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DC-Link Capacitor Packaging and Thermal Management for 48-V Hybrid Passenger Vehicles

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Outline

1. Introduction (3-driven factors for 48v MHV market)

- ✓ Hybrid System
- ✓ New Concept Bus-Bar

2. Thermal Management (Thermal Behavior)

- ✓ Single Capacitor (Modeling, Thermal Sim. and Expt.)
- ✓ Bus-Bar Heat Generation (Thermal Sim. and Expt.)
- ✓ Change in Cupper Thickness of Bus-Bar
- ✓ Influence of Heat Conduction from Bus-Bar
- ✓ C-Module Heat Generation (Thermal Sim. & Expt.)
- ✓ Outcome with Suitable Thermal Management

3. Life Analysis (Predicted Life at Worst Case Study)

4. Conclusions

1. Introduction (3-driven factors for 48v MHV market)

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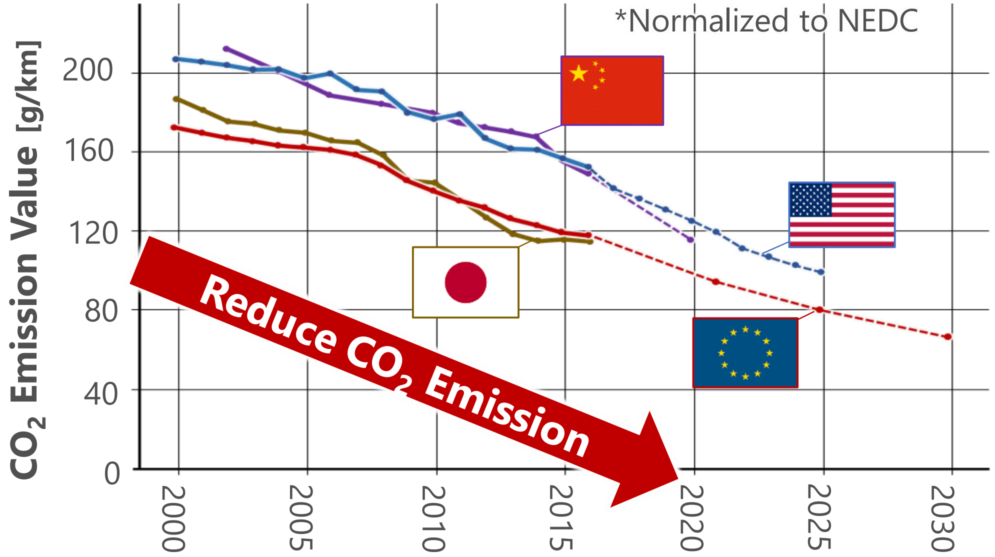
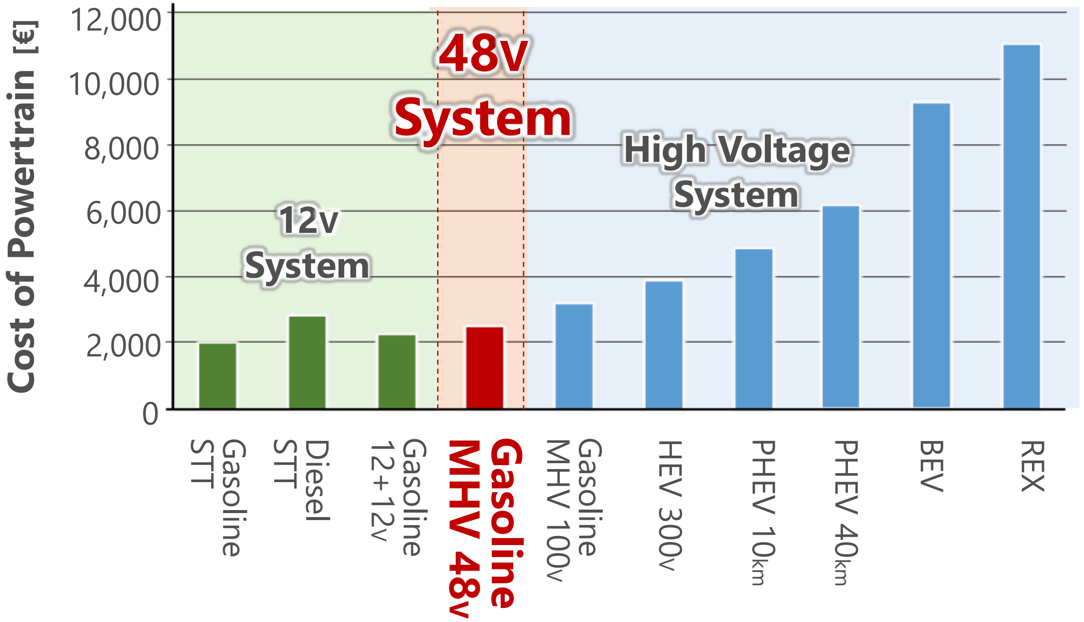
● CO_2 Emission Regulation



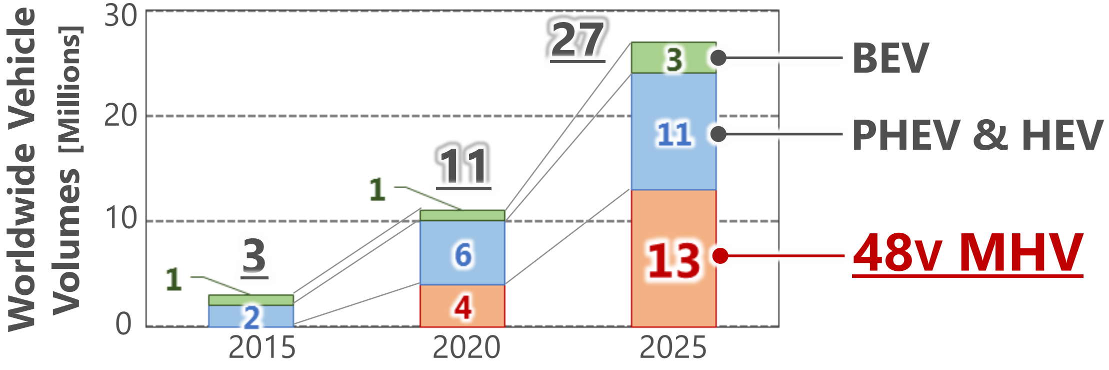
*Source: Own illustration of data from "https://www.theicct.org/chart-library-passenger-vehicle-fuel-economy"

● Better Cost Performance



*Source: Own illustration of data from "Valeo at 4th International Conference Automotive 48V Power Supply System Berlin, 29-30 November 2016"

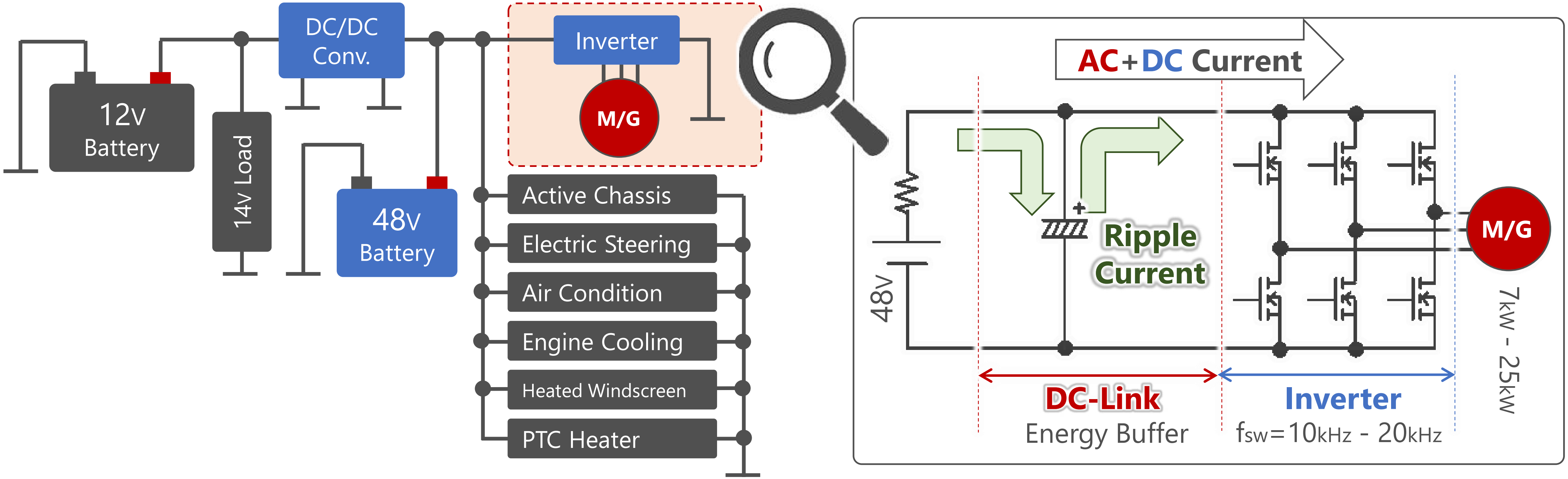
● 48v MHV will be approx. 50% by 2025



*Source: Own illustration of data from "Continental at Driven Innovation Workshop Washington, DC September 2016"

1-1. Hybrid System

● DC-Link Capacitor Module for 48v MHV System



AC Current (100Arms-300Arms) & **DC Current** (100Adc-500Adc) → **Heat Generation**

1-2. New Concept Bus-Bar

● C-Module (Capacitor Module Packaging)

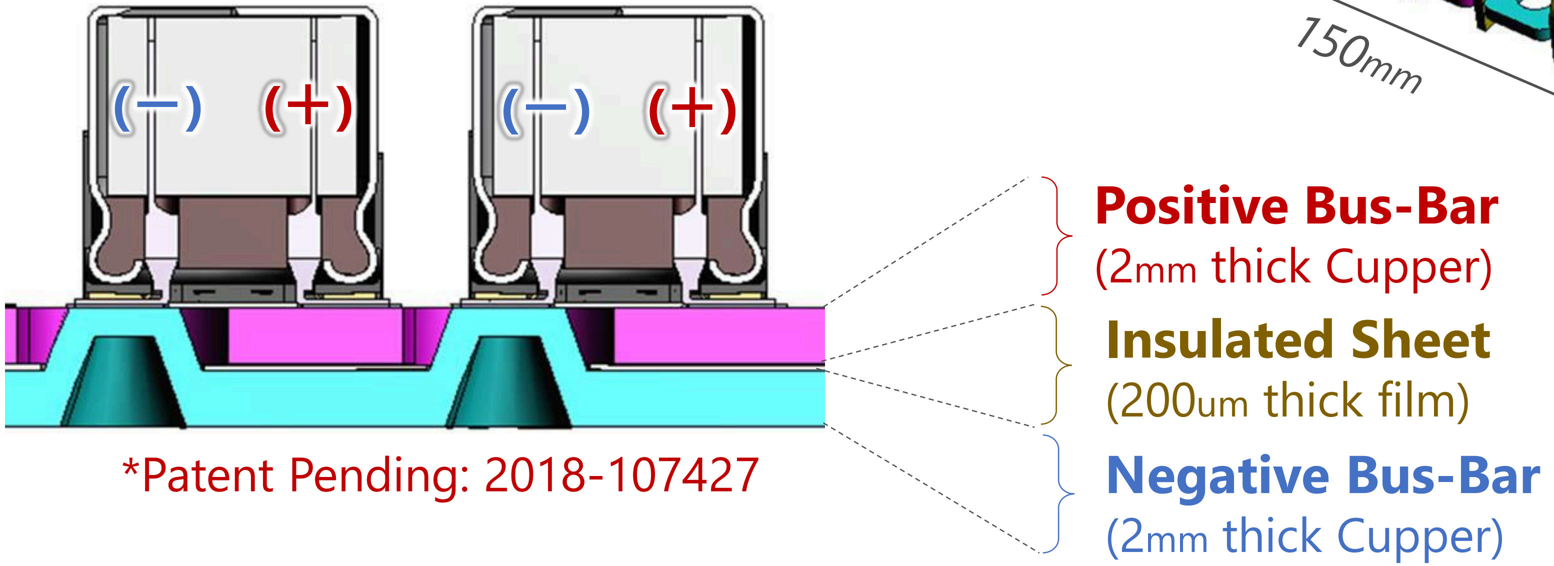
(ex. Mounted 48pcs. Parallel Capacitors)

✓ High Heat Conduction (Cu: 372W/mK)

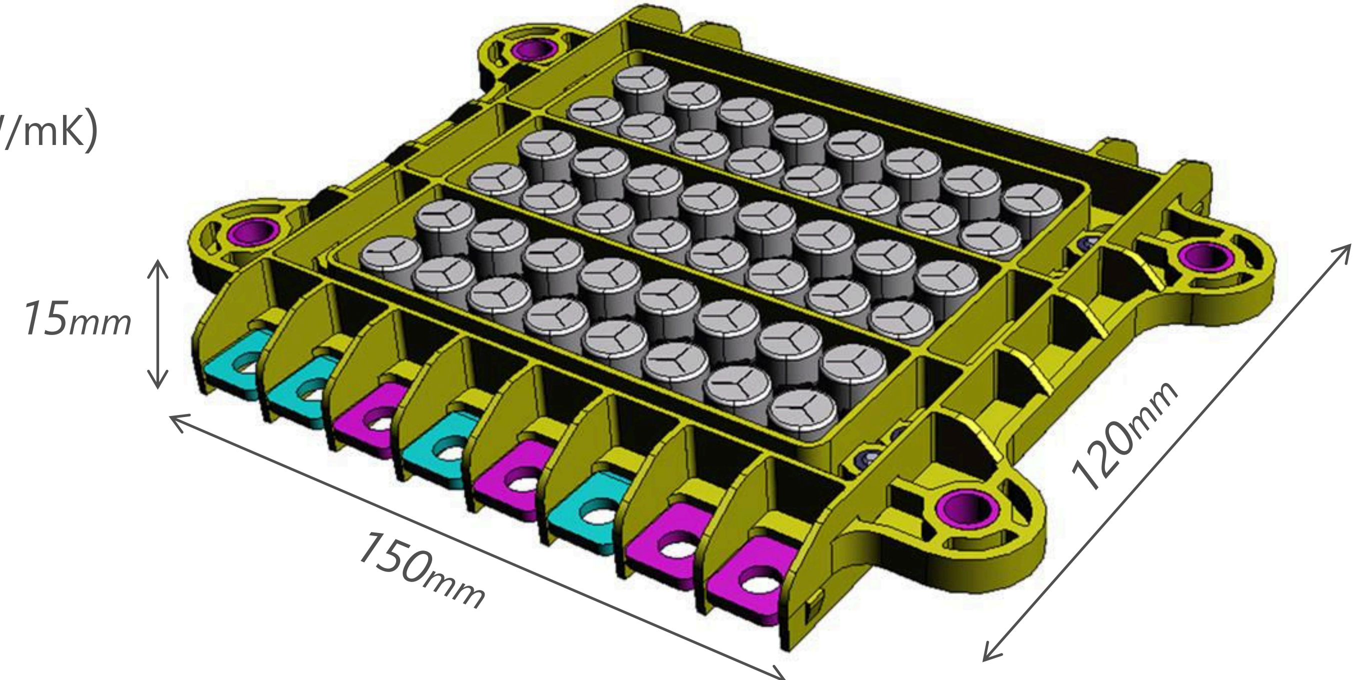
✓ Low Resistance (0.8mΩ / 10kHz)

✓ Low Inductance (5.4nH / 1MHz)

HXC-series SMD HYB-Capacitor
(63V82uF, φ10×10L, Nippon Chemi-Con)



*Patent Pending: 2018-107427



C-Module

2. Thermal Management (Thermal Behavior)

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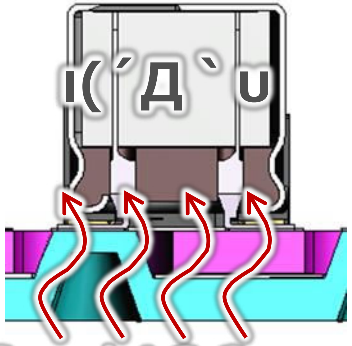
● Three key points for suitable solution of "Thermal Management"

1. Self-Heating **2. Heat Conduction** **3. Heat Radiation/Convection** (Air-flow)

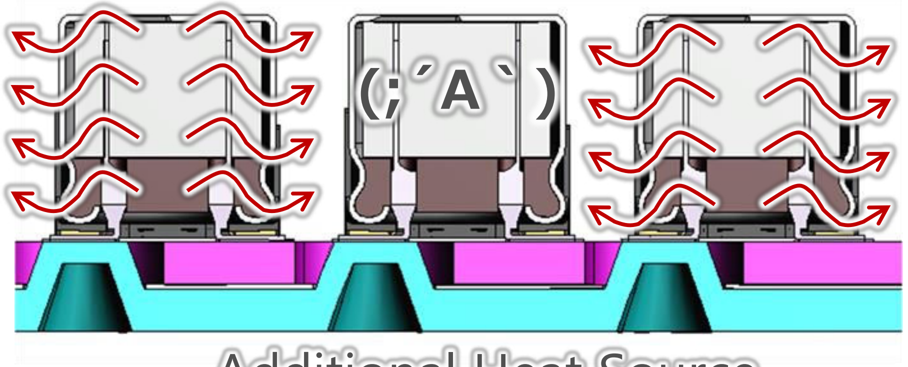
Ripple-Current

+



DC and AC Current

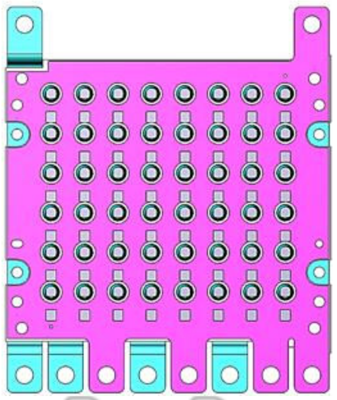
+



Additional Heat Source

Single Capacitor

&



Bus-Bar

● Understanding thermal behavior

✓ Single-capacitor and bus-bar modeling.

✓ Fine tuning of simulation parameters.

✓ Comparison of thermal Sim. & Expt.

✓ Confirm accuracy of thermal Sim. & Expt.

2-1. Single Capacitor (Modeling, Thermal Sim. & Expt.)

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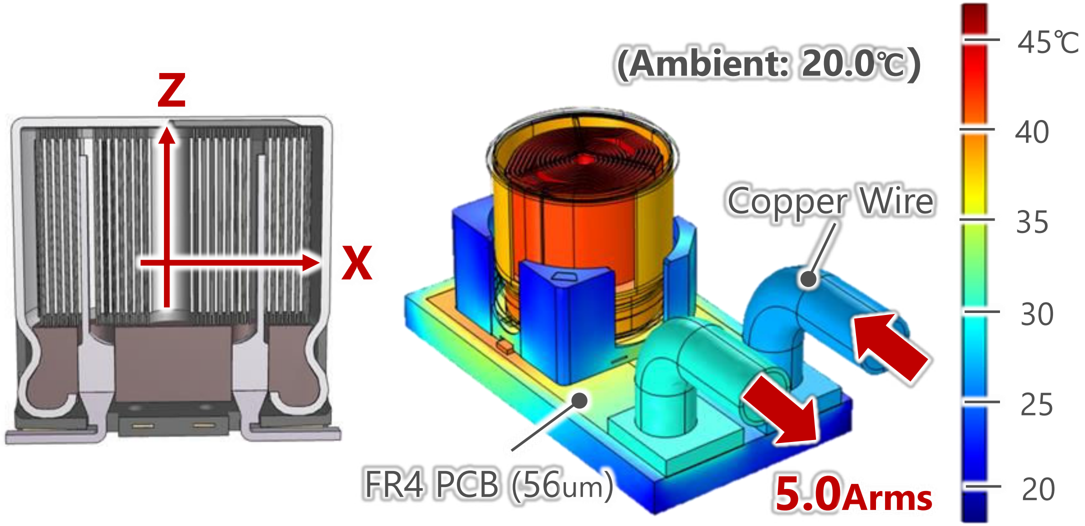
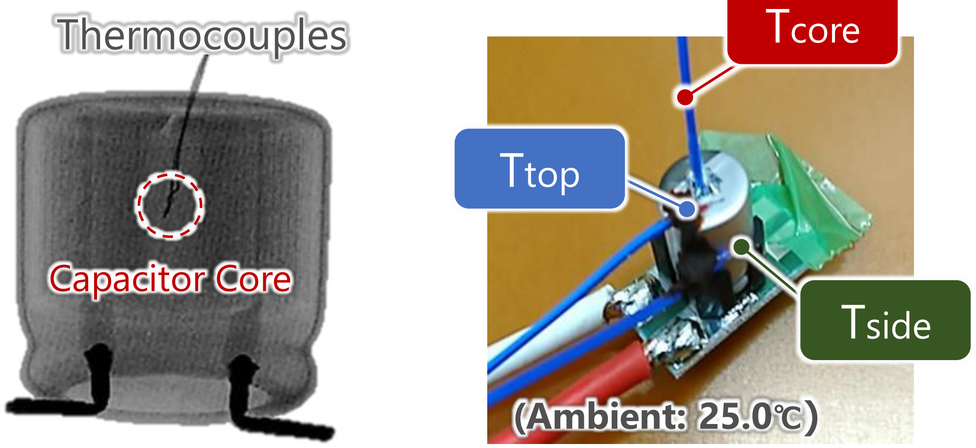
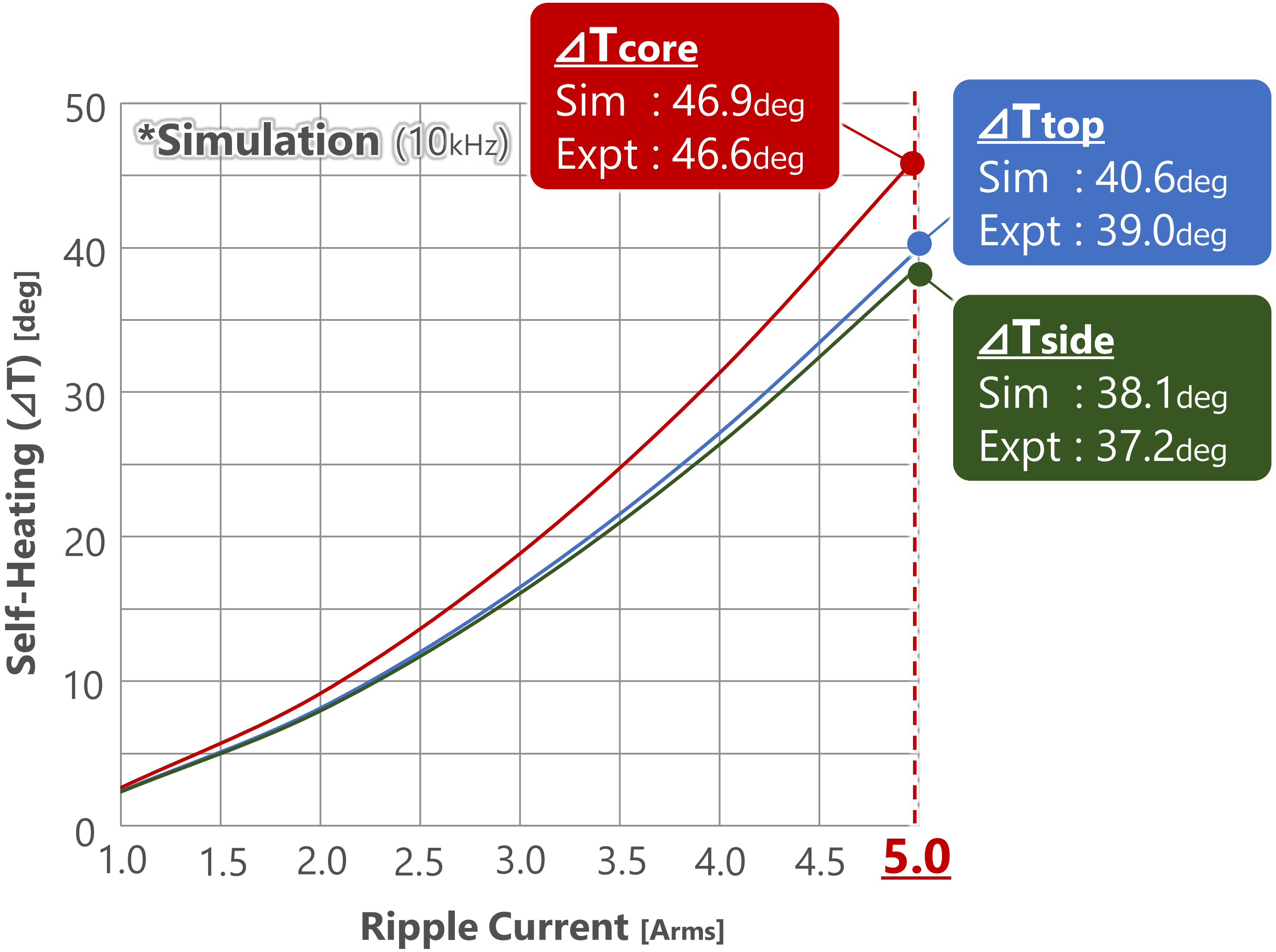
● Simulation



● Experiment

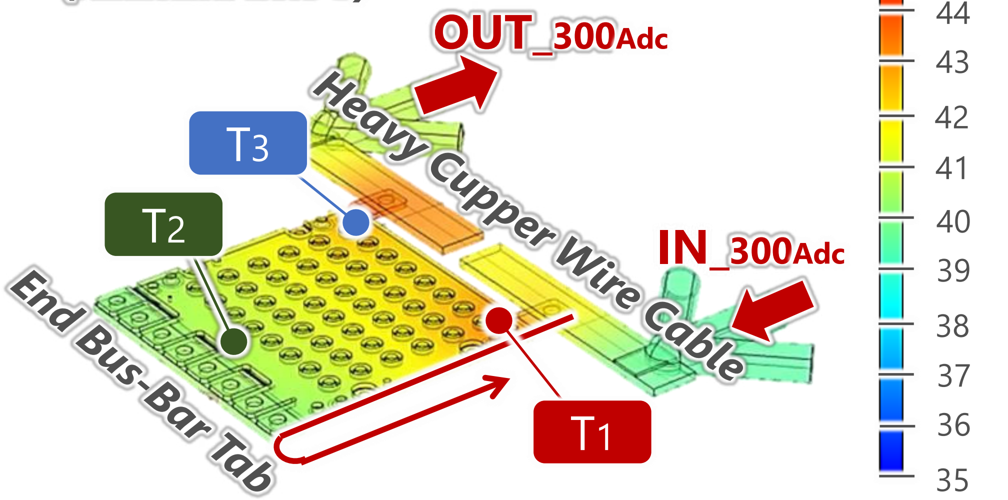




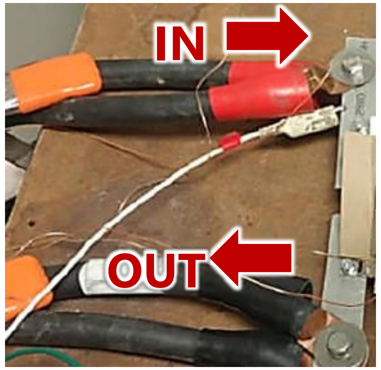
✓ Sim. & Expt. agree each other quite well.

2-2. Bus-Bar Heat Generation (Thermal Sim. & Expt.)

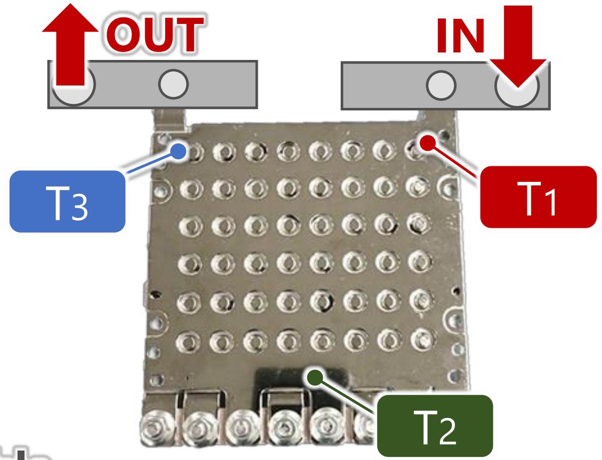
- **Simulation**
  (Ambient: 20.0℃)

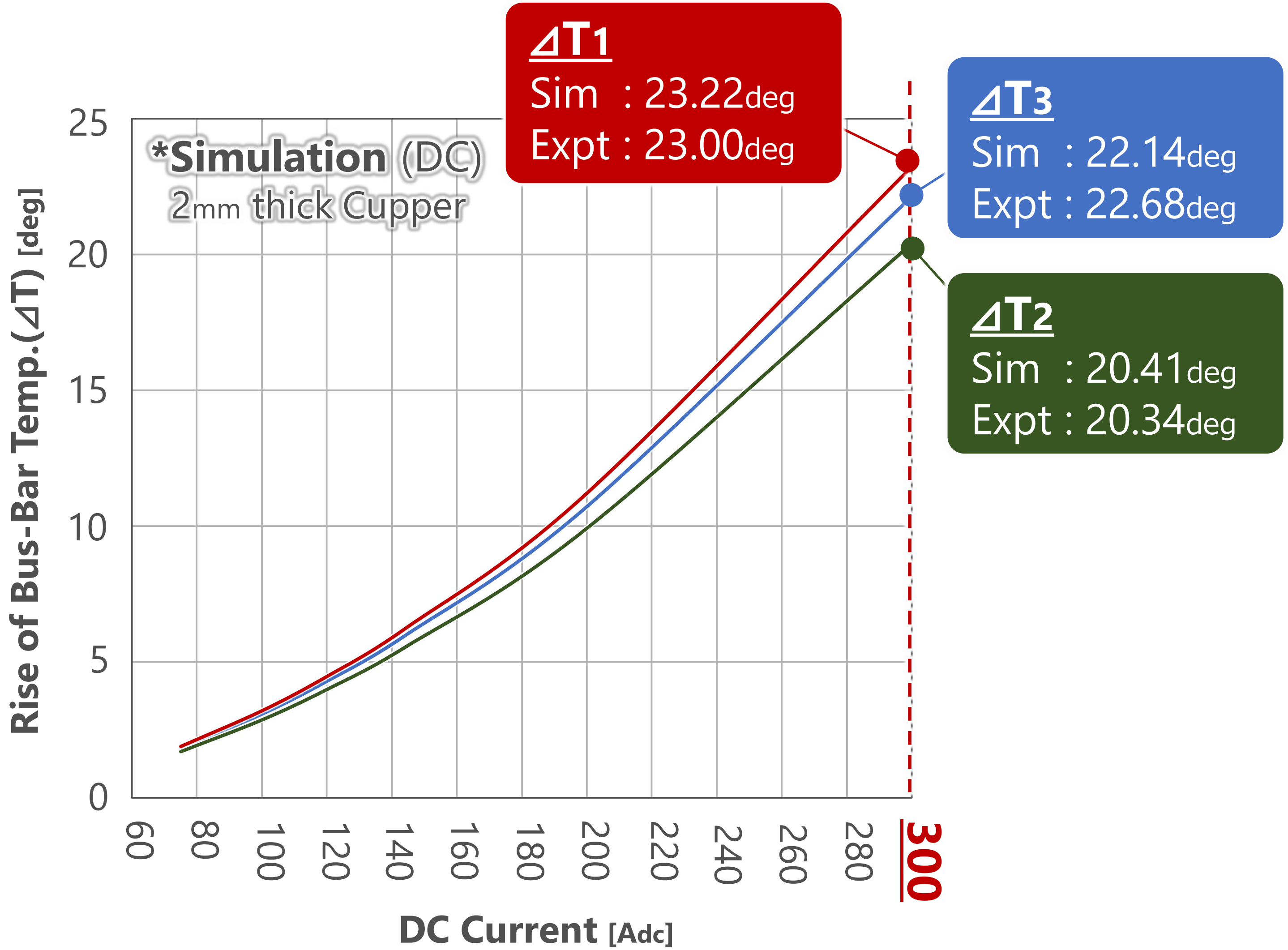


- **Experiment**
  (Ambient: 22.7℃)



Heavy Cupper Wire Cable





✓ Sim. & Expt. agree each other quite well.

2-3. Change in Cupper Thickness of Bus-Bar

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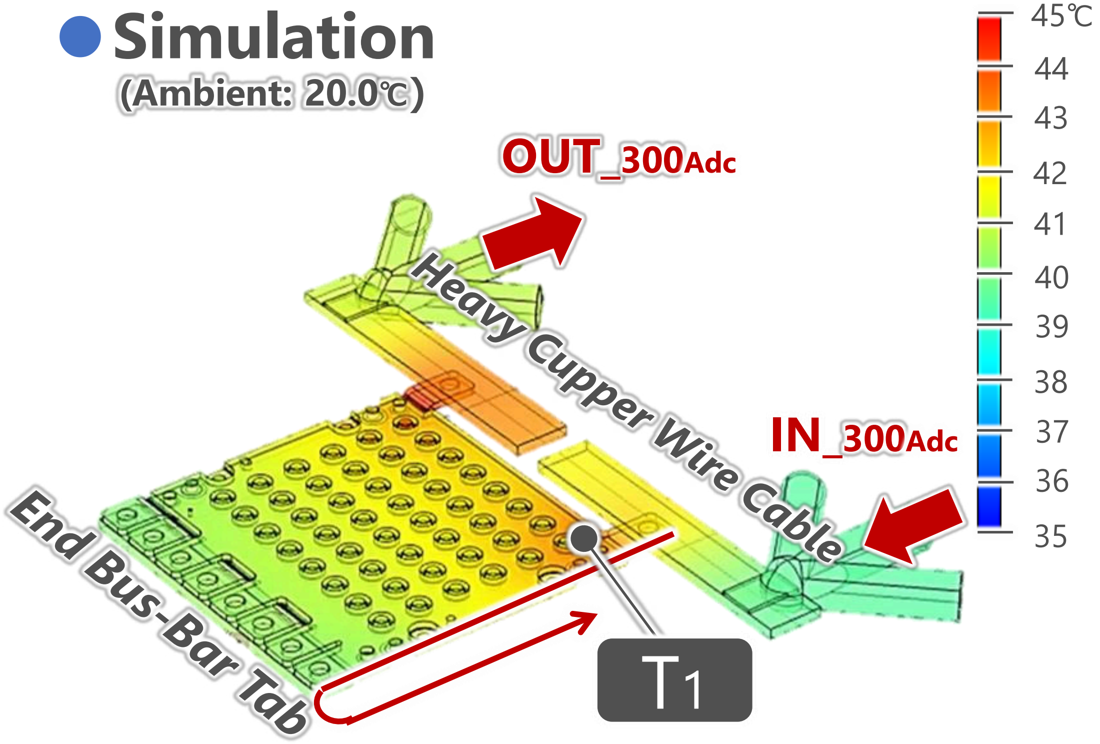
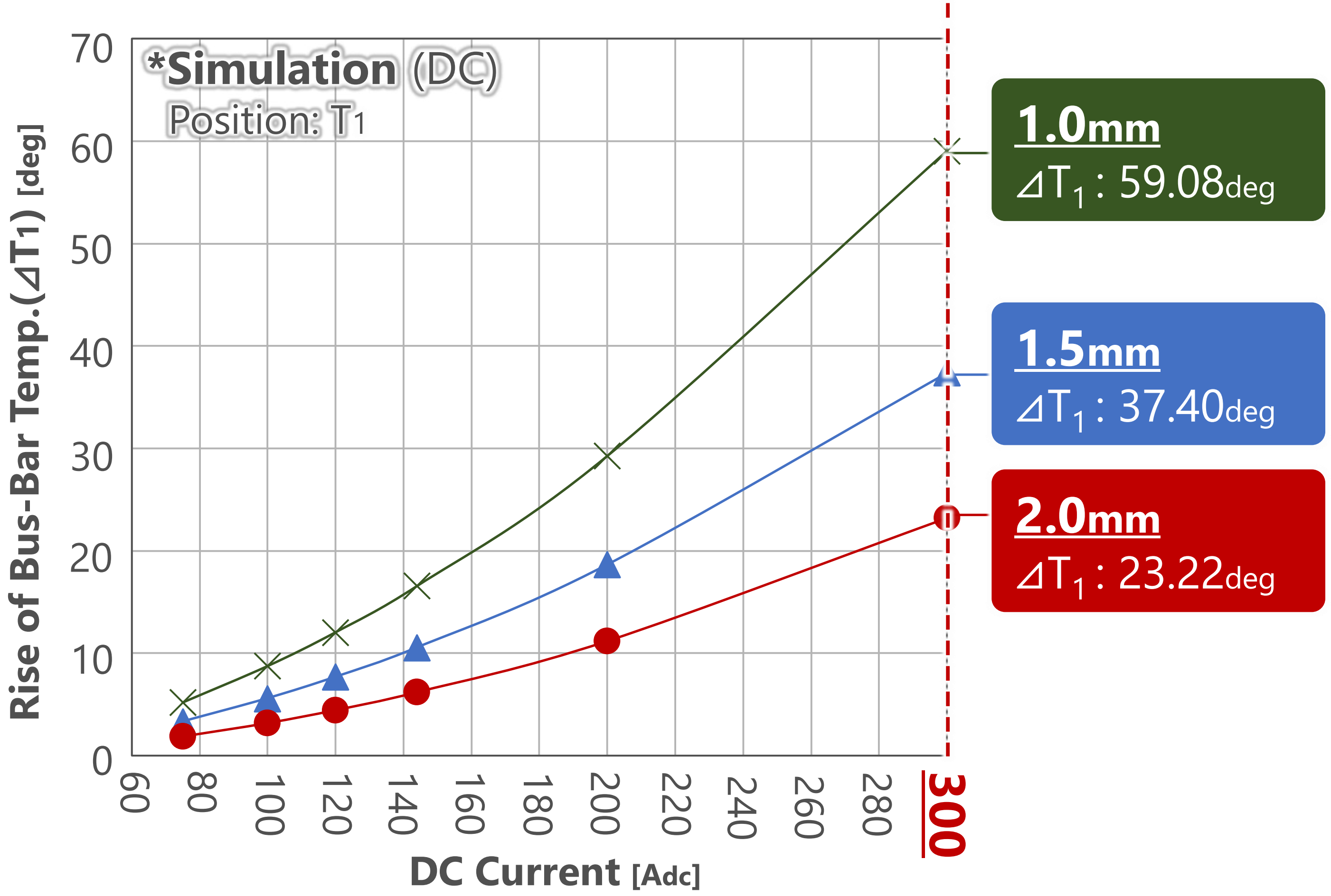
● Simulation

(Ambient: 20.0℃)





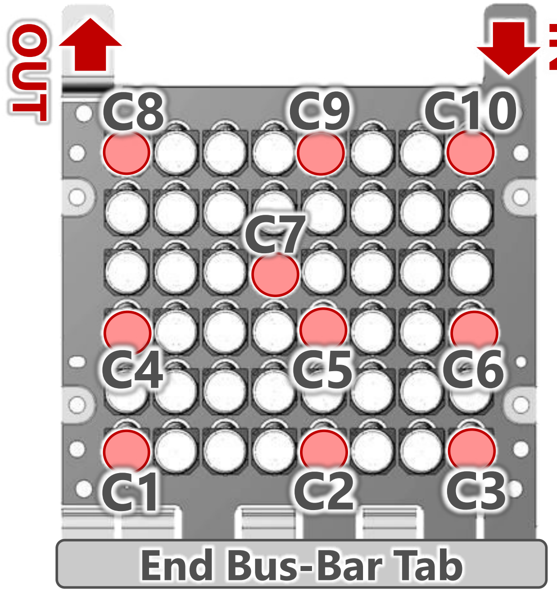
✓Changing Bus-Bar Thickness

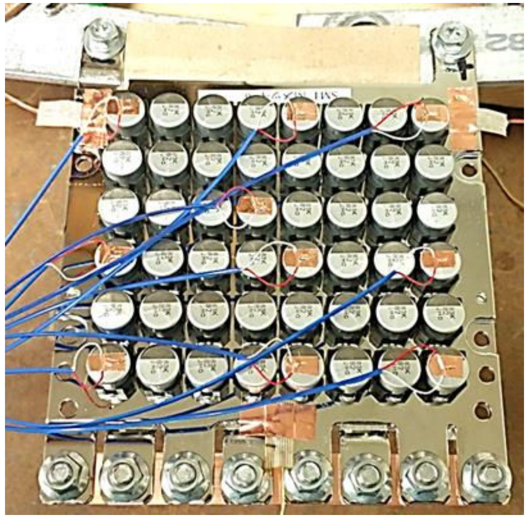
t=2.0mm (⊿T1) → t=1.5mm (⊿T1) → t=1.0mm (⊿T1)

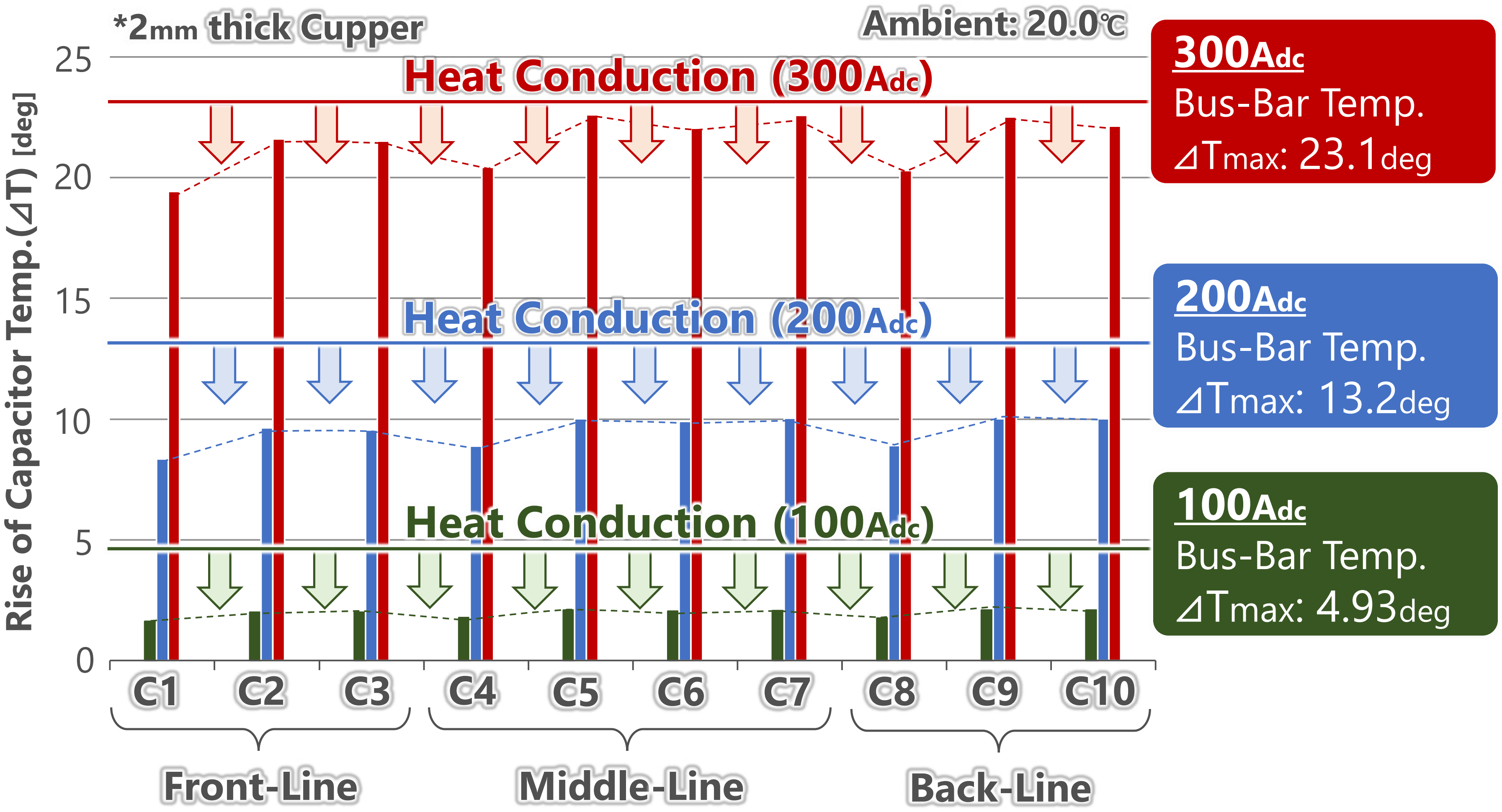
✓ Thin bus-bar has more heat generation.
⇒ Higher ESR value.

2-4. Influence of Heat Conduction from Bus-Bar

● Experiment





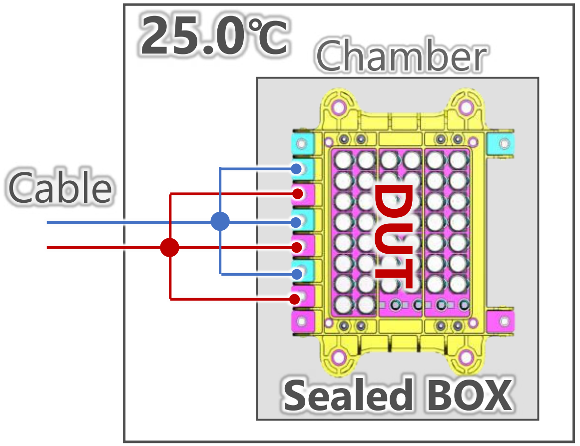


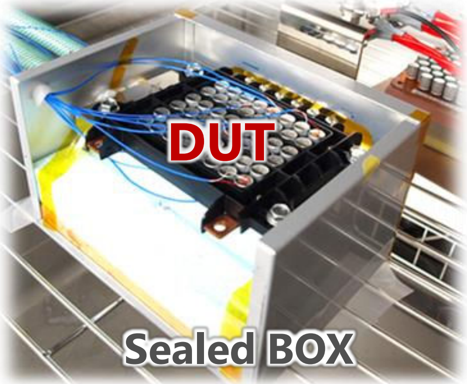
✓ Temperature to capacitors mounted on bus-bar show clearly impacted by conductive heat form bus-bar.

2-5. C-Module Heat Generation (Thermal Sim. & Expt.)

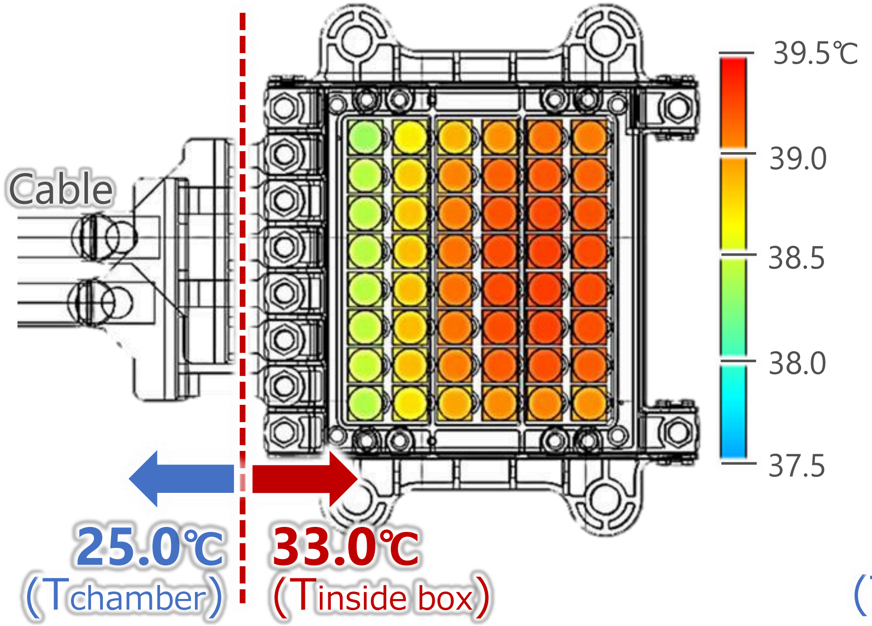
● Conditions

✓ Iripple: 90Arms (10kHz)
✓ Vbias: 52Vdc
✓ Tchamber: 25.0℃



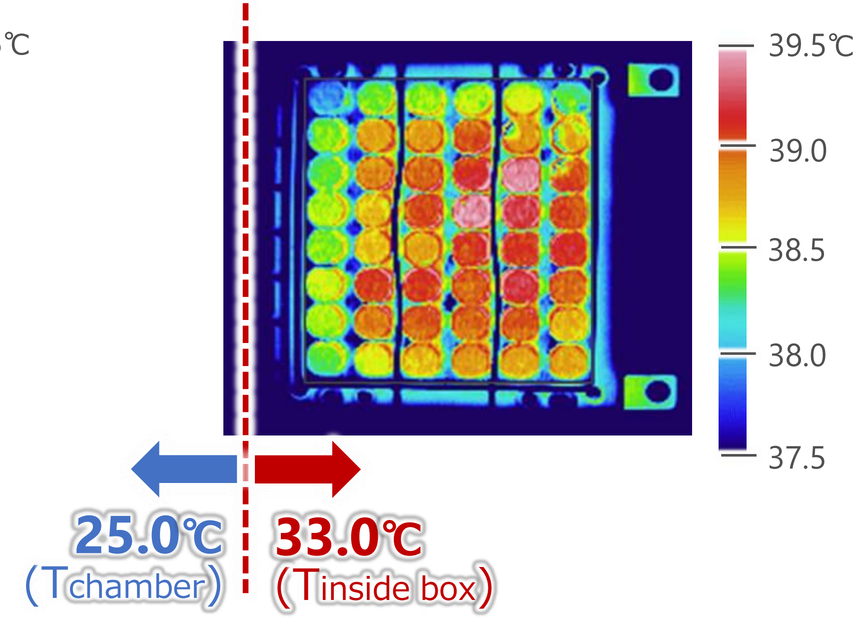


● Simulation



● Experiment

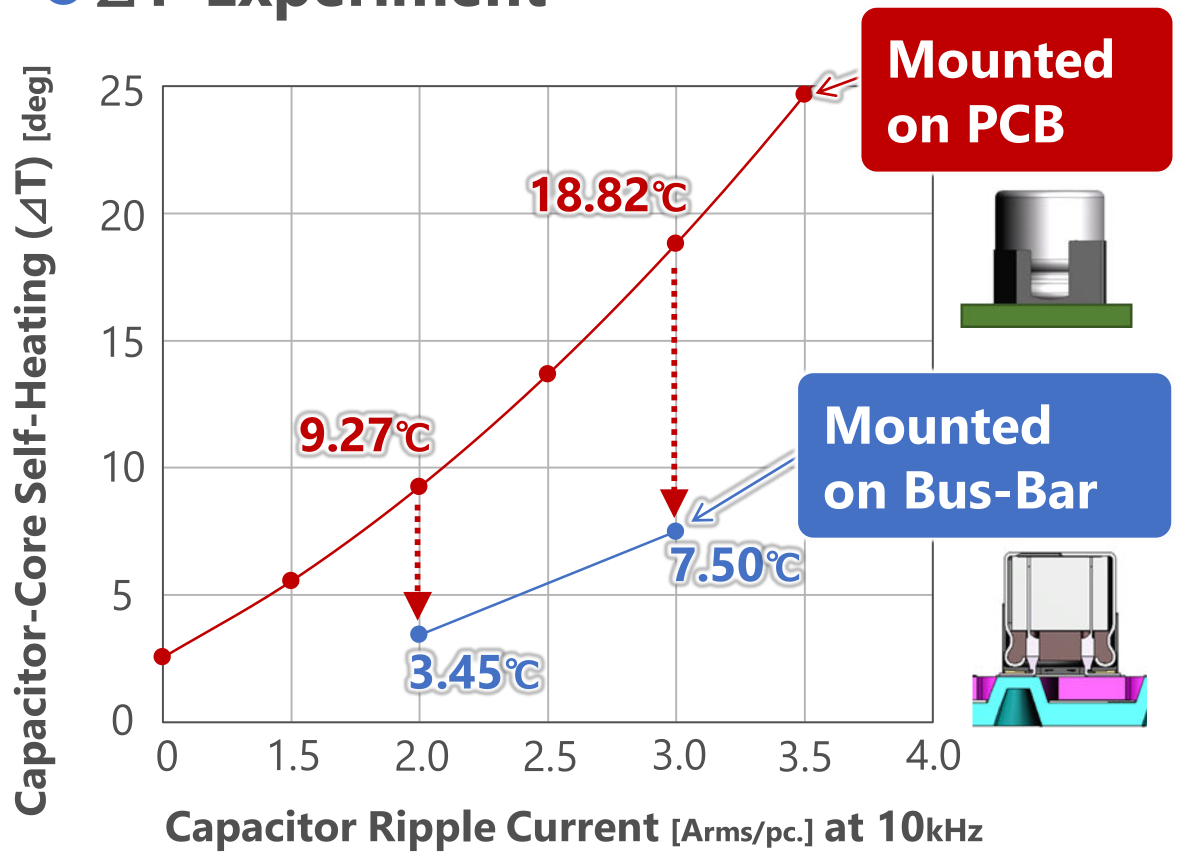
(IR thermometer image)



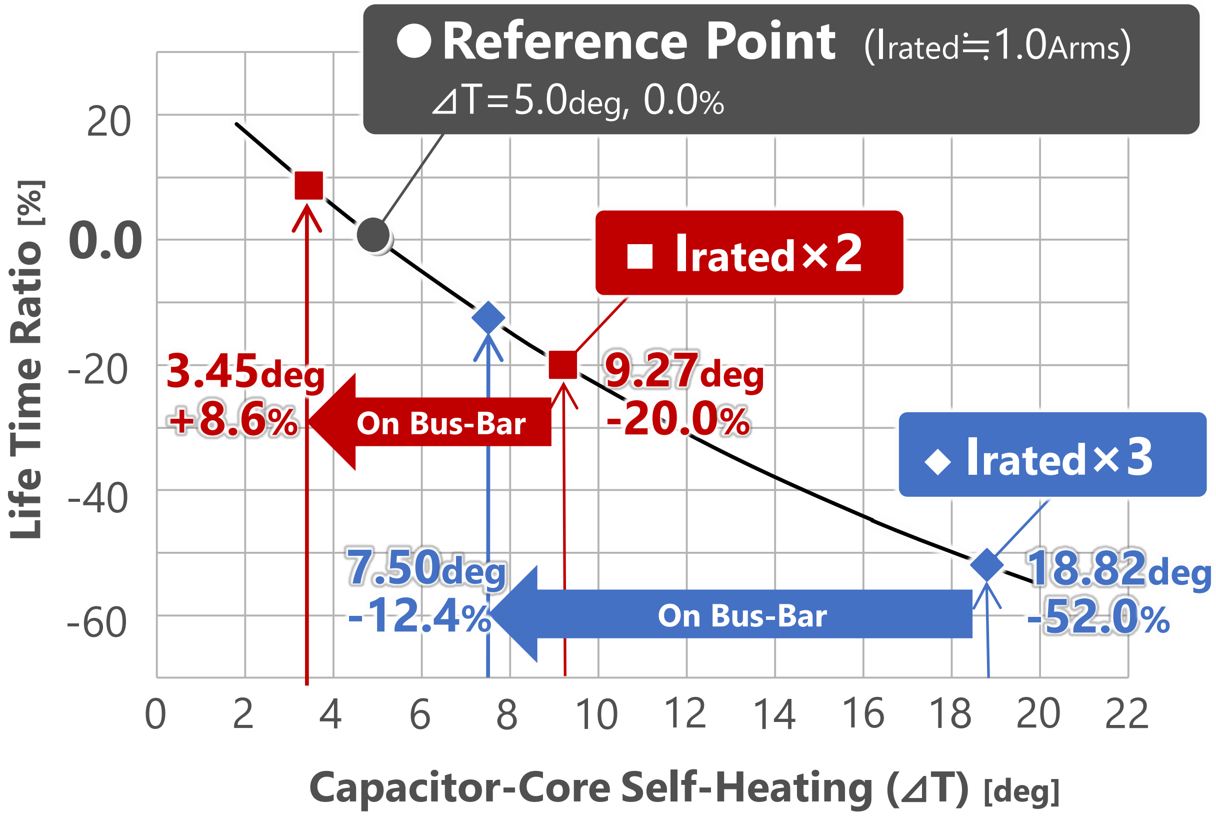
✓ It will be very possible to proceed the thermal management design of C-module with simulation prior to the final packaging design.

2-6. Outcome with Suitable Thermal Mgmt.

● ⊿T-Experiment



● Life time Simulation



✓ **With effective thermal management**

- The core self-heat can be significantly reduce.
- The capacitor life can be improved because of it.

3. Life Analysis (Predicted Life at Worst Case Study)

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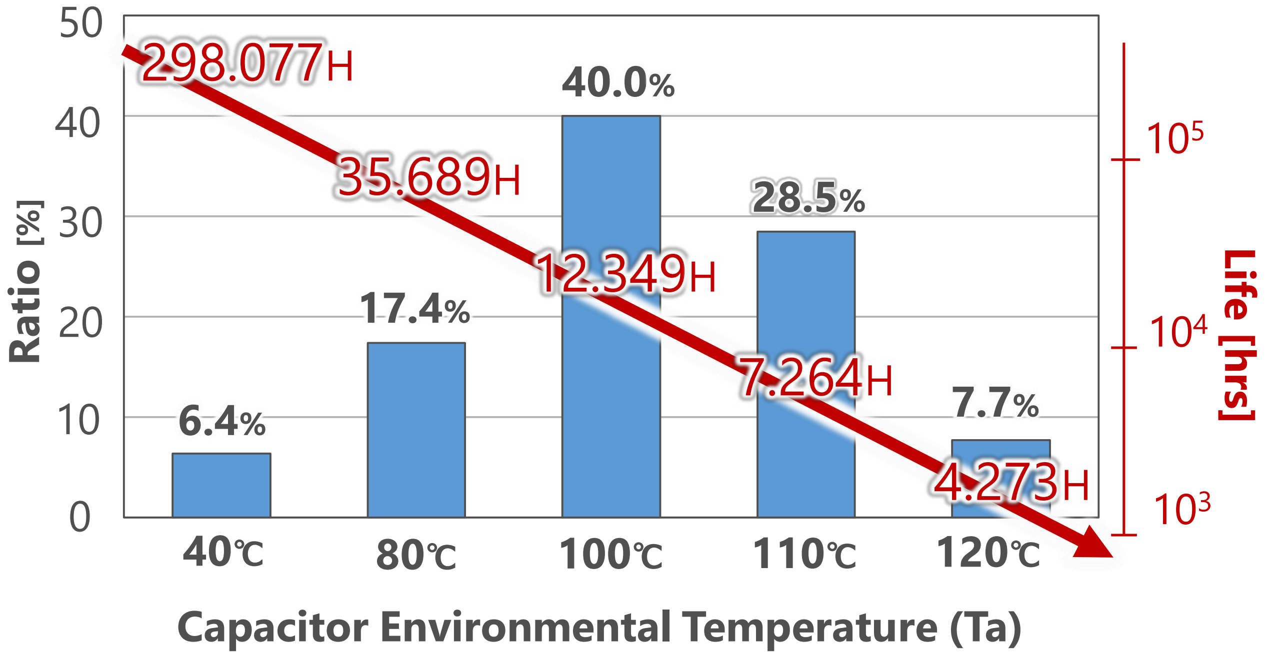
● Example of Worst Case Scenario

	48pcs. C-Module, 90Arms	
Numbers	**16**pcs. (1/3)	**32**pcs. (2/3)
Capacitance	98.6uF/pc. (+20%)	65.6uF/pc. (-20%)
Ripple Current	2.41Arms/pc.	1.61Arms/pc.
ESR	28.88mΩ/pc. (ESRave+4σ)	24.65mΩ/pc. (ESRave)
Self-heat Power	2.68W (**56.8**%)	2.04W (**43.2**%)
Core ⊿Tx	**11.20**deg	**4.98**deg



● Life Estimation Formula

$$L(\varDelta Tx, Ta) = Lo \cdot K_1^{K_2[(T_0 - T_a)+(\Delta T_0 - \Delta T_X)]} \quad \ldots\ldots \text{(1)}$$

● Combined Life Formula (Miner's Rule)

$$Life(module) = 1 \Big/ \sum_{n=1}^{m} \frac{Ratio_n}{L_n} \quad \ldots\ldots\ldots\ldots \text{(2)}$$

● **Predicted Module Life**

10,555hrs

● **Typical Life requirements**

8,000～9,000hrs

✓ Meets requirements of application!!

4. Conclusions

- An advanced new concept bus-bar has been proposed as a suitable thermal management solution.
- The hybrid capacitor modeling and simulation was performed and compared with actual temperature measurement.
- The low profile hybrid capacitor mounted on the new concept bus-bar has fully demonstrated that efficiently handles heat generated by the high ripple current.
- Life of new module under the assumption of worst case scenario meet passenger vehicles life requirement.

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Thank you for your kind attention

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