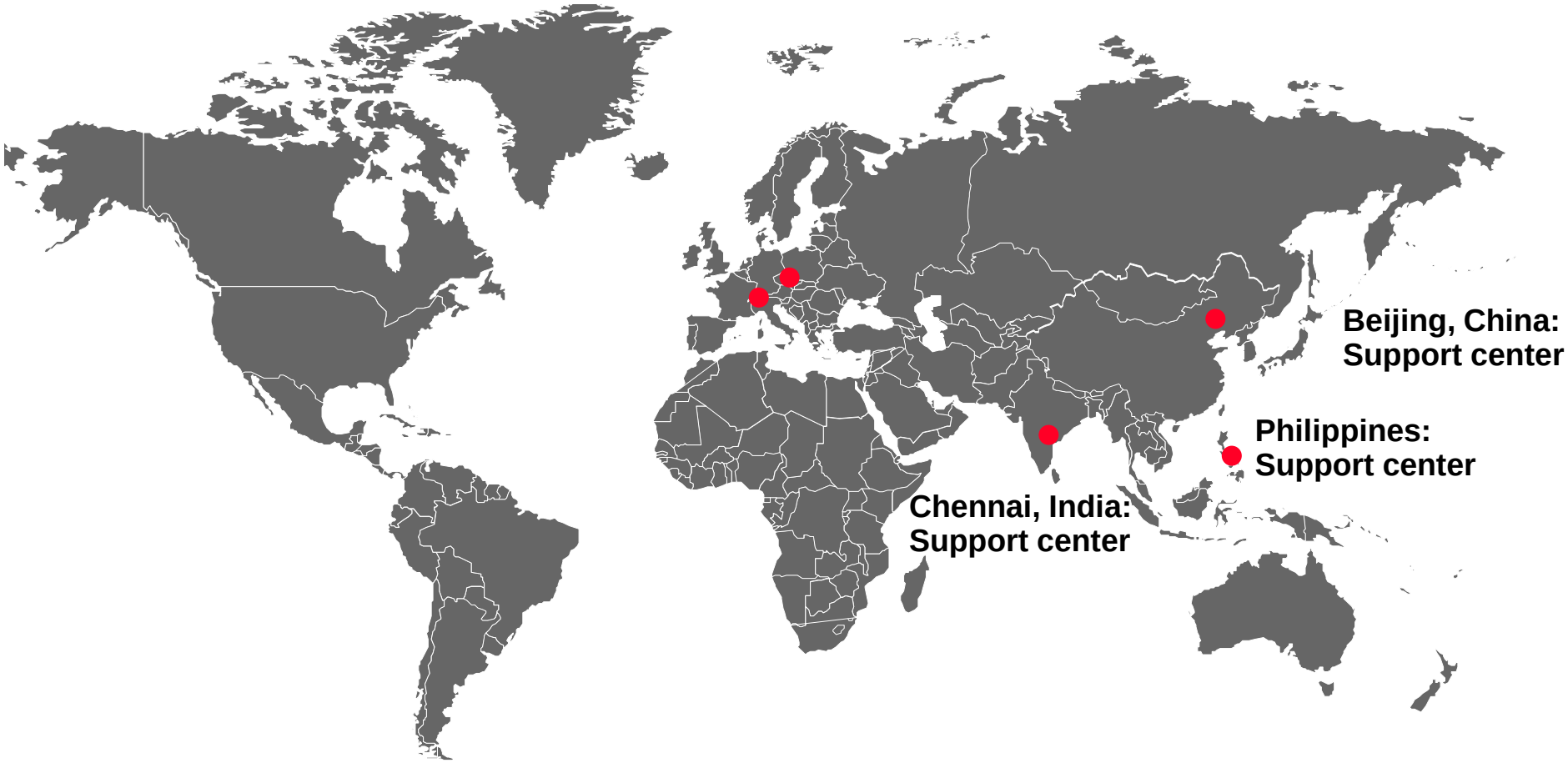
Highly specialized production units with front-end and back-end facilities and technical support centers

Lenzburg, Switzerland

Prague, Czech Republic



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Portfolio and Applications

HE Semiconductors

HITACHI ABB POWER GRIDS

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Power Semiconductors Product Portfolio

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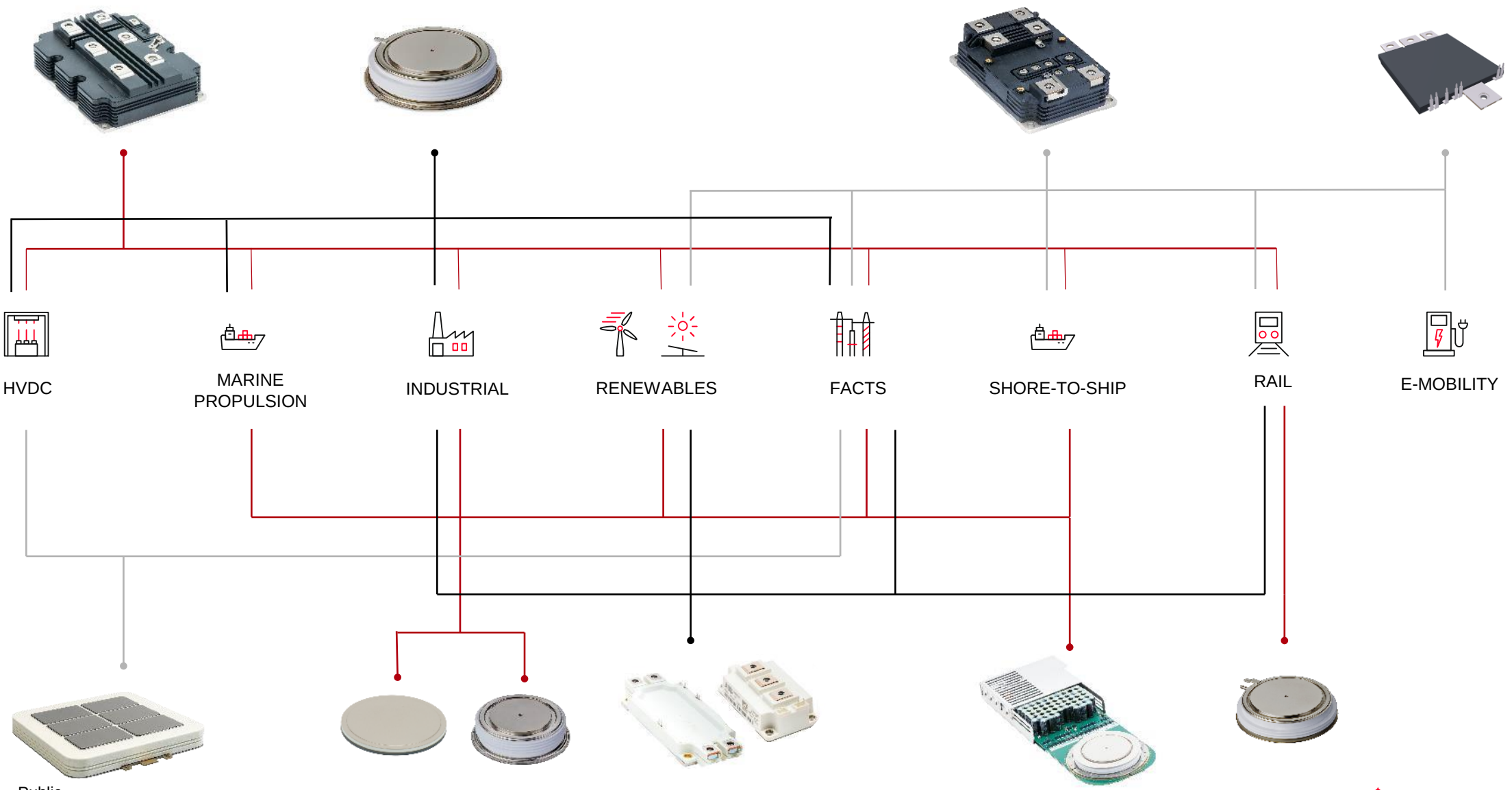

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Portfolio Bipolar

HITACHI ABB POWER GRIDS

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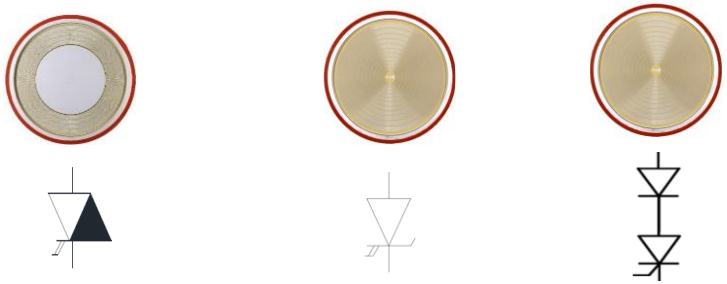
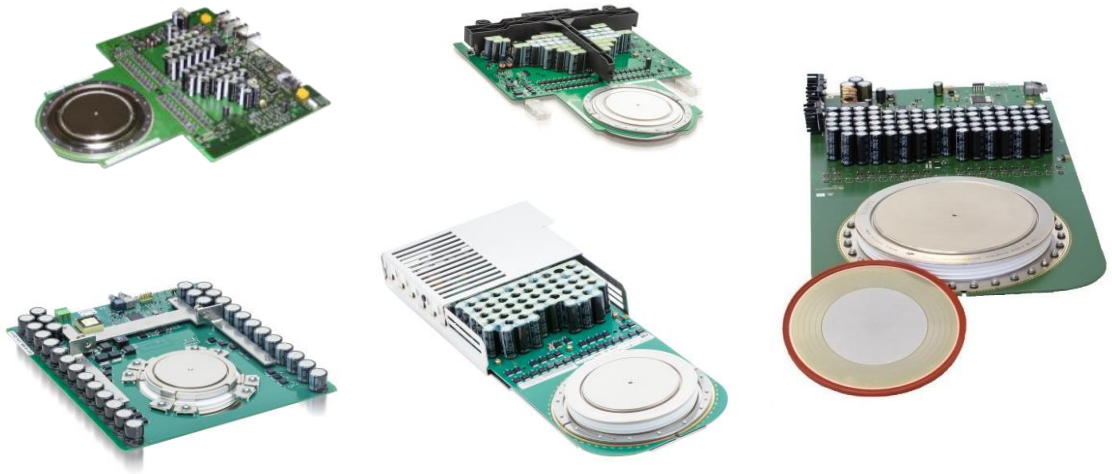
IGCT overview



		Reverse Conducting (RC)			Asymmetric	Reverse Blocking (RB)	
Voltage classes, V	10000						
	6500						
	5500						
	4500						
	2500						
		F / H	L	Y	L	H	L
		47/63	85	138	85	63	85
		Housing / Pole-piece diameter (mm)					

Product
Sample

- Introduced >25 years ago by Hitachi Energy.
- Various sizes and voltage classes.
- Three device variants.
- Used in wide application range.



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New Gen 3, 4.5 kV Asymmetric (AS) and Reverse Conducting (RC) IGCT

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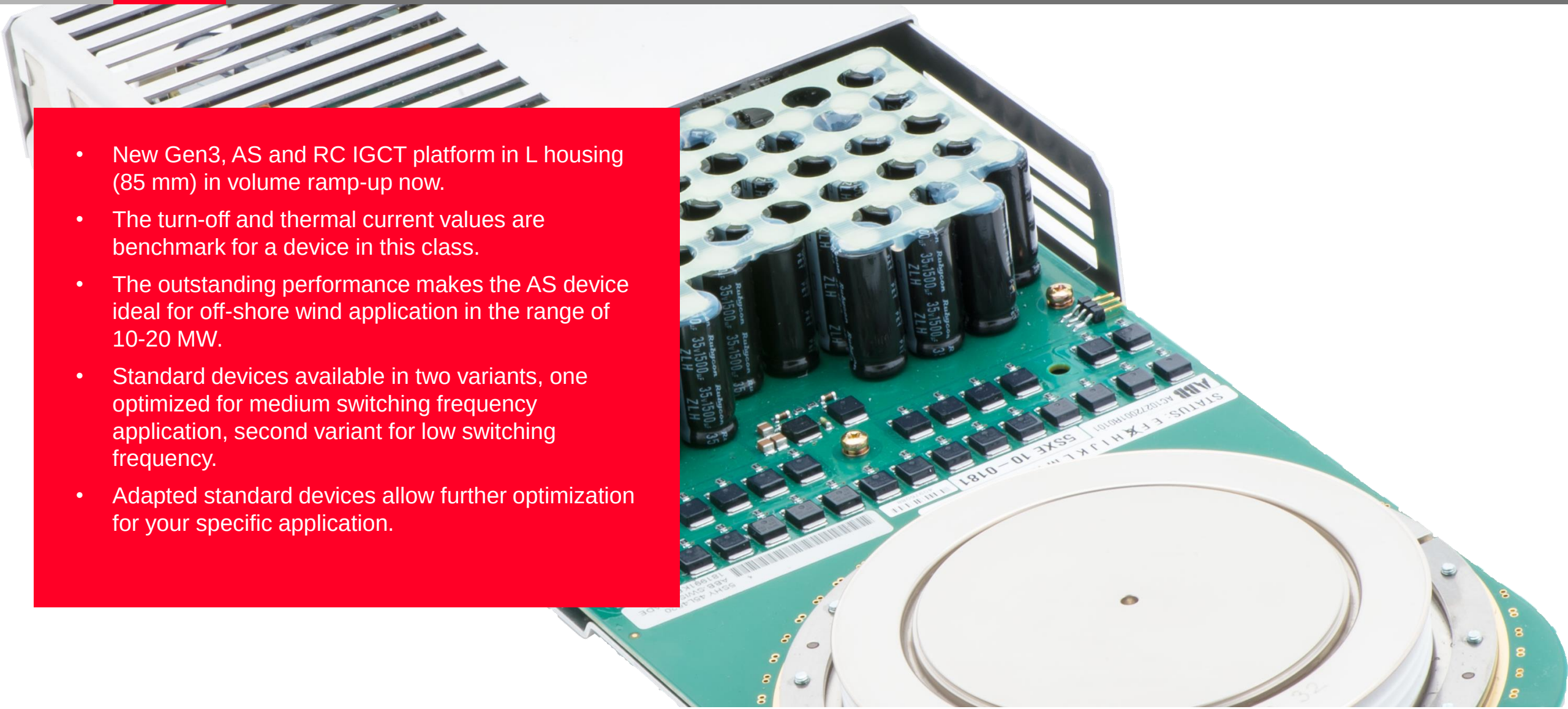
- New Gen3, AS and RC IGCT platform in L housing (85 mm) in volume ramp-up now.
- The turn-off and thermal current values are benchmark for a device in this class.
- The outstanding performance makes the AS device ideal for off-shore wind application in the range of 10-20 MW.
- Standard devices available in two variants, one optimized for medium switching frequency application, second variant for low switching frequency.
- Adapted standard devices allow further optimization for your specific application.



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New Gen 3 IGCT device features

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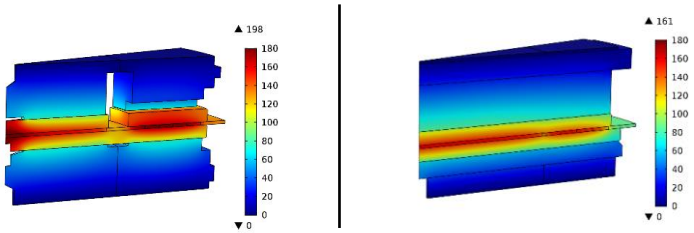
Gen 3 features

- Applied to our latest 4.5 kV RC and AS IGCTs
- Retain outer dimensions for compatibility with application and integrated gate unit.

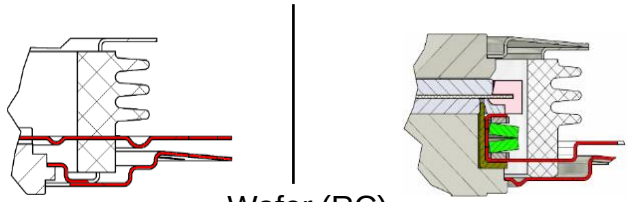
- Gen 3 optimization focus: turn-off and thermal performance
  - Minimize gate-circuit impedance:
    - Moved gate contact infrastructure to device periphery.
    - Optimized routing of gate contact through the housing.
  - Improved thermal performance by using monolithic Mo disk and asymmetric anode and cathode side pole piece thickness.
  - Increased device diameter through efficient use of raw silicon wafer.
  - Turn-off current increased by adjusting doping profile

Previous versus New Generation

Packaging design



Gate contact infrastructure



Wafer (RC)

30 % more performance. Footprint unchanged.

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T. Wikström, M. Alexandrova: A Technology Platform for Reverse-Conducting Integrated Gate Commutated Thyristor with 94mm Device Diameter, Proc. PCIM Europe 2017, pp. 806-810

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New 4.5 kV asymmetric (AS) IGCT device performance

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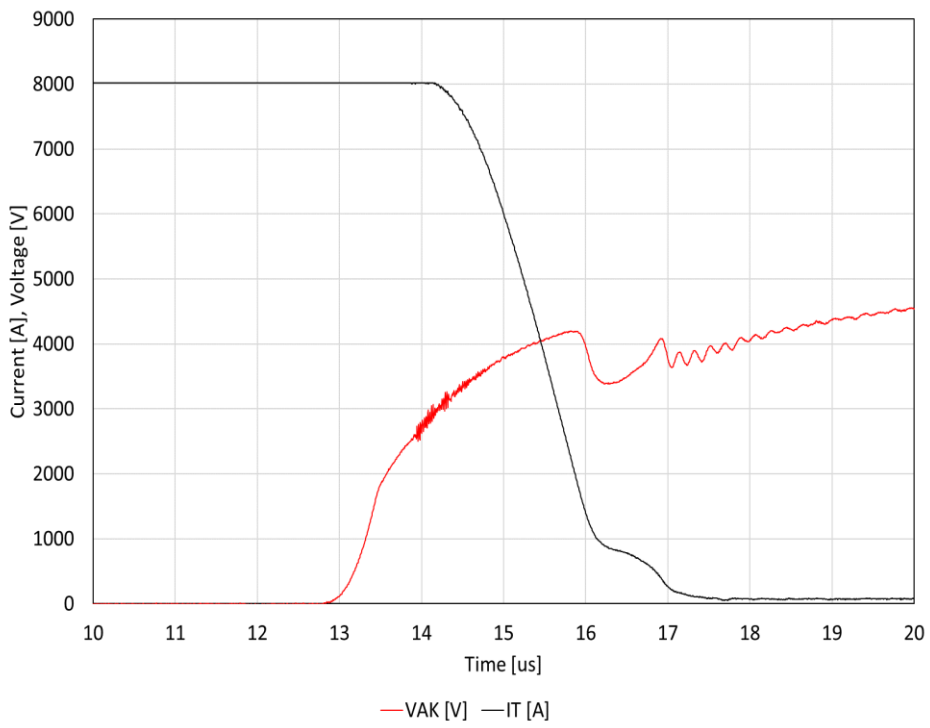
Key device parameters

	Generation 1	Generation 2	Generation 3
Parameter	**5SHY 35L4520**	**5SHY 55L4520**	**5SHY 65L4521**
Status	**Product**	**Product**	**Product**
Tjmax (°C)	**125**	**125**	**140**
Rthjc (K/kW)	**8.5**	**8.5**	**6.8**
ITGQM (kA)	**4 kA (@2.8kV)**	**5 kA (@2.8kV)**	**6.5 kA (@2.8kV)**

SOA - Example for turn-off capability

- VDC = 2.8 kV
- Tj = 140 °C
- IT = 8 kA



T. Wikström, D. Cottet: A 6500 A, 4500 V, 94mm Asymmetric IGCT, Proc. PCIM Europe 2020, pp. 757-761

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New 4.5kV Fast Recovery Diode (FRD) platform in L size (85 mm)

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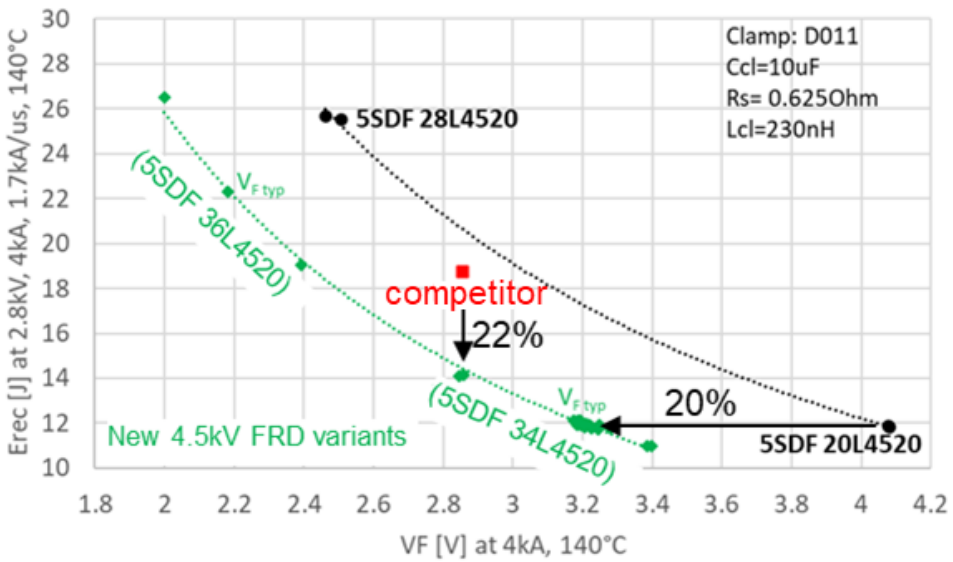
Increase performance with cathode segmentation

- For full utilization of Gen 3 IGCT platform we have developed a powerful new 4.5 kV FRD device.
- Matching new Gen 3 4.5 kV IGCT platform.
- Standard devices available in two variants, one optimized for medium switching frequency application, second variant for low switching frequency.
- Diode cathode segmentation enables
  - To make the device on thinner Silicon, lower losses in Diode
  - While improving Diode reverse recovery softness & Turn-off SOA robustness
- Status: in volume ramp-up.

Technology trade-off performance



New 4.5kV FRD offers

- 20% lower V_F compared to our existing FRD
- More than 20% lower E_{rec} compared to competitor device

New FRD allows the full utilization of Gen 3 IGCT platform

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New 8.5kV devices: IGCTs & FRD (85mm pole piece, L-package)

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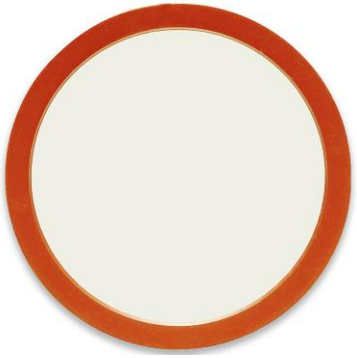
High voltage device platform

- Targeting highest-power applications e.g. offshore wind or MVD.
- Higher voltage ratings allow for lower currents at same power handling capability and same number of devices.
- Smaller cross-section of bus bars and cabling enabling compacter converter designs.
- Monolithic construction supports optimal utilization of Si even for 8.5 kV. Active area only insignificantly reduced by larger edge termination.
- Status: samples available for entire platform.

RC-IGCT

RC-IGCT
SOA : 5.3kV, 1.8kA

FRD

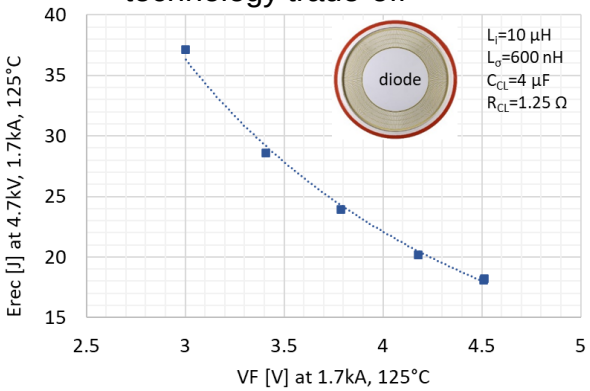


FRD (as NPC, clamp, FWD)
SOA : 5.3kV, 2.7kA

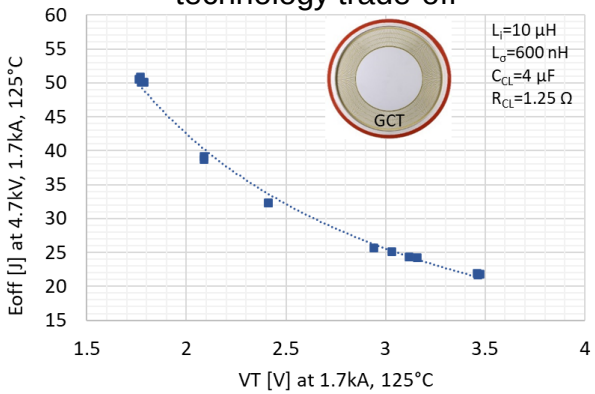
AS-IGCT

AS-IGCT
SOA: 5.3kV, 2.7kA

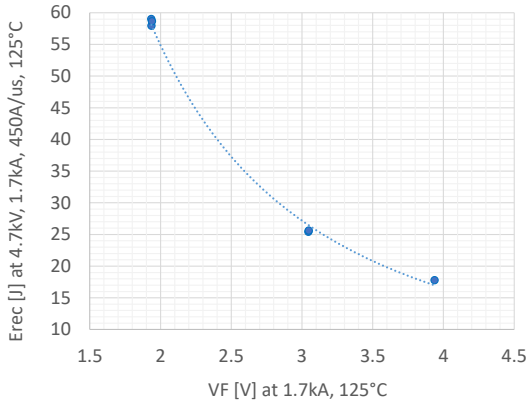
RC-IGCT in Diode-mode technology trade-off



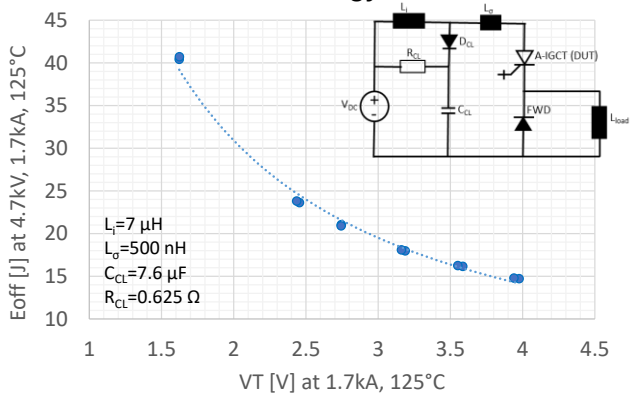
RC-IGCT in GCT-mode technology trade-off



FRD: technology trade-off



AS-IGCT: technology trade-off



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U. Vemulapati et al.: An improved performance of high voltage RC-IGCT for applications up to 5.3 kVDC, Proc. PCIM Asia 2021, pp. 34-39.
U. Vemulapati et al.: High-Voltage (8.5 kV) Asymmetric IGCT for MVD and HVDC applications, Proc. ICPE 2023 ECCE Asia (to be published)

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2.5kV RB-IGCT and Sacrifical Bypass thyristor

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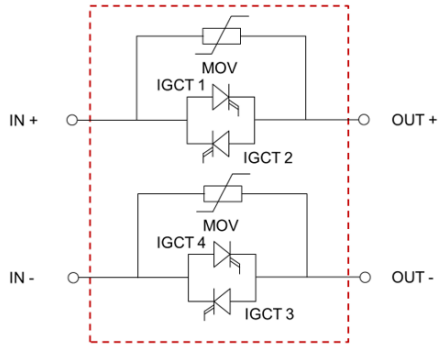
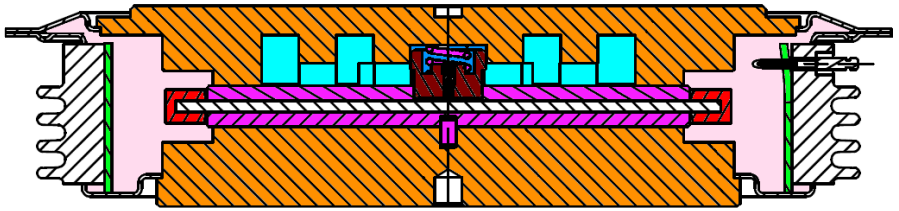
2.5 kV Reverse blocking IGCT [1]

- Designed and optimized for extreme low conduction losses and highest turn-off current capability (up to 6kA).
- Record low on-state losses of below 1 kW at 1 kA, enables customer to design applications with highest efficiency ratings.
- Optimized for DC Solid State Circuit Breaker (SSCB) application. SSCB allows to interrupt fault currents faster than ever before, 100 times compared to traditional electro-mechanical breakers.
- Qualified product available in volume now

Sacrificial Bypass thyristor [2]

- Bypass thyristor to shorten faulty cells in a multilevel converter topology (MMC).
- Cell voltage of up to 4.6 kV DC. Device will not rupture up to, or exceeding, 360 kA or 215 MA^2s.
- After a fault, the device displays a stable short circuit for more than a year, conducting 1300 ARMS with a voltage drop below 1.75 VRMS.
- Qualified product available in volume now





SSCB: schematic and reference used from https://new.abb.com/news/detail/26578/ultra-fast-high-current-dc-breaker-innovates-marine-applications-and-beyond

[1] Umamaheswara Vemulapati et al. ***Reverse blocking IGCT optimised for 1 kV DC bi-directional solid state circuit breaker,*** Proc. IET Power Electronics 2015
[2] T. Wikstroem, B. Ødegard, R. Baumann, ***An 8.5kV Sacrificial Bypass Thyristor with Unprecedented Rupture Resilience,*** Proc. ISPSD 2019 Shangai

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IGCT reliability

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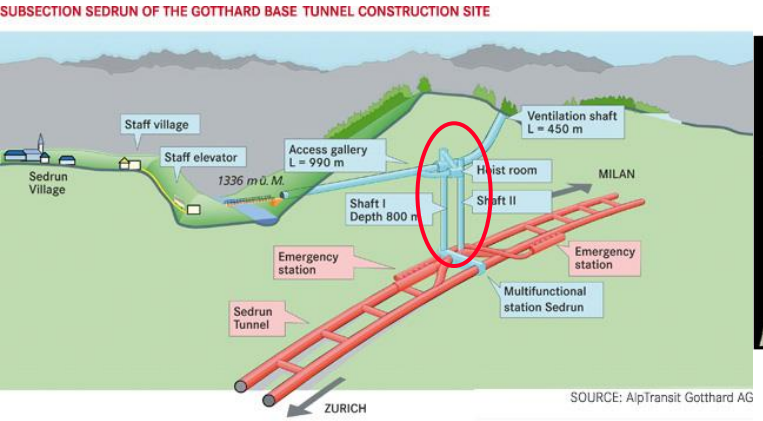
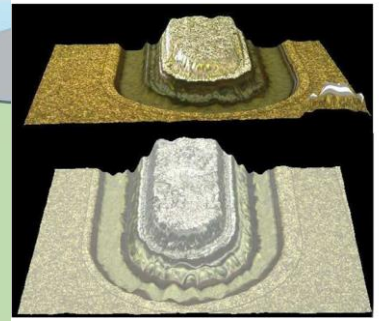
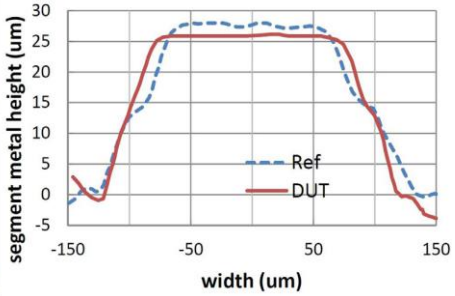
Field reliability "Gotthard lift" [1]

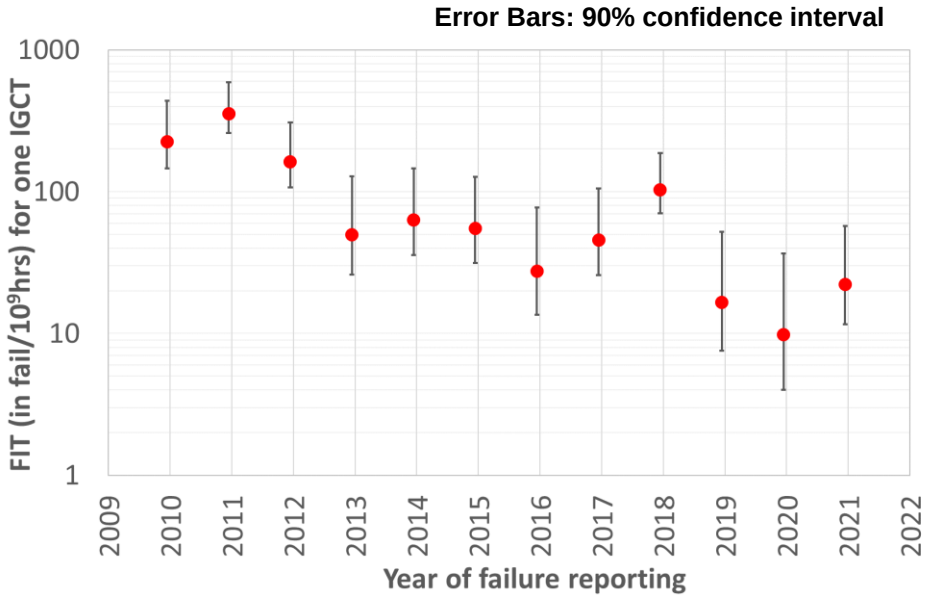
- Gotthard lift: 850 m vertical lift shaft, located in Sedrun, significant part of the new 57 km Gotthard railroad tunnel excavated with lift.
- Lift drive equipped with IGCT, analysis done after finalization of the tunnel.
- 15 years heavy duty operation.
- Traces of wear-out were found but degradation was low.
- Picture shows the neglectable degradation of the cathode metallization.







Field Failure Rate (FIT) of GCT and gate unit



Field reliability of IGCTs is state-of-the art and improving over time.

[1] Th. Stiasny, O. Quittard, Ch. Waltisberg, U. Meier. Reliability evaluation of IGCT from accelerated testing, quality monitoring and field return analysis. Proc. ESREF, Denmark, 2018.

Field failure rate FIT: Device field failure of specific customers are monitored. r: reported field failures per reporting year. Device failures are analyzed: Number N of devices in this application known. Uptime per year estimated to T = 6000h/year. Field failure rate is calculated in FIT (device failure in 10^9 device hours). Field failure rate = $(r \cdot 10^9)/(N \cdot T)$

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Thyristor overview

Voltage classes, V	D	F	H/K	L/M	N/Q	U	Y
8500					■	■	■
7200					■	■	■
6500	■	■	■	■	■	■	
5200	■		■	■	■	■	
4200	■	■	■	■	■		
2800	■	■	■	■	■		
1800	■	■	■	■	■		
	34	47	63	78	100	110	143
	Housing / Pole-piece diameter (mm)						

■ Product

- Most complete portfolio consisting of small size low voltage up to large size and high voltage devices.
- Highest performance and reliability, lowest losses.
- Wide application range.

In addition:

– Crowbar/Bypass thyristor.

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Next Generation 6.5 kV Industrial Thyristor and Diode

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Thyristor / diode in N housing, 100 mm pole piece

- Next-generation high-end industrial thyristor and diode improve device current performance significantly
- First products, a thyristor and diode, rated 6.5 kV in N-housing, offer **performance increase up to about 30-40%** compared to actual devices **with same footprint.**
- New thyristor uses a leading snowflake gate design structure and the latest backend technology features.
- Application
  - Diode: Rectifier, Front end drive
  - Thyristor: LCI, SVC, Rectifier
- As well available in explosion protected housing.
- Status: qualified, in volume ramp-up.

Rating comparison

Device / Target rating		Itavm [A]	Vrrm [V]	ITSM [kA]
Thyristor	New: 5STP 40N6500	3780 +31%	6500	65
Thyristor	Ref: 5STP 26N6500	2810	6500	65
Rectifier Diode	New: 5SDD 57N6500	5850 +28% / +39%	6500 +18% / +8%	110 +51% / +55%
Rectifier Diode	Ref: 5SDD 50N5500	4570	5500	73
Rectifier Diode	Ref: 5SDD 50N6000	4210	6000	71.2

Ideal for powerful MVD front-end, LCI, Rectifier and SVC. Footprint unchanged.

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Diode overview

Rated voltage, V	B	C	X	Z	D	F	H/K	L	N/Q	Y
8500										
6000										
5000/5500						Rectifier diodes				
3800/4000										
2600-3200										
1700-2400										
200/400		Welding diodes								
Housing / Pole-piece diameter (mm)	44	57	44	53-64	34	47	63	78	100	143

Product

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60Pak thyristor / diode modules

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- After successfully launching IGBT medium power modules, Hitachi Energy is now introducing the BiPolar power module platform.
- First product launched is the the 60Pak in various configurations.
- The key benefits of the 60Pak are highest performance and outstanding reliability.

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60Pak - Thyristor / Diode Modules

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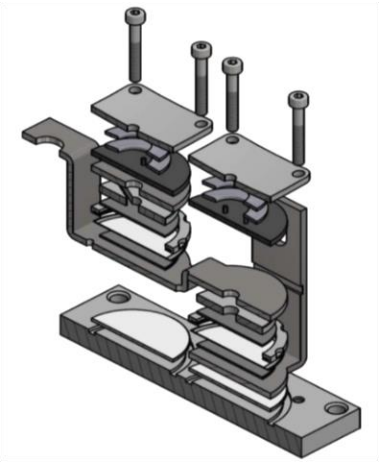
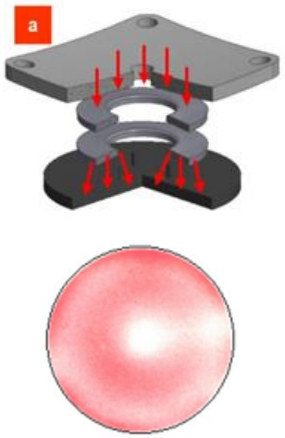
60Pak - Module features

- 60 mm industry-standard housing
- Baseplate insulate by AIN ceramic ensures excellent heat transfer and high insulation voltage level
- Very low losses together with the highest operating temperatures.
- Pressure contacts for high reliability and load cycling capability
- Ideally for demanding applications: Input rectifiers for drives. Soft-starter, DC power supply.

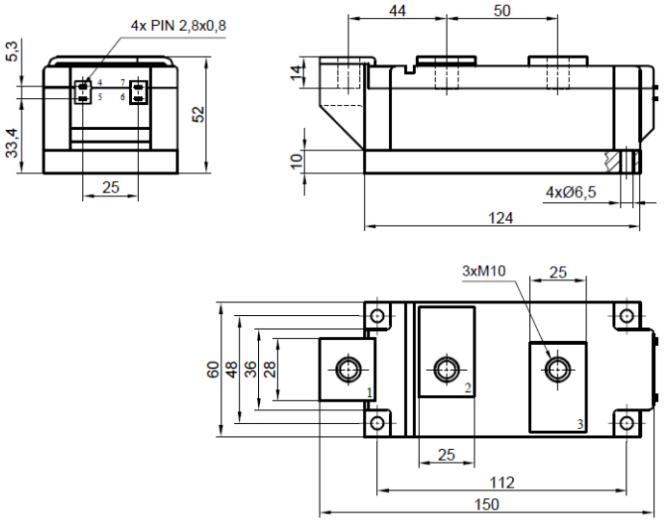


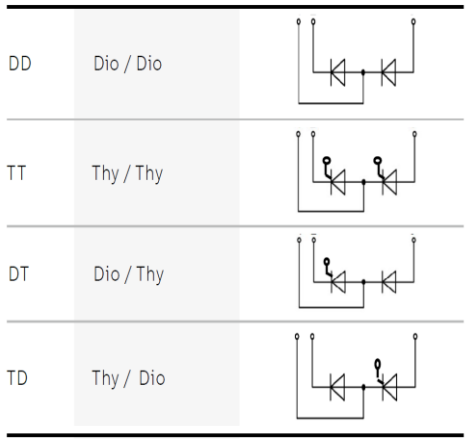


60Pak - Portfolio

Voltage (V)	Ampere (A)	Configuration
1800	522	TT, DT, TD
2200	890	DD
6500	600	DD *)

*) in qualification





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Portfolio BiMOS

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BiMOS Overview

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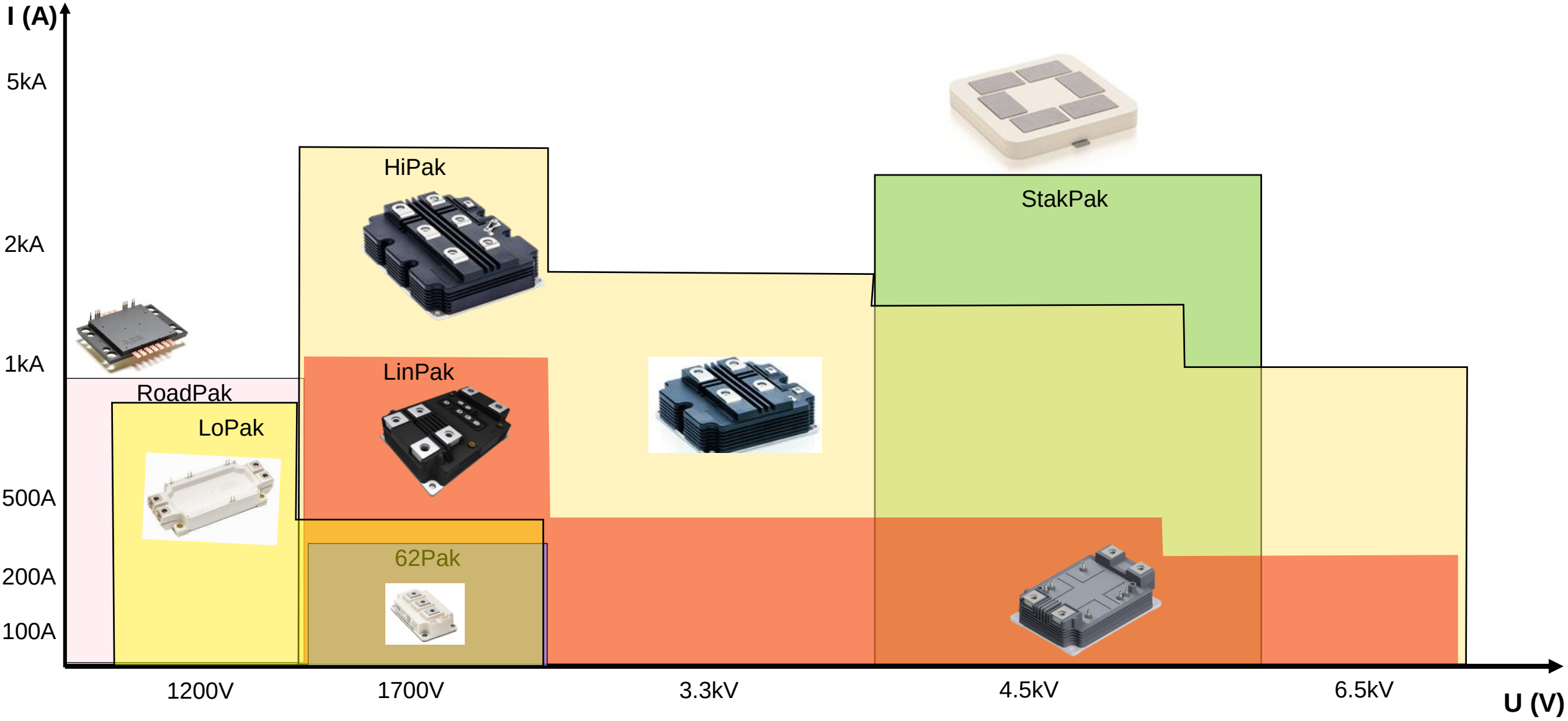

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StakPak

The Strongest IGBT module outthere

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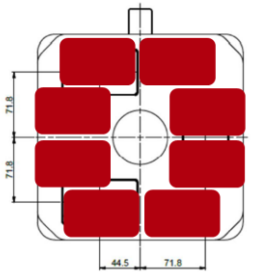
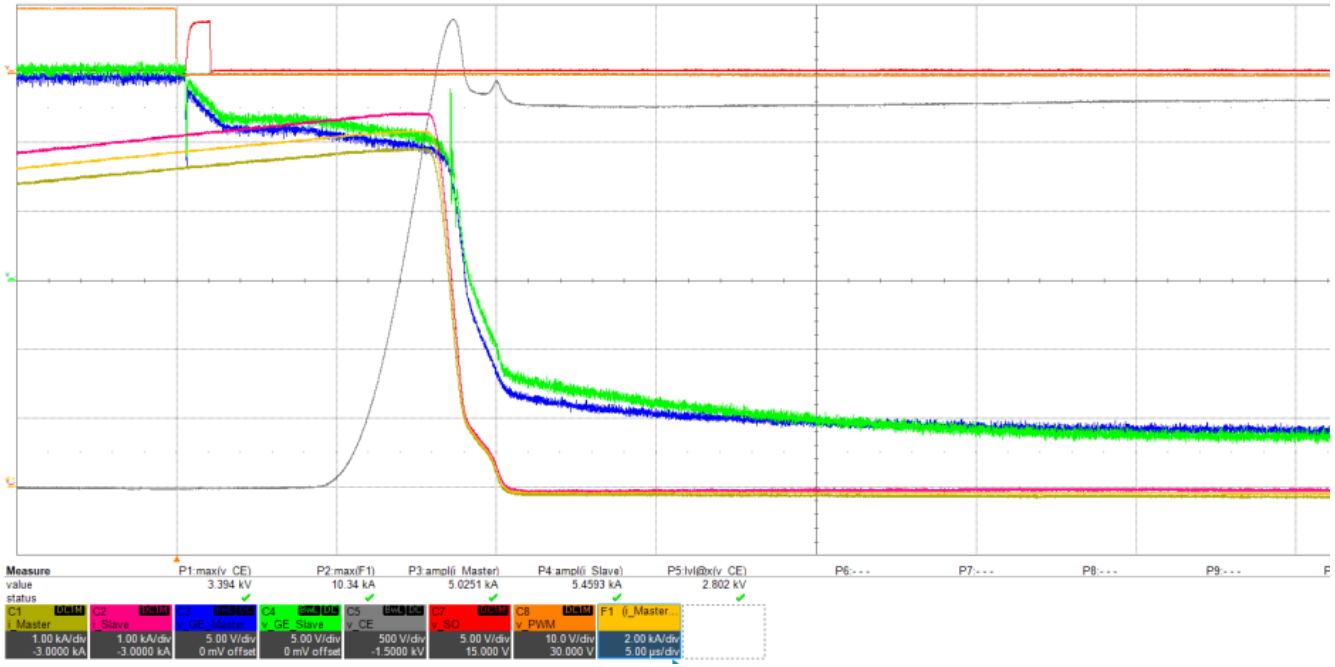
StakPak from record to record

- Most powerful IGBT package
- Heavily used in Grid Applications
- Uses both the classical «2 Chip solution» as well as BIGT
- Easily scalable with the nr. of submodules
- In development 5 and 6kA, 4.5kV devices
- Multiple sources



Turn-off, 2in Parallel, 2 x I_{nom} (20kA), V_{DC}=2.8kV



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LV Modules

Increased Reliability

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1700V 62Pak Half Bridge Module Family

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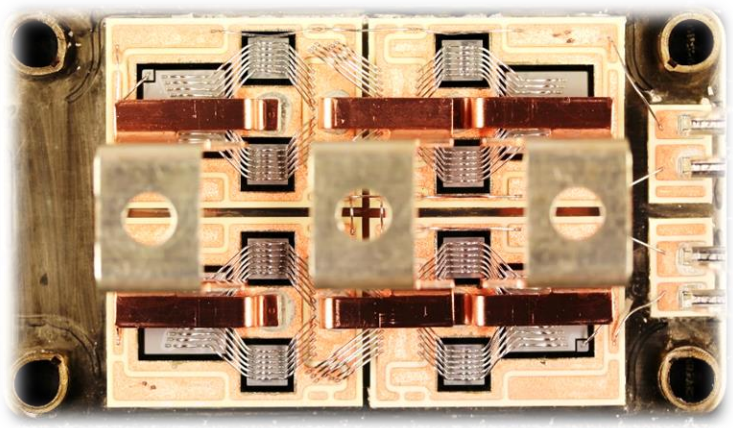

Hitachi Energy's 62Pak modules have an advanced packaging technology that leverages the performance of the latest silicon technology:

- 1700 V SPT^{++} fast switching IGBT / diode chipset with lowest switching losses
- Full 175 °C operation temperature with full square SOA
- Best-in-class temperature cycling performance of bond-wire chip connection
- Standard package allowing drop-in replacement

Configurations

150 A X 2
200 A X 2
300 A X 2

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1700V 62Pak - Modules Features

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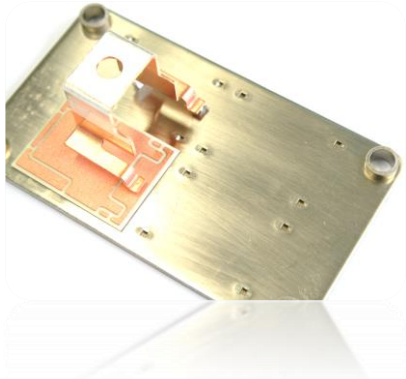
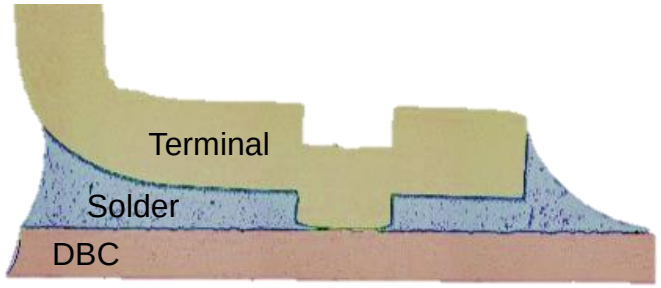
Forefront package technology – proven concepts of HiPak modules applied

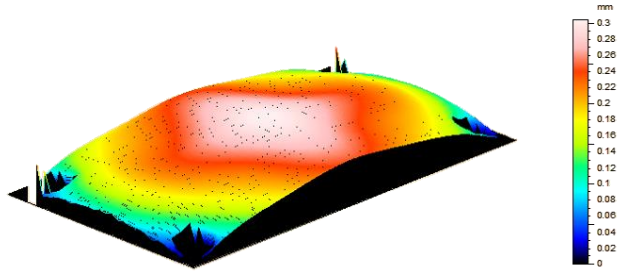
Spacer for substrate solder



Spacer for terminal solder



Pre-bowed and stamped baseplate



Customer value

Higher lifetime under cyclic load

- Homogeneous solder thickness

Customer value

Higher lifetime under cyclic load and robust against vibrations

- Homogeneous solder thickness

Customer value

Higher thermal utilization → more power and/or higher lifetime

- Reduced gap and lower interface resistance to heat sink
- Minimized grease pump-out

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1700V 62Pak - IGBT RBSOA @ T_{case} = 175°C

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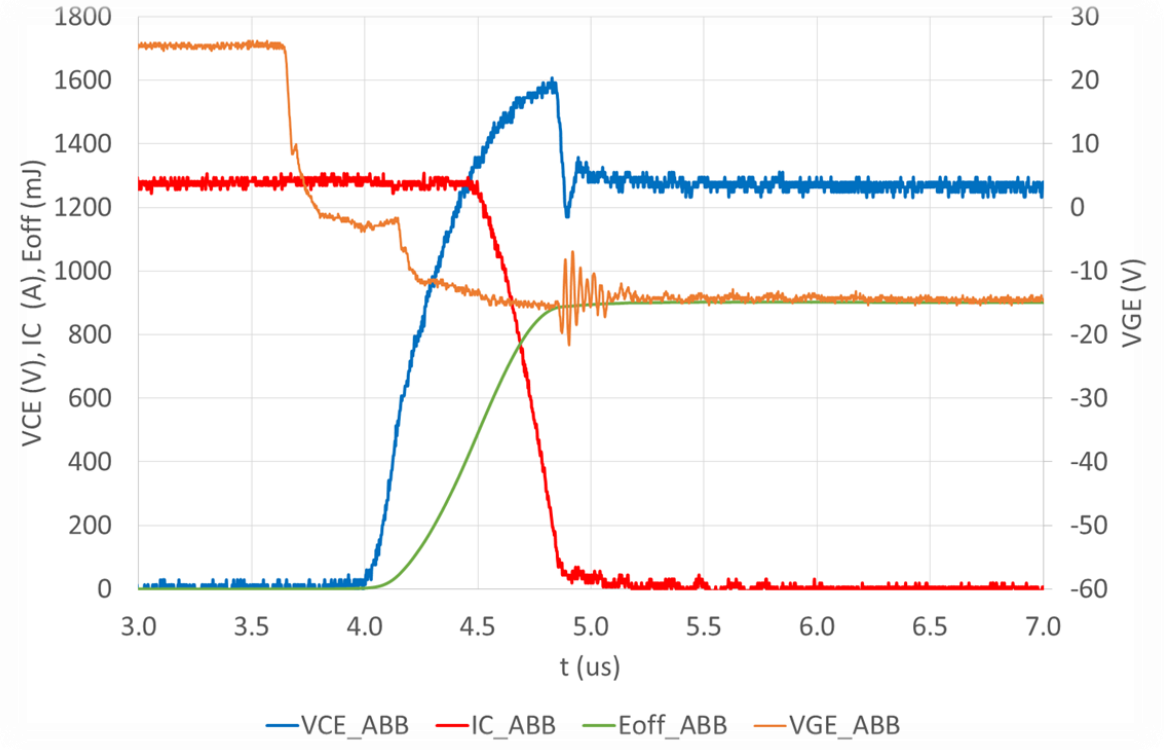
Hitachi Energy's unrivaled robustness

Hitachi Energy's offers a unique margin for excellent safe operating area.
Above 90% of the devices still pass 4 x I_{Cnom} turn-off at 175°C!
This is significantly above the desaturation/short circuit current with V_{GE}=15V.

Simply unbreakable

Conditions

- T_{vj} =175°C
- V_{CC} =1300V, I_C =1300A
- L_σ =60nH
- R_G =2.2Ω , V_{GE} =20V



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1700V 62Pak - IGBT RBSOA @ T_{case} = 175°C

HITACHI
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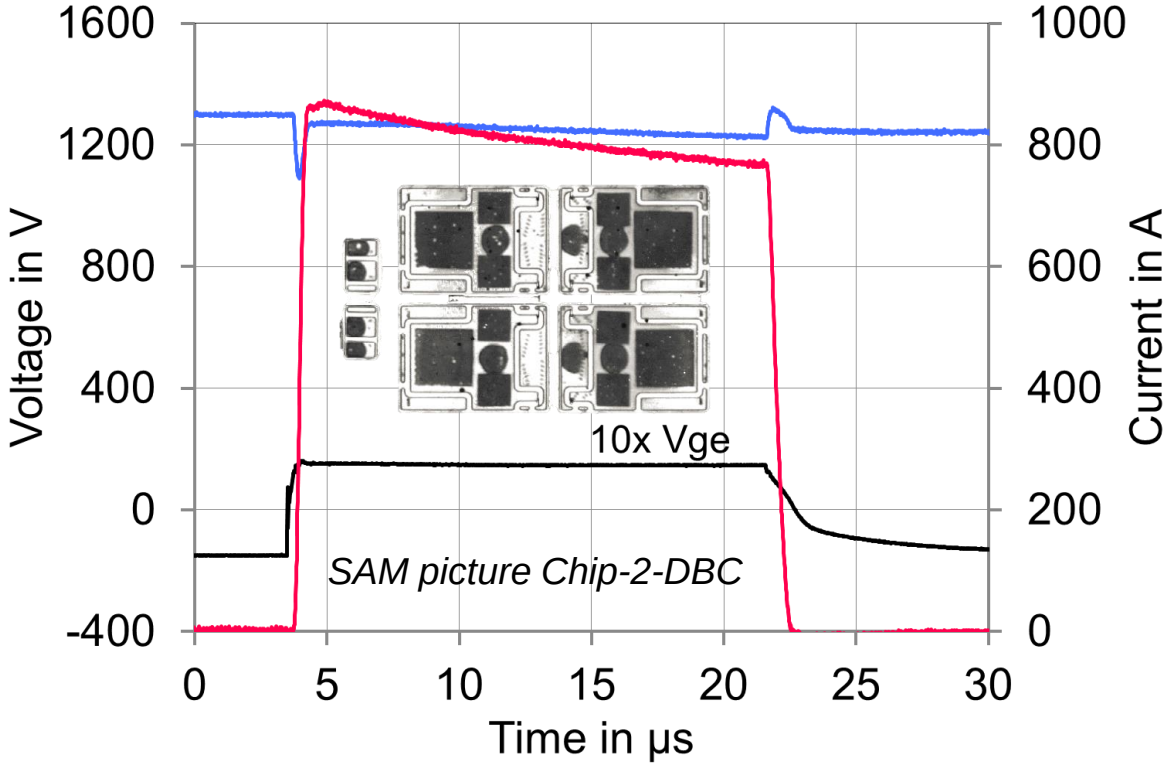
Hitachi Energy's unrivaled robustness

Hitachi Energy offers full short circuit safe operating area (SCSOA) up to $T_{vj(op)}$ =175°C.

Scanning acoustic microscopy (SAM) confirms perfectly soldered interfaces of chips to substrate

Conditions

- T_{vj} =175°C
- V_{CC} =1300V, t_p = 10µs,
- L_σ =60nH
- R_G =2.2Ω , V_{GE} =15V



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LoPak

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1200V and 1700V LoPak Power Modules Families

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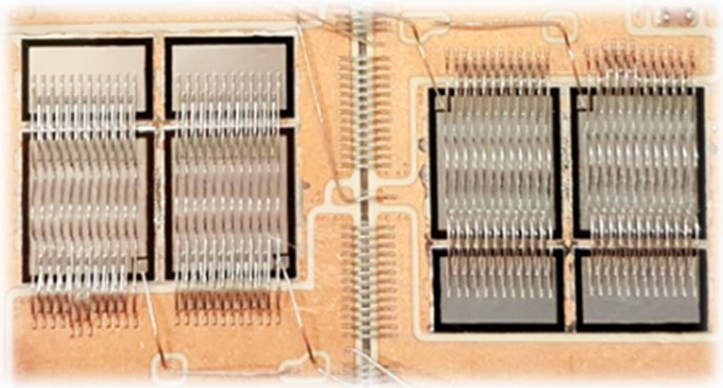
ABB's LoPak is 100 % mechanically compatible with the Econo-type dual IGBT modules. It sets a new benchmark with full switching performance up to 175 °C. It is specifically designed for excellent internal current sharing, offering optimal thermal utilization and increased robustness. Customers can expect larger safety margin and increased lifetime. Typical applications include:

- Wind power converters
- Variable speed drives
- Power supplies
- Power quality
- UPS
- Renewable energies

1700V

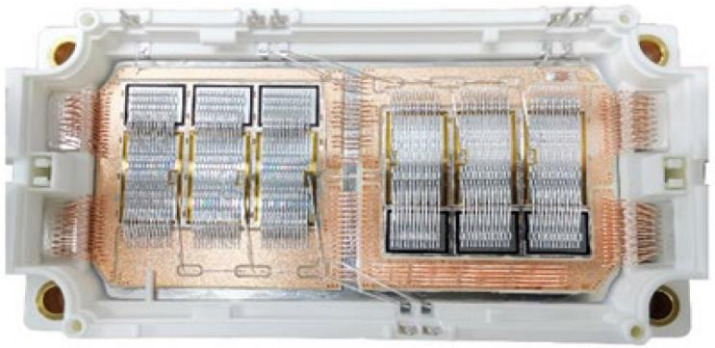
450A X 2
225 A X 2
300 A X 2



SPT^{++} fast switching IGBT / diode chipset with lowest switching losses

1200V

900 A X 2
600 A X 2



Ultra-low-loss, rugged Trench IGBT / diode chipset

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1200V and 1700V LoPak Power Modules - Features

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Embedded terminals

Customer value

Press-fit auxilliary connections and main terminals are molded into the housing frame

- Higher lifetime under cyclic load and robust against vibration
- Easy mounting of the driver PCB

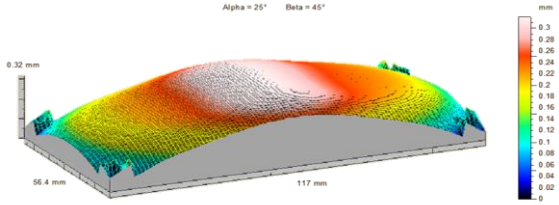
Spacer for substrate solder

Customer value

Higher lifetime under cyclic load

- Homogeneous solder thickness

Pre-bowed and stamped Cu baseplate

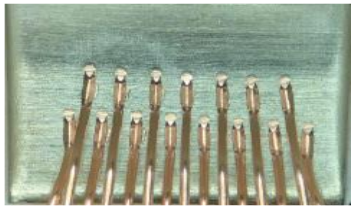


Customer value

Higher thermal utilization → more power and/or higher lifetime

- Reduced gap and lower interface resistance to heat sink
- Minimized grease pump-out

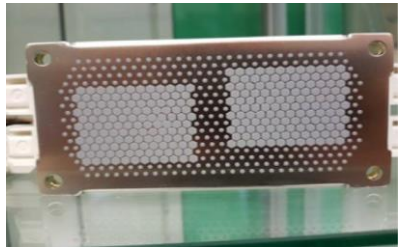
Cu wires for Power terminal connectio



Customer value

Higher current carrying ability with lower resistance and lower temperature

Optional pre-applied TIM on base plate



Customer value

Use of Thermal Interface Material (TIM) can lower thermal resistance between case and heatsink : Rth(c-s)

State of the art technology in a cost-effective module

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LoPak 1.2kV 900A - IGBT RBSOA @ T_{case} = 175°C

Hitachi Energy offers a unique margin for excellent safe operating area.

Conditions:

Vcc = 900 V

Ic = 2700 A

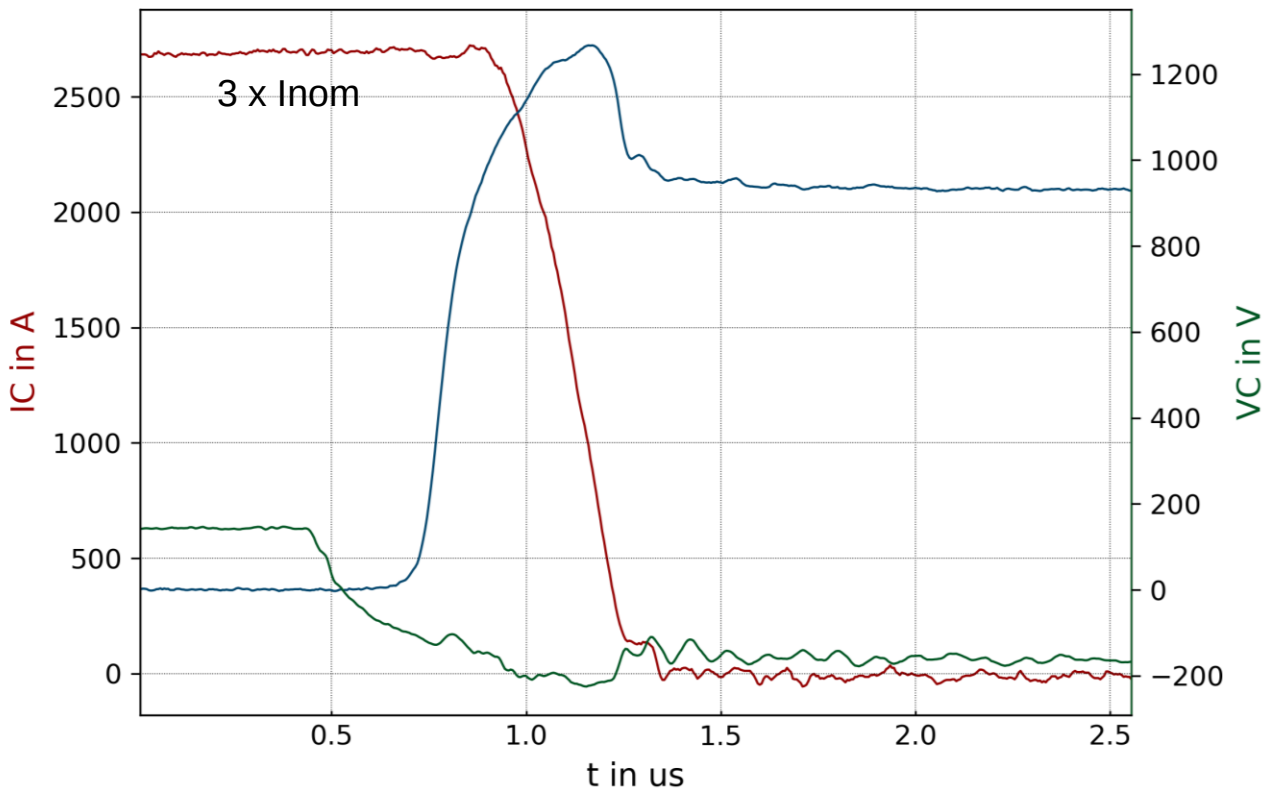
Rg = 0.51 Ω

Vge = ± 15 V, Ls = 30 nH

Red trace: Ic in A

Blue trace: Vce in V

Green trace: 10*Vge in V



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LoPak 1.2kV 900A - IGBT SCSOA @ T_{case} = 175°C

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Hitachi Energy offers full short circuit safe operating area (SCSOA) up to $T_{vj(op)}$ =175°C.

Conditions

Vcc = 900

V, Rgon = 0.51 Ω,

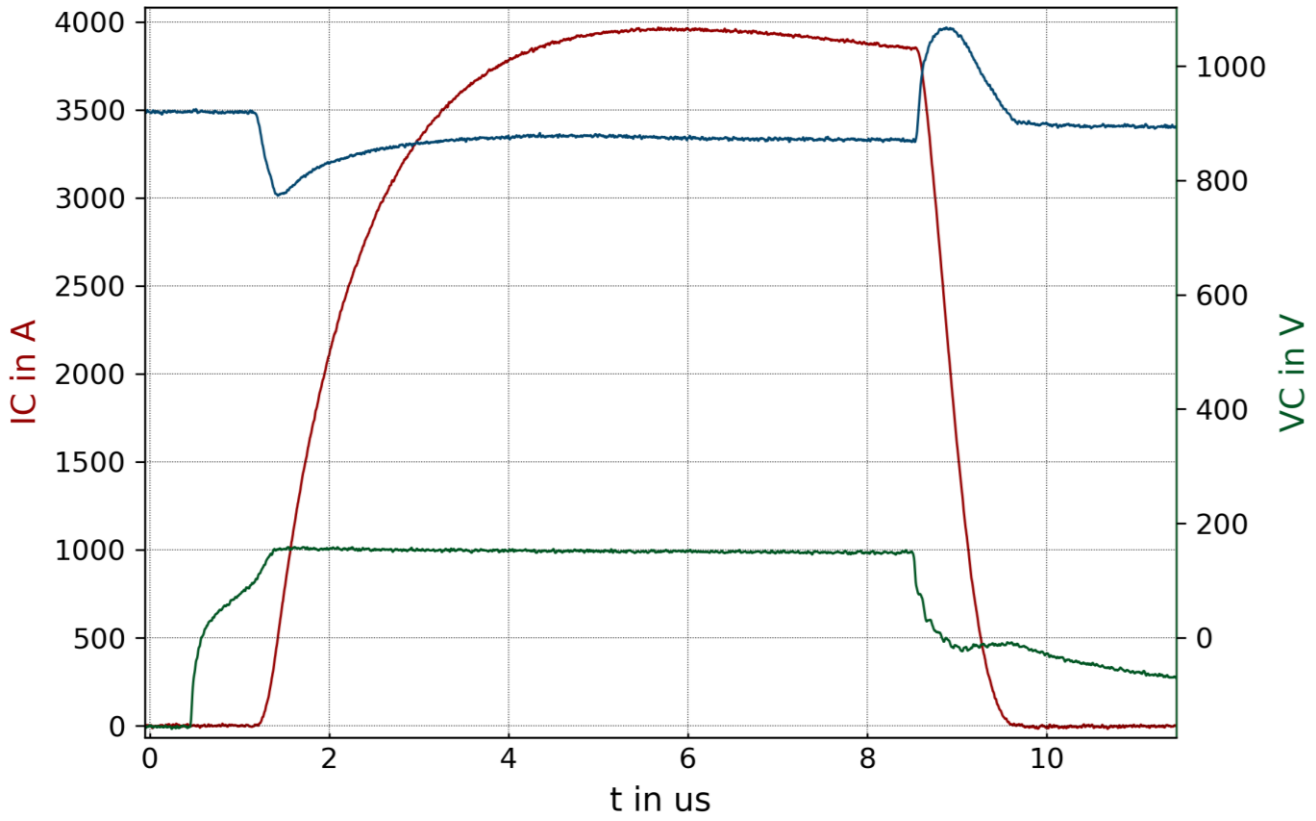
Rgsoff = 15 Ω, Vge = ± 15 V,

Ls = 30 nH, tp = 8 µs

Red trace: Ic in A

Blue trace: Vce in V

Green trace: 10*Vge in V



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LinPak

The newest standard

HITACHI ABB POWER GRIDS

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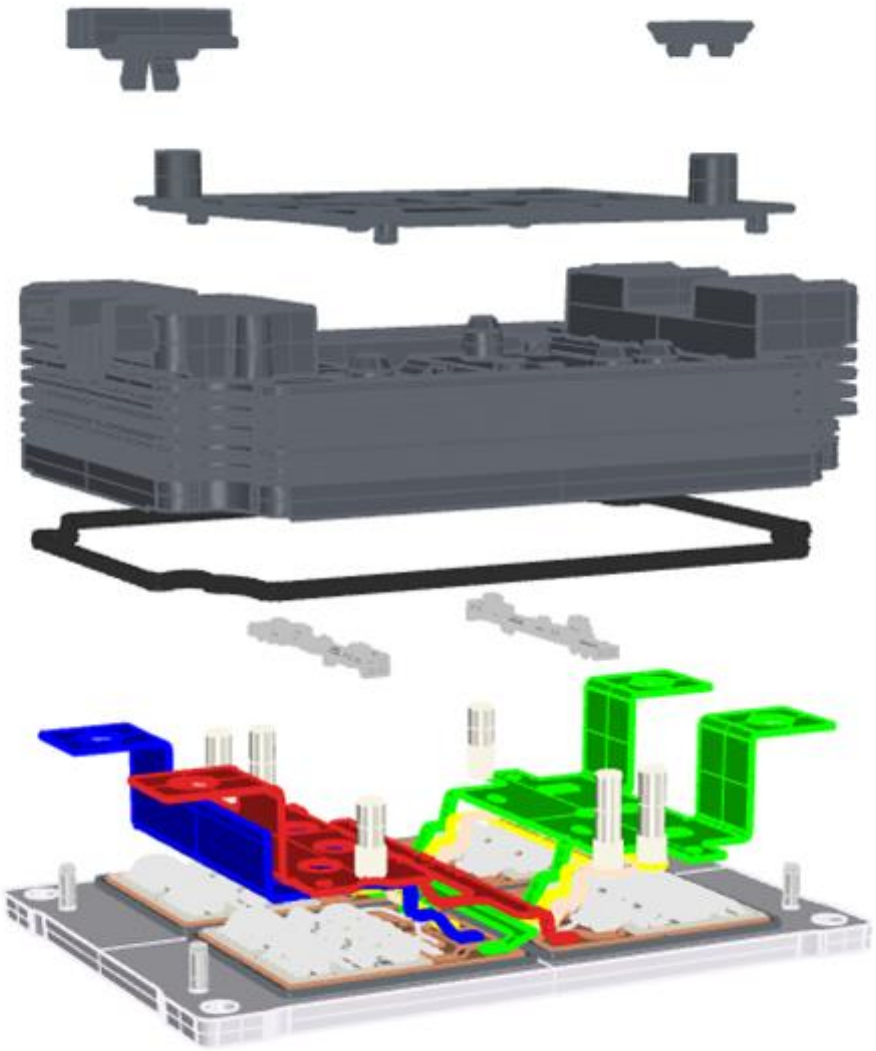
HV LinPak



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HV LinPak Module Development

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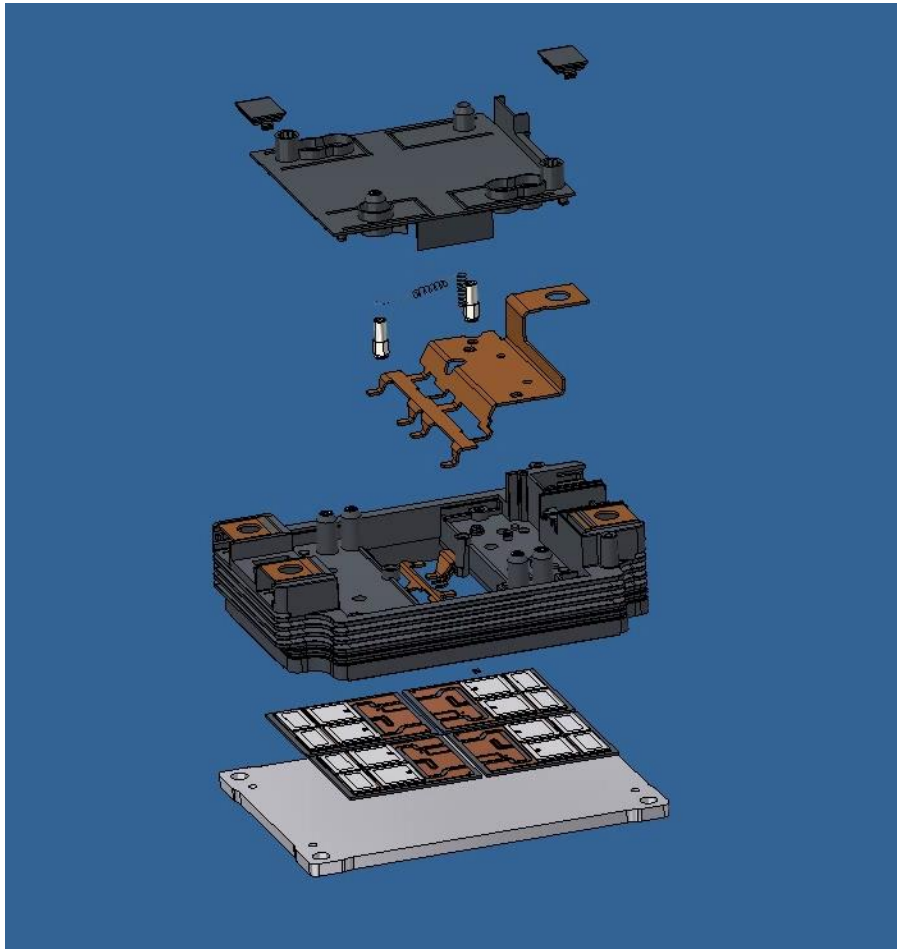
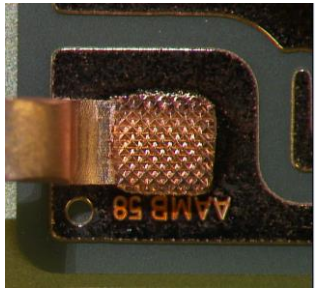
HV LinPak 3D components

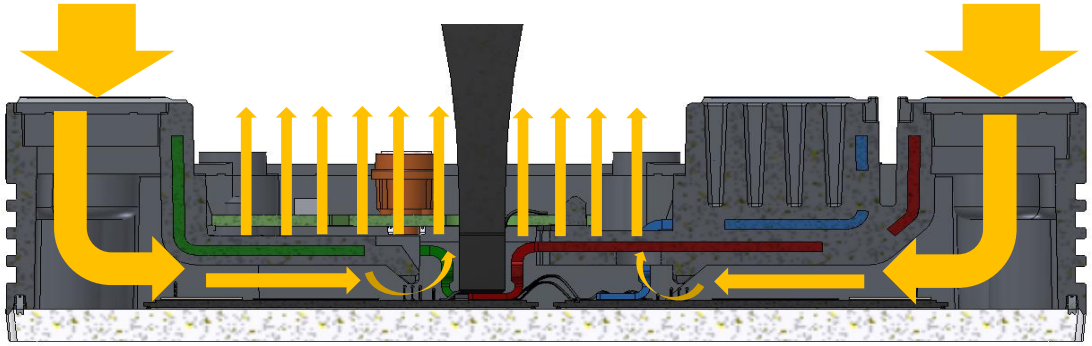


In-situ particle during ultrasonic welding

Analog to LV LinPak

- All Terminal connections in the center of the module
- Chips are protected by housing geometry
- Air blast during ultra sonic welding





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HV LinPak 6.5kV 300A - IGBT Switching – 2x I_{nom}

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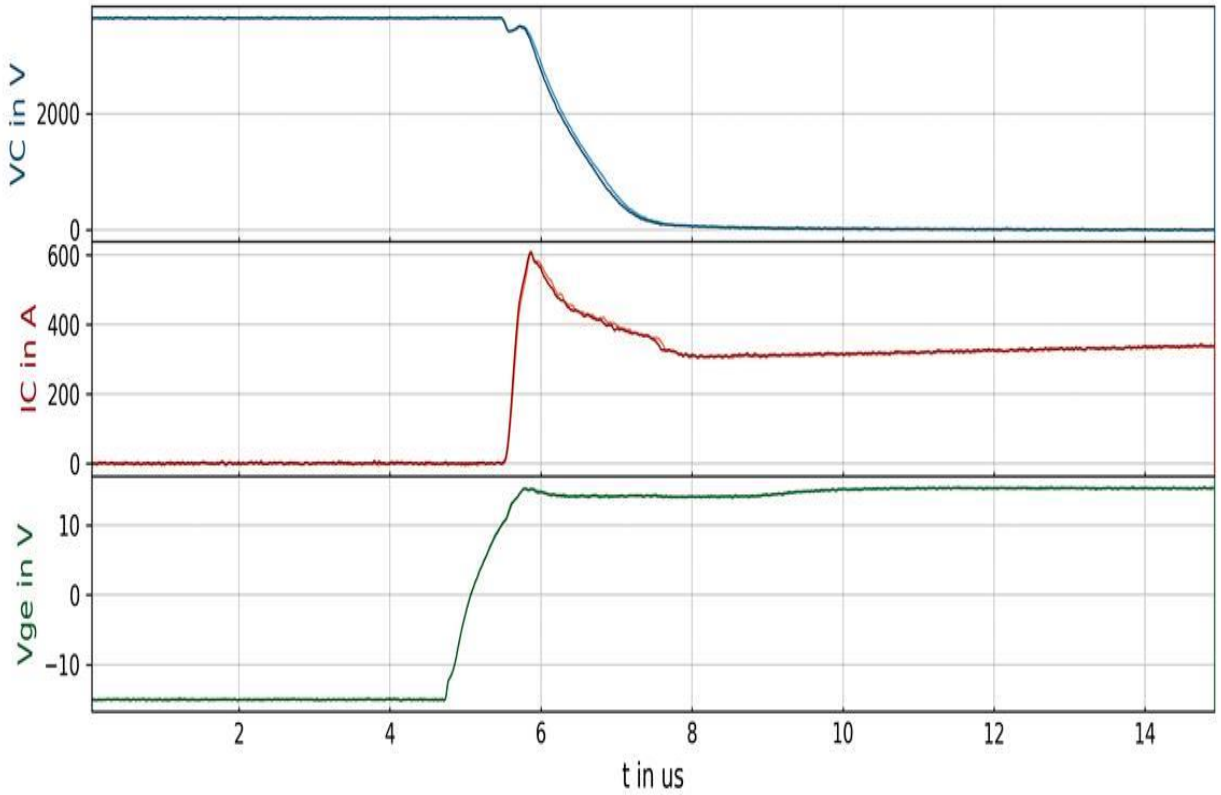
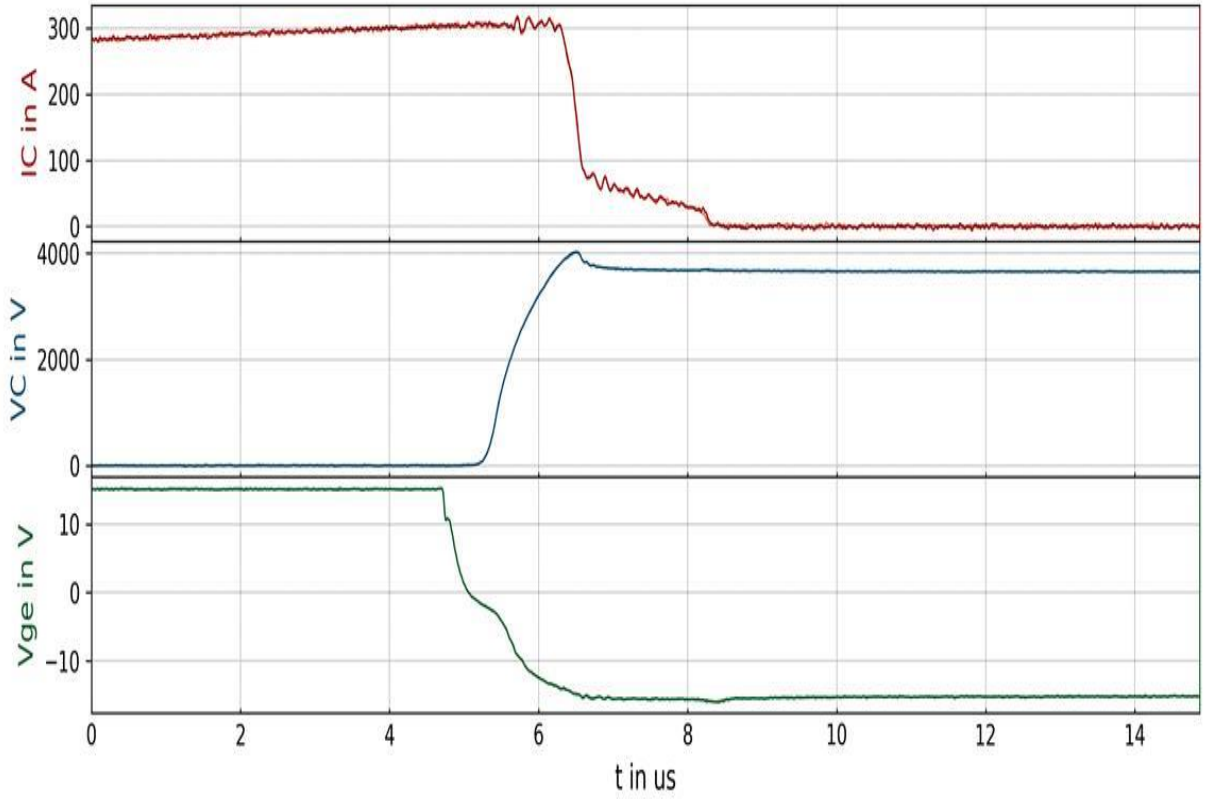
IGBT turn on at 3600 V, 600 A, 25 C



IGBT turn off at 3600 V, 600 A, 25 C



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HV LinPak 6.5kV 300A – Short Circuit SOA

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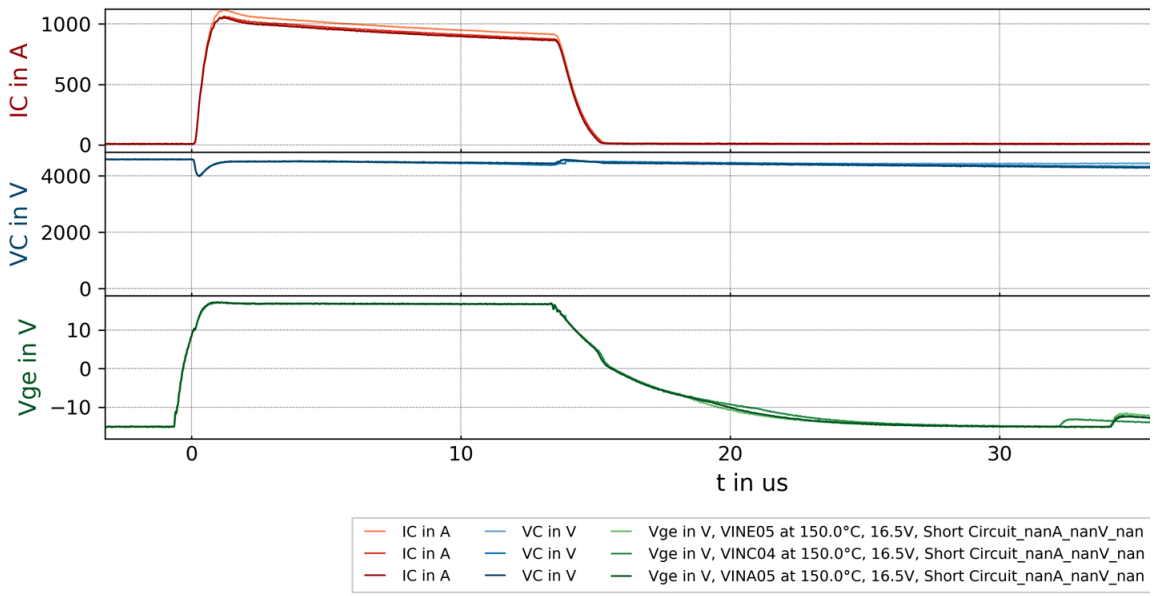
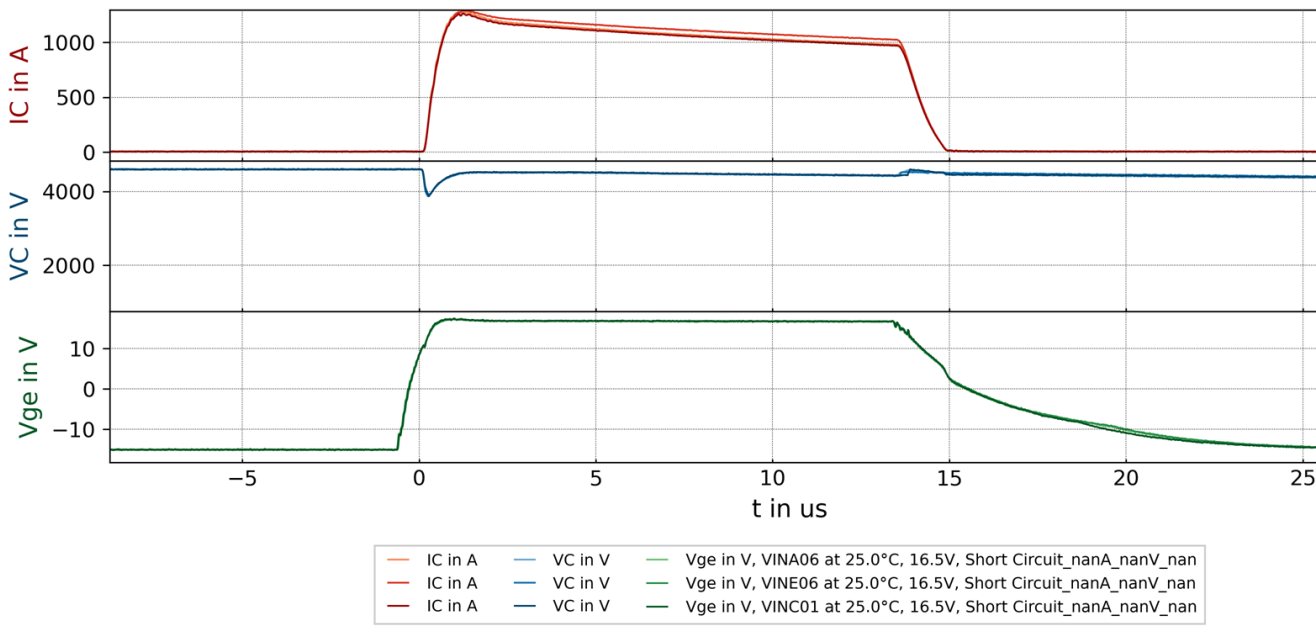
Vge= 16.5 V, Vce= 4.5 kV, 12 us, 150 C



Vge= 16.5 V, Vce= 4.5 kV, 12us, 25 C



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HV LinPak 3.3kV 600A – Switching Behavior

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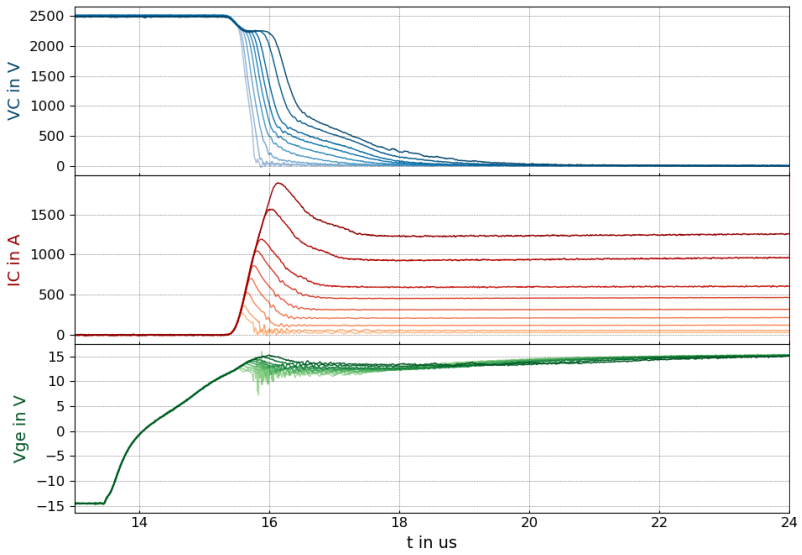
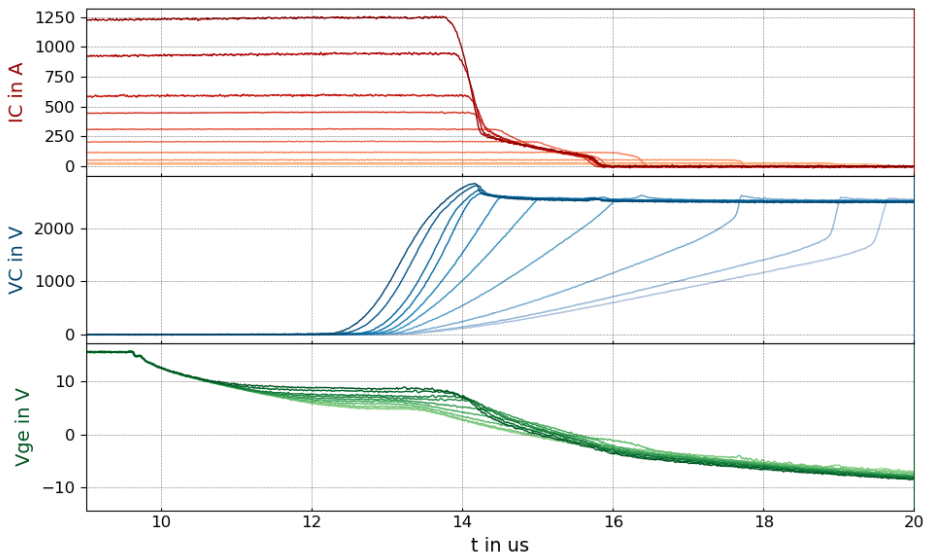
IGBT Turn-on



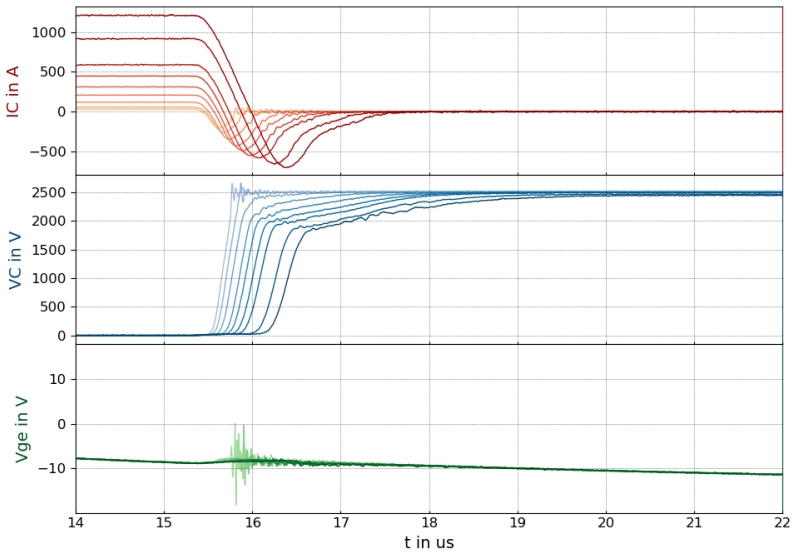
T_{vj}=25°C, V_{cc}=2500V, I_c=0.1 .. 2 x I_{nom}

IGBT Turn-off



T_{vj}=150°C, V_{cc}=2500V, I_c=0.1 .. 2 x I_{nom}

Diode Reverse Recovery



T_{vj}=25°C, V_{cc}=2500V, I_c=0.1 .. 2 x I_{nom}

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LV LinPak

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LinPak 1.7kV 1500A – Next Gen Chip Set

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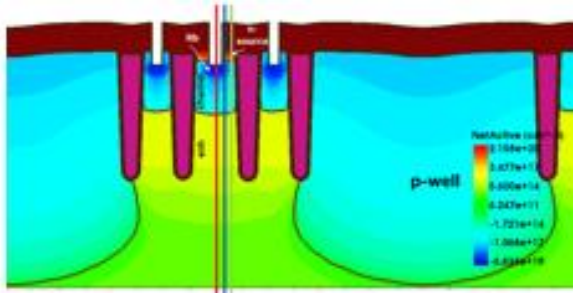
Goal: development of an improved 1.7 kV chipset suitable for a 1500 A LV LinPak module.

Target product: 1.7 kV LV-LinPak 1500 A (+50% current rating).

Target technology: Trench Fine Pattern (TFP) IGBT, Taiko diode.

Key improvements:

- Trench Fine Pattern IGBT with plasma flow control
- Ultra-thin diode: big improvement in tech. curve



1.7 kV LV-LinPak

1000 A → 1500 A

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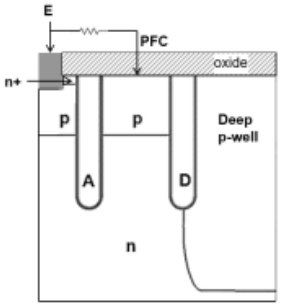
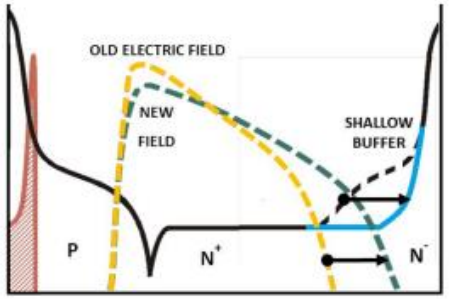
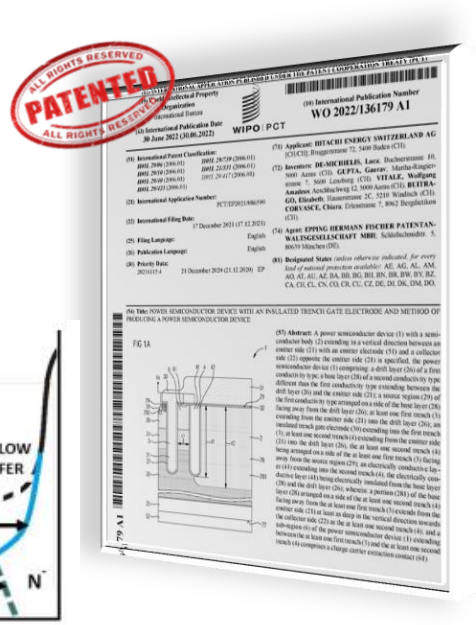
New LV IGBT and diode chipset





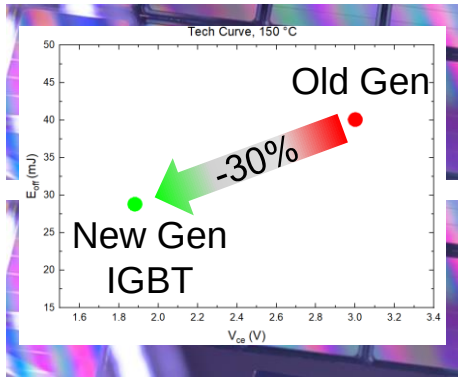


Find more on:

- Rugged LV Trench IGBT with Extreme Stability in Continuous SOA Operation: Next Generation LV Technology at Hitachi ABB Powergrids; E. Buitrago et al., **PCIM 2021, Nuremberg**.
- Next Generation LV Trench IGBT Design Featuring Plasma-Flow Control for Improved Switching Losses and Turn-on dV/dt Controllability; G. Gupta et al., **PCIM 2022, Nuremberg**.
- Next Generation 1.7 kV Chipset: Fine-Pattern Trench IGBT and Ultra-Thin FSA Diode for Traction Applications; W. Vitale et al., **PCIM 2022, Nuremberg**.

IGBT Highlights

- New generation FP trench front-side design with patented “Plasma Flow Control” technology
- Robust degradation-free Trench IGBT Technology experimentally demonstrated
- New aggressive ring termination design
- Ultra-thin device thickness for improved losses produced by Taiko processing
- Ultra-shallow buffer design for extremely low leakage current and high temperature operation



Diode Highlights

- New Field Shielded Anode diode design with novel termination design for maximized active area
- Ultra-thin Taiko wafer for reduced losses
- Larger IGBT/diode ratio
- Ultra-shallow buffer by laser-annealing, enabling reduced leakage and high temperature op.
- Low resistivity Silicon material for enhanced softness

Powerful LV Technology Platform

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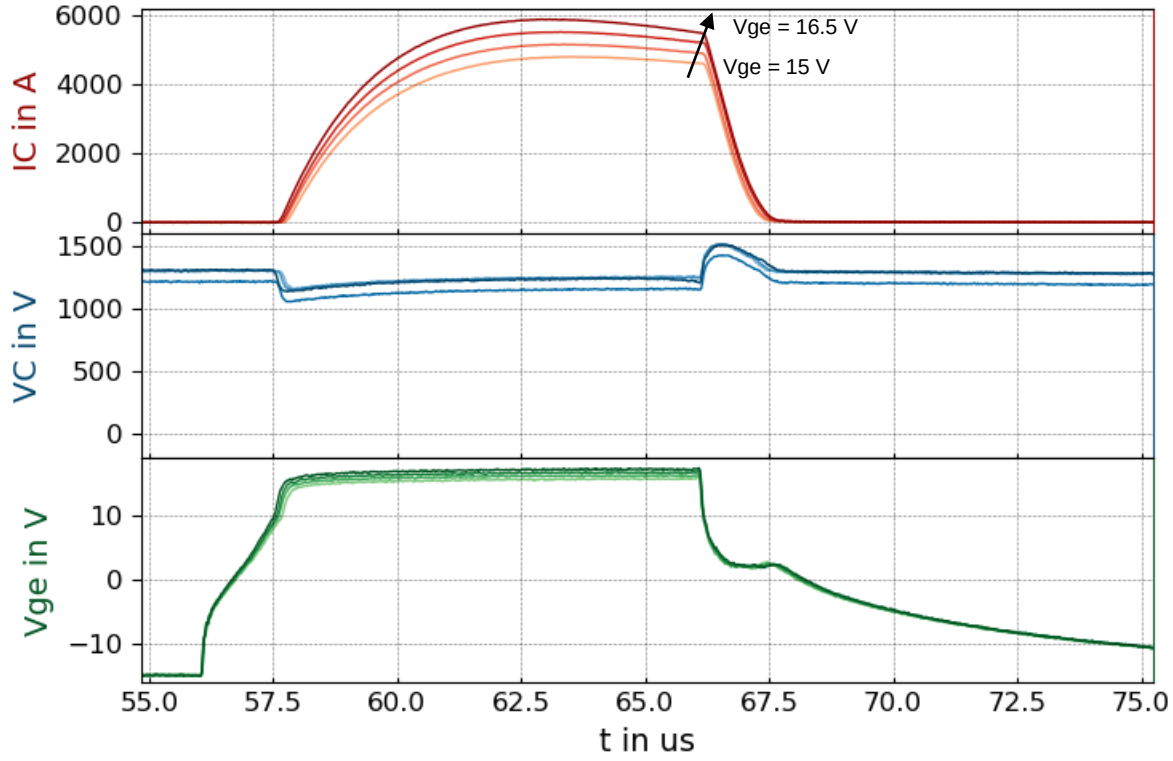
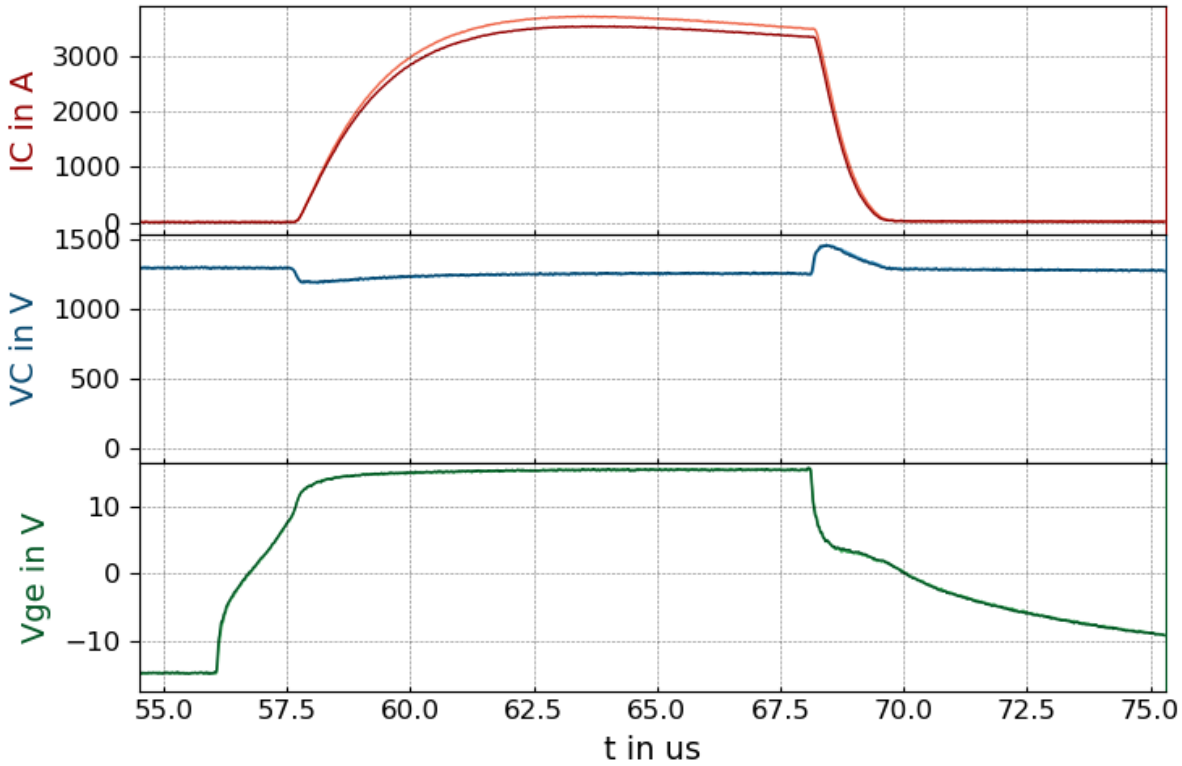
LV LinPak 1.7kV 1500A - Short Circuit SOA

T = 25 °C



T = 175 °C



SCSOA cold pass Vge = 16.5 V; SCSOA hot last pass at tp = 11 us.

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LV LinPak 1500A 1.7kV - RBSOA (1.3 kV, 2.6x Inom)

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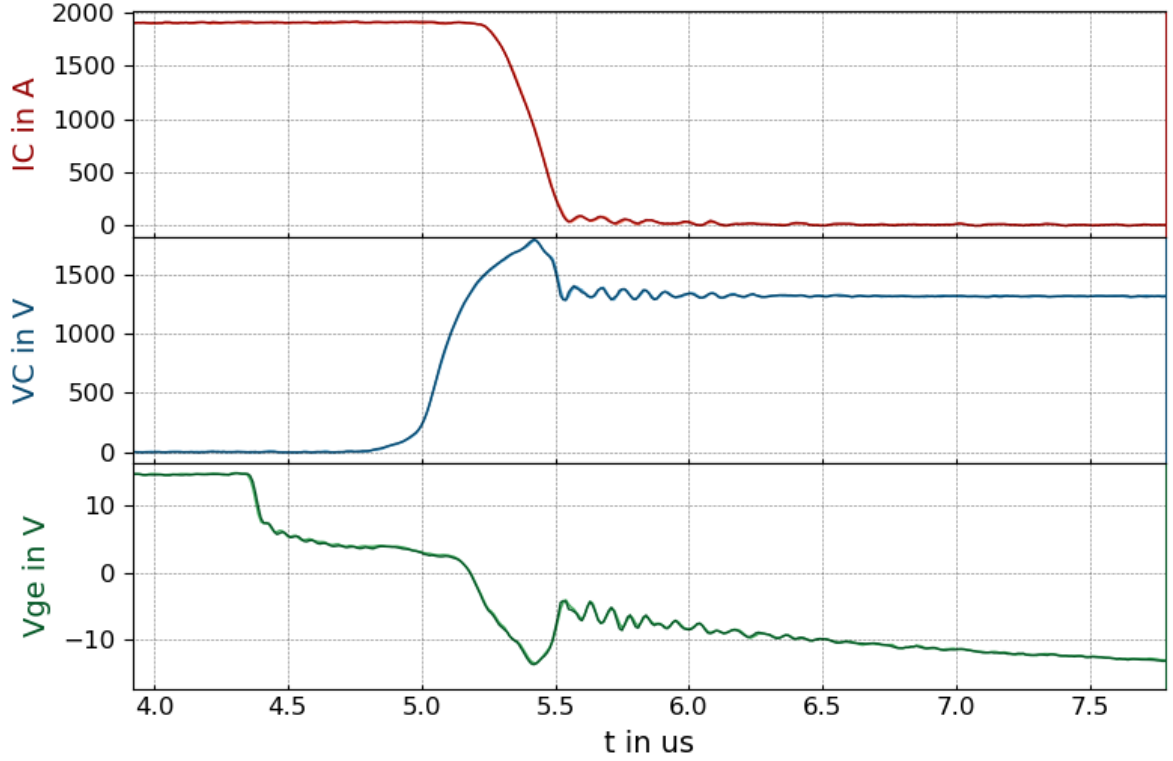
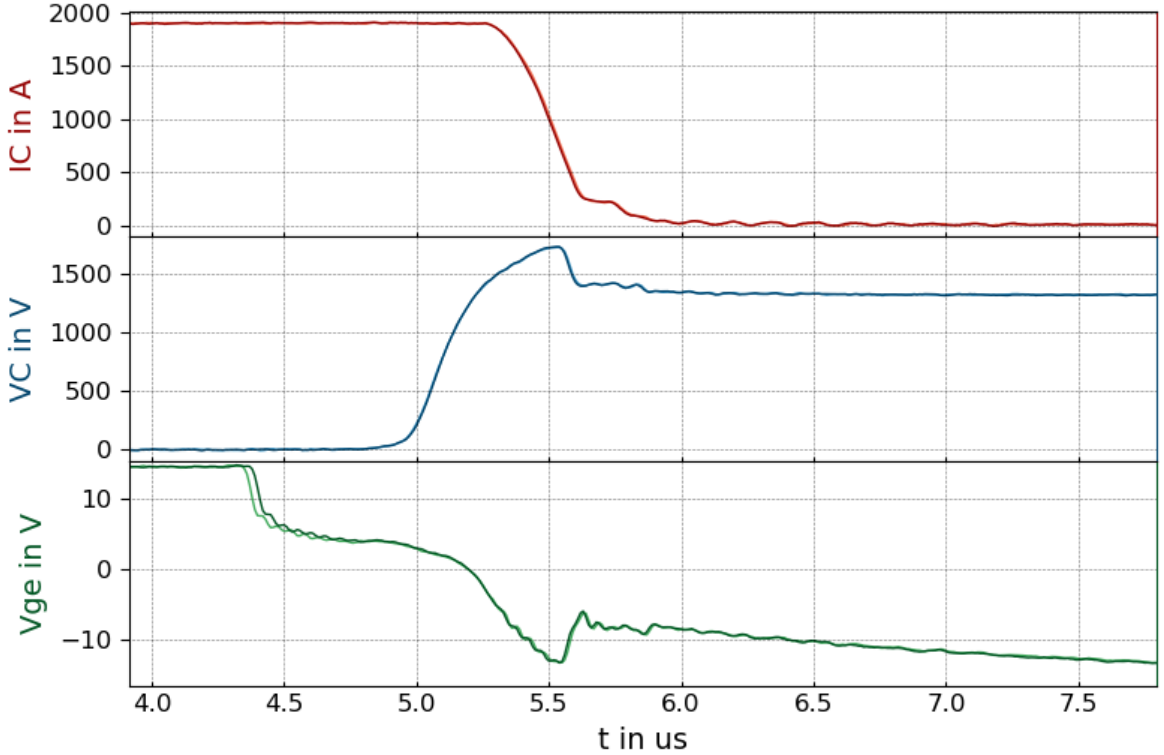
T = 25 °C; Rg_off = 4.7 Ohm; Ls_mod = 35 nH



T = 175 °C; Rg_off = 4.7 Ohm; Ls_mod = 35 nH



RBSOA pass at 2.6x Inom

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LV LinPak 1500A 1.7kV - Parallel Operation

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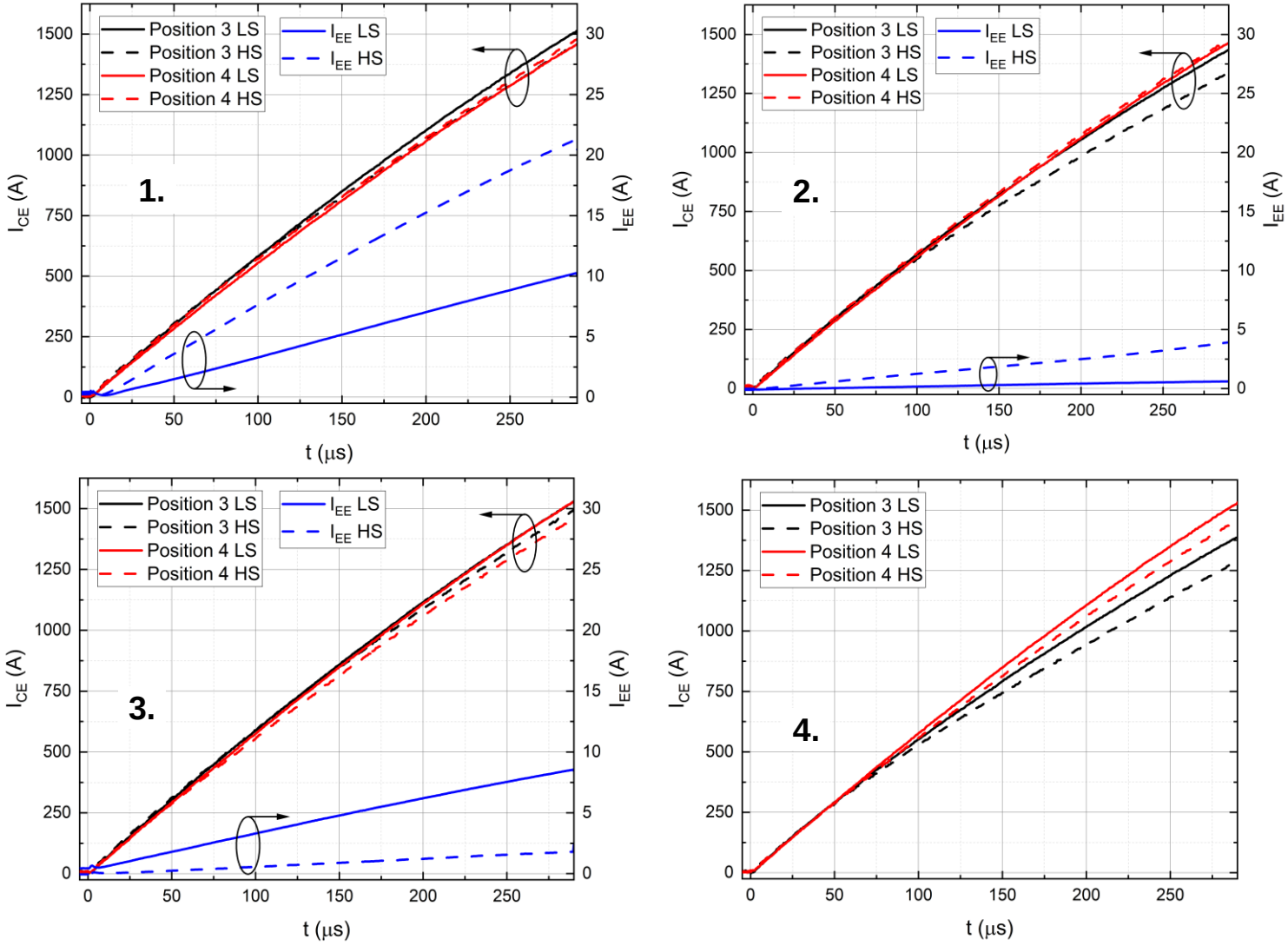
1. **Common emitter**
   - Symmetrical current distribution, high cross-currents
2. **Common mode choke**
   - Less symmetrical current distribution, reduced cross-currents
3. **Starpoint emitter**
   - Symmetrical current distribution, reduced cross-currents
4. **No emitter**
   - Asymmetrical current distribution, no cross-currents



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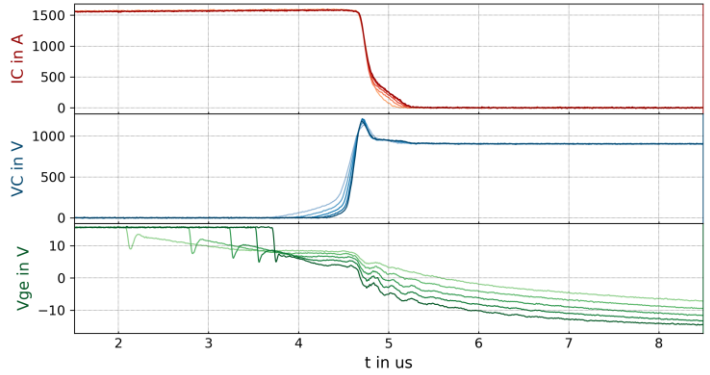
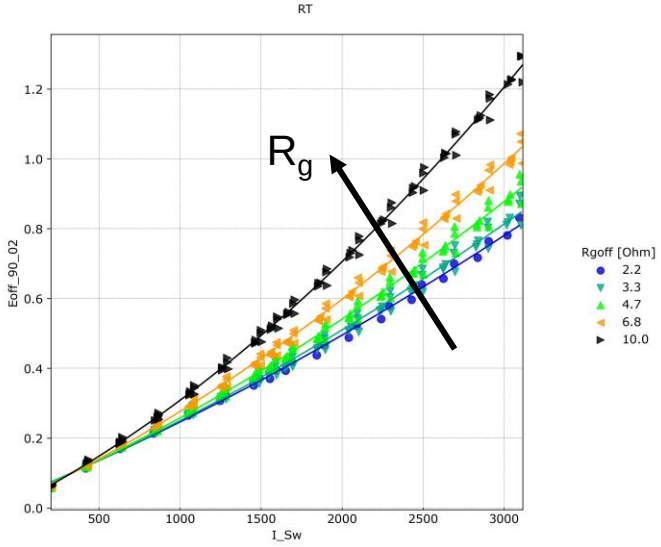
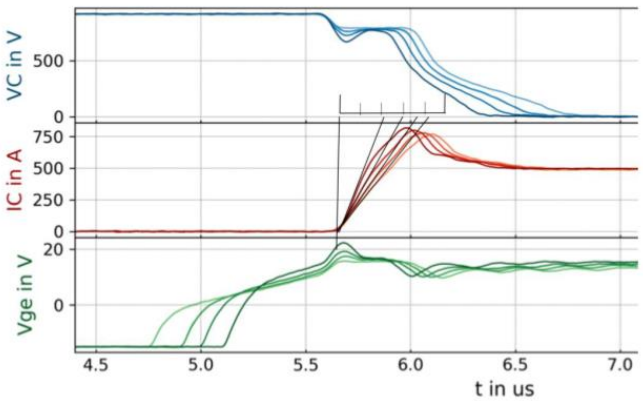
LV LinPak 1500A 1.7kV - Good Controlabiliy with Rg

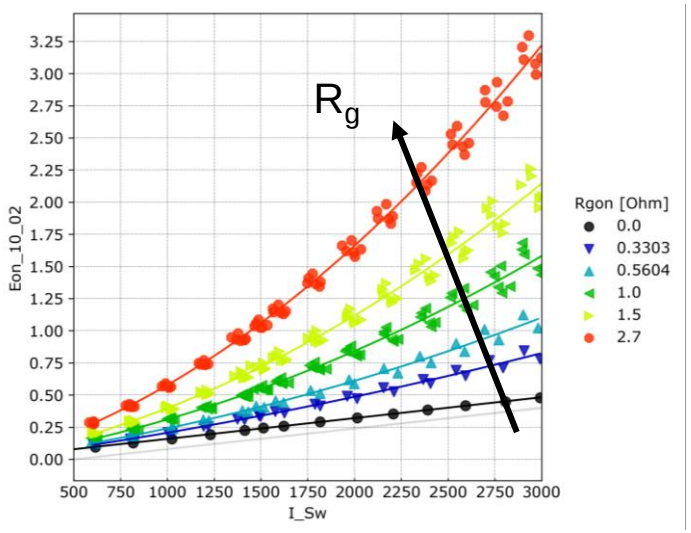
Turn off





Turn on





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DigitalizatI/On

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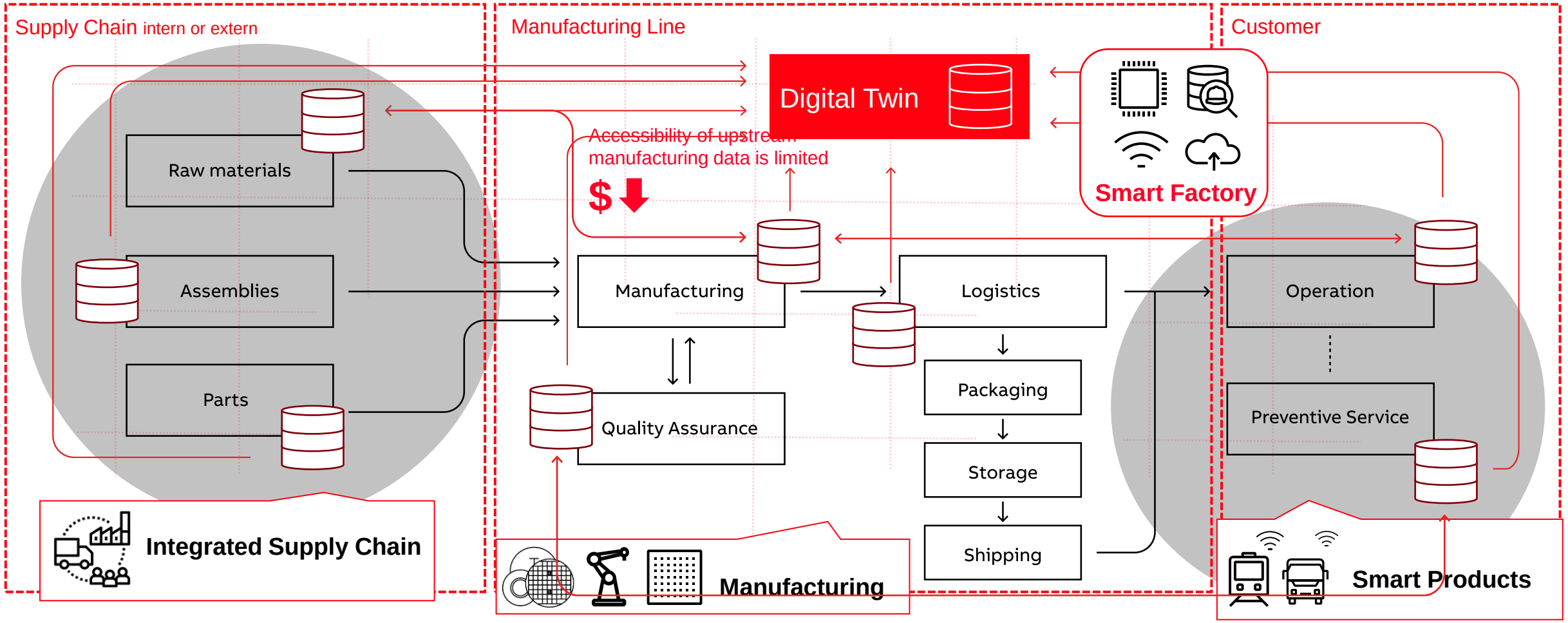
Vision: Digital ValueAdd Semiconductors



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Power semiconductors going smart

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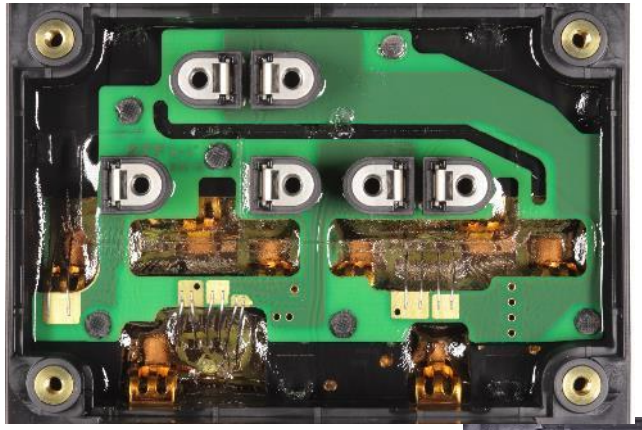
Semiconductors with internal sensors (e.g. temperature, humidity), for cloud-based monitoring & analytics, to define the lifecycles etc.

Standard LinPak



Smart LinPak

Condition monitoring within operations for specific parameters such as junction temperature, U, I. humidity, ambient temperatures or vibrations.

Create real **Digital Twin** combining process- & product data with real-life product data in its operation. Apply learnings of data analytics in development lifecycles and manufacturing systems.

Spare parts condition monitoring based on “SMART semiconductors” DIF model of semiconductors products.

Semiconductors lifetime predictability model
Develop lifetime predictability model and apply it to devices in operations.

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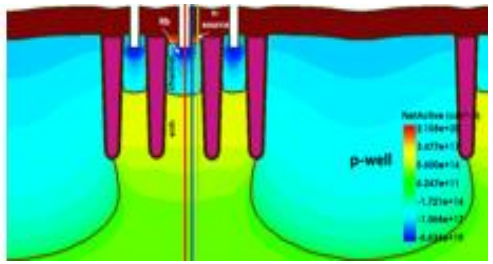

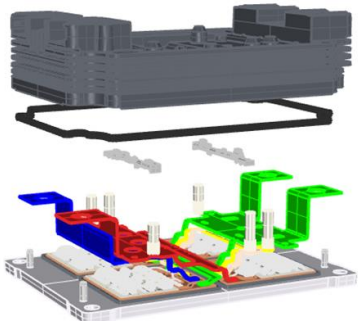

Chip

Increase current densities with planar chip

Develop innovative robust trench designs

Un-matched chip environmental protection (i.e. Robust Passivation)

Novel Semiconductor materials (i.e. SiC)

Package

Innovative Packages (LinPak, RoadPak) with lowest stray inductance, good paralleling, ideal form-factor, high current density

Robust joining techniques, ideal cooling path and un-matched power cycling capability (i.e. sintering, pin-fin, TIM, die top systems, etc.)

Manuftr.

Increase wafer size for increased capacity

Automation of BackEnd for augmented quality, flexibility and capacity (i.e. Industry 4.0)

De-risk availability by using foundaries for FE and EMS partners for BE

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