



DEVELOPMENT OF POWER CONTROL UNIT FOR COMPACT-SIZE VEHICLE



@EVSymposium29

#EVS29

Masaru Nakashima,

Takaji Kikuchi, Osamu Kitazawa, Hajime Kosugi, Takahisa Kaneko

Electric Vehicle Symposium & Exhibition

June 19-22, 2016 | du 19 au 22 juin 2016

Montréal, Québec, Canada

Organized by:



Hosted by:



In Collaboration with:



Platinum Sponsors:



DRIVE ELECTRIC INNOVATION
PROPULSER L'INNOVATION EN MOBILITÉ ÉLECTRIQUE

TOYOTA

EVS29.ORG

1. Introduction
2. Power Control Unit (PCU) Specifications and Structure
3. New Technology of Each Component
4. Conclusion

1. Introduction

2. Power Control Unit (PCU) Specifications and Structure

3. New Technology of Each Component

4. Conclusion

1. Introduction

Major issues of mobility today

- **Global warming** induced by CO₂ emissions
- **Air pollution** through tailpipe emissions

One of the solutions



Toyota has been working
to develop and popularize hybrid vehicles

1. Introduction

2. Power Control Unit (PCU) Specifications and Structure

- HV System Specifications
- PCU Mounting
- PCU Specifications
- PCU Structure

3. New Technology of Each Component

4. Conclusion

2. PCU Specifications and Structure

HV System Specifications

Evolution of Hybrid Vehicles (1997 ~)

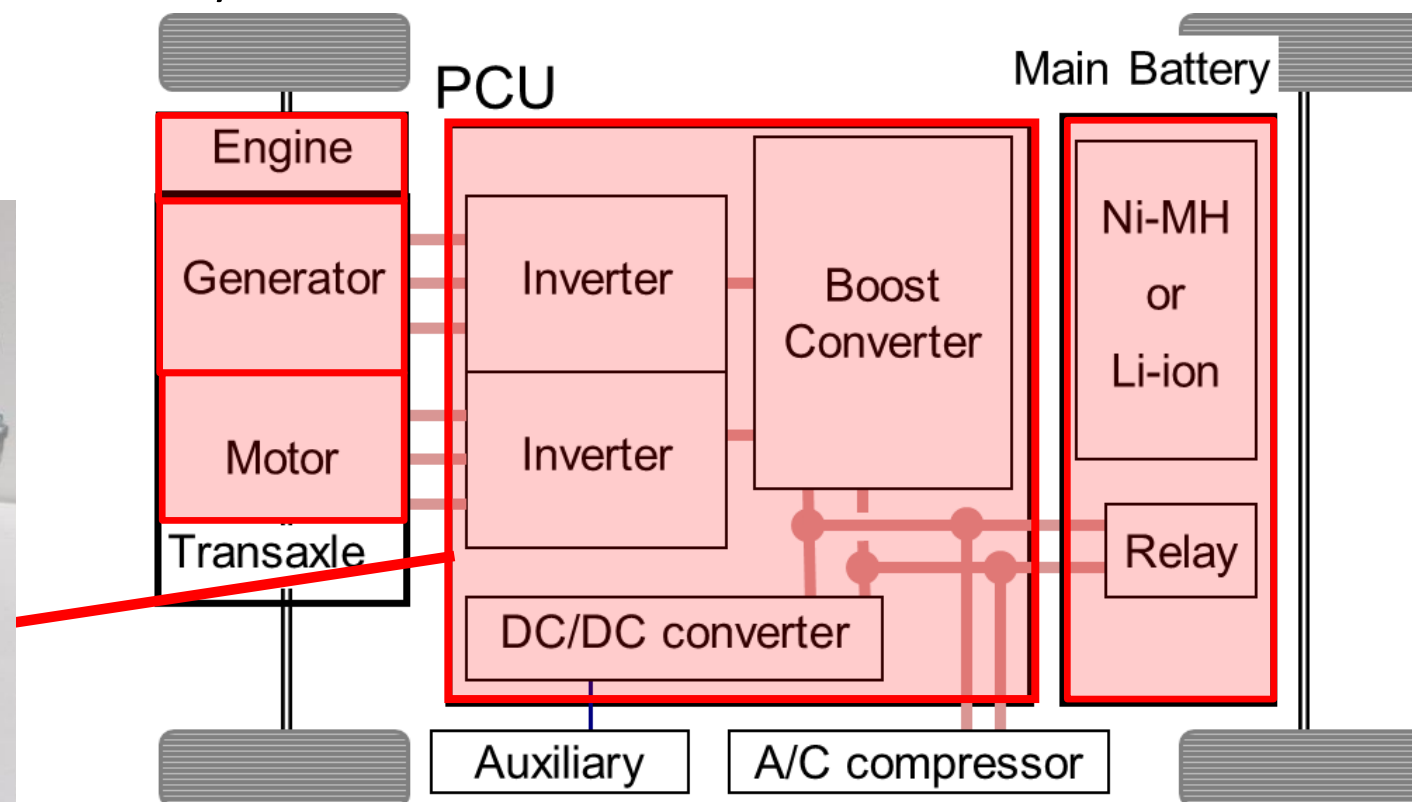
	3 rd model (2009) - 3 rd generation -	New model (2015) - 4th generation -
Objective	• Compact hybrid system units • fuel economy	• Further enhanced fuel economy • Pleasurable driving experience
Fuel economy	32.6km/L(JC08) 50 mpg	40.8km/L(JC08) 56 mpg
Vehicle exterior		

2. PCU Specifications and Structure

HV System Specifications

Further Enhancement of Fuel Efficiency

Power Control Unit



- Improved thermal efficiency of gasoline engine
- Reduced electric loss of hybrid system components
- Reduced current by the operation of motor at higher speeds

2. PCU Specifications and Structure

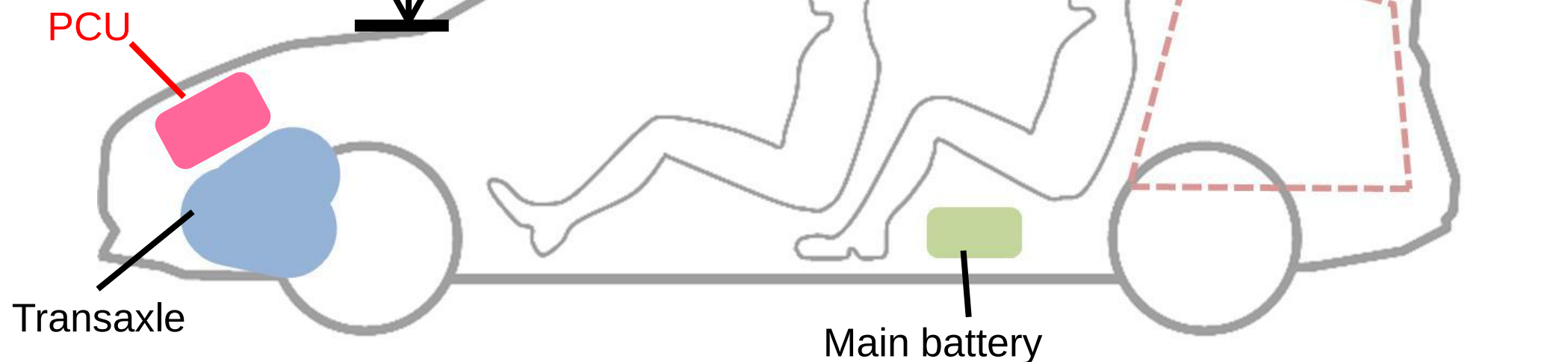
HV System Specifications

Pleasurable Driving Experience

Lower overall height

Bigger luggage area

Lower cowl height



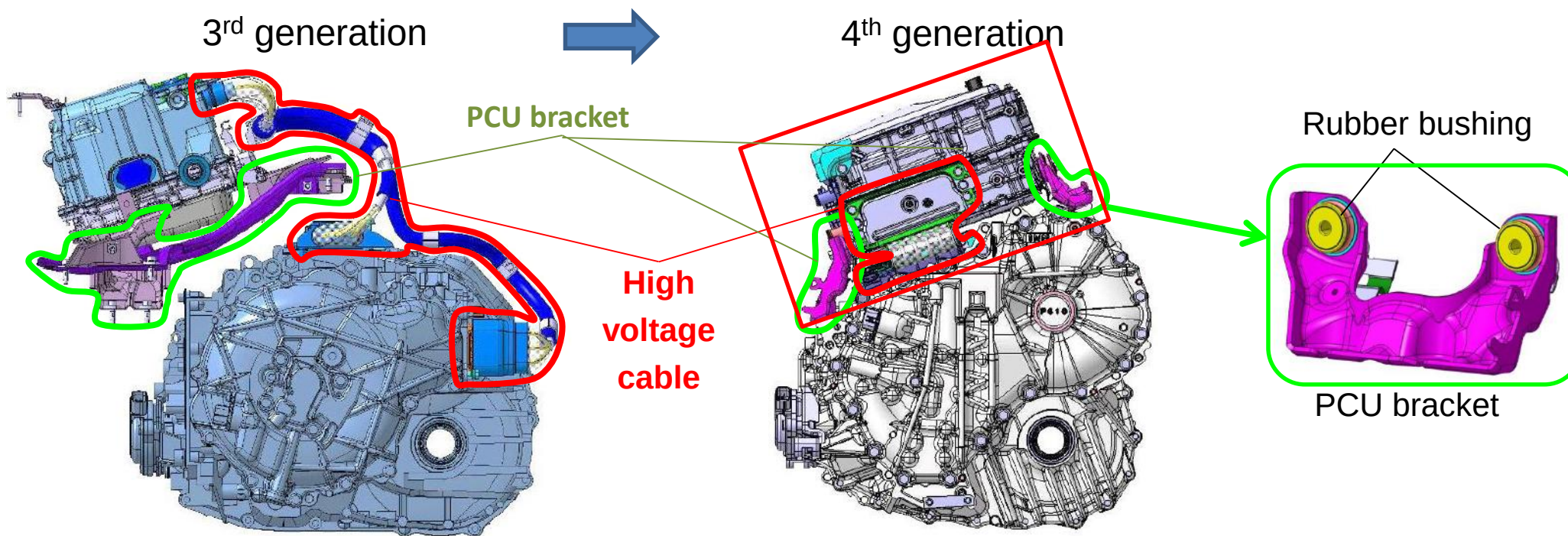
The first vehicle adopting Toyota New Global Architecture (TNGA)

- Highly stiff body
- Lower center of gravity of power train units and body

2. PCU Specifications and Structure

PCU Mounting

The PCU is mounted upon the transaxle directly



Advantages

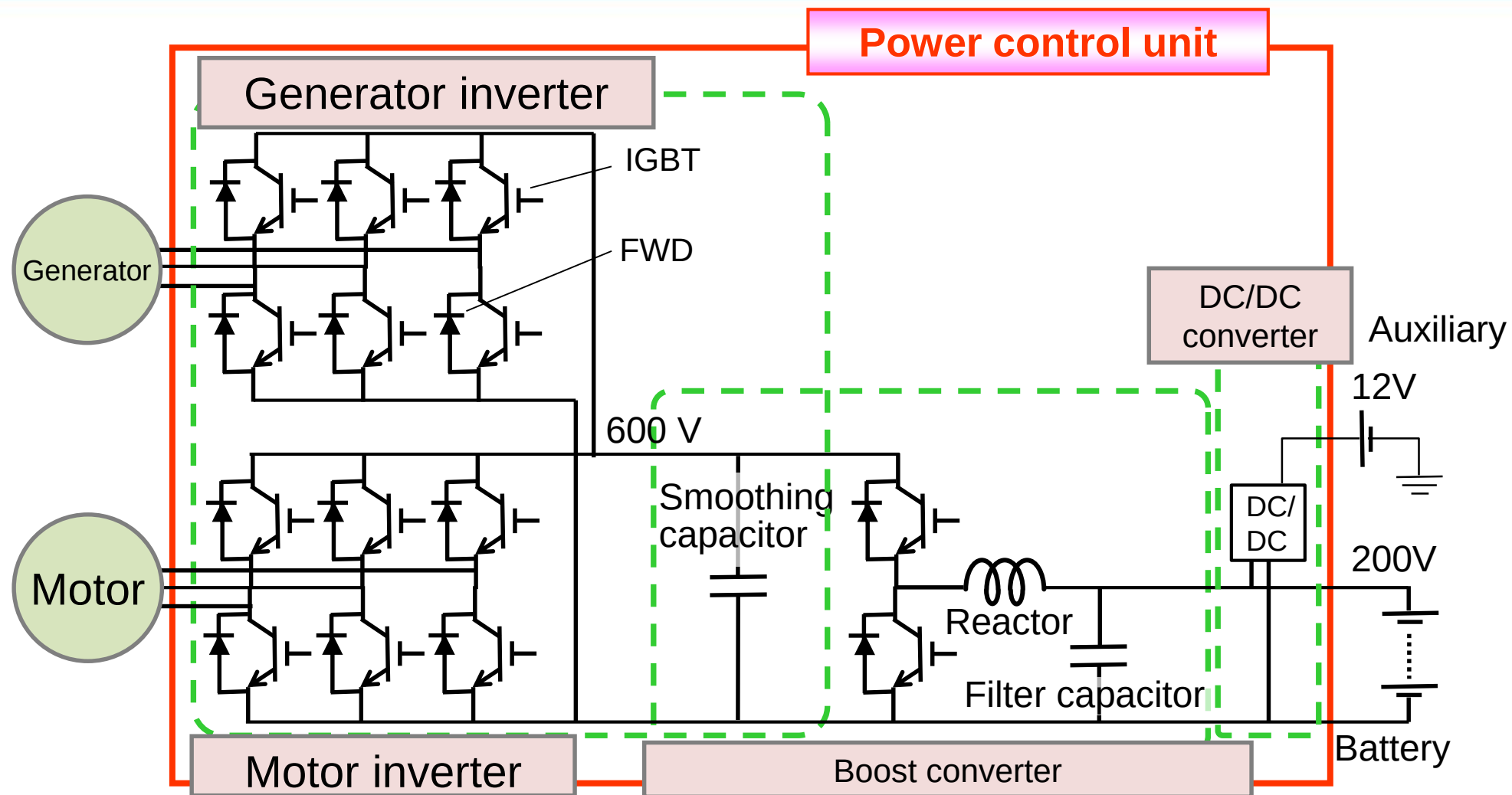
- Reduced length of the high voltage cable (→Lightweight)
- Simplified bracket (→Downsizing and lightweight)

Disadvantage

- Engine vibration transferred to the PCU
→ Rubber bushing into the bracket

2. PCU Specifications and Structure

PCU Specifications (Electric construction)



2. PCU Specifications and Structure

PCU Specifications

Volume and weight reduction of the 4th generation PCU

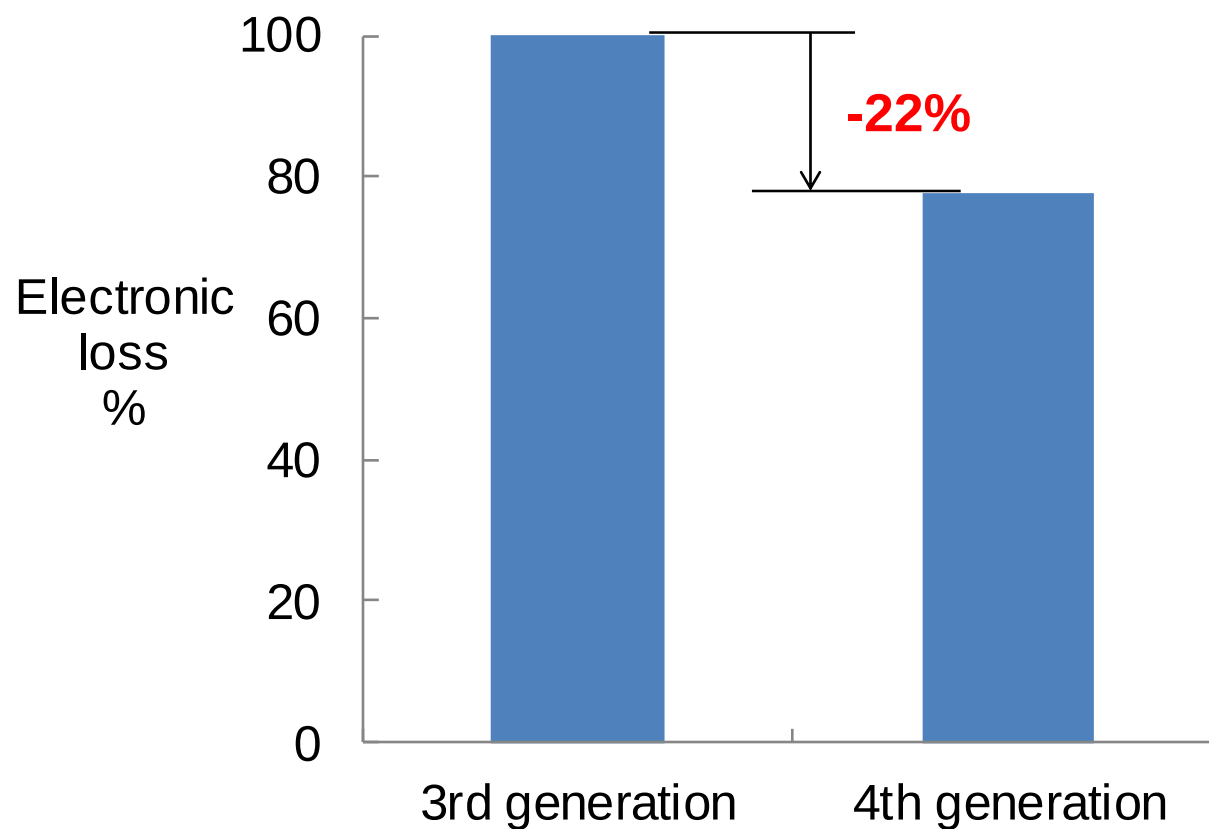
	3 rd generation	4 th generation	
Max total output	177.8 kVA	162.2 kVA	
Weight	13.5 kg	<u>11.9 kg</u>	-12%
Volume	12.5 L	<u>8.4 L</u>	-33%
Max output density	14.2 kVA/L	<u>19.3 kVA/L</u>	+36%

- Main items
- Double-sided cooling structure
 - volume and weight reduction of each component ,and optimization of component layout

2. PCU Specifications and Structure

PCU Specifications

Improvement of electronic loss of the PCU

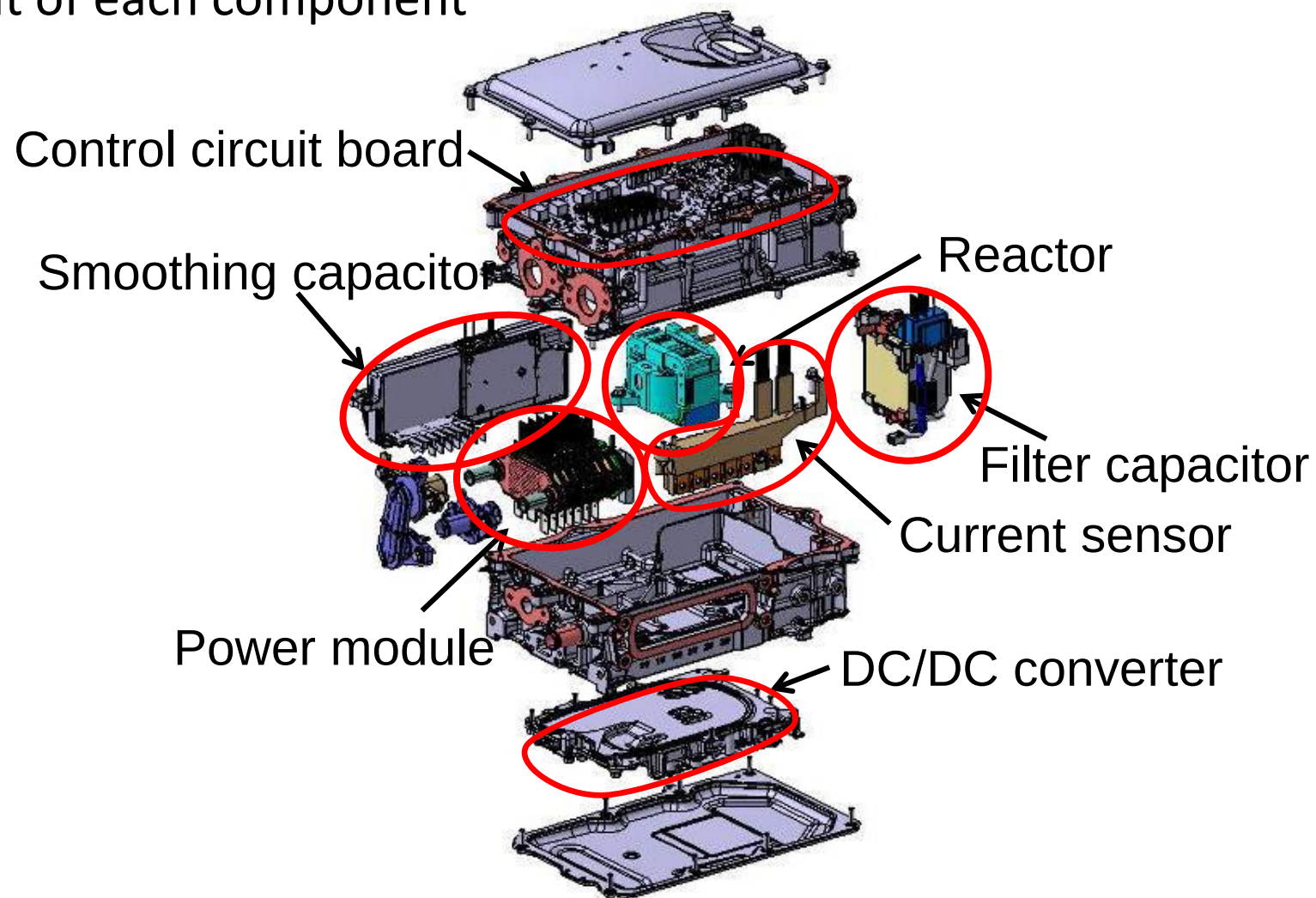


- Main items
- Lower loss IGBT
 - Low inductance structure

2. PCU Specifications and Structure

PCU Structure

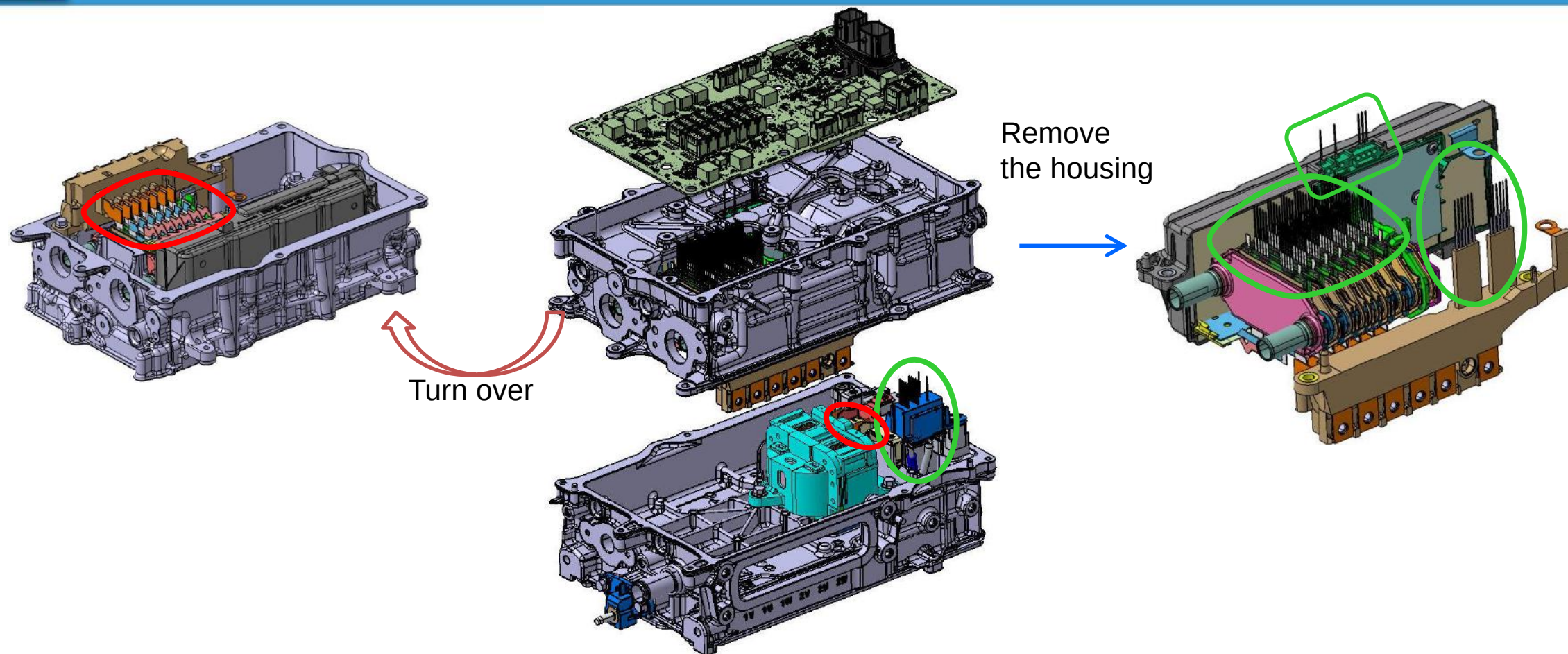
The layout of each component



➤ components are arranged as close as possible

2. PCU Specifications and Structure

PCU Structure



- The busbar connected with welding of laser (circled with red line)
- Signal line W/H integrated with each component (circled with green line)
- Reduced volume with optimization of component layout and method of connection

1. Introduction

2. Power Control Unit (PCU) Specifications and Structure

3. New Technology of Each Component

- Power Module

- Control Circuit Board

- Current Sensor

- Capacitor

- Lower Loss IGBT



Downsizing and light weight



Reduction in electronic loss

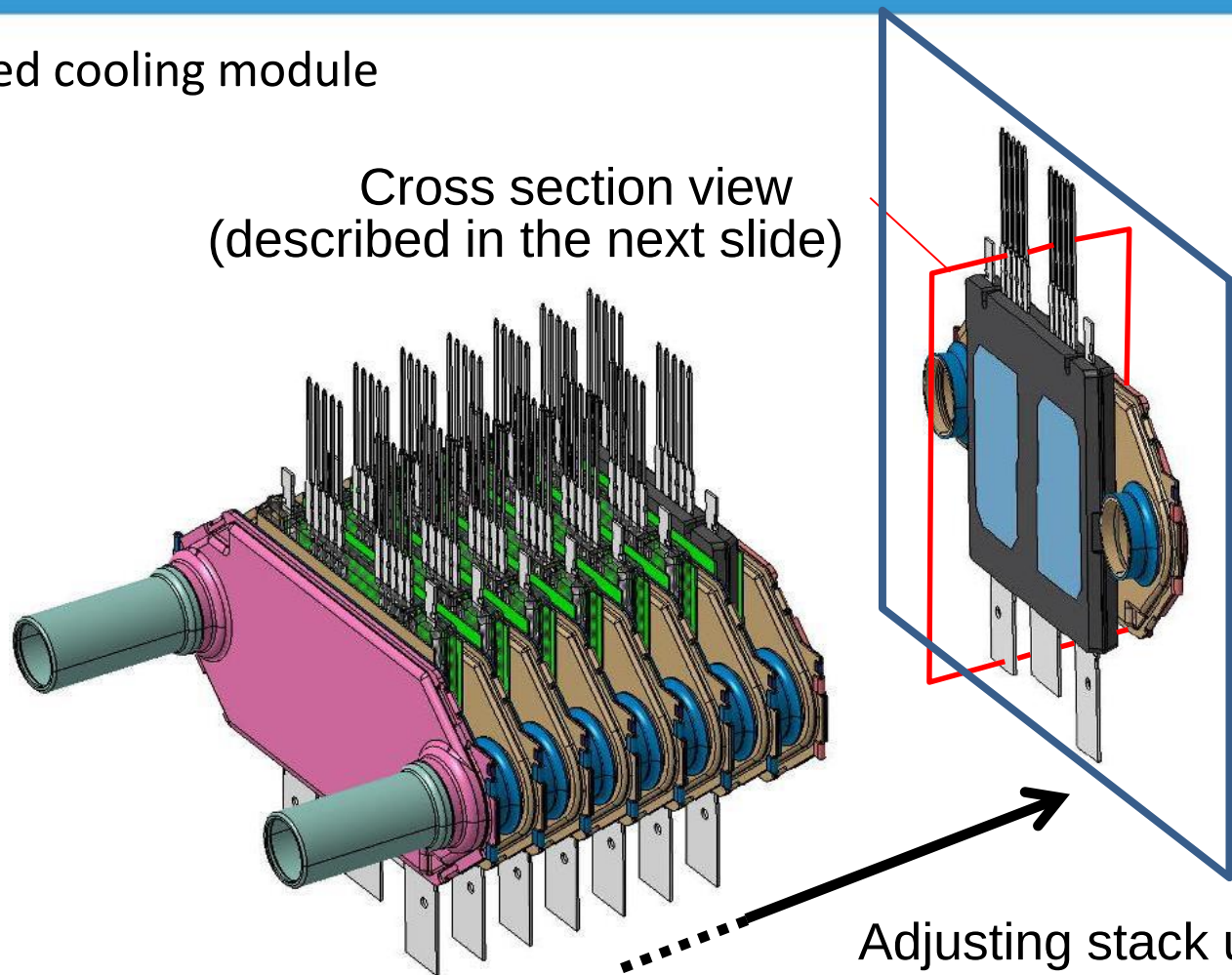
4. Conclusion

3. New Technology of Each Component

Power Module

Double-sided cooling module

Cross section view
(described in the next slide)



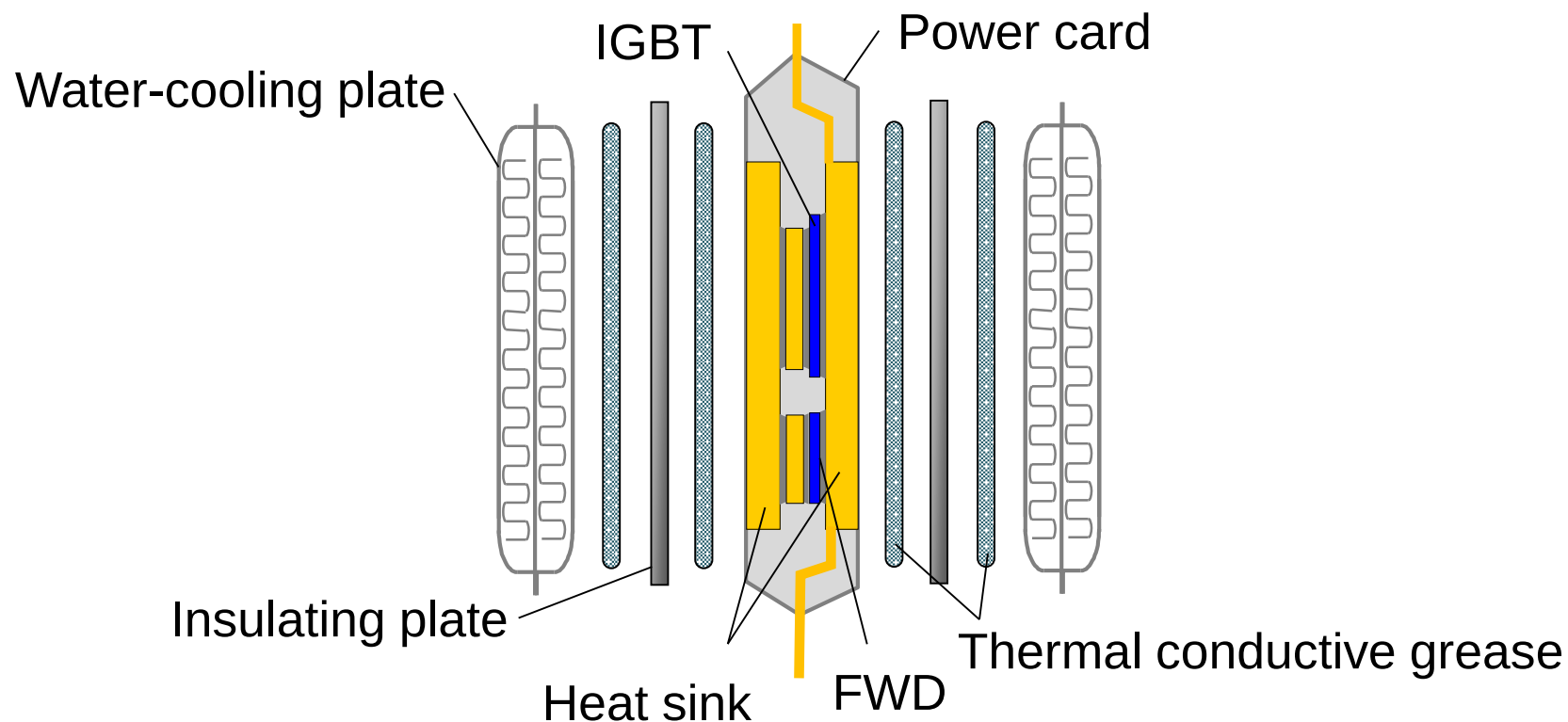
Adjusting stack up module for the vehicle size

Effects ➤ Enhanced application to various vehicle models

3. New Technology of Each Component

Power Module

Double-sided cooling module (cross section view)



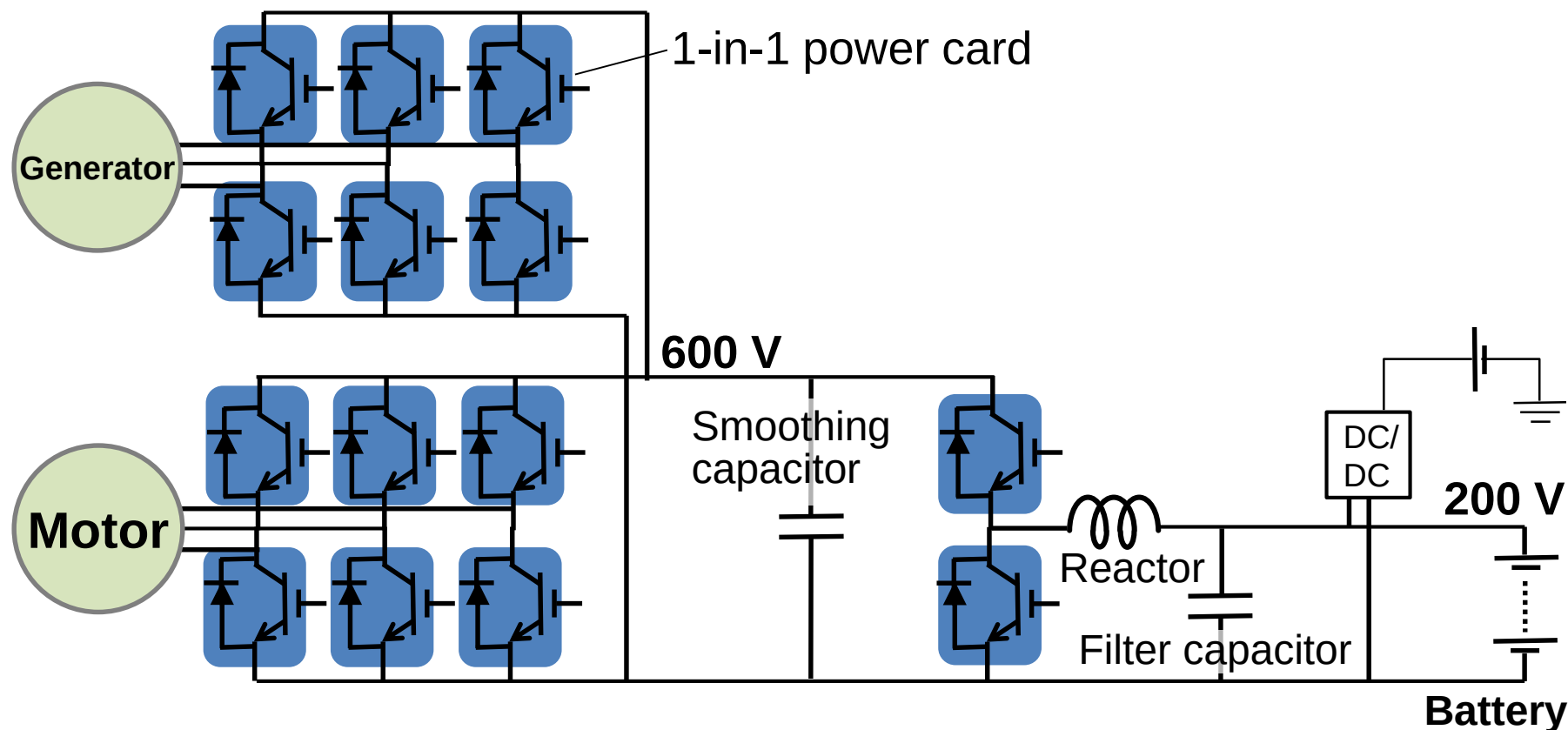
- Effects
- Enhanced the cooling performance
 - Reduced volume (using the newly developed power card)

3. New Technology of Each Component

Power Module

Previous model power card (1-in-1 power card)

→ one pair of IGBT and Diode is one package

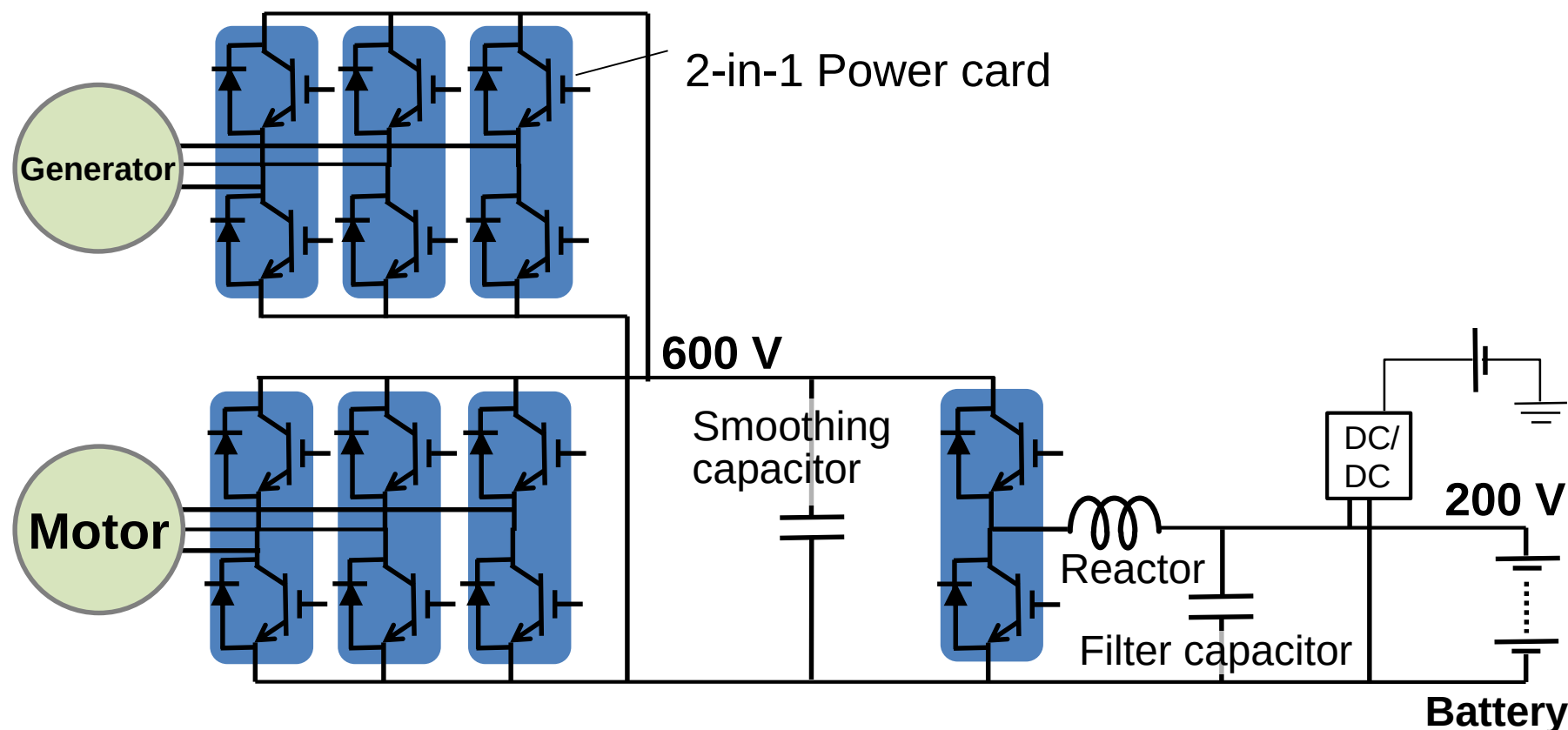


3. New Technology of Each Component

Power Module

New model power card (2-in-1 power card)

→ 2 pairs of IGBTs and Diodes of the upper and lower arm is one package

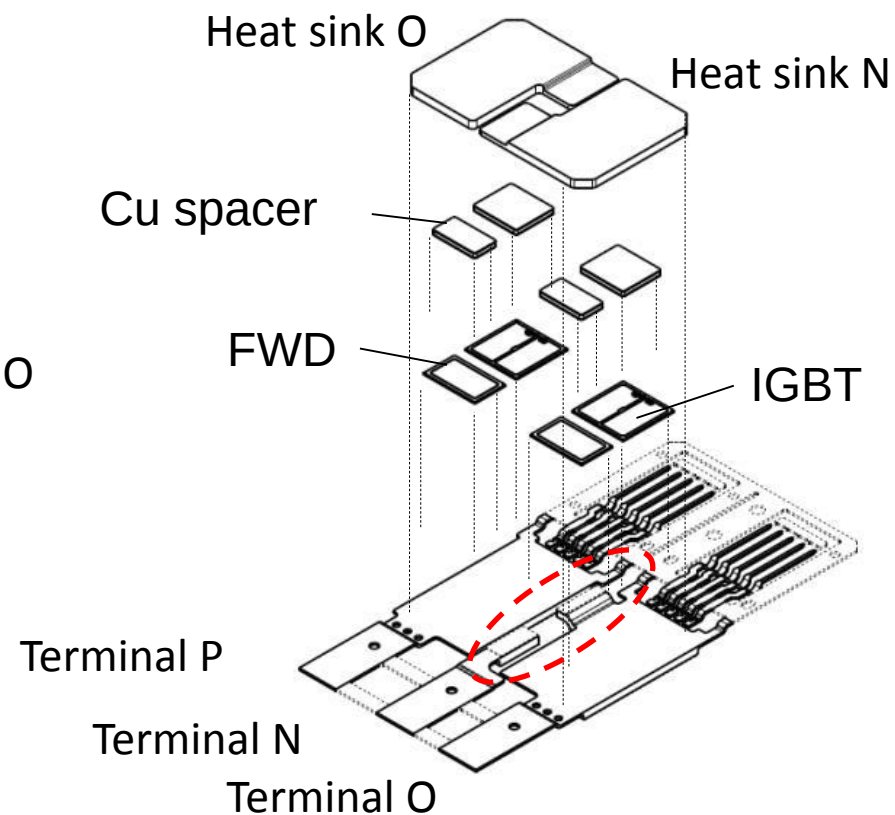
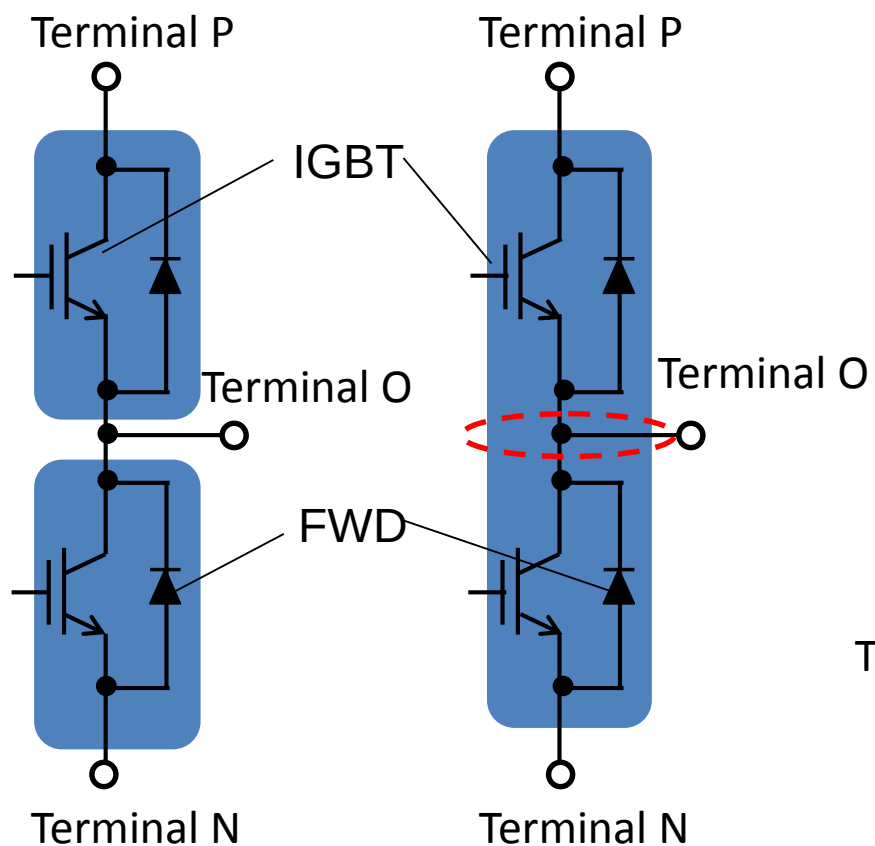


3. New Technology of Each Component

Power Module

Construction of 2-in-1 power card

1in1 power card 2in1 power card

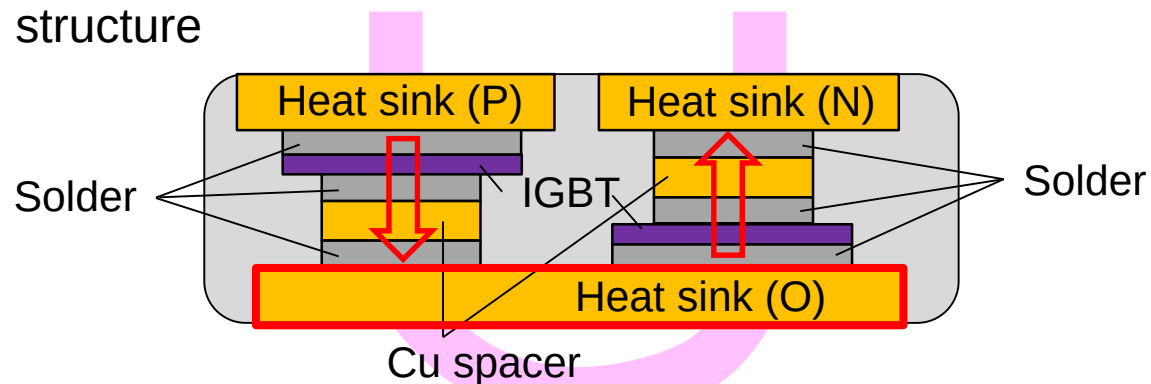


3. New Technology of Each Component

Power Module

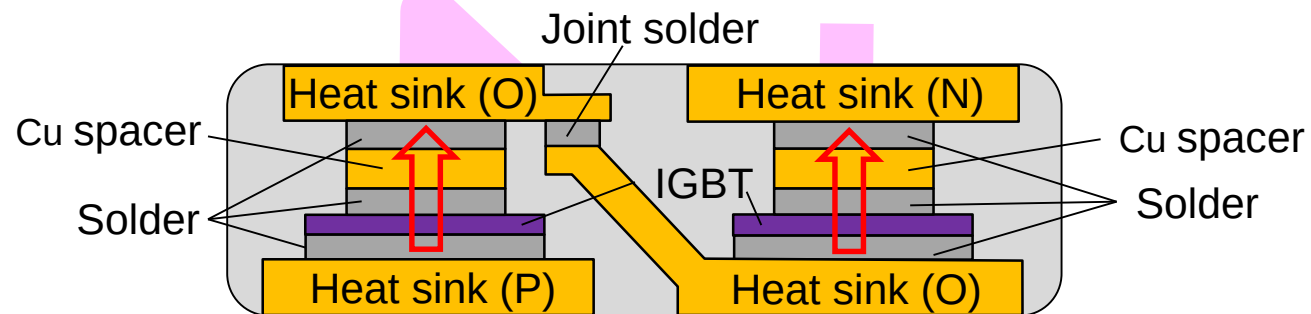
Construction of 2-in-1 power card

U structure



- It's simple, but the management of the solder melting process is very difficult

Adopted structure (N structure)

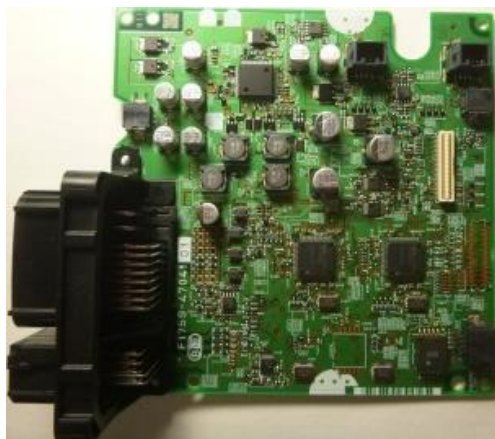


3. New Technology of Each Component

Control Circuit Board

Downsizing the control circuit board

3rd generation



ECU for motor/
generator control

+



Control circuit of the
intelligent power module



4th generation



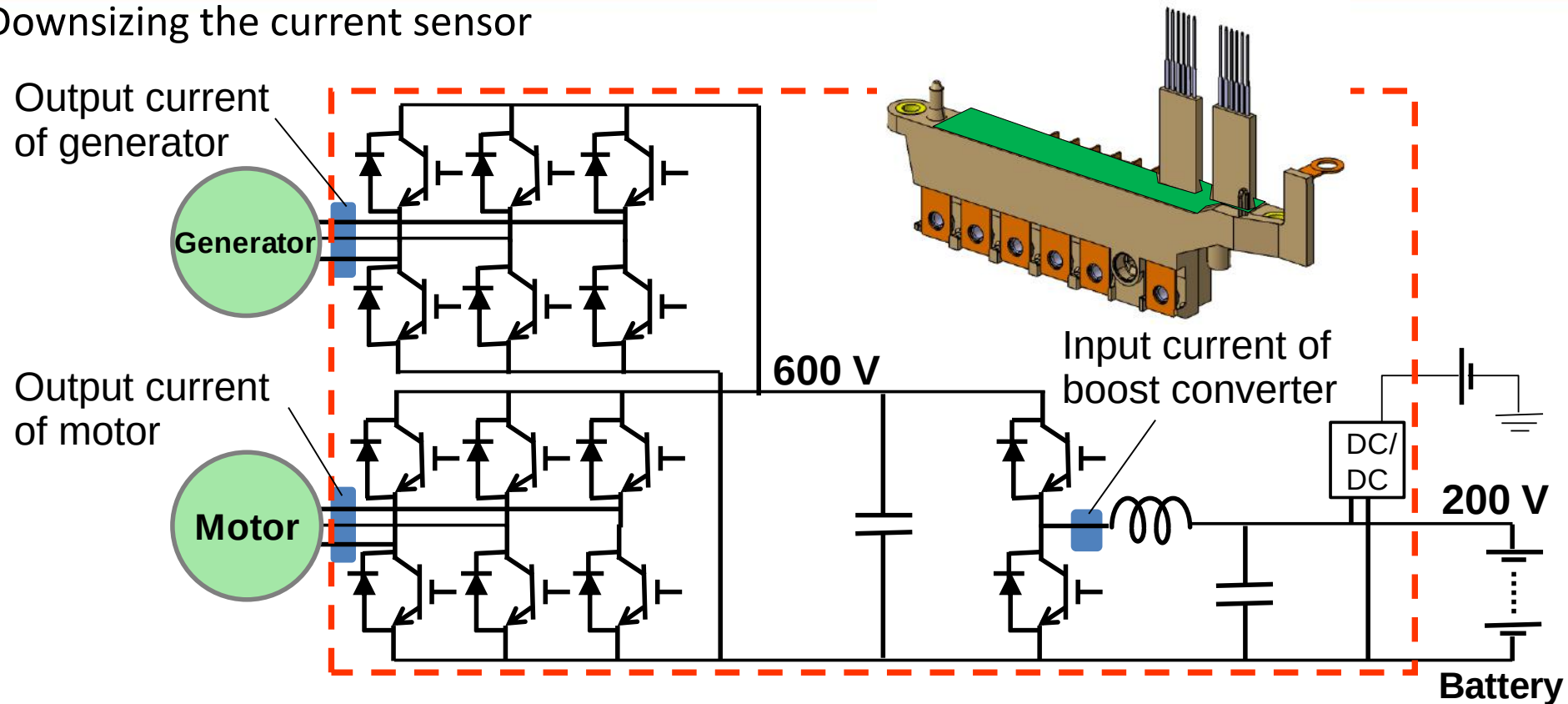
To achieve integration

- Reduced the number of electronic devices (adopting hybrid processing IC etc.)
- Improved layout flexibility (adopting smaller discrete devices)

3. New Technology of Each Component

Current Sensor

Downsizing the current sensor

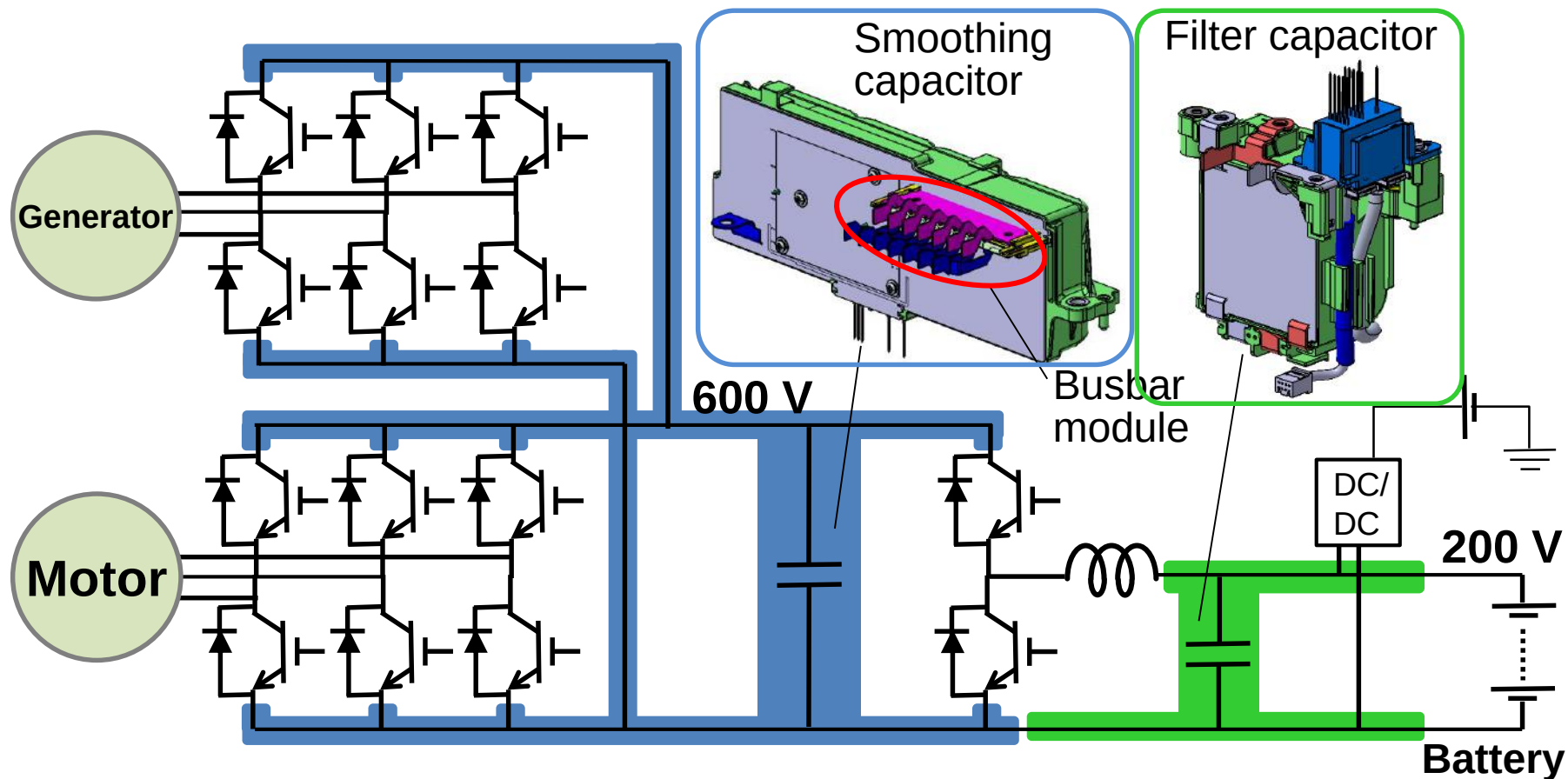


- Integrated the function of the output terminal
- Adopted an IC which has both Hall element and detecting circuit
- Integrated the function of detecting the input current of boost converter (contributing the reduction in the capacitance of smoothing capacitor)

3. New Technology of Each Component

Capacitor

Downsizing the capacitor module

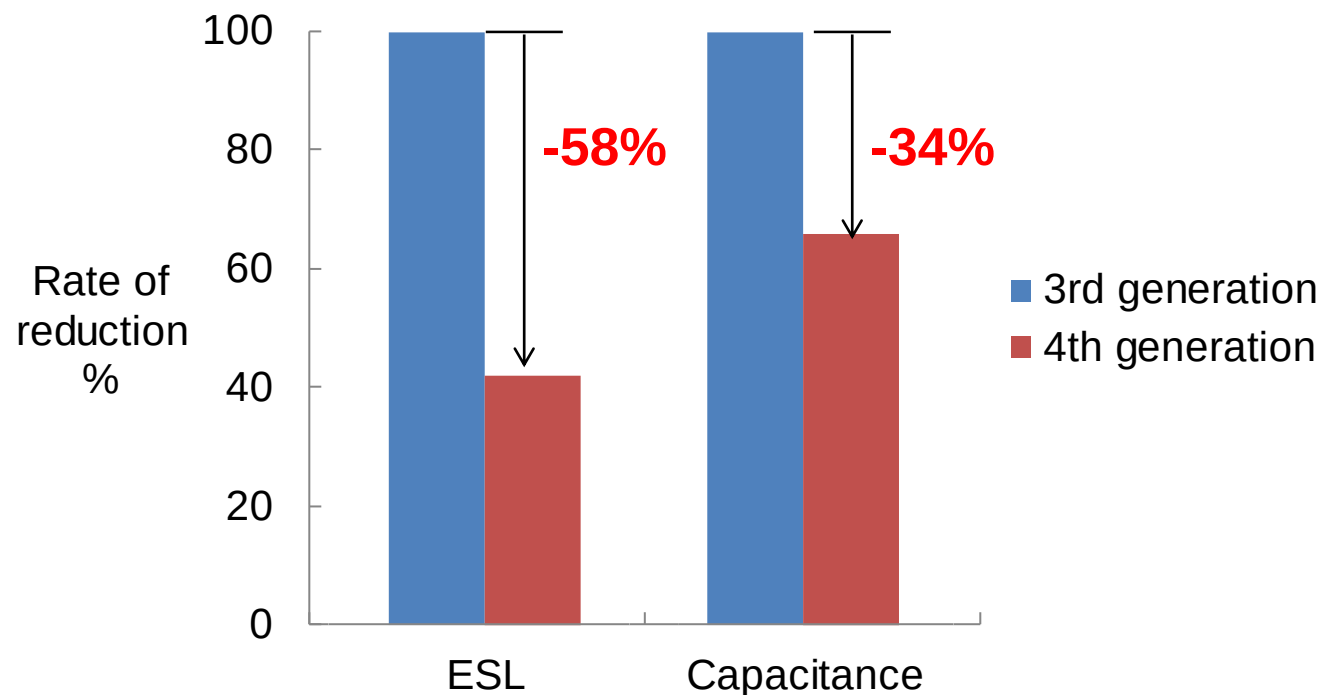


- Integrated the busbar module (contributes to reduced inductance)

3. New Technology of Each Component

Capacitor

Downsizing the capacitor module



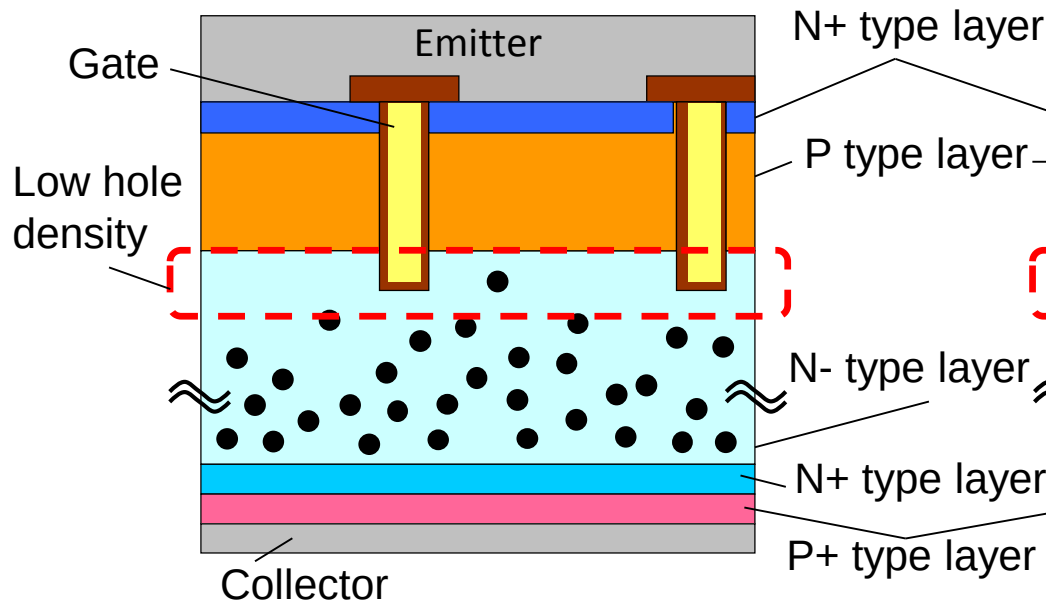
- Integrated the busbar module (contributes to reduced inductance)
- Reduced the capacitance of smoothing capacitor
(stabilized system high-voltage using boost converter current sensor)
- Adopted much thinner, newly developed polypropylene films

3. New Technology of Each Component

Lower Loss IGBT

New technology for low electronic loss

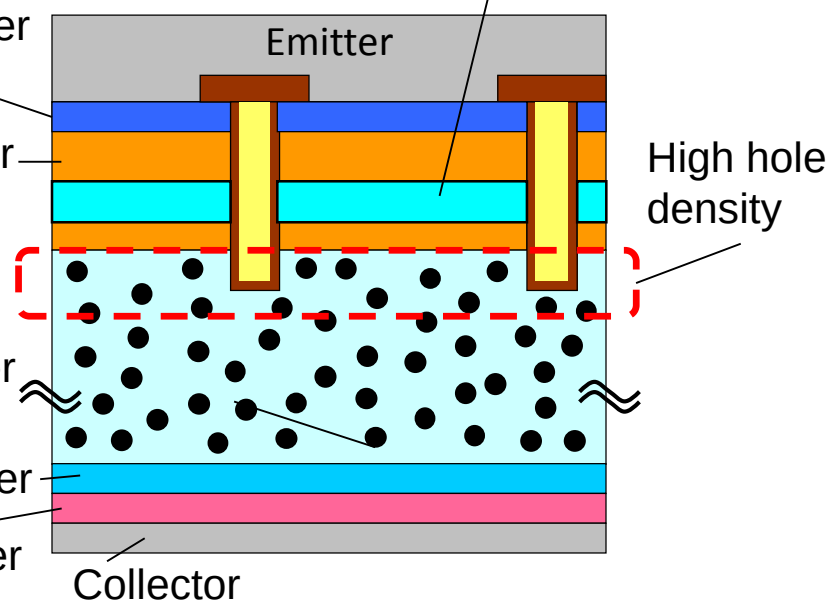
3rd generation



Low hole density leads to decrease
in conductivity modulation effect

4th generation

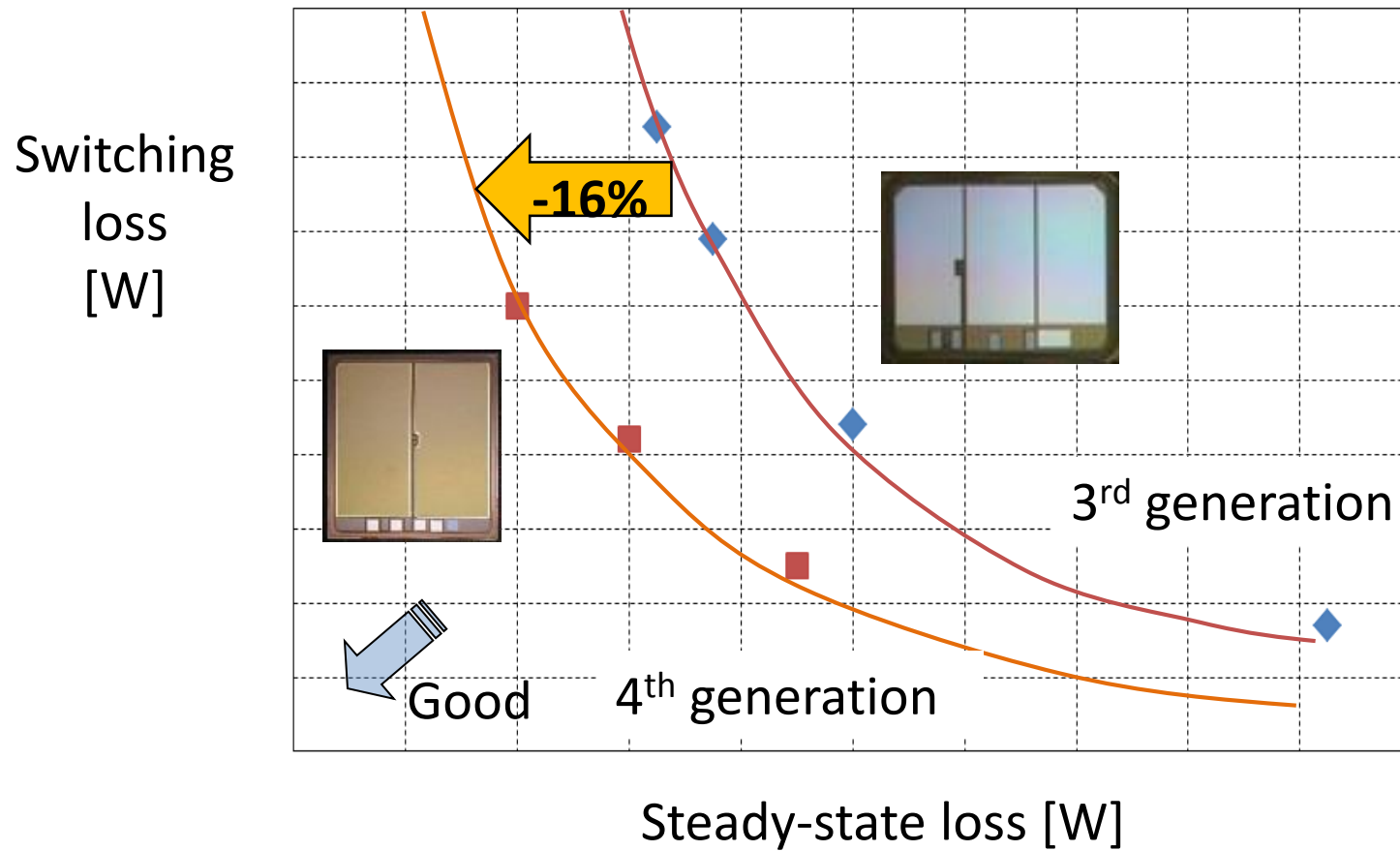
Super Body Layer (SBL) (N type)



- Increased electron hole density by SBL
(improved steady-state loss without worsening switching loss)

3. New Technology of Each Component

Lower Loss IGBT



1. Introduction
2. Power Control Unit (PCU) Specifications and Structure
3. New Technology of Each Component
- 4. Conclusion**

4. Conclusion

Reduction in volume and weight of the PCU (volume:- 33%,weight:-12%)

- Mounting the PCU upon the transaxle reduces cabling and bracket size
- Reduction in volume with complicated layout
- Adopting a modular 2-in-1 power card structure with double-sided cooling and stack ability
- New technology of each component for reducing size and weight
(control circuit board, current sensor, capacitor module)

Improvement in electric energy loss of the PCU (-22%)

- Adopting a lower loss IGBT and low inductance structure



**PCU contribute to Toyota's 4th generation HV
achiving high fuel efficiency and pleasurable driving experience**

* . PCU Specifications and Structure HV System Specifications

Evolution of Hybrid Vehicles

	1 st model (1997) - 1 st generation -	2 nd model (2003) - 2 nd generation -	3 rd model (2009) - 3 rd generation -	New model (2015) - 4th generation -
Objective	First mass-produced HV	Improved power performance using boost converter	• Improved fuel economy • Compact units	• Further improved fuel economy • Pleasurable driving experience
System output	74 kW	82 kW	100 kW	90 kW
Fuel economy	(41 mpg) (US comb.)	46 mpg	50 mpg	56 mpg
Vehicle exterior				

* . PCU Specifications and Structure

PCU Specifications

Volume and weight reduction of the 4th generation PCU

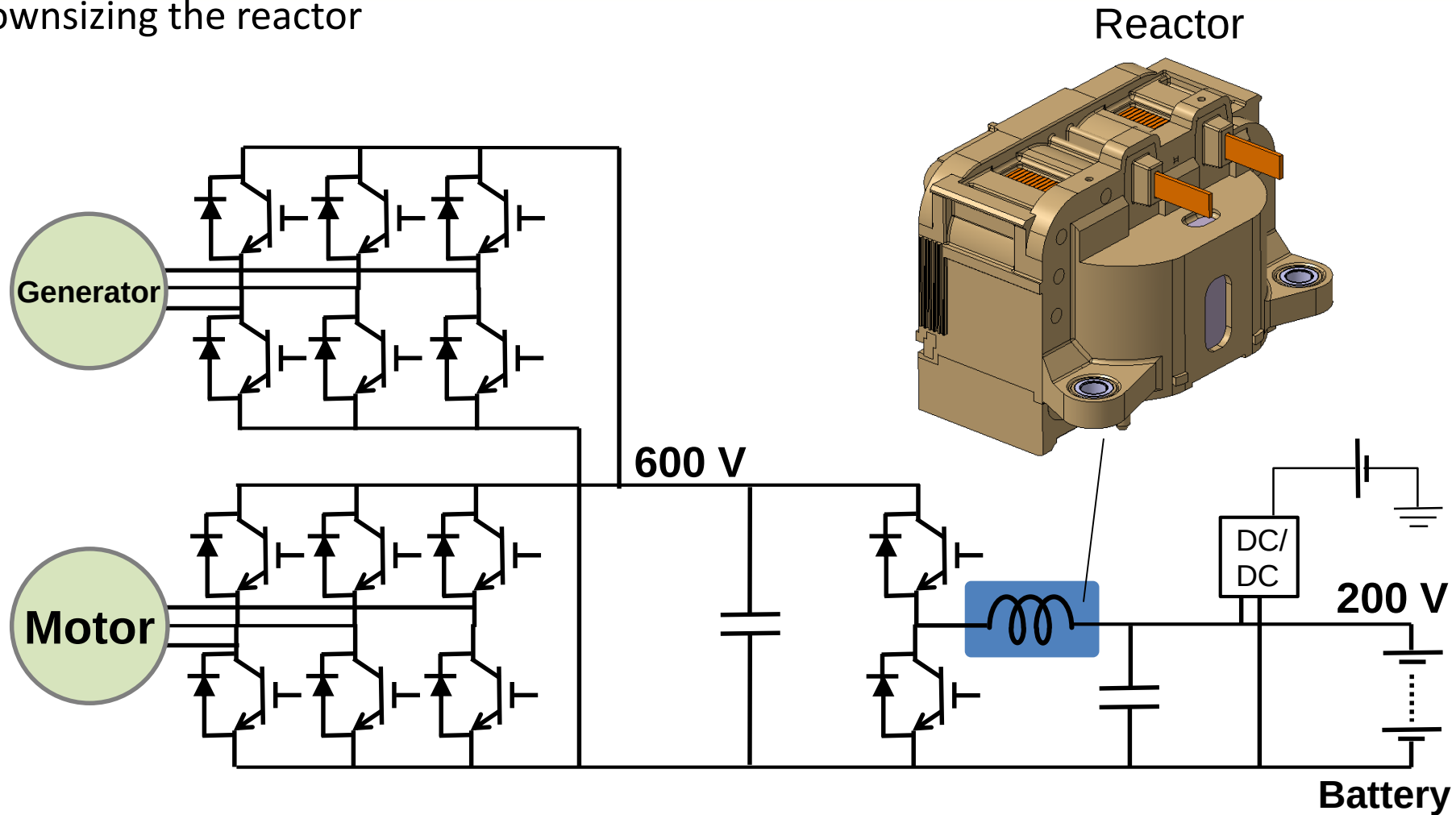
	3 rd generation	4 th generation	
Max total output	177.8 kVA	162.2 kVA	
Max boost voltage	650 V	600 V	
Motor max current	170 Arms	180 Arms	
Generator max current	88 Arms	75 Arms	
Weight	13.5 kg	<u>11.9 kg</u>	-12%
Volume	12.5 L	<u>8.4 L</u>	-33%
Max output density	14.2 kVA/L	<u>19.3 kVA/L</u>	+36%

- Main items
- Double-sided cooling structure
 - Reduced volume and weight of each component

3. New Technology of Each Component

Reactor

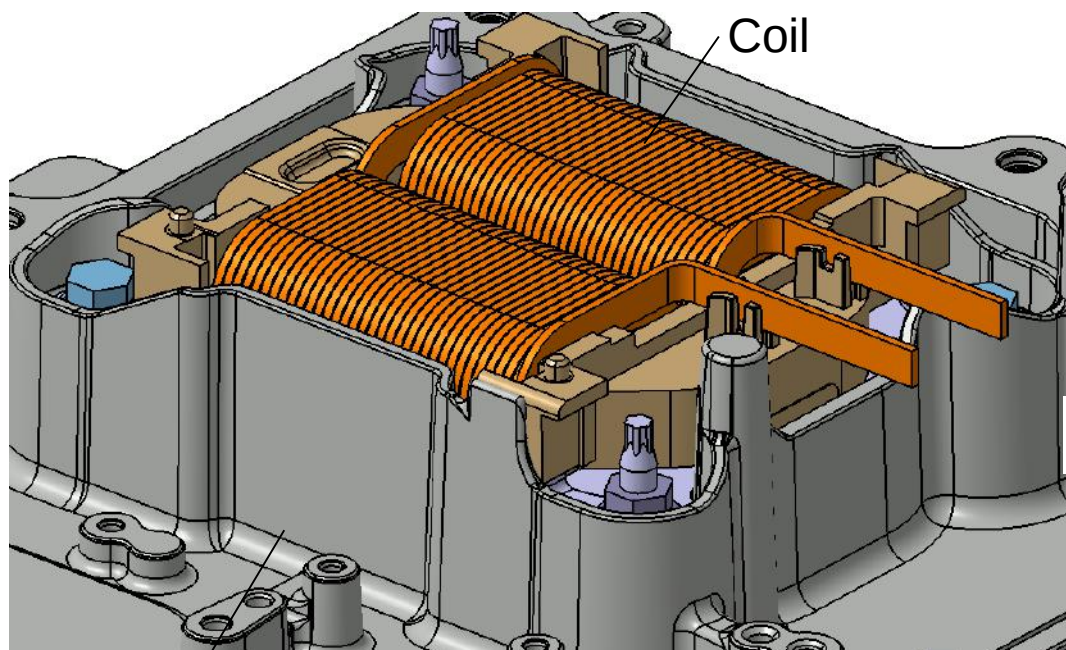
Downsizing the reactor



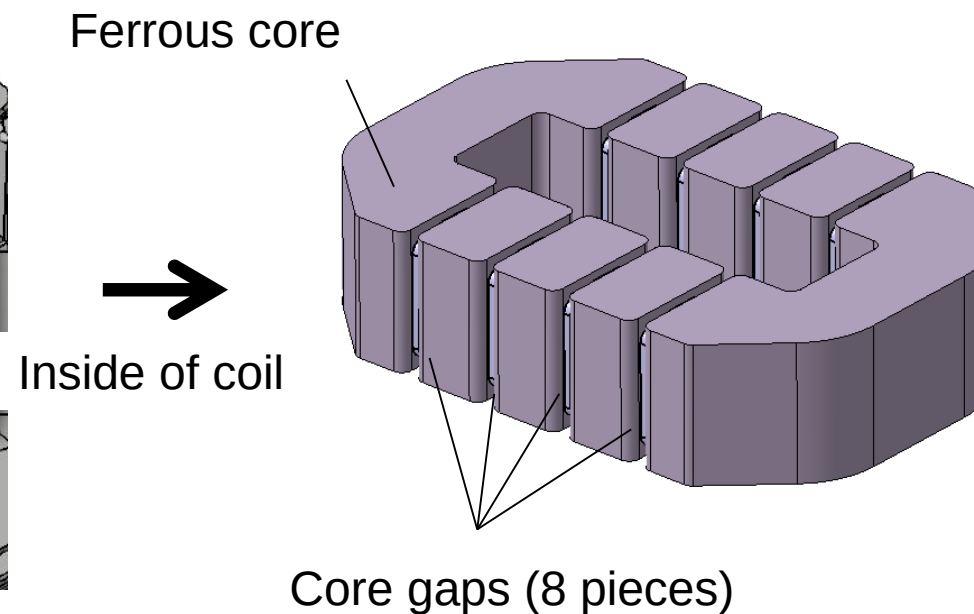
3. New Technology of Each Component

Reactor

Downsizing the reactor
3rd generation

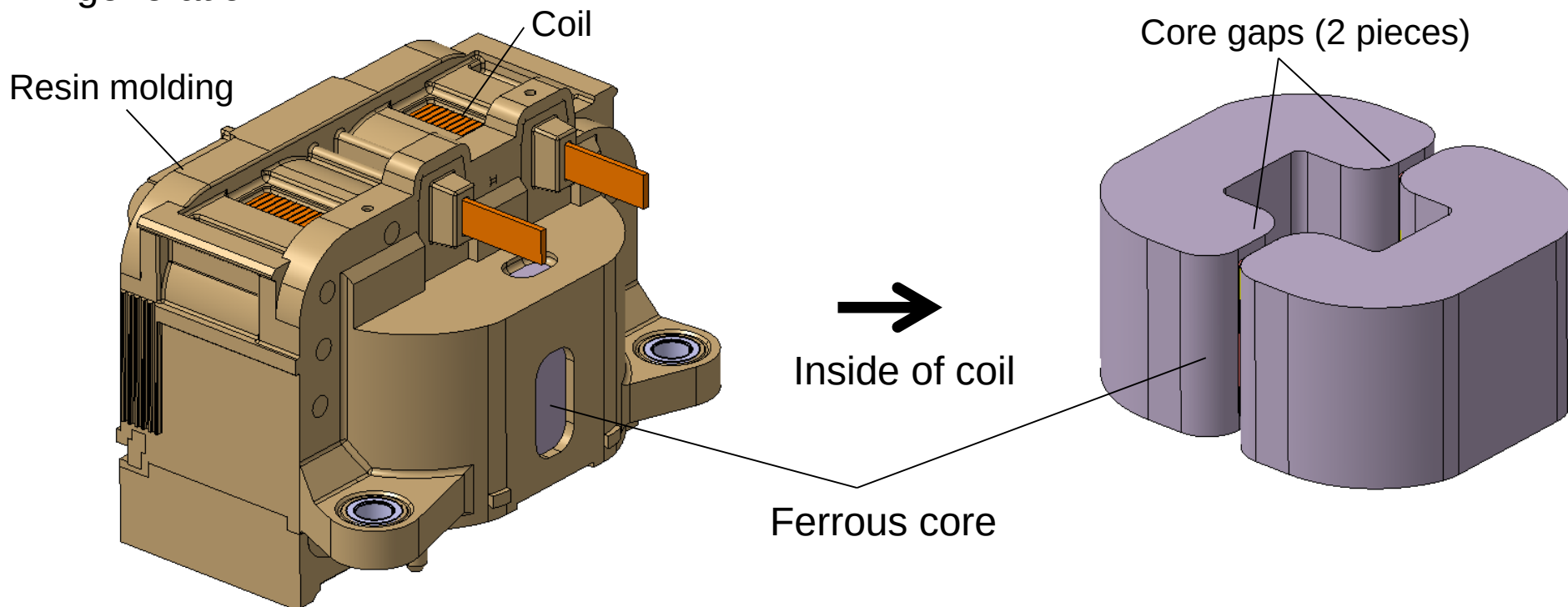


The reactor is fixed on the aluminum case
(Silicon resin fills up the inside of case)



3. New Technology of Each Component Reactor

Downsizing the reactor
4th generation

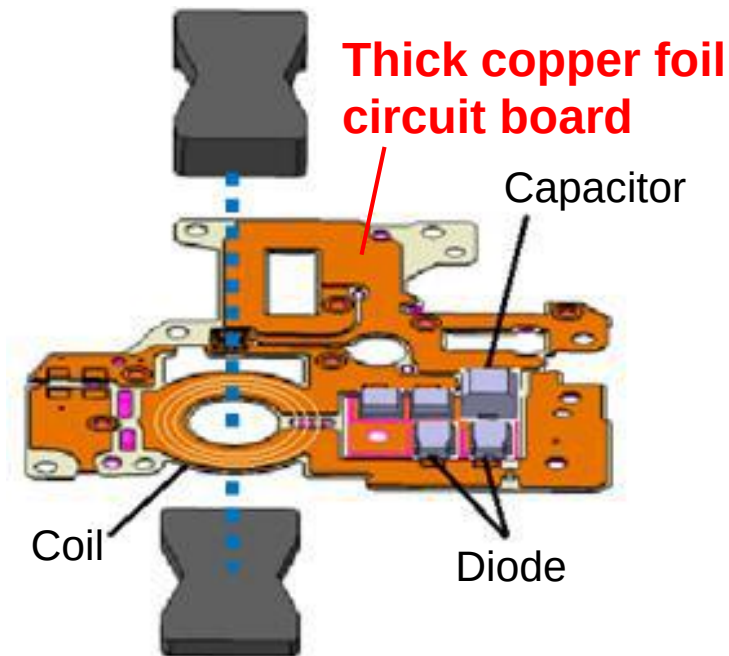
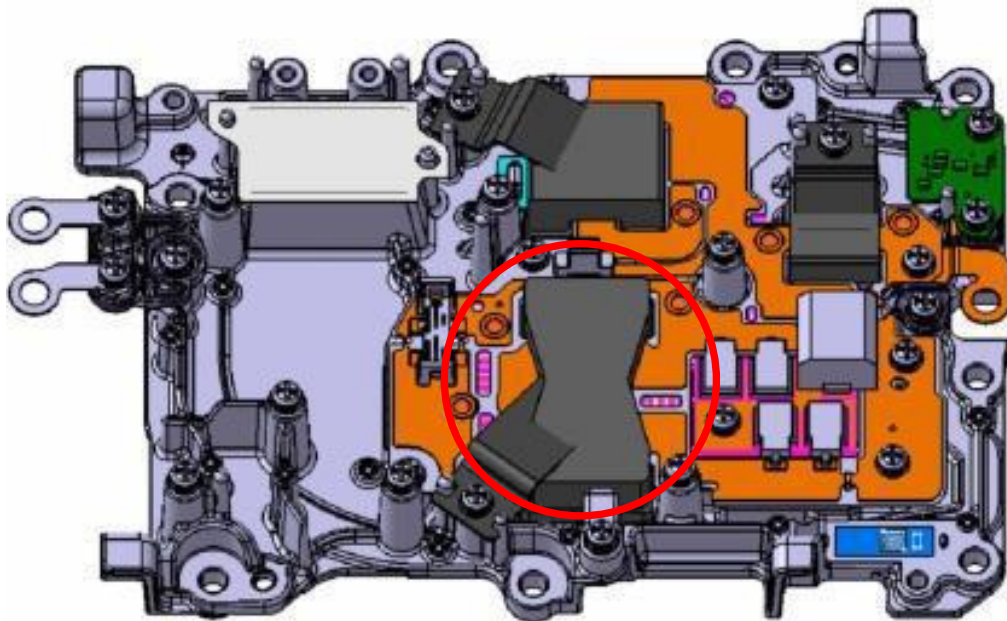


- Reduced the ferrous core gaps (8→2 gap)
- Unified resin molded structure

3. New Technology of Each Component

DC/DC Converter

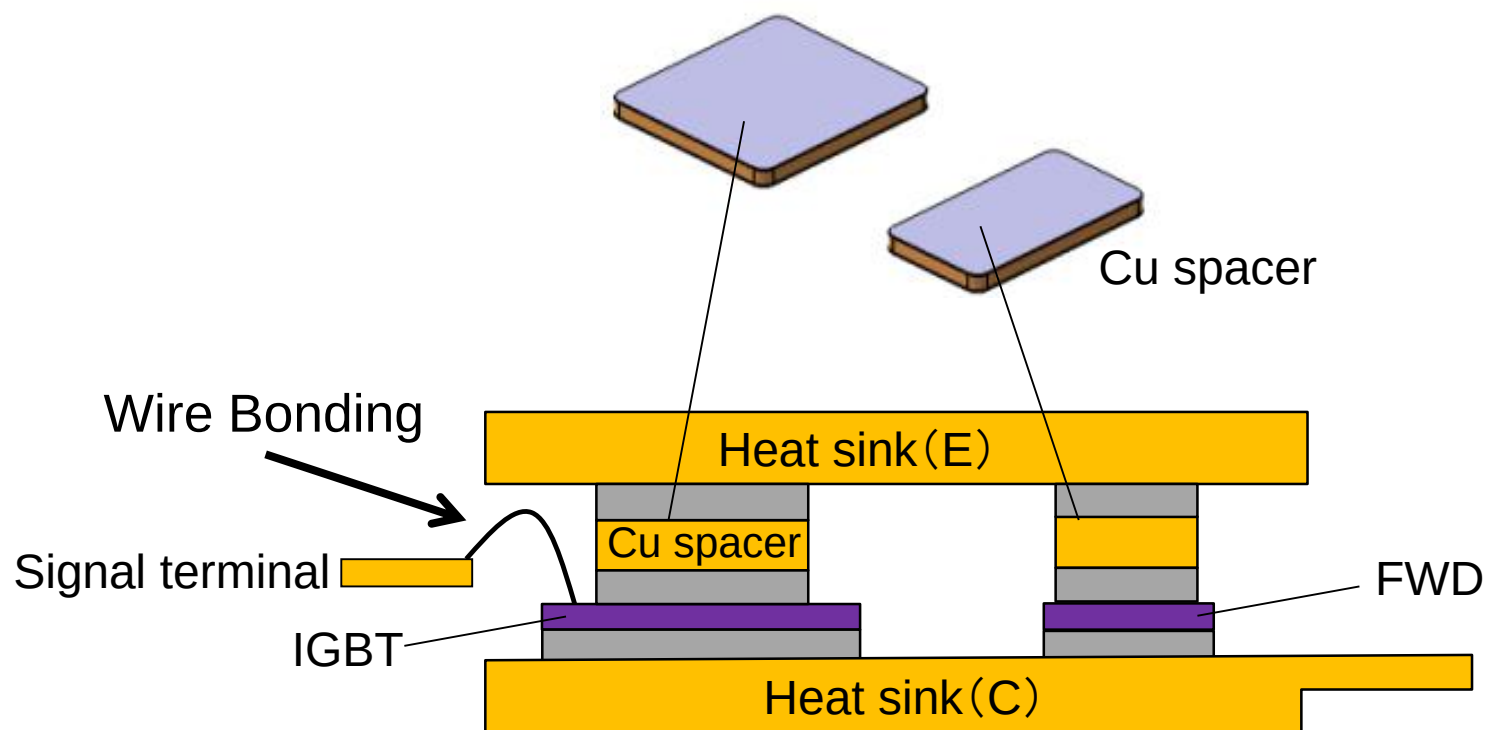
Downsizing the DC/DC converter



Electronic devices mounted to the circuit board directly
→ Adopted a press process instead of etching process

Advantage ➤ Circuit connection without busbar (→ size and weight reduction)

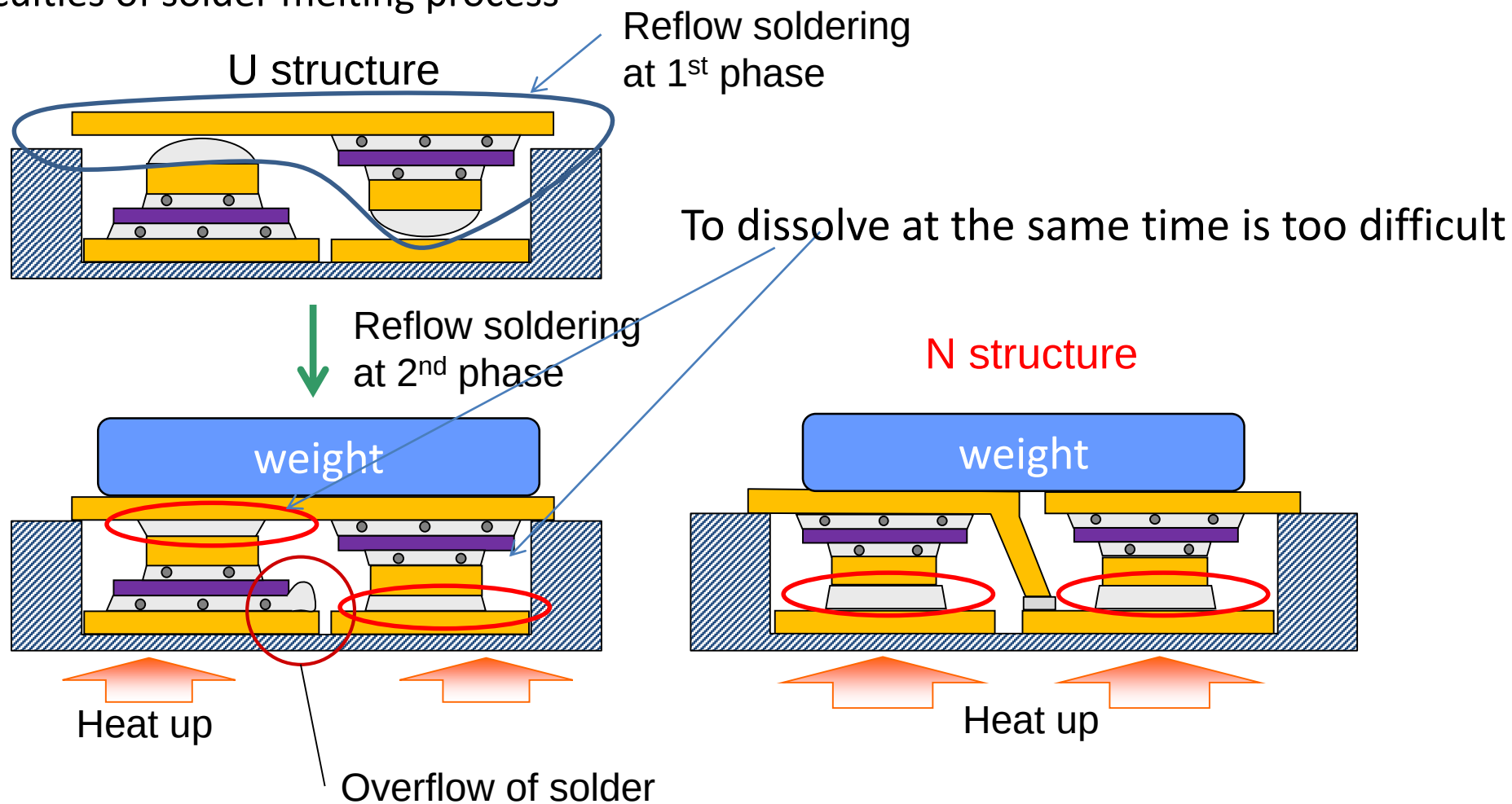
The function of Cu spacer



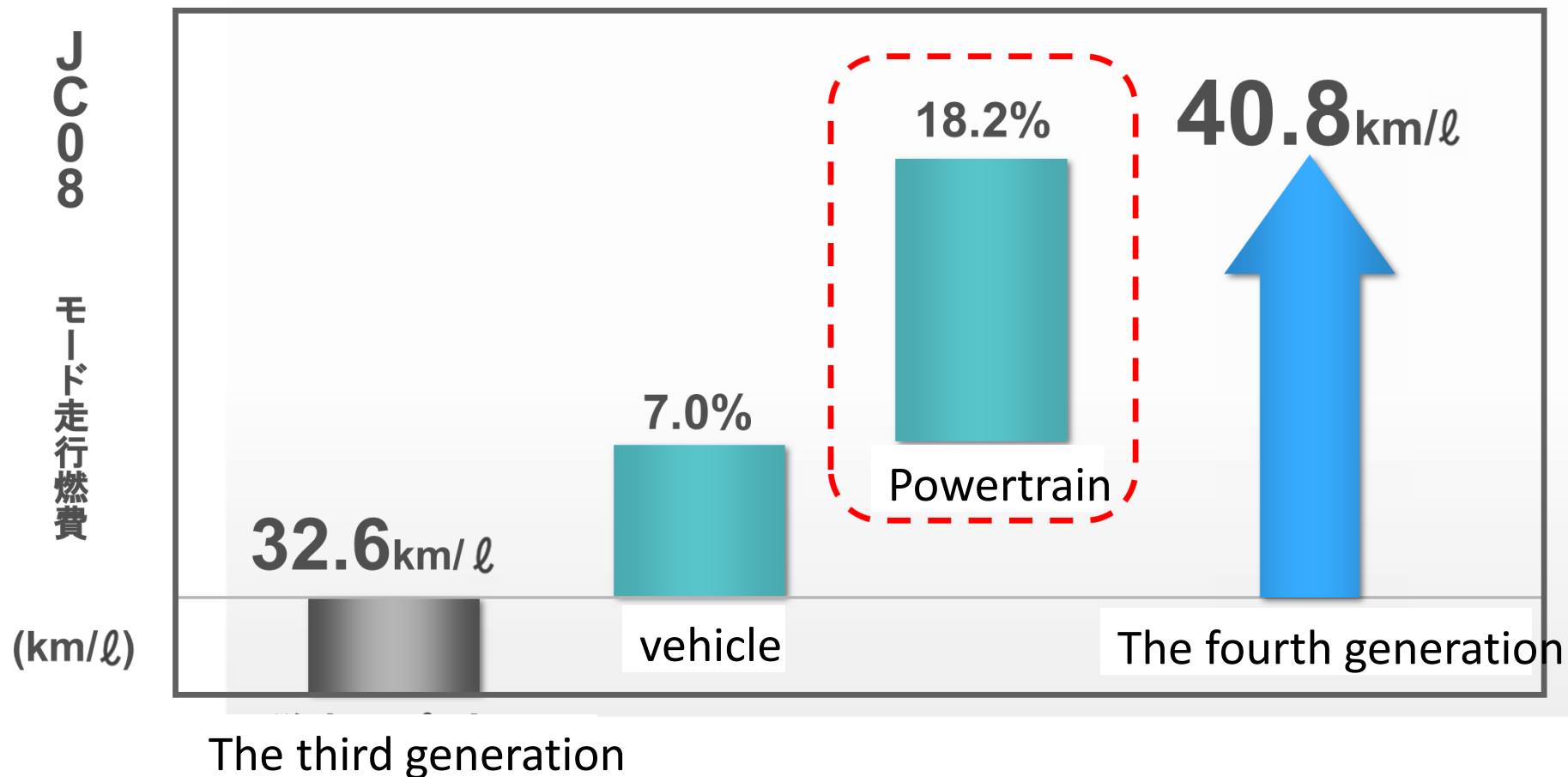
- Cu spacer need to remain space for wair bonding

* . New Technology of Each Component Power Module

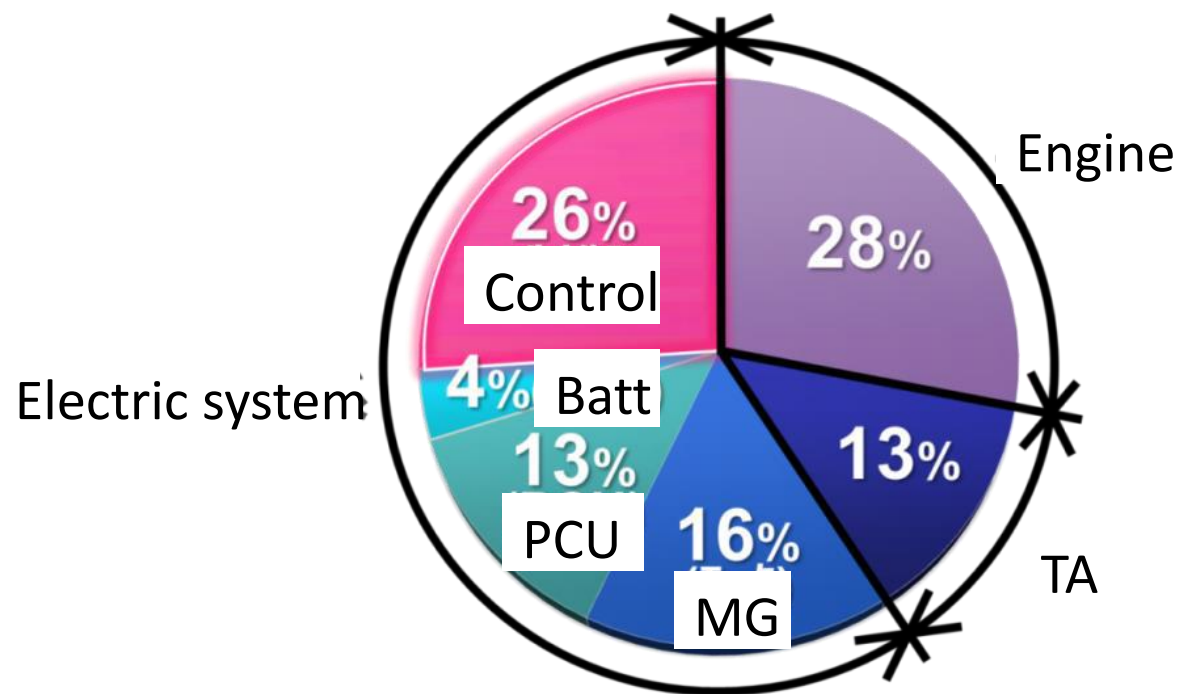
The difficulties of solder melting process



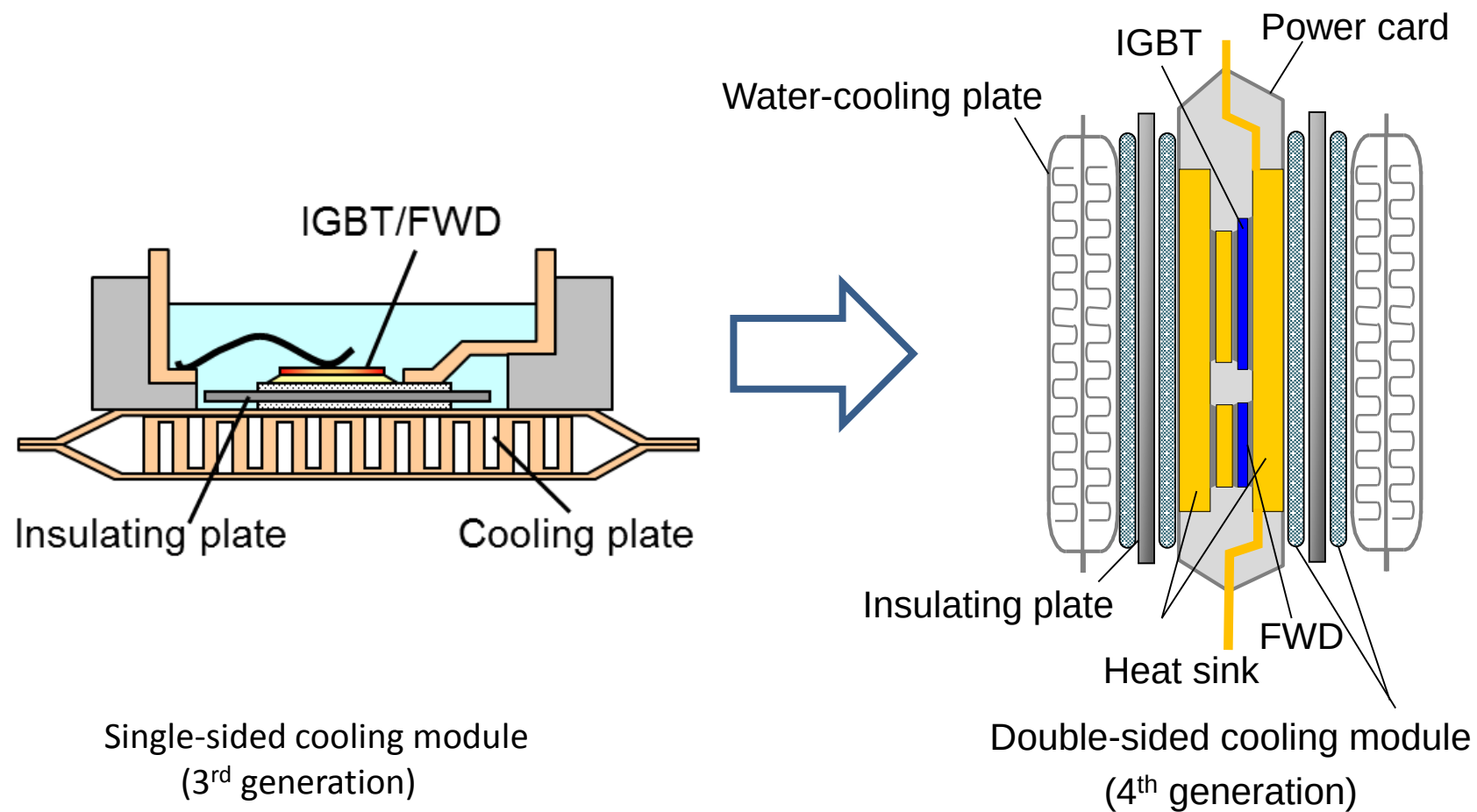
Fuel Economy improvement Contribution



Fuel Economy improvement Contribution

Fuel Economy improvement item details of the powertrain

- PCU contributes to Fuel Economy improvement of Approximately 0.2km/L



➤ Thermal resistance improved about 3 times