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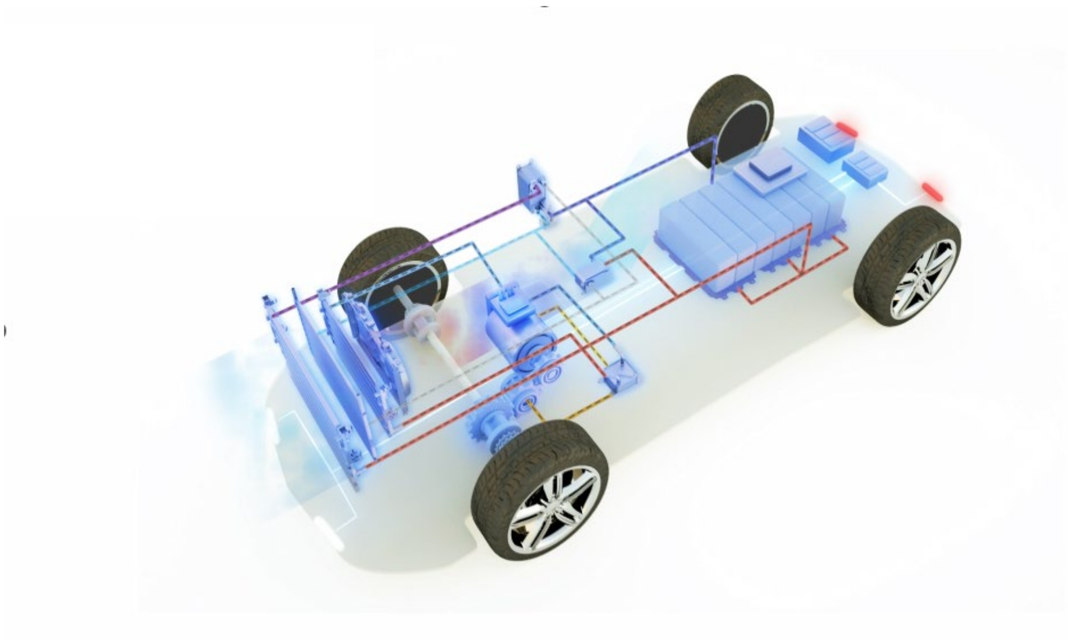
COOLING CHANNEL OPTIMIZATION IN POWER INVERTER DESIGN

Alpiovezza Fabio– R&D Power Electronics – ePT BU

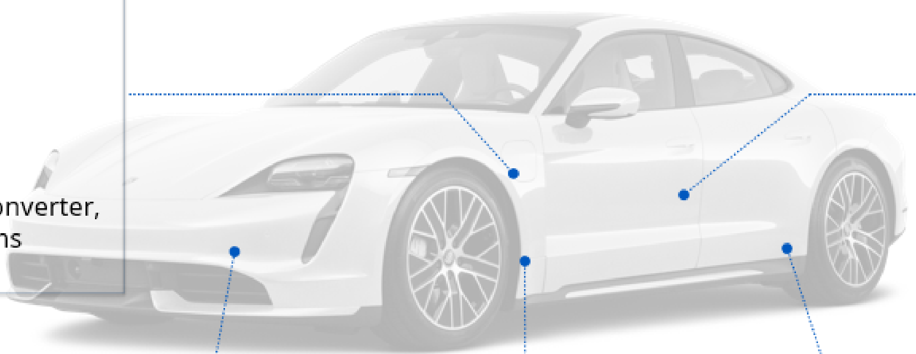
Introduction| Cooling channel optimization in power inverter design

Electric vehicle power electronics:

- Energy efficiency
- Cost optimized
- Weight optimized



Core technologies| Cooling channel optimization in power inverter design



Power Electronics

OnBoard charger, DC/DC converter, PDU and other electrical systems

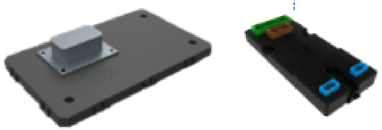
e-Motor

The traction motors must be designed according to the battery voltage range, with an impact on performance and validation

Battery Pack

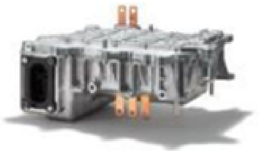
The battery pack is composed by several cells related to the required voltage

BMS



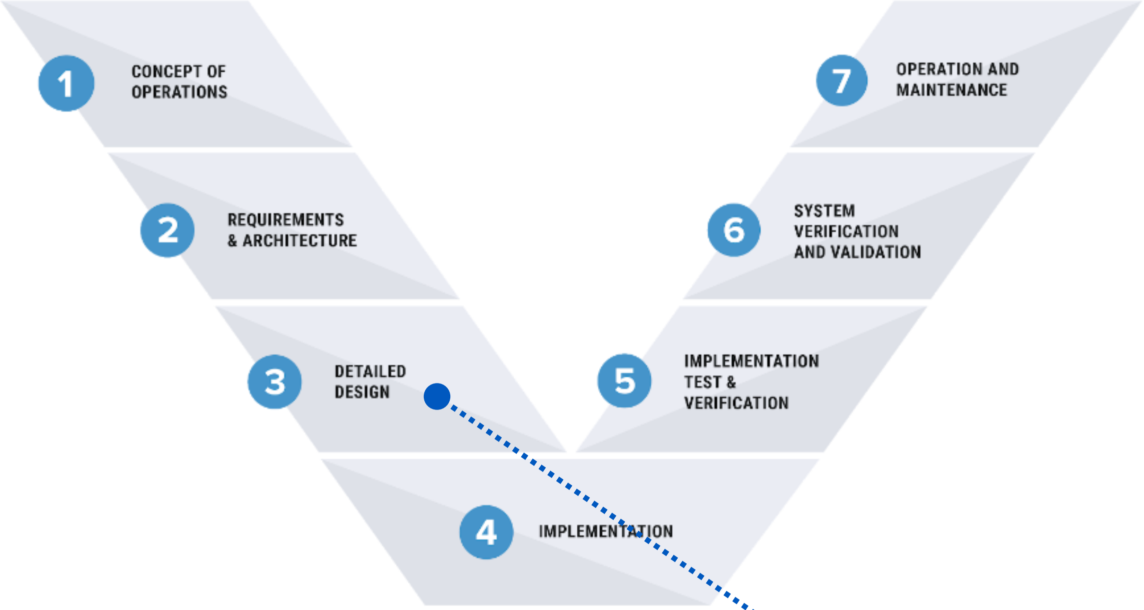
The BMS must be specifically designed for the battery pack, thus deedicated high voltage sensor and layout must be considered

Inverter



The inverter must be equipped with a DC link (filter and capacitors) specifically designed. Dedicated power module technologies related to performances

V workflow process| Cooling channel optimization in power inverter design



Design optmization

Baseline configuration| Cooling channel optimization in power inverter design

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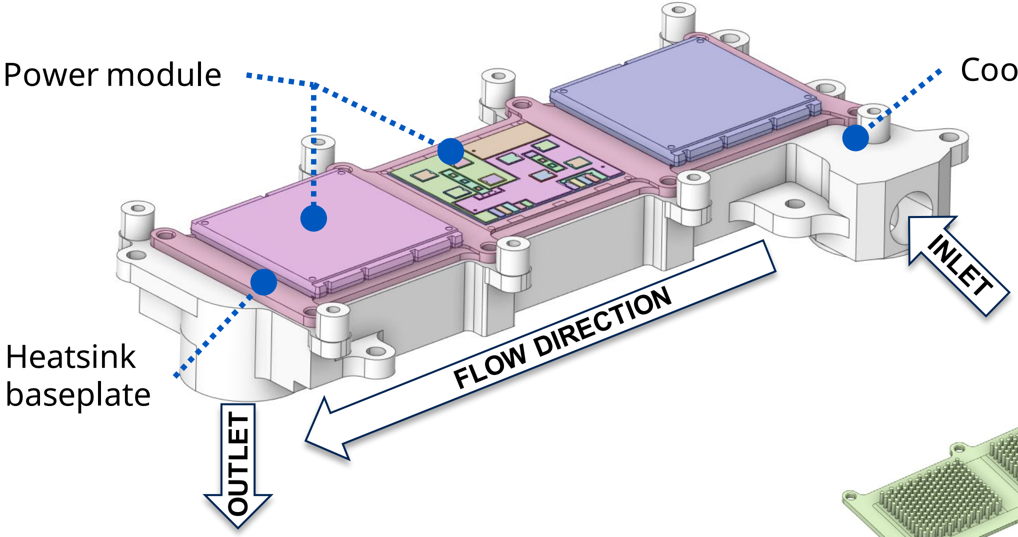
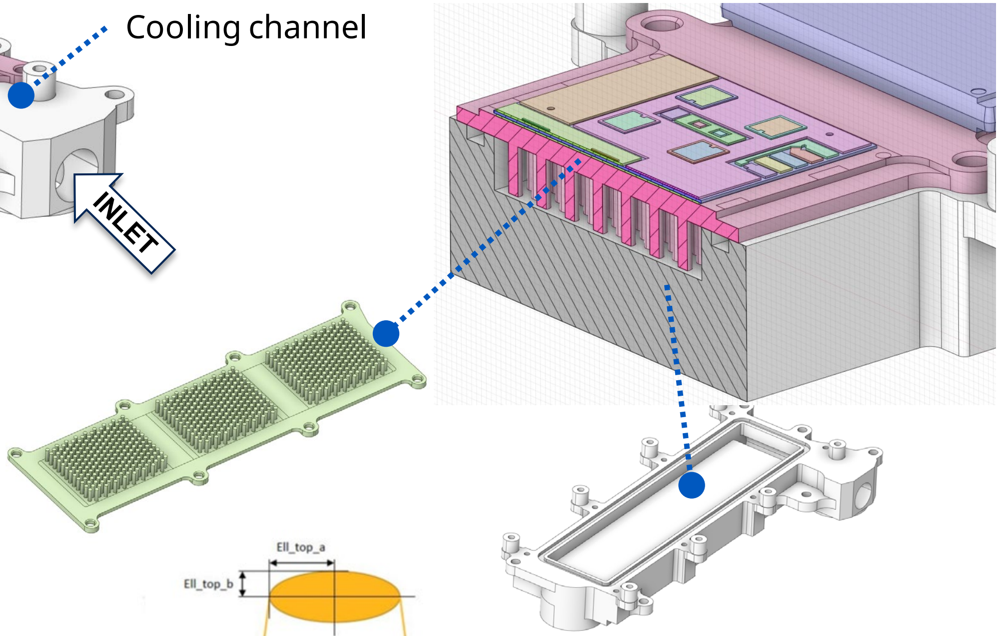
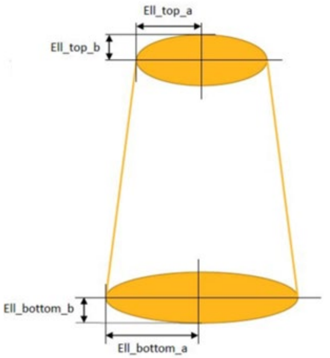




ID	PARAMETER
1	Elliptical shape of the pins
2	Channel width
3	Channel height
4	X spacing of pins
5	Y spacing of pins
6	Pin pattern angle
7	Pin orientation angle
8	X spacing dep on pins size
9	Y spacing dep on pins size
10	Constant channel gap
11	Constant pins height gap



Analysis| Cooling channel optimization in power inverter design

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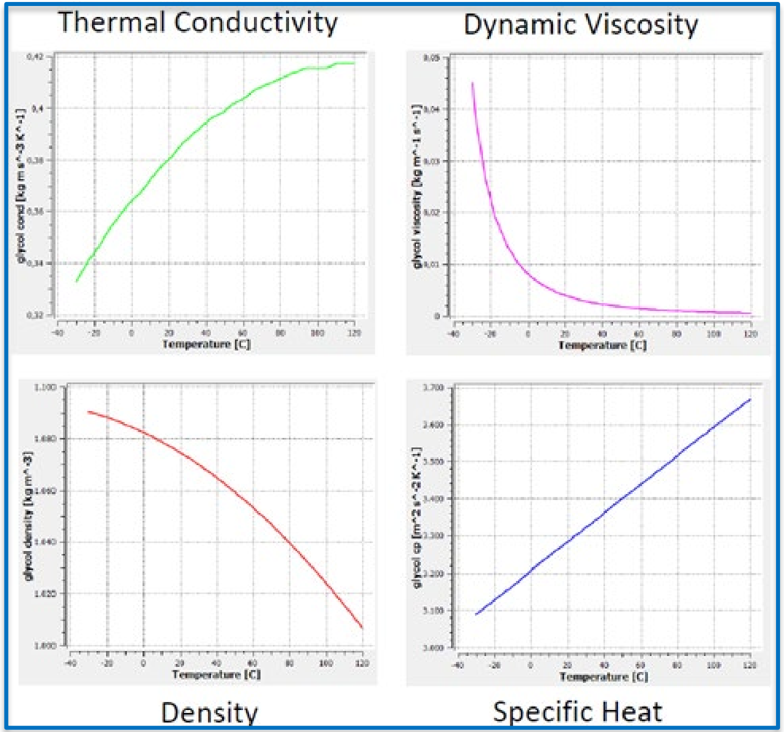
TYPOLOGY OF ANALYSIS		
CFD STEADY – STATE ANALYSIS		
MATERIALS		
HEATSINK	COPPER	
DIEs	SiC	
BOUNDARY CONDITIONS		
PARAMETER	**VALUE**	**UNIT**
FLOW RATE	8	lpm
INLET TEMP.	65	°C
HEAT SOURCE	160	W/die
TOT PWM LOSS	3840	W
CONSTRAINT		
PARAMETER	**VALUE**	**UNIT**
PRESS. DROP	$100 \leq \Delta p \leq 150$	mbar
COST FUNCTION AND OBJECTIVES		
FUNCTION	TEMPERATURE ON SiC DIEs	
OBJECTIVE	TO MINIMIZE FUNCTION	



Sensitivity analysis| Cooling channel optimization in power inverter design

SENSITIVIY MATRIX FOR DIE TEMPERATURES

Total effects

	Ell_bottom_a	Ell_bottom_b	Ell_top_a	Ell_top_b	Channel_Width	Channel_Height	Pin_Orientation_Angle	X_Spacing_Pin	Y_Spacing_Pin	Total
Max_T_Pad6_4	6.0 %	6.4 %	1.0 %	1.4 %	0.0 %	9.2 %	0.0 %	42.0 %	31.1 %	92.5 %
Max_T_Pad6_3	2.9 %	6.0 %	2.9 %	0.8 %		8.8 %		40.1 %	34.9 %	91.9 %
Max_T_Pad6_2	3.5 %	3.8 %	4.3 %			9.1 %		39.6 %	36.9 %	94.5 %
Max_T_Pad6_1	3.2 %	4.3 %	3.7 %			6.9 %		39.2 %	38.5 %	94.2 %
Max_T_Pad5_4	3.8 %	4.5 %	4.0 %			6.2 %		41.3 %	37.6 %	94.7 %
Max_T_Pad5_3	4.0 %	4.4 %	4.1 %			6.5 %		41.7 %	38.1 %	95.1 %
Max_T_Pad5_2	1.7 %	2.6 %				6.2 %		42.4 %	39.8 %	92.6 %
Max_T_Pad5_1	1.5 %	3.1 %				5.5 %		42.4 %	39.8 %	92.6 %
Max_T_Pad4_4	3.0 %	4.5 %	2.9 %	0.9 %		6.5 %		42.1 %	36.2 %	91.7 %
Max_T_Pad4_3	1.8 %	2.9 %				4.3 %		43.9 %	40.8 %	92.2 %
Max_T_Pad4_2	2.8 %	5.4 %	4.1 %	1.4 %		6.7 %		42.2 %	35.4 %	94.5 %
Max_T_Pad4_1	3.6 %	4.1 %	4.8 %			5.5 %		41.0 %	40.2 %	94.6 %
Max_T_Pad3_4	3.8 %	3.7 %	4.8 %			5.2 %		40.3 %	40.1 %	95.2 %
Max_T_Pad3_3	4.2 %	4.6 %	4.6 %			6.0 %		41.3 %	38.8 %	95.3 %
Max_T_Pad3_2	3.5 %	3.3 %	5.0 %			4.9 %		40.4 %	40.5 %	94 %
Max_T_Pad3_1	1.5 %	3.4 %				5.0 %		42.7 %	40.9 %	93.3 %
Max_T_Pad2_4	2.6 %	4.0 %	3.8 %		0.6 %	5.8 %		40.0 %	40.4 %	93.7 %
Max_T_Pad2_3	2.0 %	3.0 %				3.2 %		43.8 %	41.1 %	91.9 %
Max_T_Pad2_2	3.6 %	4.9 %	4.4 %			5.0 %		42.0 %	38.3 %	95 %
Max_T_Pad2_1	5.0 %	4.5 %	4.3 %			3.6 %		42.6 %	39.1 %	95.4 %
Max_T_Pad1_4	6.0 %	7.2 %	5.4 %	1.5 %		3.2 %		43.8 %	35.9 %	96.1 %
Max_T_Pad1_3	6.0 %	7.3 %	4.8 %	2.0 %		2.8 %		45.9 %	37.4 %	96.5 %
Max_T_Pad1_2	4.7 %	6.8 %	3.3 %	1.4 %		4.5 %		43.9 %	35.4 %	95.2 %
Max_T_Pad1_1	4.5 %	7.7 %	2.9 %	1.5 %		4.5 %		44.8 %	35.4 %	95.7 %

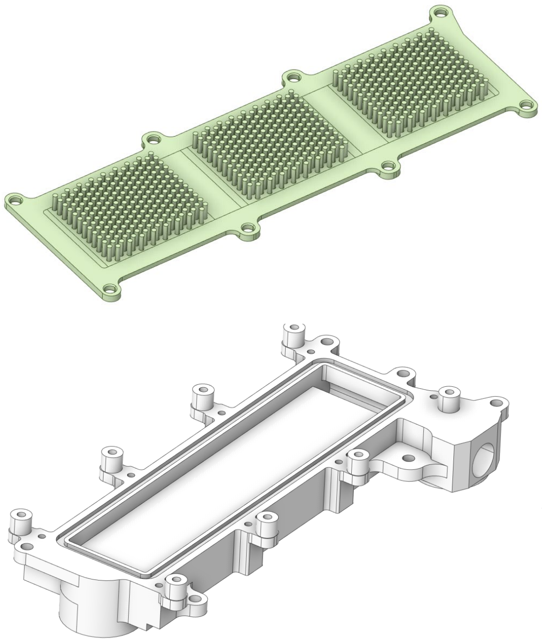
SENSITIVIY MATRIX FOR COOLING CHANNEL PRESSURE DROP

Total effects

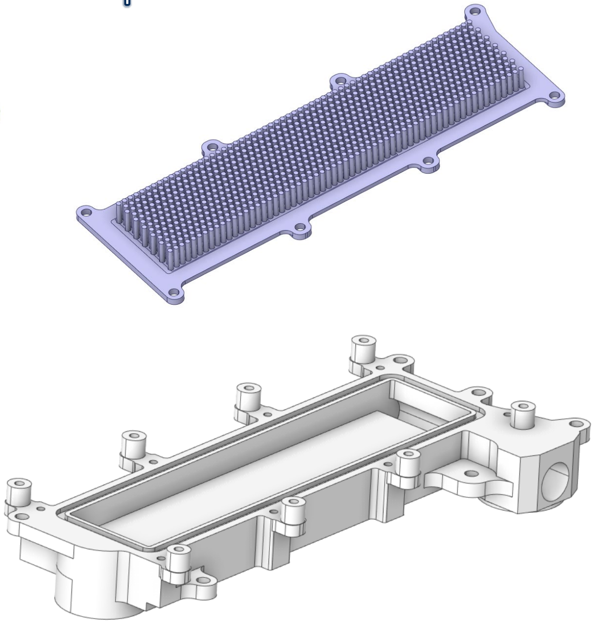
	Ell_bottom_a	Ell_bottom_b	Ell_top_a	Ell_top_b	Channel_Width	Channel_Height	Pin_Pattern_Angle	Pin_Orientation_Angle	X_Spacing_Pin	Y_Spacing_Pin	Total
p_plane4						86.5 %			0.8 %		87.5 %
p_plane3	2.3 %		7.9 %	3.8 %	2.8 %	68.7 %			14.9 %	14.4 %	93.1 %
p_plane2		18.3 %	28.3 %	0.0 %		48.0 %		0.0 %	53.1 %	34.4 %	93.2 %
p_plane1		8.4 %	20.6 %	3.4 %		26.6 %		6.3 %	43.9 %	30.5 %	88.3 %
p_outlet				7.1 %		59.0 %		15.1 %	17.5 %	11.0 %	68.9 %
p_inlet		11.9 %	15.5 %	3.2 %		53.9 %			51.3 %	39.4 %	93.2 %
dp_p4_outlet						86.9 %			1.1 %		87.5 %
dp_p3_p4	4.4 %			5.4 %	6.5 %	71.9 %			14.8 %	15.8 %	93.2 %
dp_p3_outlet	2.5 %		8.4 %	3.4 %	1.5 %	68.4 %			16.1 %	14.5 %	93.1 %
dp_p2_p3	0.0 %	0.0 %	22.9 %	2.9 %	18.6 %	51.6 %	0.0 %	8.1 %	55.9 %	47.5 %	93.3 %
dp_p1_p2		13.9 %	18.6 %	1.4 %		63.5 %			57.4 %	43.7 %	94 %
dp_inlet_p2		15.7 %	15.9 %	5.5 %	20.1 %	54.5 %	5.4 %	9.1 %	30.2 %	25.2 %	94.2 %
dp_inlet_p1			31.9 %		6.1 %	58.5 %		22.1 %	53.7 %	37.8 %	93.6 %
dp_inlet_outlet		11.1 %	16.0 %	2.7 %		52.5 %			56.7 %	41.4 %	93.2 %

Results – Opt design| Cooling channel optimization in power inverter design

Baseline



Optimum



HEATSINK DESIGN		
TYPE OF PINS	ELLIPTICAL PIN-FINS	
NR. OF PINS	787	
GEOMETRY CHARACTERIZATION OF HEATSINK PIN-FINS		
PARAMETERS	**VALUE**	**UNIT**
Ell_top_A	1	mm
Ell_top_B	1.1	mm
Ell_bottom_A	1.2	mm
Ell_bottom_B	1.3	mm
Height	10.3	mm
COOLING CHANNEL DESIGN		
PARAMETERS	**VALUE**	**UNIT**
CHANNEL DEPTH	10.8	mm
CHANNEL WIDTH	42	mm

Results – Δp and T | Cooling channel optimization in power inverter design

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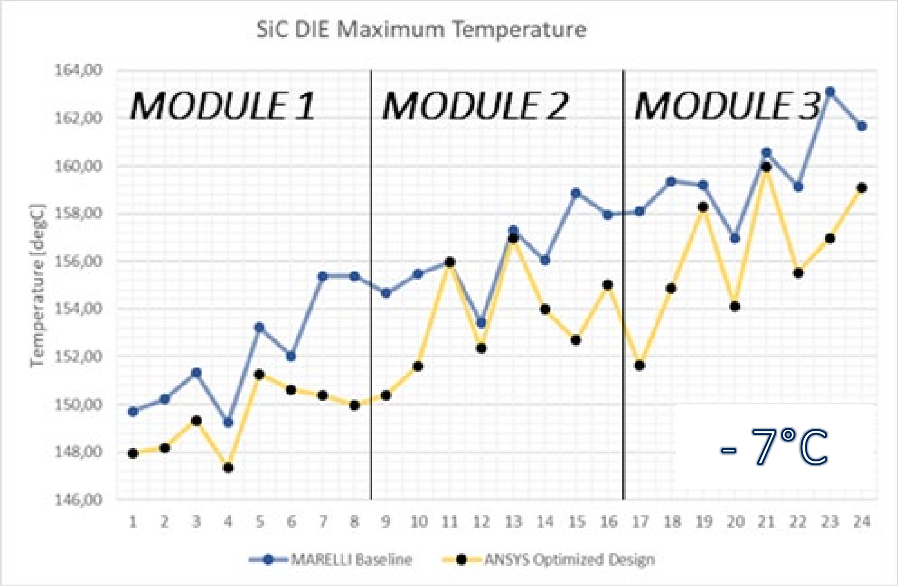
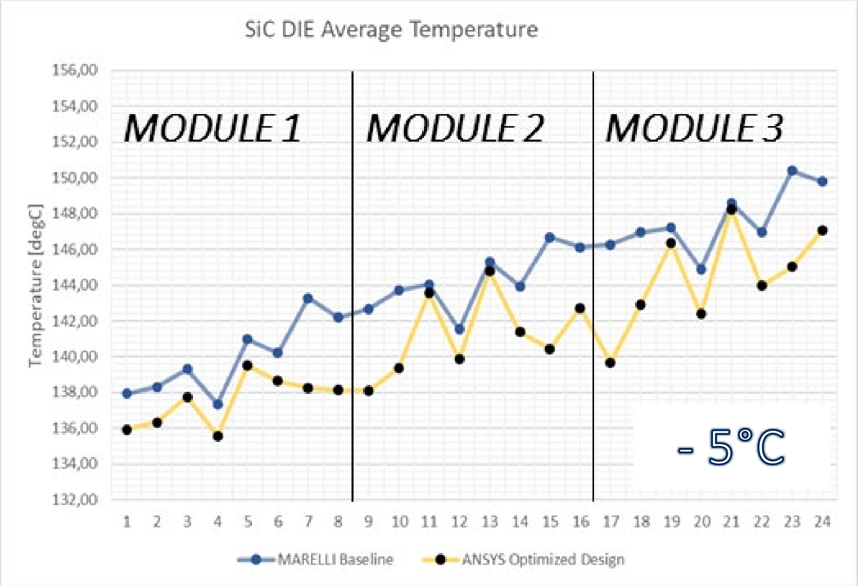
CONFIGURATIONS	Δp	UNIT
Baseline design	128	mbar
Optimum design	115	mbar
Δ	13	mbar
Δ	-10	%

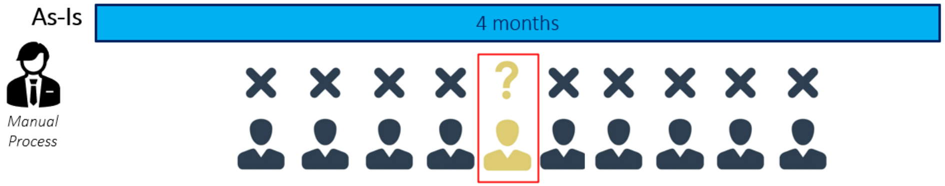




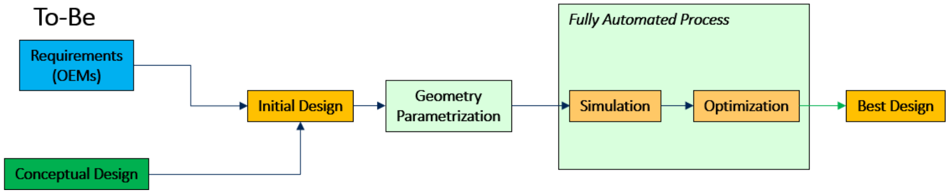
Conclusions| Cooling channel optimization in power inverter design

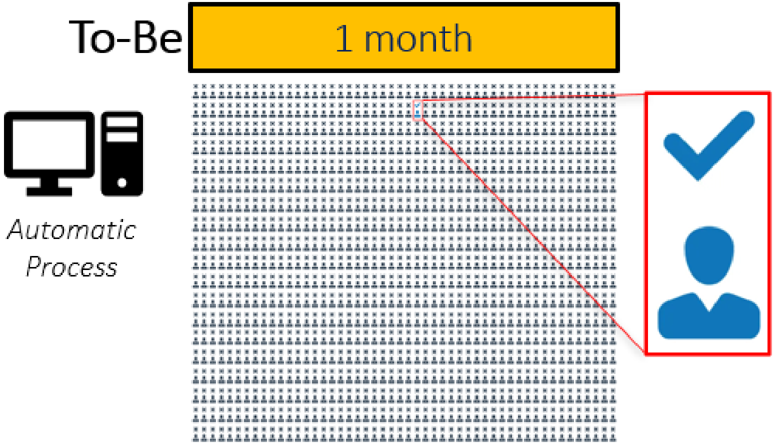
Reduction in time and cost improvement

As-Is



To-Be





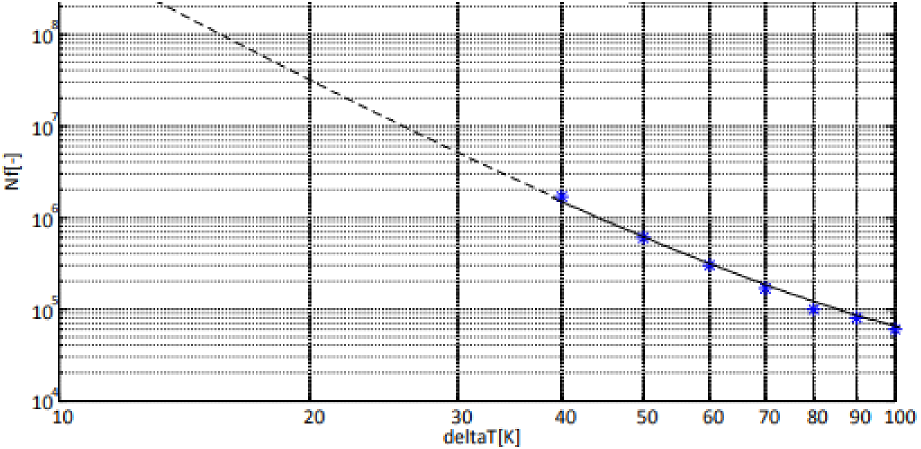
75% time reduction

75% cost reduction

Conclusions| Cooling channel optimization in power inverter design
Power module reliability and lifetime expectations

5% Rth improvement

~ 10% Increased lifetime expectation



Test on samples scheduled to verify Rth improvement

AQG 324 test scheduled to verify improvement on lifetime

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OUR VALUES

INNOVATION
DIVERSITY
COLLABORATION
SUSTAINABILITY
EXCELLENCE (Monozukuri)