Double-sided Cooling Integrated Power Module and Power Control Unit

Dynex Semiconductor

AESIN Conference - October 20th 2016

中车时代电气功率半导体英国研发中心
TEC Power Semiconductor R&D Centre（UK）
英国 林肯, Lincoln, United Kingdom

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CONTENT

PART 1	COMPANY PROFILE
PART 2	HEV/EV Application
PART 3	Capabilities
PART 4	Performance

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1. COMPANY PROFILE

Dynex

Dynex has more than 50 years experience in the design and production of high power semiconductors…

One constant throughout all this change is that our manufacturing and R&D has been based in Lincoln UK since 1956

This has maintained continuity of personnel which is important for:

- **R&D**
- **Manufacturing expertise**
- **Our customers**

2008

75% owned by CSR Times Electric

A significant change to Dynex…

With major implications to our future development and the products and services we provide to our customers around the world

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1. COMPANY PROFILE

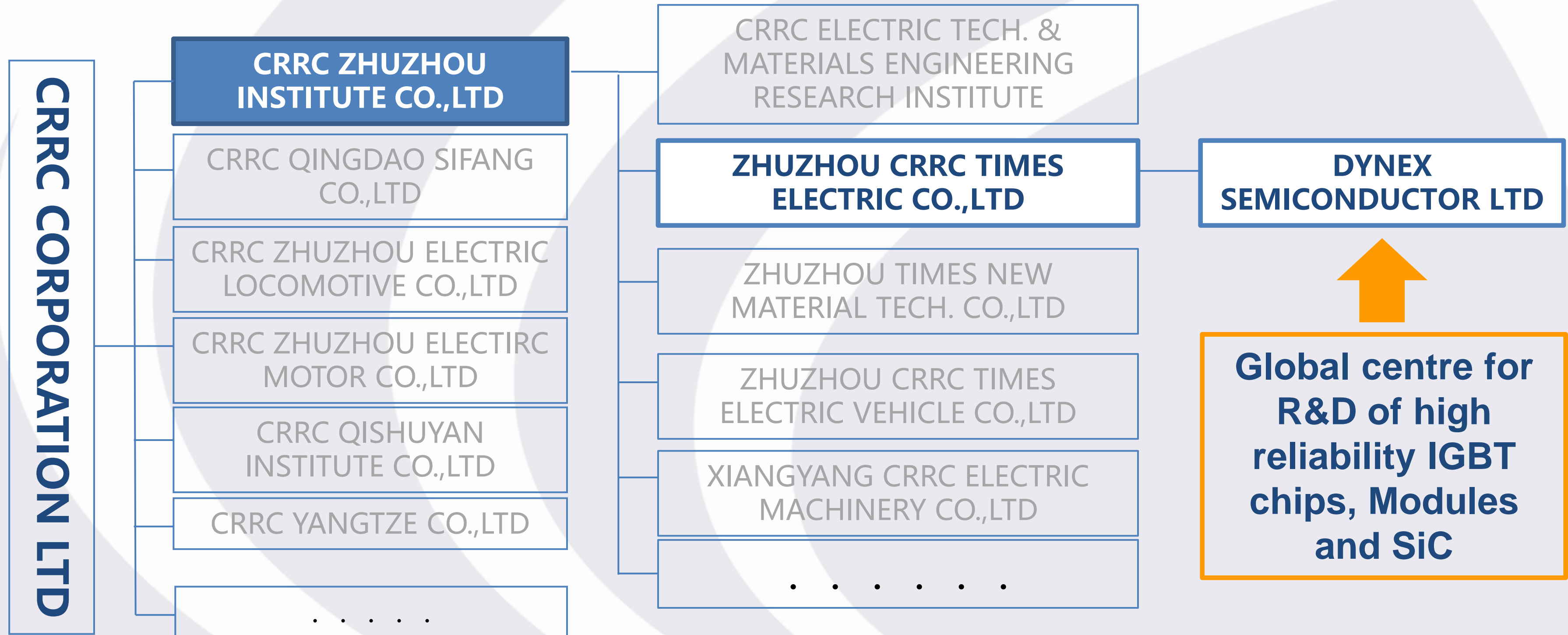
Overview

Railway Developed Technologies Applied to EV

The company has developed a series of products including Electric drive systems, hybrid power system assemblies and complete electric vehicles, etc., incorporating proprietary technologies, through nearly 10 years of research and application by extending core technologies that CRRC accumulated in the field of rail transit over the past 50 years to the field of electric vehicles. These technologies include electric motors and control systems, converter systems and network control.

1. COMPANY PROFILE

Structure Overview



CSR ZHUZHOU INSTITUTE CO.,LTD :

- 10 subsidiaries，20k employees， US$ 4.7 billion in 2015
- Rail transportation(traction drive system, the control network system, on-board information system and auxiliary power supply system), electric vehicles, wind/photovoltaic power generation, marine propulsion, Engineering machinery, Mining/Special vehicles
- Member of SoE Electric Vehicle Industry Alliance，Drive system and its generic technology

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Package Requirements of Vehicle Power Electronics

Challenges of Vehicle Electronics Package	
Electrical	High power density, high switching frequency, low loss, low parasitics, and high SOA
Thermal	High operation temperature, low thermal resistance, matched CTE
Mechanical	Anti mechanical vibration and shock capabilities, small volume, light weight
Reliability	Thermal cycling and power cycling capabilities, high mechanical reliability

Development Target of Vehicle Electronics Devices

Year	Cost($/kW)	Power Ratio (kW/kg)	Power Density (kW/l)	Efficiency
2015	5	12	12	93%
2020	3.3	14.1	13.4	94%

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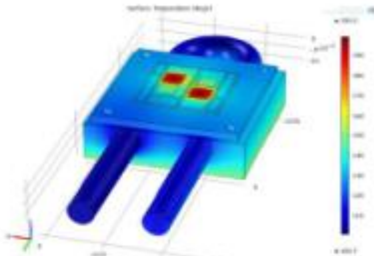
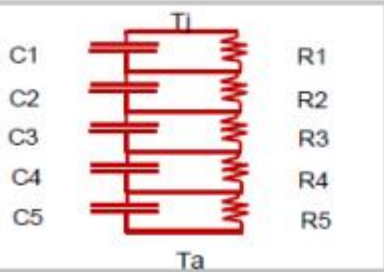
Integrated Power Module

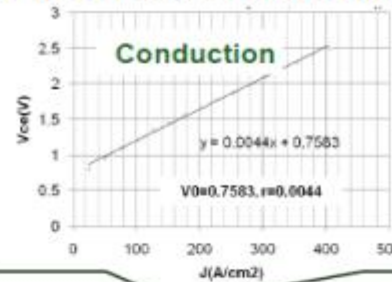
Four Main Features of IGBT Power Module

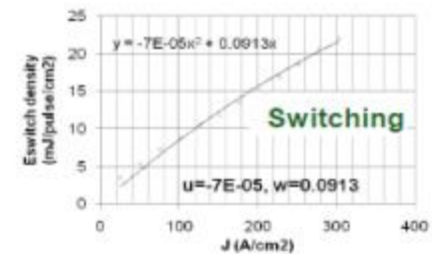
Thermal Impedance



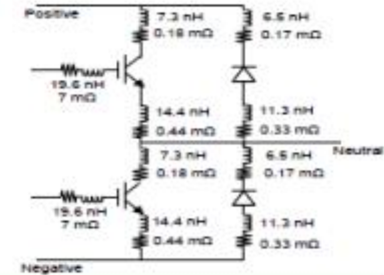


Power Device Performance

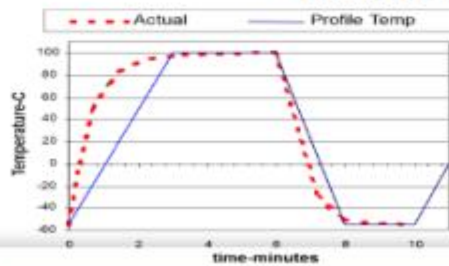


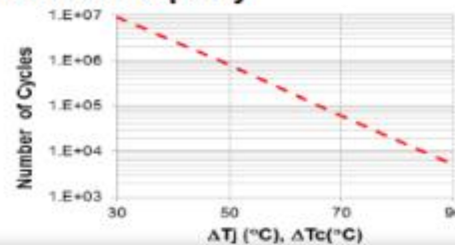


Electrical Parasitic Parameters



Thermal-mechanical Property





OAK RIDGE NATIONAL LABORATORY

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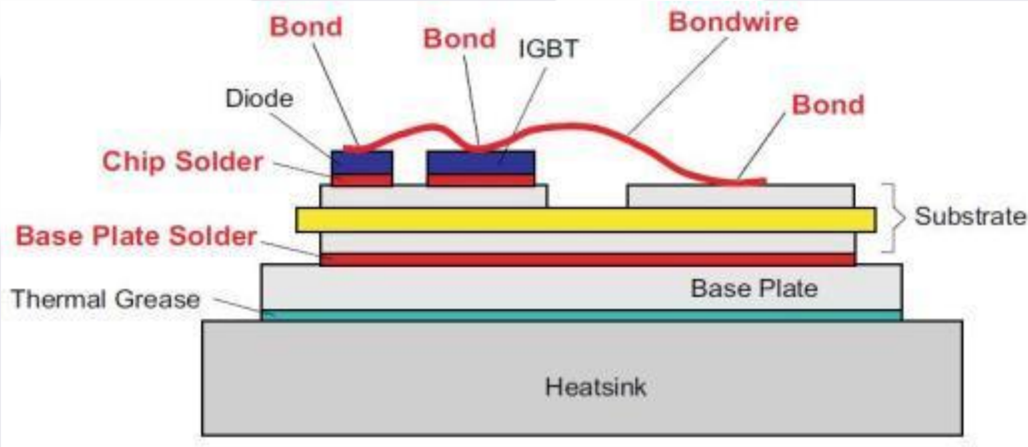
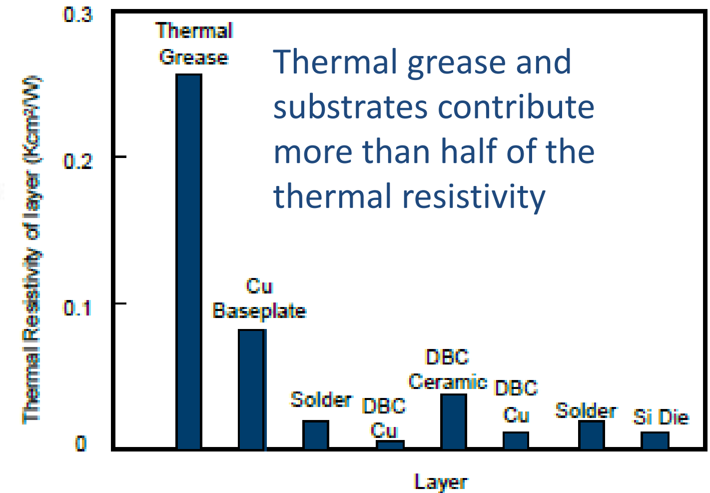
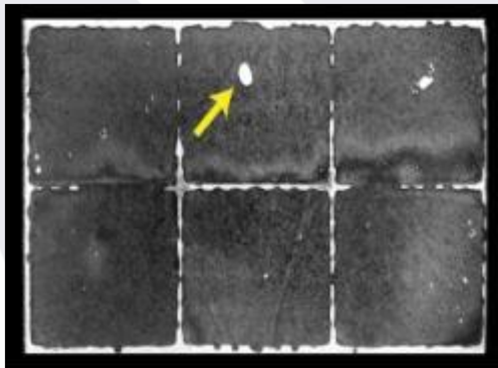
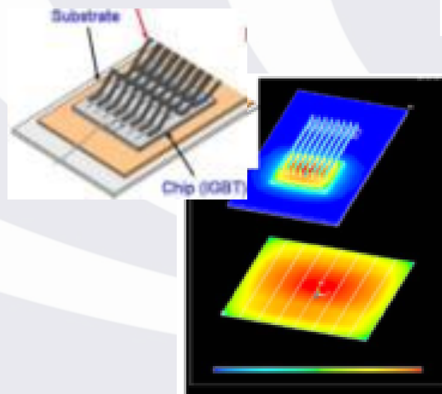
Integrated Power Module

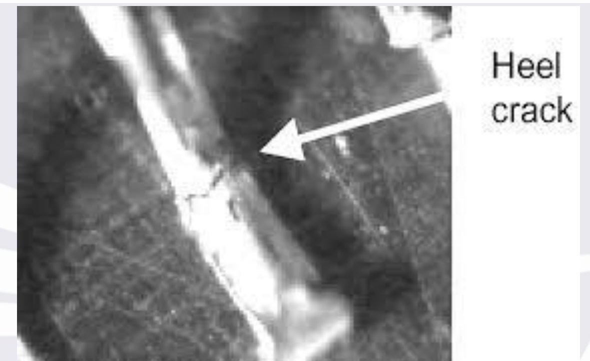
Issues in Conventional IGBT Module Packaging











The broken aluminum wire bond, high parasitic inductance and unevenly distributed temperature of dies lead to issues of product performance and reliability.

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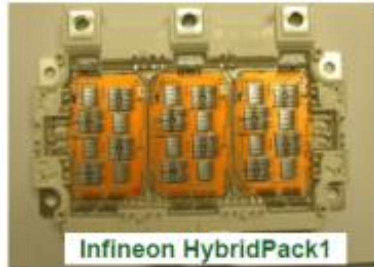
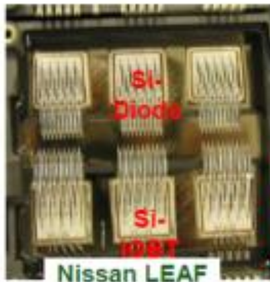
Package Technology of Power Module

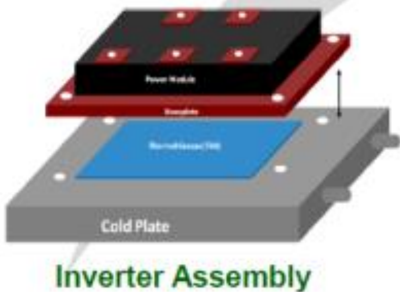


Infineon HybridPack1



Nissan LEAF

Gen_I
- Wire Bond
- Single Side Interfacial Cooling

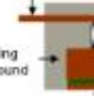


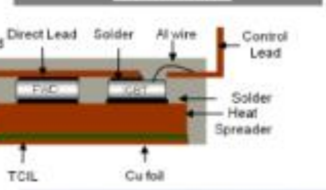
Inverter Assembly

Toyota Prius'10

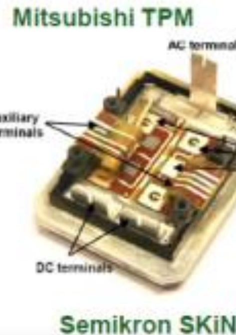
Infineon HybridPack

Gen_II
- Planar Bond
- Integrated Cooling
- Reliability Enhancement





Mitsubishi TPM

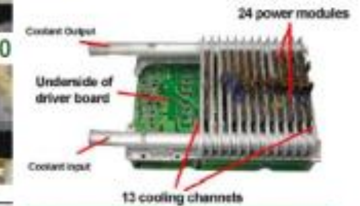


Semikron SKiN

Infineon .XT

Gen_III
- Dual Planar Bond
- Double Sided Cooling
- Integrated Double Sided Cooling

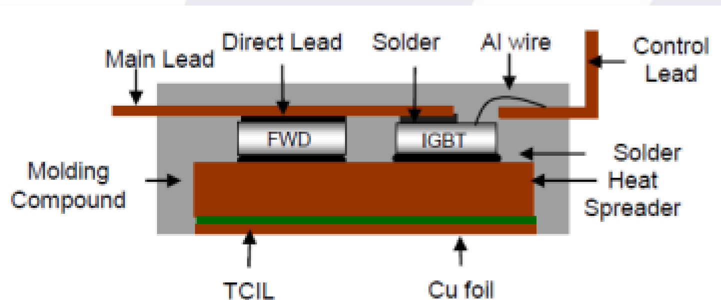
Toyota LS600

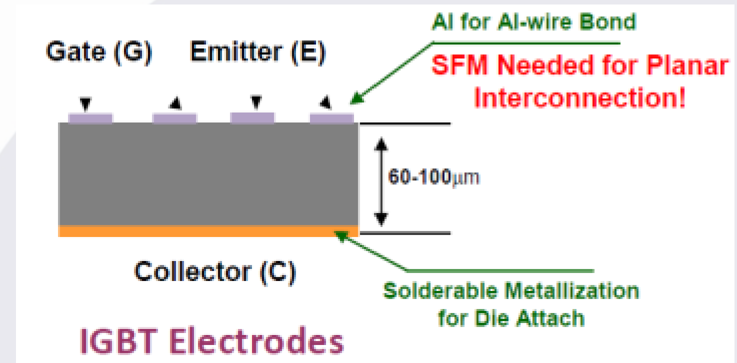


Hitachi DCPM

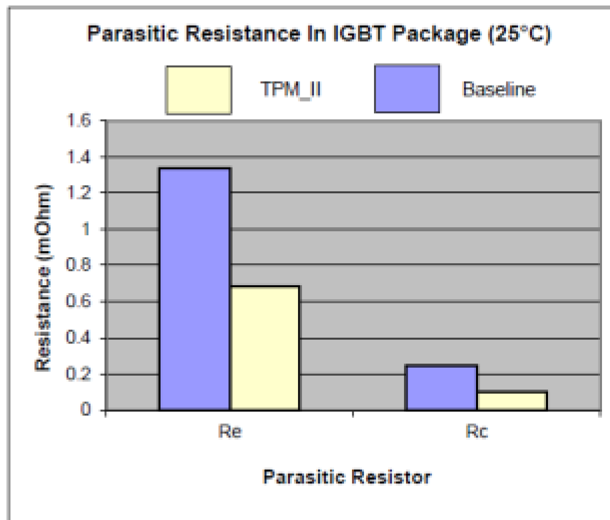
Package Technology of Power Module

- **Planar bonding – Enhance the reliability and performance**

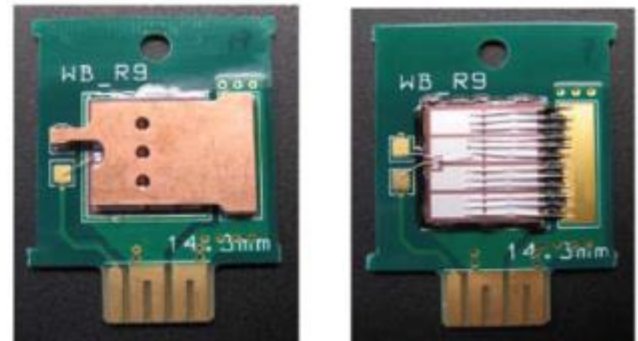




- **Failure of Eliminating Aluminum wire bond, parasitic reduces by 80%**



- **Special metalisation of the front side is required**

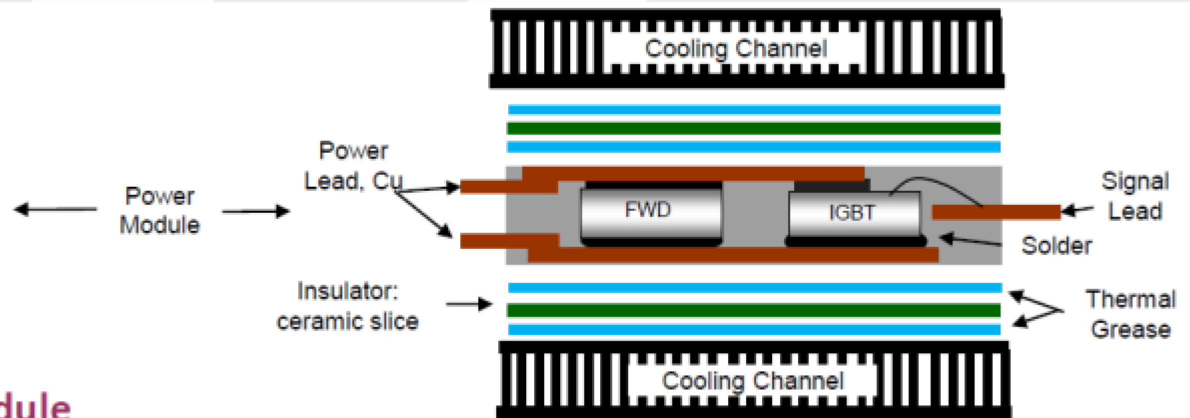


IR SFM IGBT (left)

Package Technology of Power Module

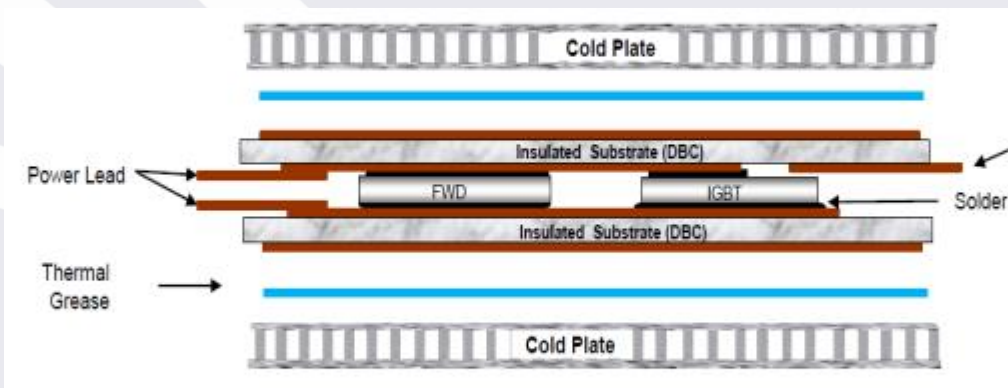
- Changes of the 3rd generation of electric vehicle IGBT package – Double-sided planar bonding, double-sided cooling, double-sided integrated heatsinks.

Toyota LS600 Module

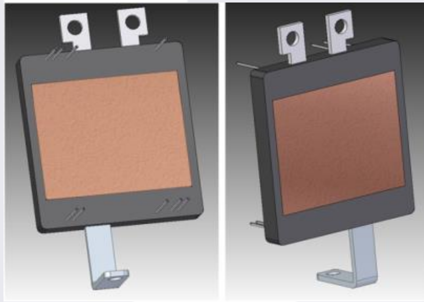


Courtesy of Delphi

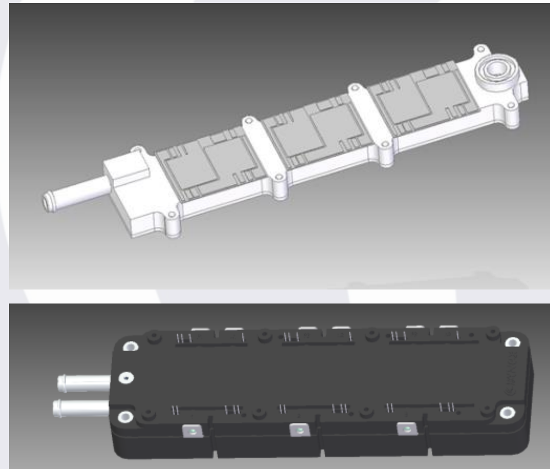
Delphi Planar Module



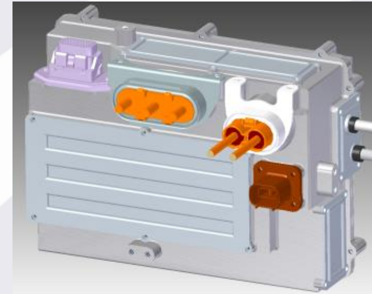
Integrated Power Module and Integrated Power Unit Systems



Double-sided Cooled
IGBT Module



Integrated Power Module
（IPM）



Integrated Power Unit
（IPU）

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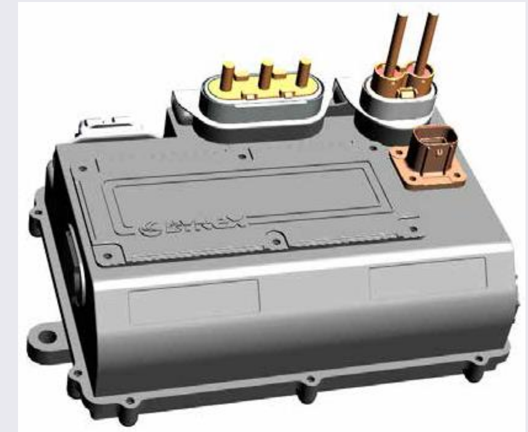
Integrated Power Unit

The Integrated Power Unit（IPU）is specially designed for electric vehicle applications, which is integrated with the bespoke IGBT module package and double sided cooling structure in order to achieve a high power density, high reliability and low cost design.

IPU Technical Specifications

Model	IPU60-120	IPU85-125
DC input voltage	DC100V-DC430V	
Rated Power	60kW	85kW
Rated output current	200Arms	288Arms
Peak Power	120kW	125kW
Peak output current	400A@30s	425A@30s
Switching frequency	5kHz-10kHz	
Cooling fluid	50% water/50% ethylene glycol, 8L/min, up to 75℃	
Operating ambient temperature	-40℃-105℃	
Design life	12 years	
Dimension, volume, mass	274×191×95, 5L	266×160×130, 5.5L
Power density	20kW/L	22.7kW/L



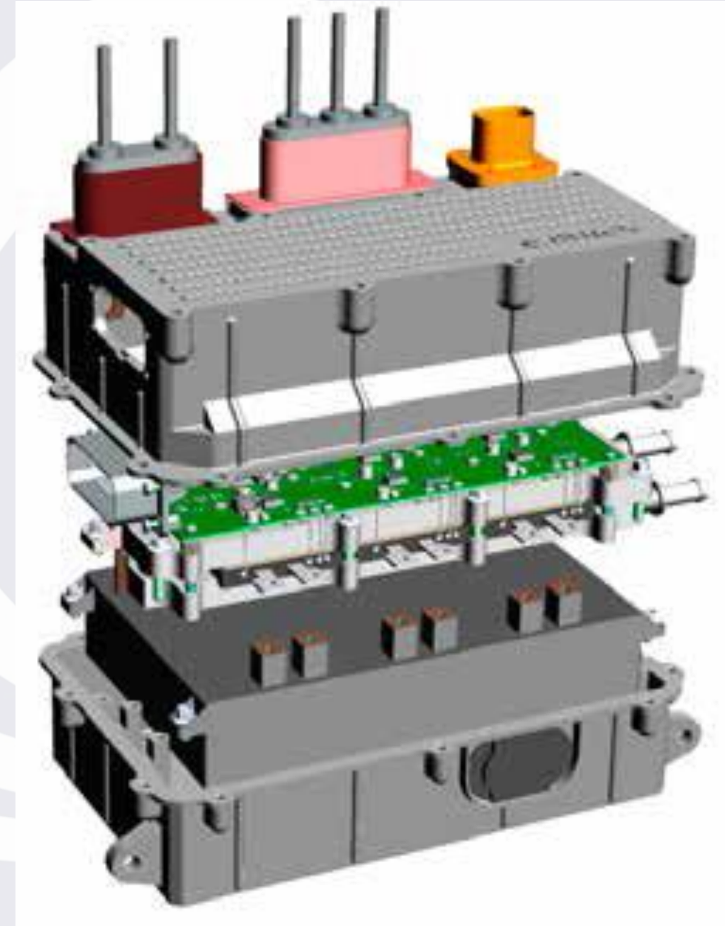
IPU60-120

Integrated Power Unit

Custom developed Integrated Power Unit (IPU)

IPU Main Features

- Bespoke power module package for HEV/EV reduces volume and mass
- Double-sided cooling with baseplate-less structure increases thermal performance and power density
- Optimised component selection and/or design make it possible to achieve higher reliability
- Based on ISO26262 certified MCU
- Customised solutions for specific applications



IPU85-125

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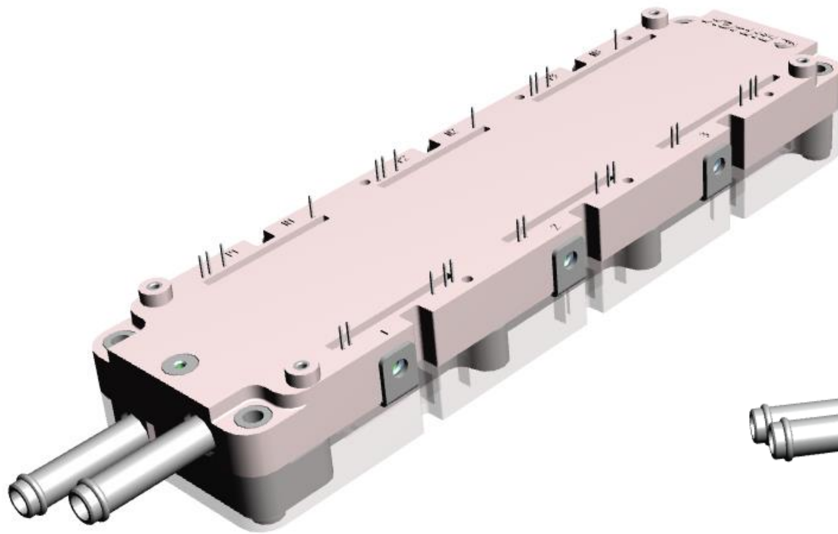
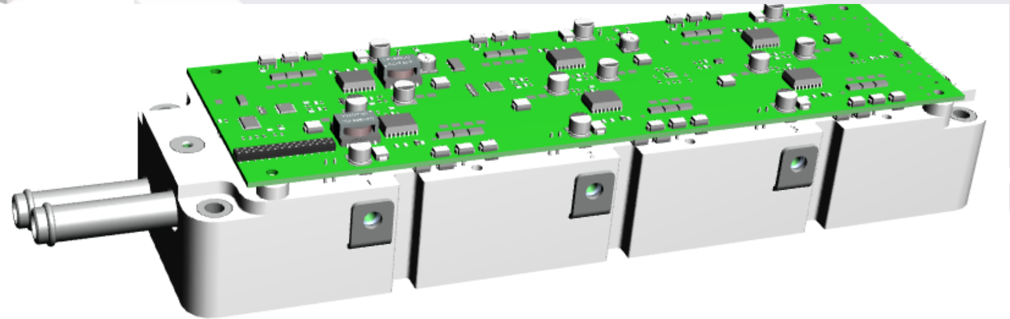
Integrated Power Module

Integrated Power Module (IPM) used in IPUs integrates three phase IGBT modules with double side cooling plates resulting in compact size and high performance for applications.

IPU Main Features

The IPM is characterised by **a double-sided cooling structure** with thin and lightweight cold plates, which increase power density by more than 30% compared with a conventional single-sided cooled module approach.





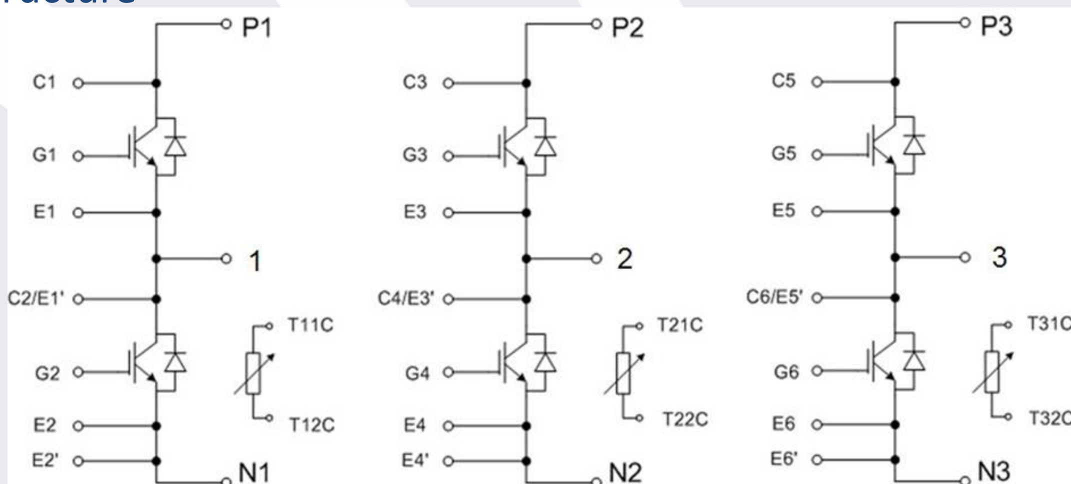
Integrated Power Module

IPM Technical Specification

Type	IPM
Configuration	6 in 1 IGBT module with thermal monitoring
Rated voltage and current	650V/600A
Maximum temperature under switching conditions	150℃
Cooling method	Double-sided liquid cooling
Per IGBT thermal resistance, junction to coolant*	0.094K/W
Per Diode thermal resistance, junction to coolant*	0.134K/W

* 50% water/50% ethylene glycol, 8L/min

IPM Circuit Structure



*** Ex' is specially designed for gate drive di/dt control.**

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DYNEX

CONTENT

PART 1 COMPANY PROFILE

PART 2 HEV/EV Application

PART 3 **Capabilities**

PART 4 Performance

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DYNEX

CAPABILITIES

Overall capabilities

Converter manufacturing capabilities

- 13 professional and flexible converter product lines
- Annual output of 10 GW converters = 100k motor controllers of 100kW
- Another 50,000 Units/Y EV inverter dedicated fab line is under construction

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DYNEX

CAPABILITIES

Motor Manufacturing Capacity

Manufacturing Capacity

Electrical Machine Pilot Test Base

As an electrical machine incubation base, it focuses on motor research, development and experimental test. It has capacity to manufacture 5000 special motor prototypes which are below 500kW annually.

Xiangyang Industrial Park

As a volume production base, it has capacity to manufacture 10000 EV&HEV motors, 4560 industrial motors, marine motors and 2080 special motors annually. The factories also reserve production capacity for 50000 passenger car motors annually.

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CAPABILITIES

Total Silicon Capabilities

IGBT manufacturing capabilities

4-inch line

- Building area：1.9 hectares
- Clean room area：2000 m^2
- Clean level：class 1000 in chip area
- Capacity：300k ppy

(ppy=pieces per year)

6-inch line

- Building area：2.2 hectares
- Clean room area：5000 m^2
- Clean level：class 100
- Capacity：100k ppy

Lincoln Headquarters

- Building area：1.4 hectares
- Clean room area：3200m^2
- Capacity(6-inch)：150k ppy

8-inch IGBT line

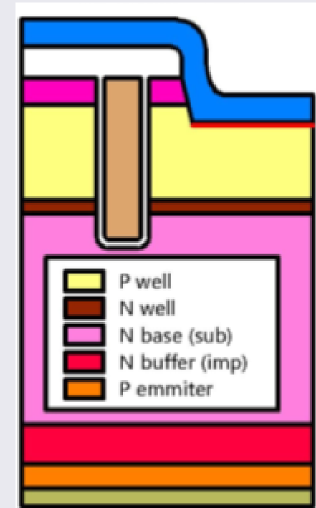
- Building area：5.2 hectares
- Clean room area：10000m2
- Clean level：class 10
- Capacity：120k ppy

2. CAPABILITIES

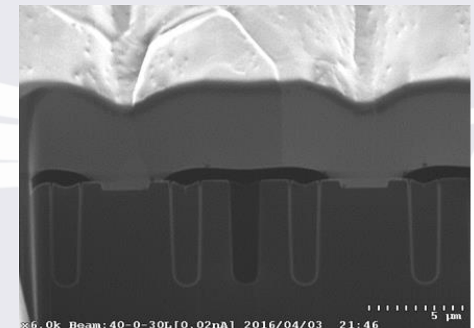
Trench Gate Field Stop IGBT Chip

Chip design and process capability, excellent overall characteristics

- **Advantages**
  - Lower on-state voltage drop
  - Better trade-off between on-state and switching loss
  - Wider SCSOA
  - Solderable top metal process in development
- **Design Features**
  - 650 to 1700V process (6500V in other IGBT technologies)
  - Tailored emitter contact
  - Low gate capacitance for shorter switching delay
  - Corner gate pad design
  - Excellent design of emitter & buffer
  - Hexagonal, stripe and circular cell structure for various applications



Cell Structure



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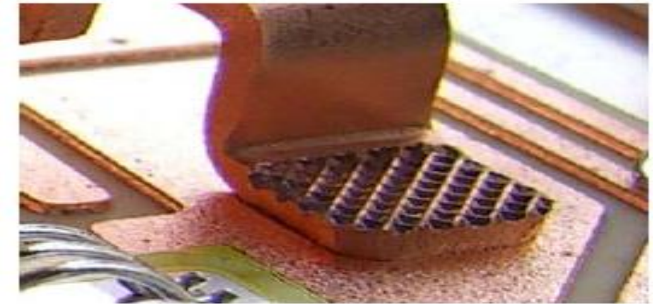
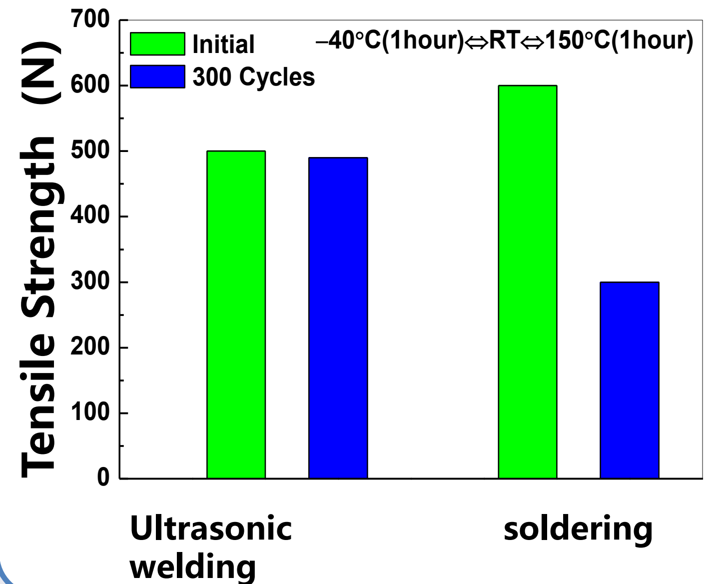
2. CAPABILITIES

State of the art packaging processes

- **Ultrasonic welding**
  - Low impedance
  - High current capacity
  - High intensity and reliability
  - Anti-shock and vibration performance

- **TLP(Transient Liquid Phase) Bonding and low temp. Silver sintering**
- **Copper/copper-clad Al wire bonding**
- **Planar bonding&Double-side cooling**

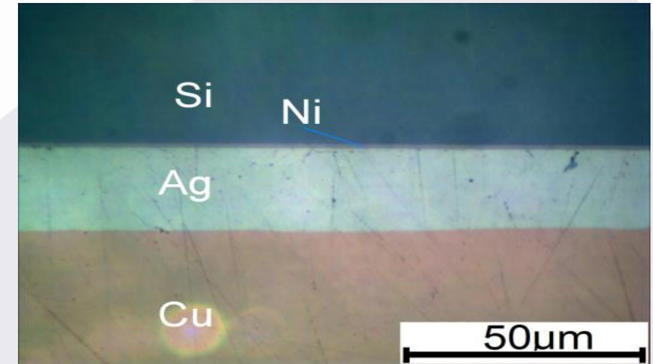




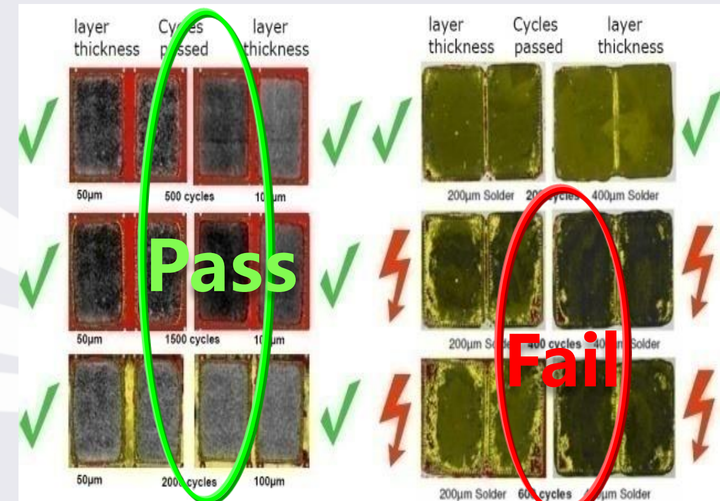
CAPABILITIES

State of the art packaging processes

- Ultrasonic welding
- TLP (Transient Liquid Phase) Bonding and low temp. Silver sintering
  - Low electrical resistivity
  - High thermal conductivity
  - High thermal stability
  - High power cycling capability
- Copper/copper-clad Al wire bonding
- Planar bonding&Double-side cooling

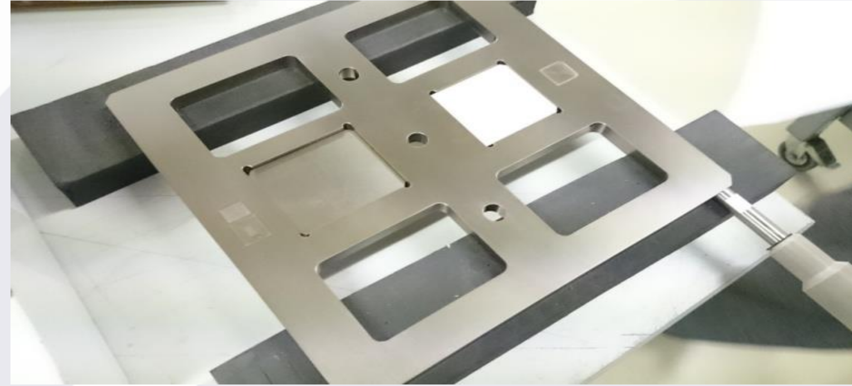


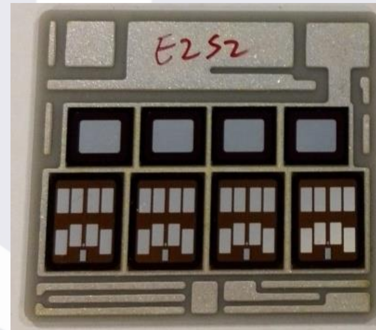
Sintering section SEM

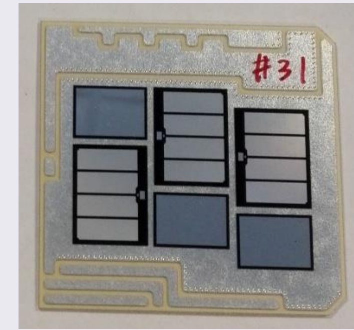


CAPABILITIES

State of the art packaging processes – Sintering Equipment







Boschman sinter Star F-XL

- Pressure unit on top of each die. Excellent pressure uniformity on dies.
- Fixed sinter tool for each product.
- N2 options for Cu surface sintering.

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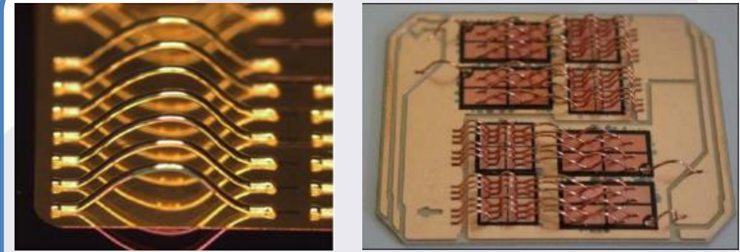
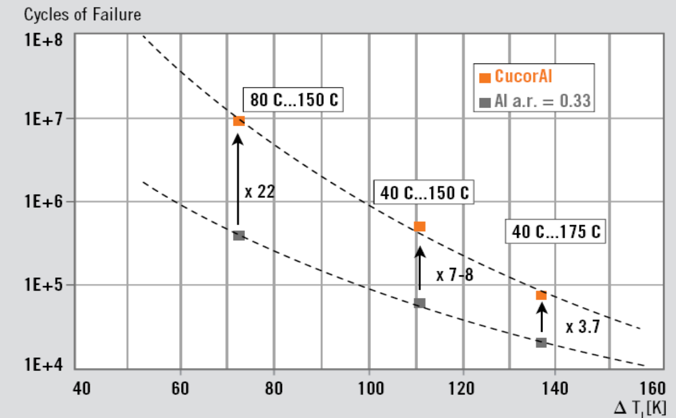
DYNEX

CAPABILITIES

State of the art packaging process

- Ultrasonic welding
- TLP(Transient Liquid Phase) Bonding and low temp. Silver sintering
- Copper/copper-clad Al wire bonding
  - Low electrical resistivity
  - High thermal conductivity
  - Low coefficient of thermal expansion
  - High power cycling capability
- Planar bonding & Double-side cooling

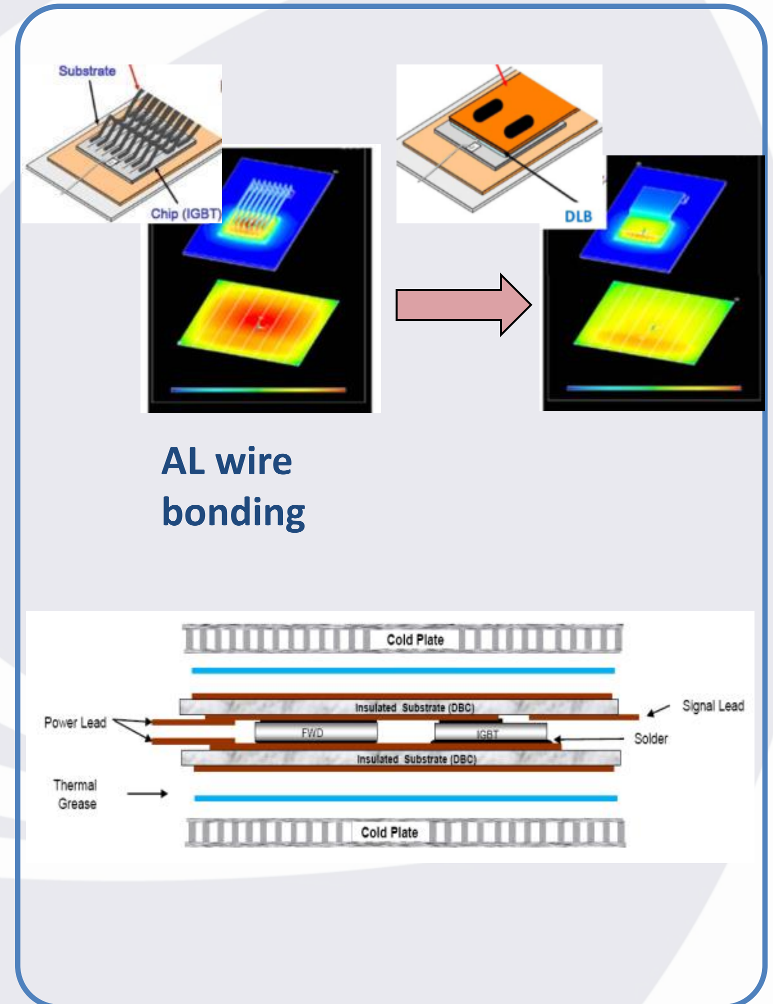




CAPABILITIES

State of the art packaging processes

- Ultrasonic welding
- Transient Liquid Phase(TLP) Bonding and low temp. Silver sintering
- Copper or copper-clad aluminium wire bonding
- **Planar bonding & Double-side cooling**
  - Parasitic inductance and resistance reduced by more than 50%
  - Heat evenly
  - Developed for automotive applications

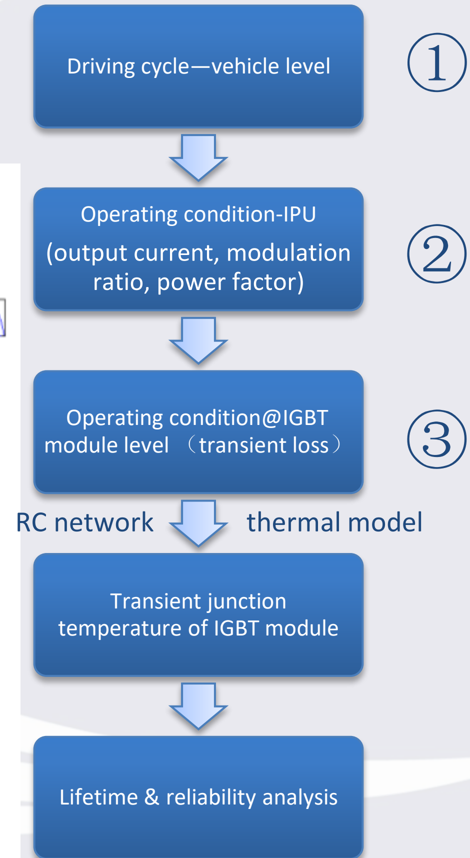


CAPABILITIES

Full condition system Design & Simulation

Through the full system simulation model, we can investigate electrical responses of all thee components under different driving cycles including NEDC(+Highway), FTP75, US06, etc.

Simulation work architecture



Electrical response of driving system under specific driving cycle

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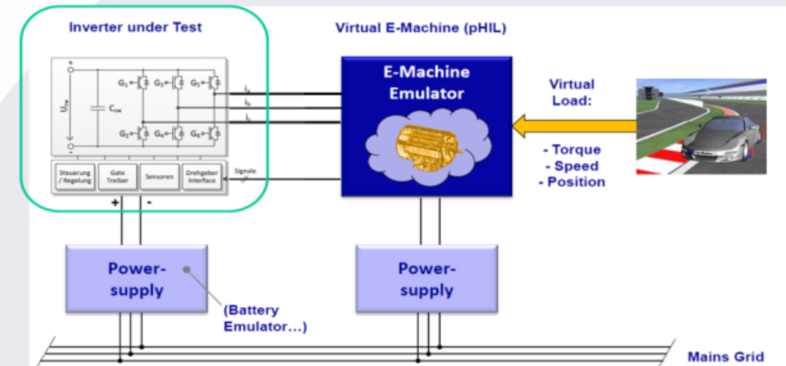
CAPABILITIES

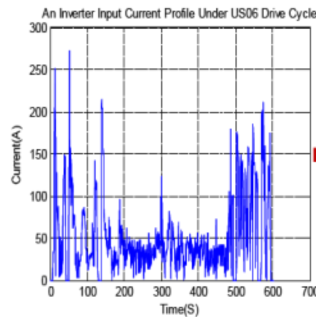
Reliability oriented design and verification platform

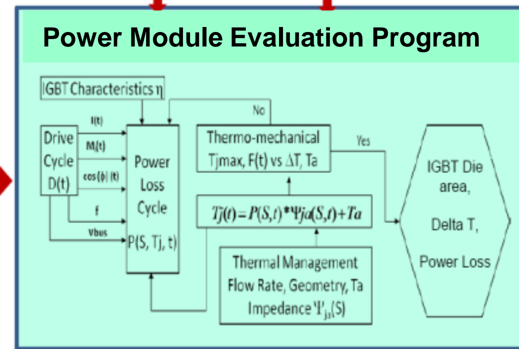
Technology studies:

- Machine-electrical-thermal-magnetic effect simulation and experiment
- High power density integration technology
- Efficient heat dissipation technology
- IGBT drive and protection technology
- Reliability & lifetime design and evaluation platform
- Power HiL simulation and verification system

Environmental chamber with temperature, vibration..



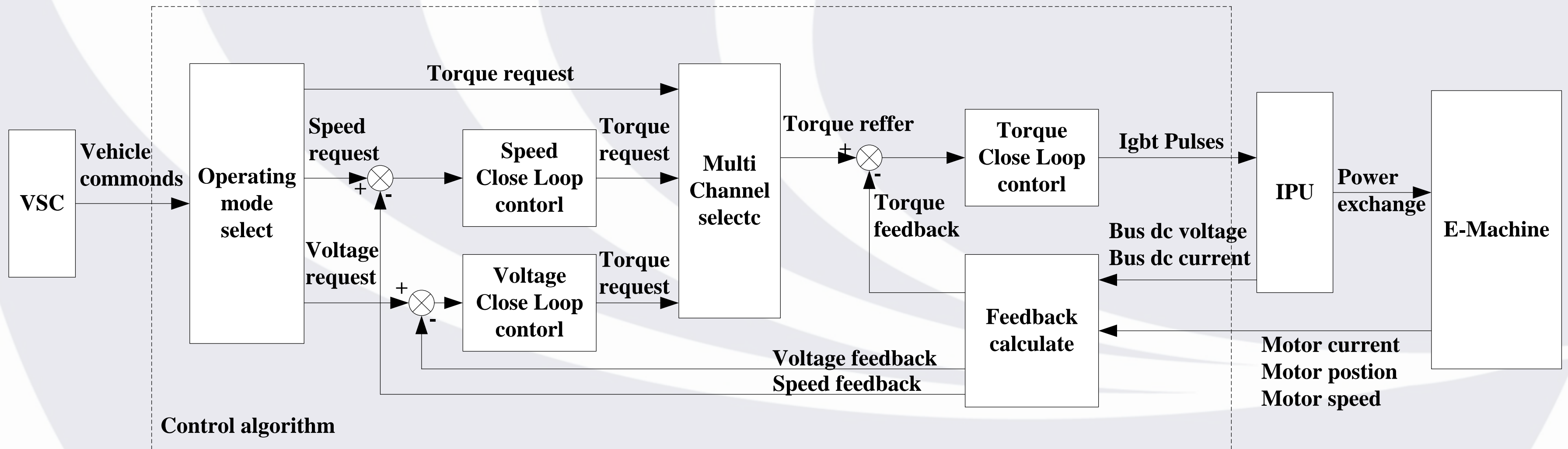




CAPABILITIES

Motor Control Software Structure

- Functions
  - EM 4-quadrant operation mode.
  - EM full speed range control.
  - MTPA control strategy.
  - Output torque/speed/voltage slope setting
  - Output torque/speed/voltage/power limitation
  - Adjustable torque/speed/voltage response overshoot
  - DC current estimation
  - Motor monitoring and de-rated operation
  - Torque prediction
  - Demagnetization detecting
  - Anti-Jerk control
  - Other functional safety requirements



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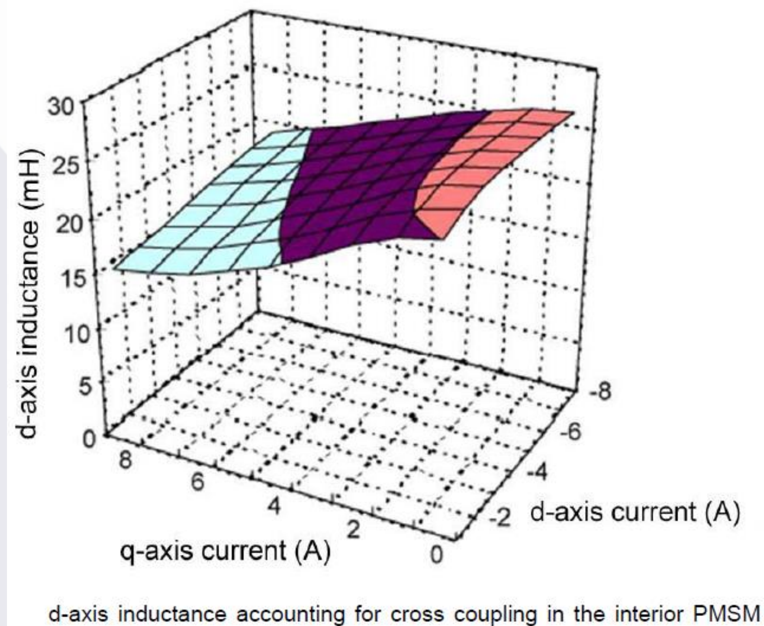
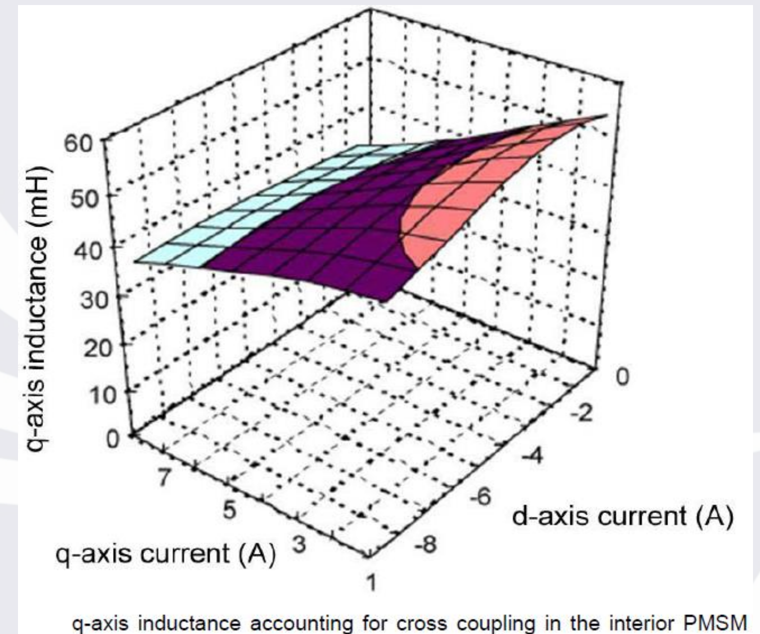
CAPABILITIES

High Performance PMSM Motor Control

- **Stator flux trajectory tracking control algorithm**
  - An optimised Direct Torque Control (DTC)
  - Excellent dynamic performance
  - Lower harmonics compared with traditional DTC control
- **Nonlinear PMSM motor parameters used in the control software**



d-axis inductance accounting for cross coupling in the interior PMSM



q-axis inductance accounting for cross coupling in the interior PMSM

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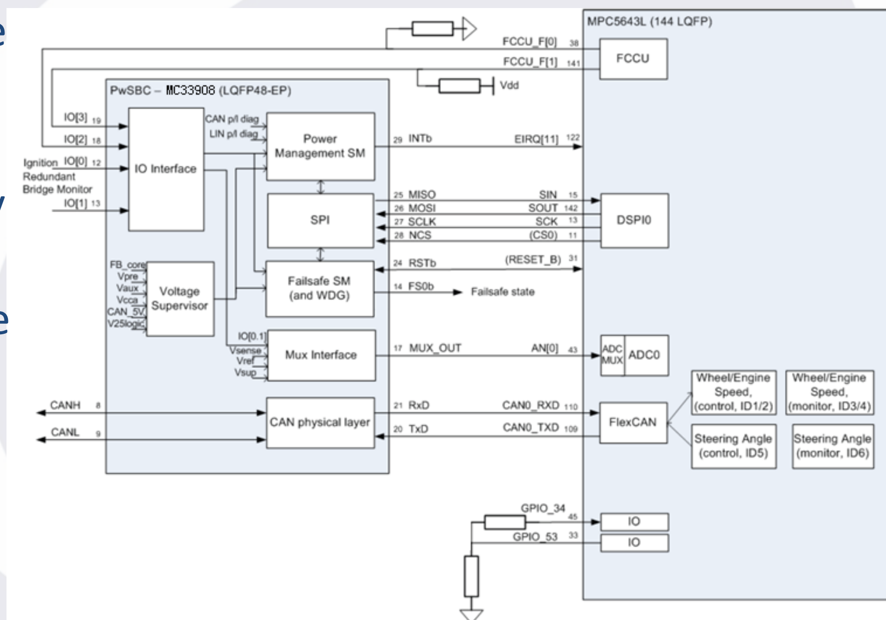
CAPABILITIES

Functional Safety Design – Dual Core lock/step micro and watchdog

- **Fundamental layer software design to ensure safety**
  - MCU is configured in dual-core lock-step mode to prevent MCU single point failure
  - Self-diagnostics mechanisms have been integrated to prevent failure
  - The MCU internal and flash power supply voltage monitoring is combined with other methods to prevent common cause failure
- **Fault collection and control unit**
- **Dual redundant approach to rotor position and speed detection**
  - Motor resolver
  - Automatic rotor position identification
- **AC current detection circuit designed with redundancy**
- **IGBT power stage protection strategy**



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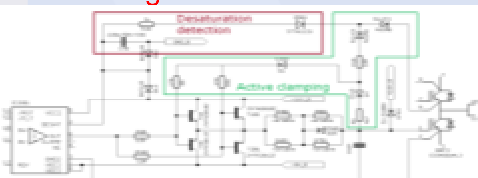
IGBT Drive Technology

Basic Function

- Isolation, drive
- Basic protection (active miller clamp, basic active clamping Vce desaturation and detecting)
- Soft shutdown/two-level shutdown happened at short circuit
- ❑ Less flexibility, excessive margin



Basic Functional Circuit

Enhanced Protection

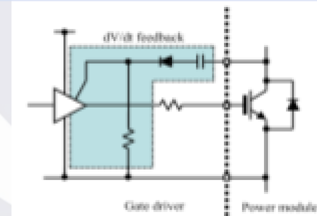
- Optimised active clamp (AAC control, double clamp threshold)
- Multi threshold desaturation and monitoring could achieve more precise over current protection
- di/dt feedback helps to increase the responding speed of primary short circuit protection
- ❑ Sacrifice the loss to a certain extent, reduce design margin and increase reliability

Optimised active clamp function

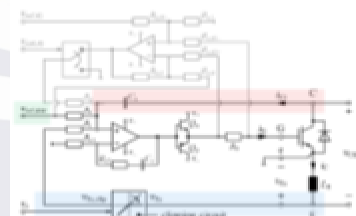
di/dt feedback and multi threshold desaturation and monitoring

Intelligent Control

- Open Loop: di/dt、dv/dt trigger feedback to control loss and suppress surge
- Closed loop: di/dt、dv/dt continuous feedback to ensure measured waveform match the preset route
- ❑ **Flexible control, maximises the loss reduction, reduces margins, and increases reliability**



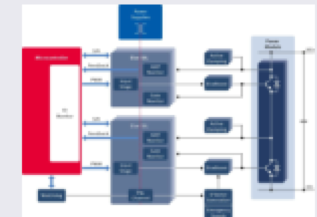
dv/dt trigger feedback



di/dt and dv/dt continuous feedback

Monitoring & Diagnosis

- Real-time online monitoring and diagnosis of key parameters, early failure detection, aging major effects
- System level diagnostics verification such as fault injection and weak to open
- Support in parameter configuration and feedback
- ❑ **Meets the functional safety requirement of ISO26262**

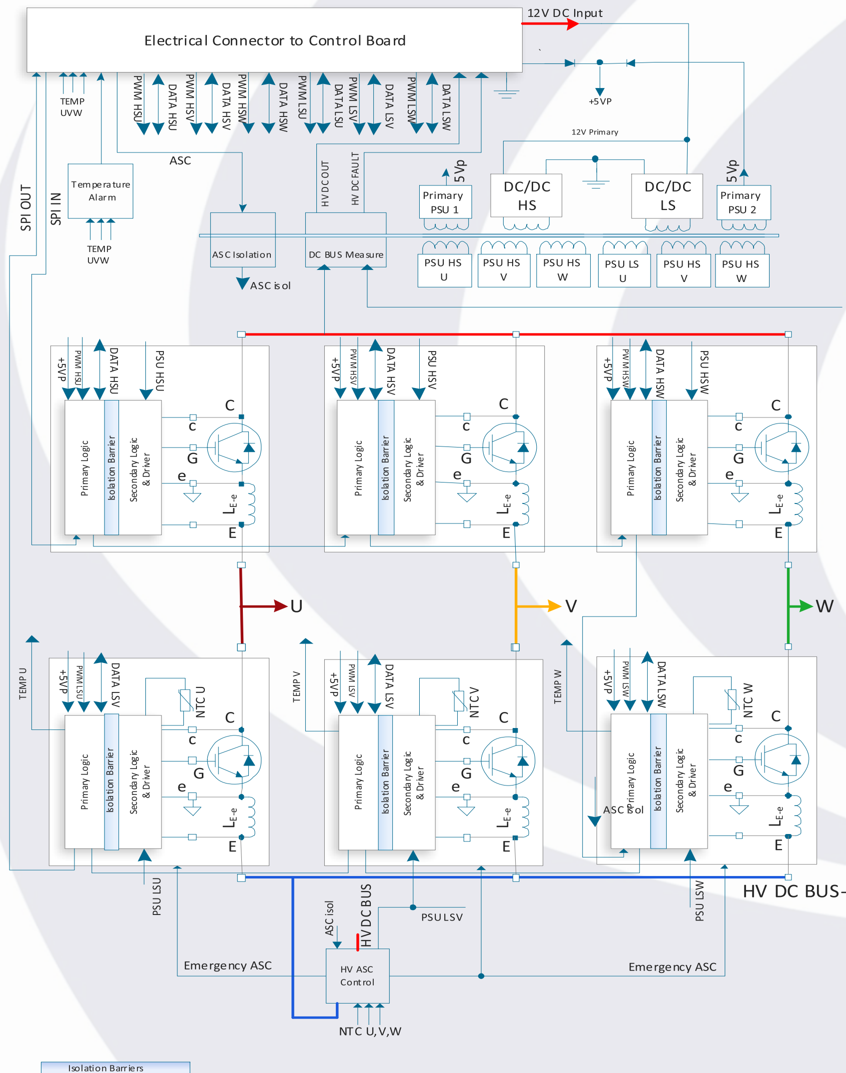


Real-time diagnosis and monitoring

Parameter configuration and feedback

CAPABILITIES

IGBT Gate Driver



Active Gate Driver Technology

- Active dI/dt Control
- Active dV/dt Limit
- Extensive and enhanced protection systems
- Multiple DC/DC converters for ASC strategy
- Extensive functional safety capabilities
- Full communications with control board for fault diagnosis and notifications

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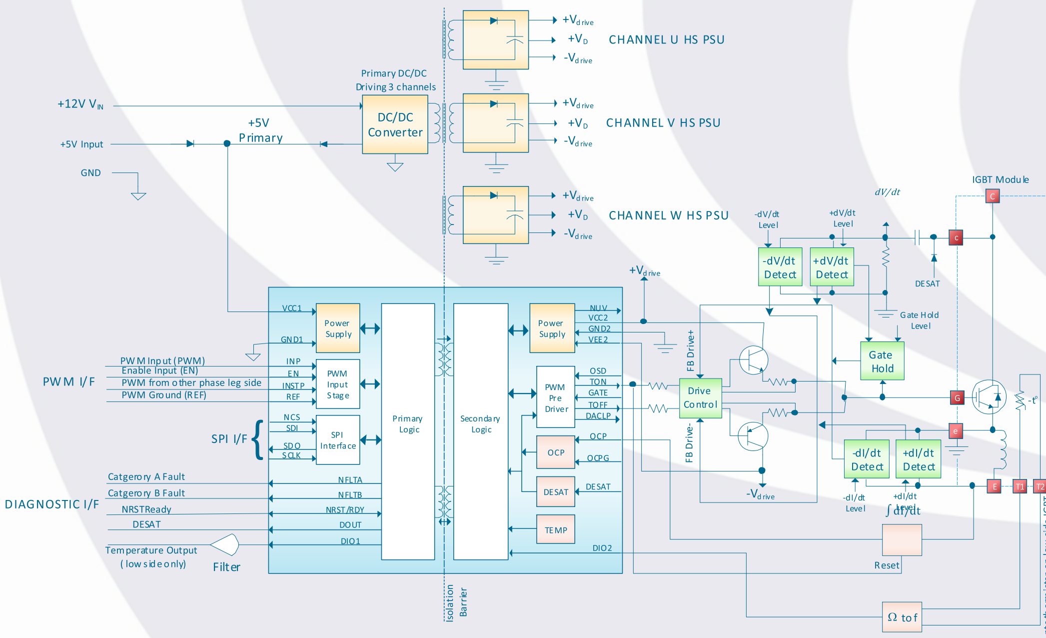
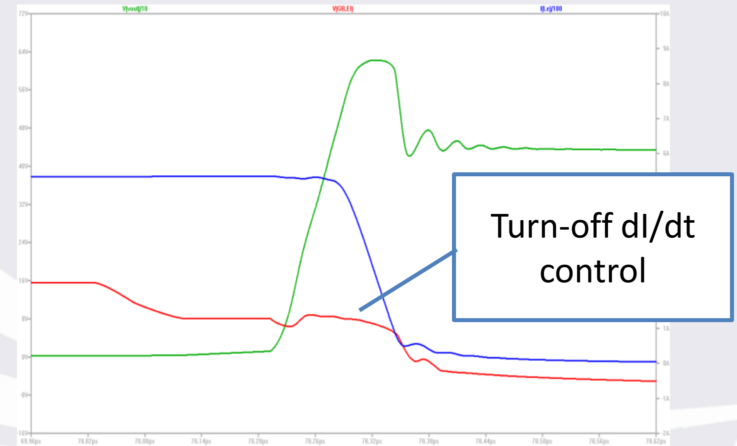
CAPABILITIES

IGBT Gate Driver

❖ Active dI/dt Control

- ❖ Removes requirement for active clamp but still controls turn-off overshoot
- ❖ Faster switching at lower currents enhances total switching losses
- ❖ Diode protected at turn-on
- ❖ Still resistor based but closed loop control is through active limiting function





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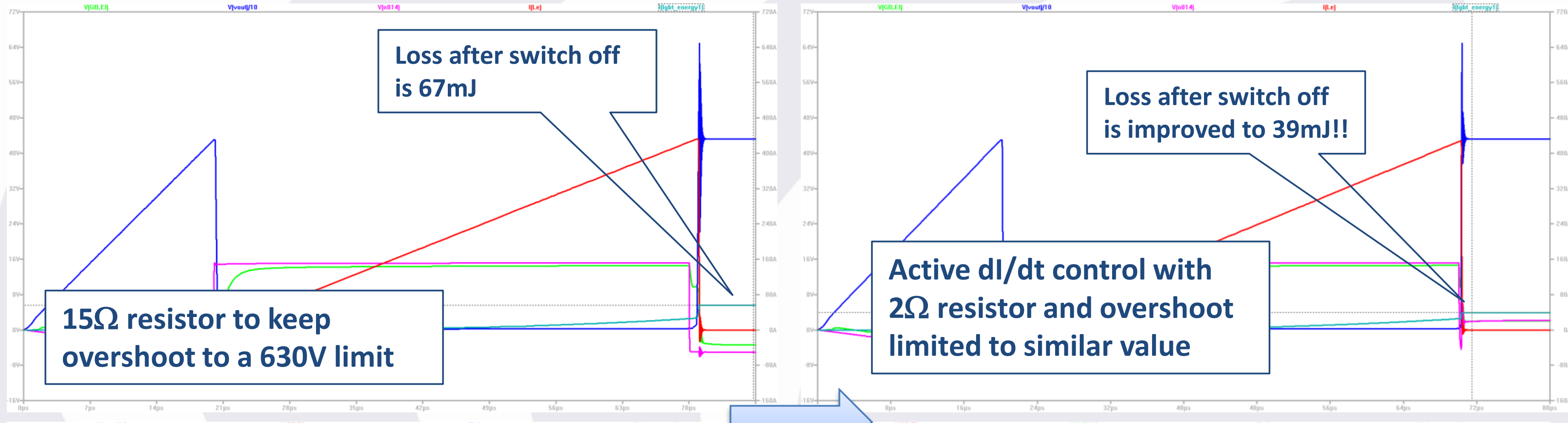
CAPABILITIES

IGBT Gate Driver

Switching Losses Reduced



Type I short-circuit energy is reduced by 100 and overshoot is controlled!

Conventional desaturation protection

Enhanced overcurrent Protection

Enhanced short circuit protection

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CONTENT

PART 1 COMPANY PROFILE

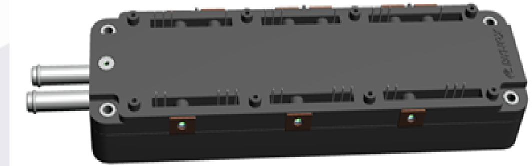
PART 2 HEV/EV Application

PART 3 Capabilities

PART 4 Performance

Verified System Performance

- ❑ Thermal resistance is reduced by 25% compared with competitor’s module at the same voltage and current level.
- ❑ Thermal resistance is even lower than competitor’s 650V/800A module.



Dynex IPM

Rth, K/W

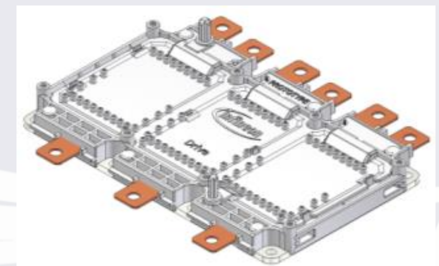
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0

Zth of Dynex IPM@8L/min, 75degC
Zth of Competitor's 650V/600A@10L/min, 75degC
Zth of Competitor's 650V/800A@10L/min, 75degC
Zth of Competitor's 750V/820A@10L/min, 75degC

0.0001 0.001 0.01 0.1 1 10 100 1000

Time, s

Competitor’s module (650V/600A, 650V/800A)



Competitor’s new generation module (750V/820A)

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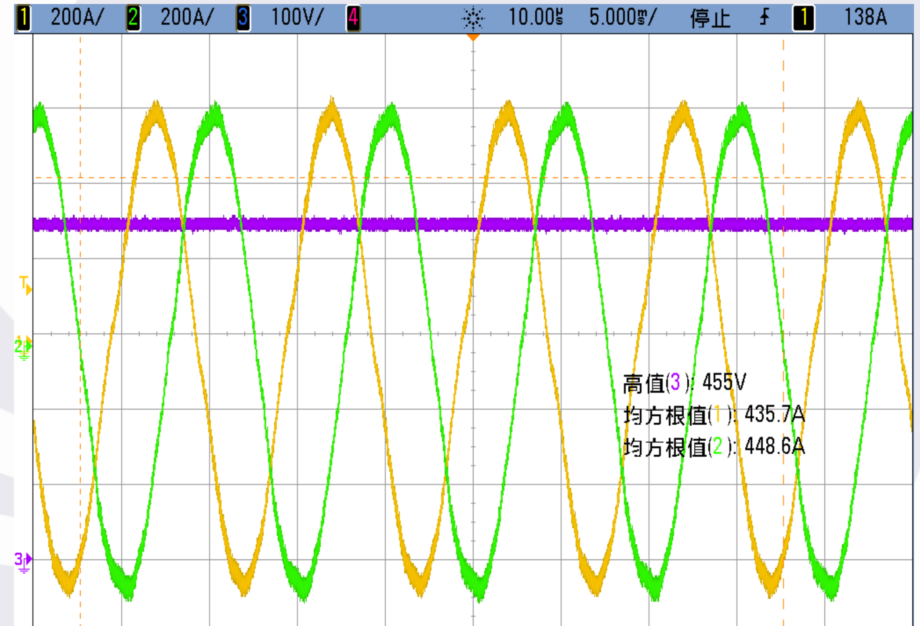
Verified System Performance

❑ Performance Highlights:

- Meet the requirements of continuously operating for 30s under the battery voltage DC450V, output current AC450Arms and 10kHz switching frequency, while with 85°C ambient temperature.

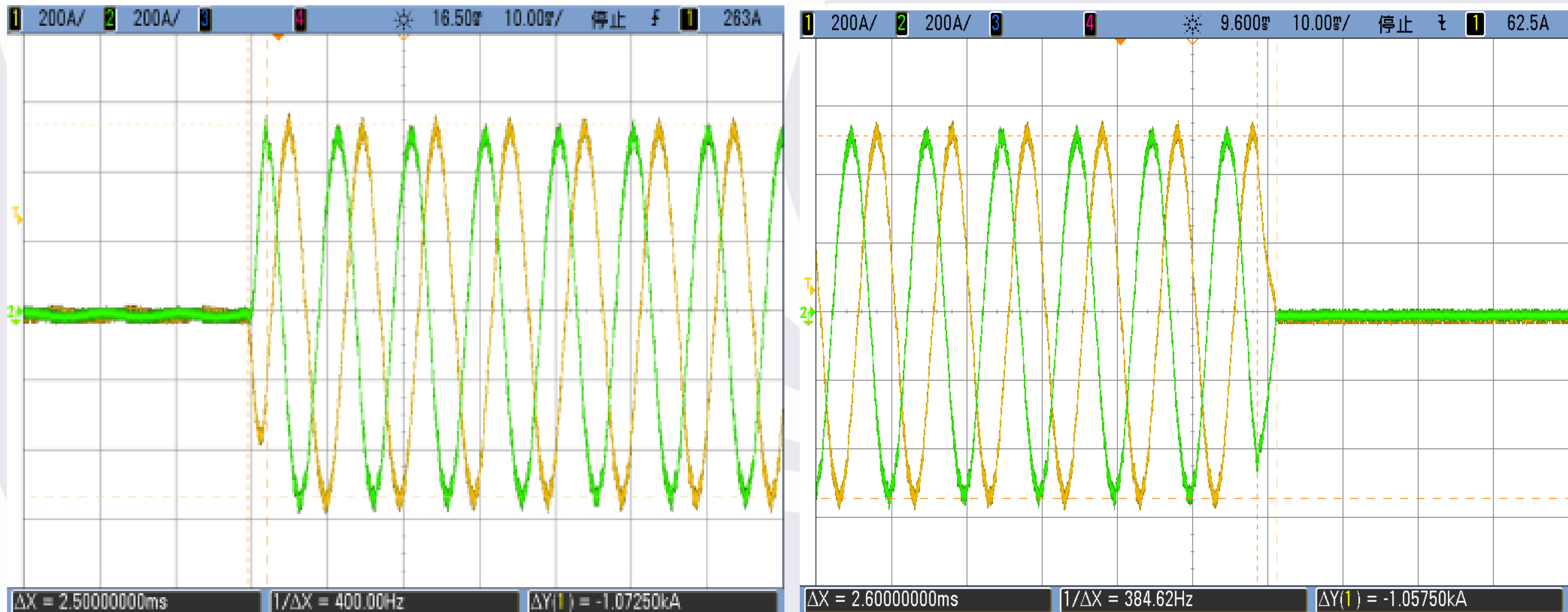


IPU operating with motor under the condition DC450V/AC450Arms

Verified System Performance

❑ Performance Highlights：

- Advanced motor control algorithm which brings extremely fast and accurate motor torque control. The action time of the motor torque can be around 2ms.



Current change with 250Nm step torque of the Motor

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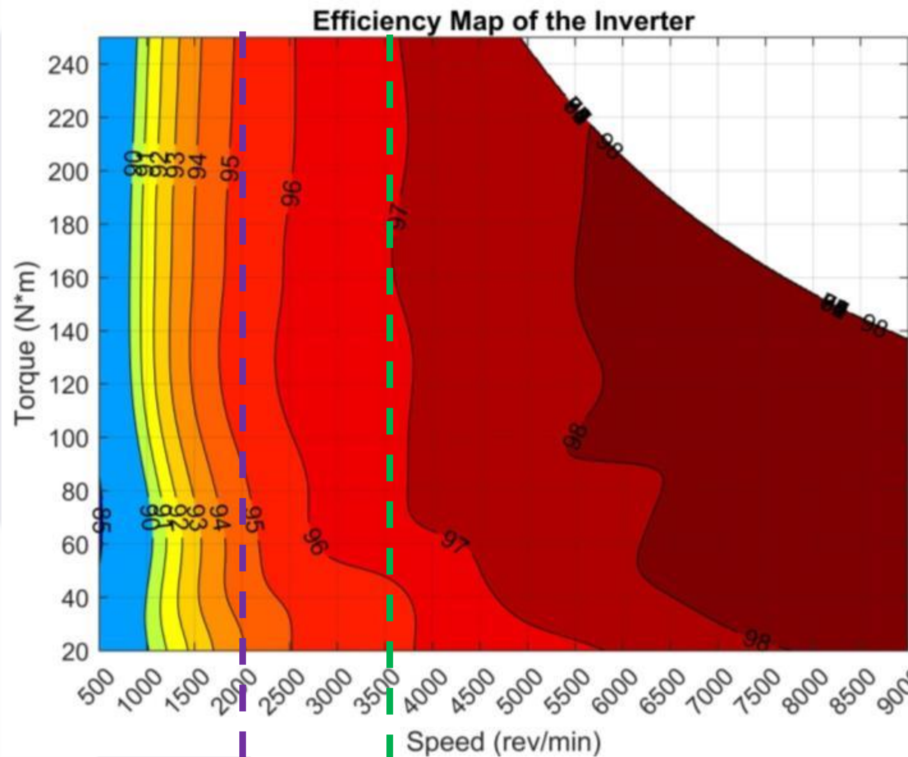
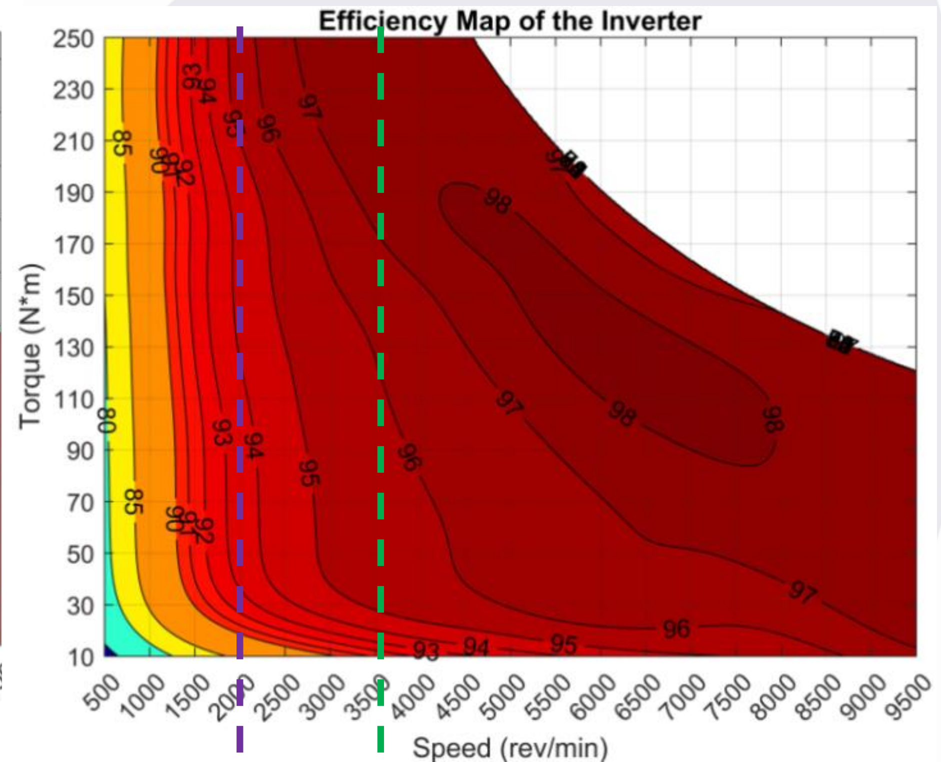
Verified System Performance

❑ Performance Highlights：

- Compared to competitors, the system has a larger high efficiency area, i.e. the high efficiency (>95%) area can reach up to 80%.





PCU System Efficiency Compare at **Traction, DC400V**
（Left-based on Dynex IPM， Right-based on **Competitor's 650V/800A Module**）

Conclusions

- Double-sided cooling of IGBT module is becoming the leading technology of PCU for EVs.
- **CRRC-Dynex has developed the known-how and expertise in double-sided cooling IGBT and PCUs based on this technology.**
- **According to the benchmarking, the designed double-sided cooling IGBT and PCU have achieved the highest performance implemented in the Power Electronics area for EVs.**
- The products will be released at the beginning of 2017.

Thank you for listening!

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