2023中国电力电子与能量转换大会
暨中国电源学会第二十六届学术年会及展览会
2023 China Power Electronics and Energy Conversion Congress
& The 26th China Power Supply Society Conference and Exhibition

Navitas GaNSafe™ and GeneSiC™ Double Engine Drive Automotive Power Future

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广州, 2023.11.13

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Outline

- New Energy Vehicle Market Trend
- Automotive Power Converter Trend
- NVTS GaNFast™ and GeneSiC™ Hybrid Solution For Auto Power
- Summary

New Energy Vehicle Market Trend

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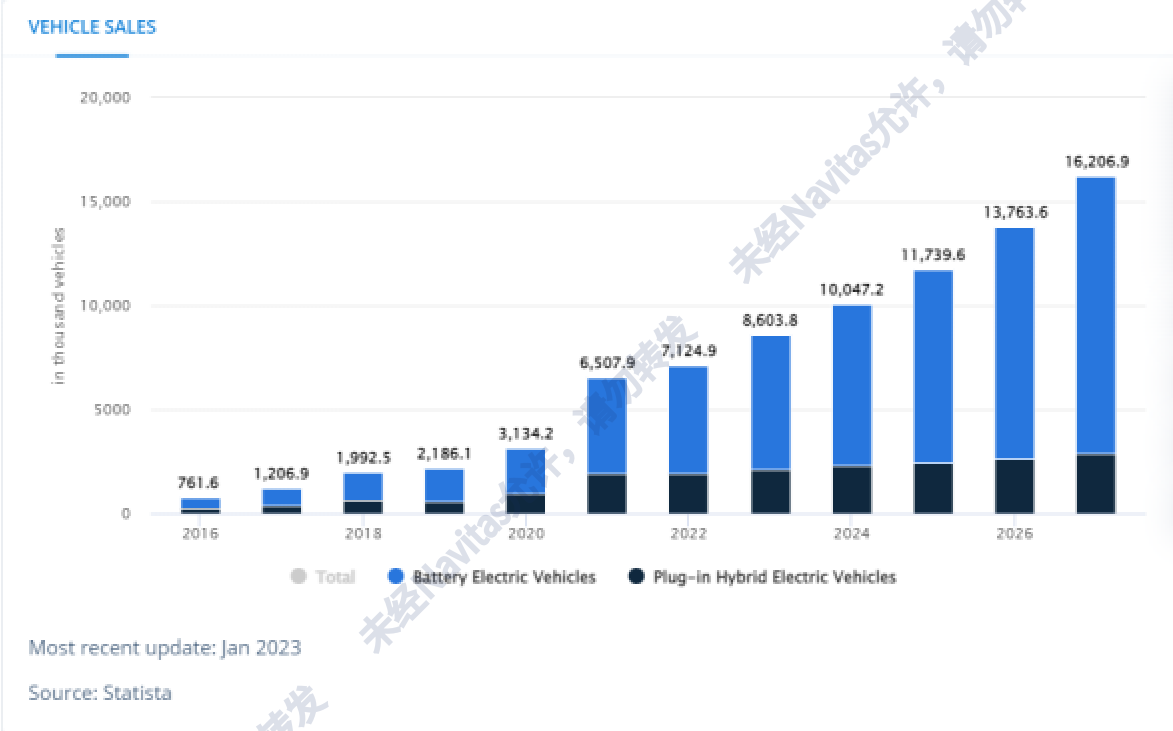
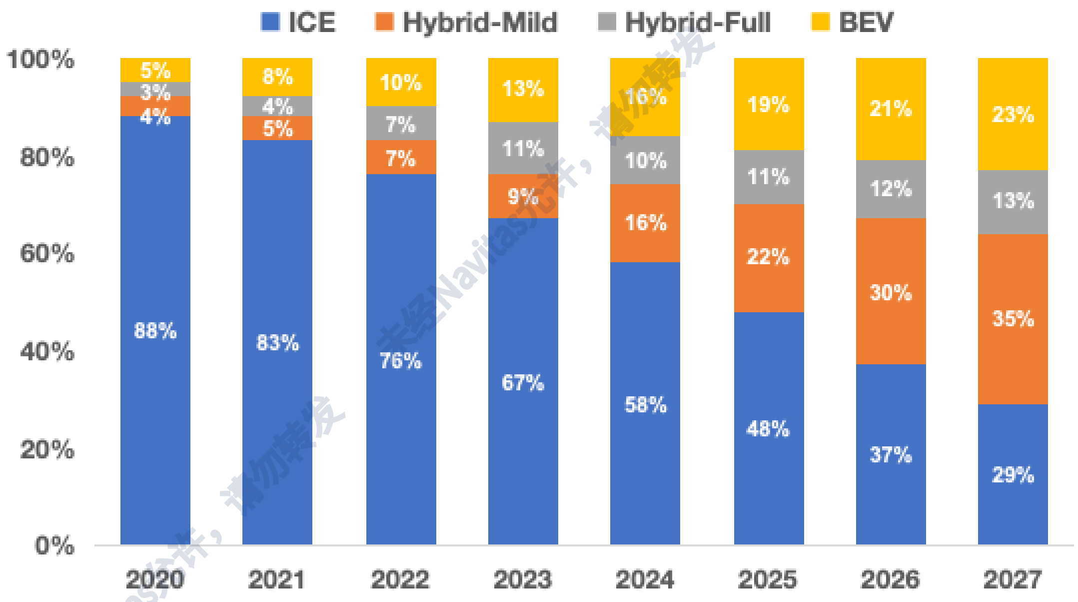
■ Global EV market trend 2016-2027



■ Chinese NEV Market trend 2020-2027



- BEV market grows fast in the next few years;
- China will be the world's largest EV market in the future;
- In China market, till to 2027, almost 70% passenger vehicle market will be occupied by electrification vehicle;
- Among these, BEV market share will be about 23% till to 2027;

EV Power Opportunity

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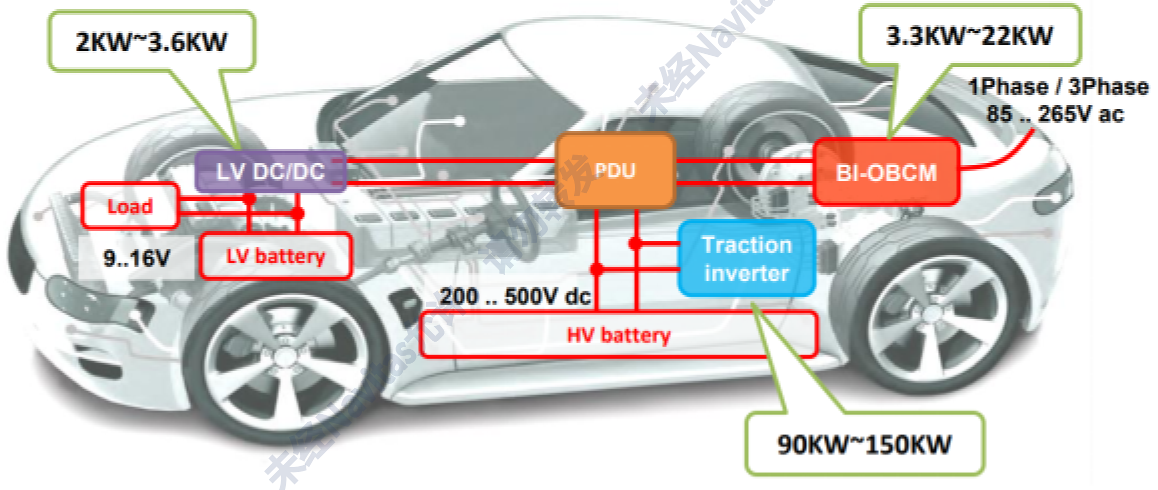
On board Auto-power

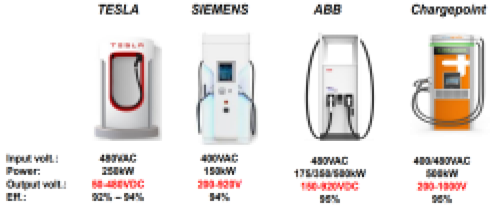


- Traction inverter (TI), On-Board-Charger(OBC), DCDC and Power Distribution Unit (PDU) are the four main power units in the EV.

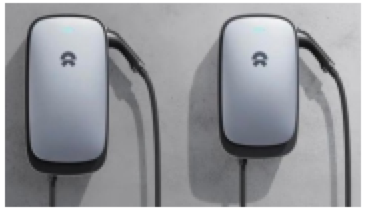
Off board Auto-power

HVDC fast charging power module

- 3PH 25-75KW power module
- 200V-1000V wide output range
- Fan coolant or liquid coolant



HVDC wall box charger



- 1PH 6.6KW
- 3PH 11KW/22KW
- 200V-500V/200V-1000V wide output range
- High to 55deg.c AMB requirement

OBC Product Introduction

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- 3ph high power OBCM will be the mainstream in EU market, and 3ph compatible with 1ph is necessary;
- 1ph 6.6kw OBC will still be the mainstream in CN market;
- 1ph 11kw~19.2kw OBC will be the mainstream in US market;
- Bidirectional function will be a must in CN and US market;

Region	AC Grid	Main Stream OBC Power Rating	Optional OBC Power Rating	Bidirectional function
China	1PH&3PH 220Vac	1PH-6.6kw	3PH-11kw/22kw compatible with 1PH-6.6kw	Needed
North America	1PH 120Vac/208Vac/240Vac	1PH-11kw	1PH-19.2kw	Needed
Europe	1PH&3PH 230Vac	3PH-11kw compatible with 1PH-7.2kw	1PH-7.2kw or 3PH-22kw compatible with 1PH-7.2kw	Needed

HV-LV DCDC Converter Introduction

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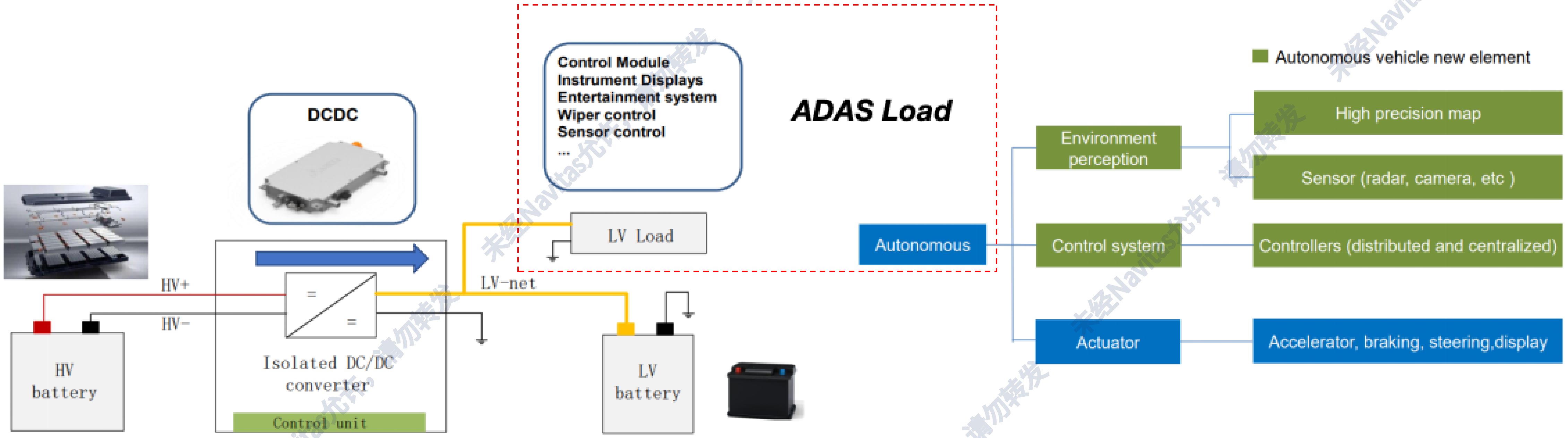

- DCDC mainly used to converter HV BAT to LV output to supply vehicle LV load;
- DCDC output usually cover from 9V to 16V and parallel with vehicle LV BAT;
- Power range from 2KW to 4KW and need to support functional safety because of ADAS system imported;
- BI-D DCDC requirement also come out to support pre-charge function to transfer energy from LV BAT to pre-charge capacitor in HV system;

EV HV Power Unit Trend

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5 **High power density for more compact size design**

- High frequency tech for **reduce component size**
- **Integrated magnetics** and advanced **packaging design**

High efficiency

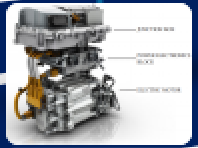
Small size

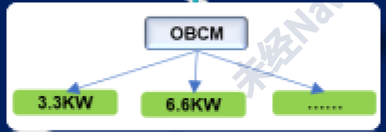
High power density

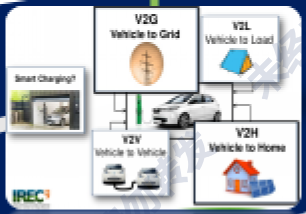
Low cost

4 **High Battery Voltage (800V)**

- Faster charging
- Less weight
- Less volume
- Higher power







3 **Compatible packaging design for more integrated functions**

- Flexibility for power & function upgrade
- Easy for OEM upgrade

2 **Power system integration (X in 1)**

- More compact size and light weight
- Reduced parts for cost saving
- System total cost saving

1 **Bi-D OBC for Mobile energy storage system**

- Additional discharge function (**V2L/V2V/V2H**)
- Compatible to support future **V2G** function

Design Challenges for EV Power

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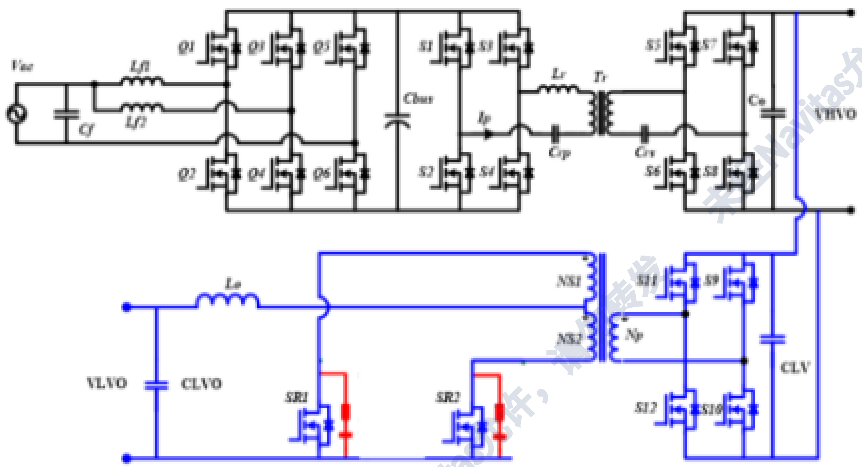
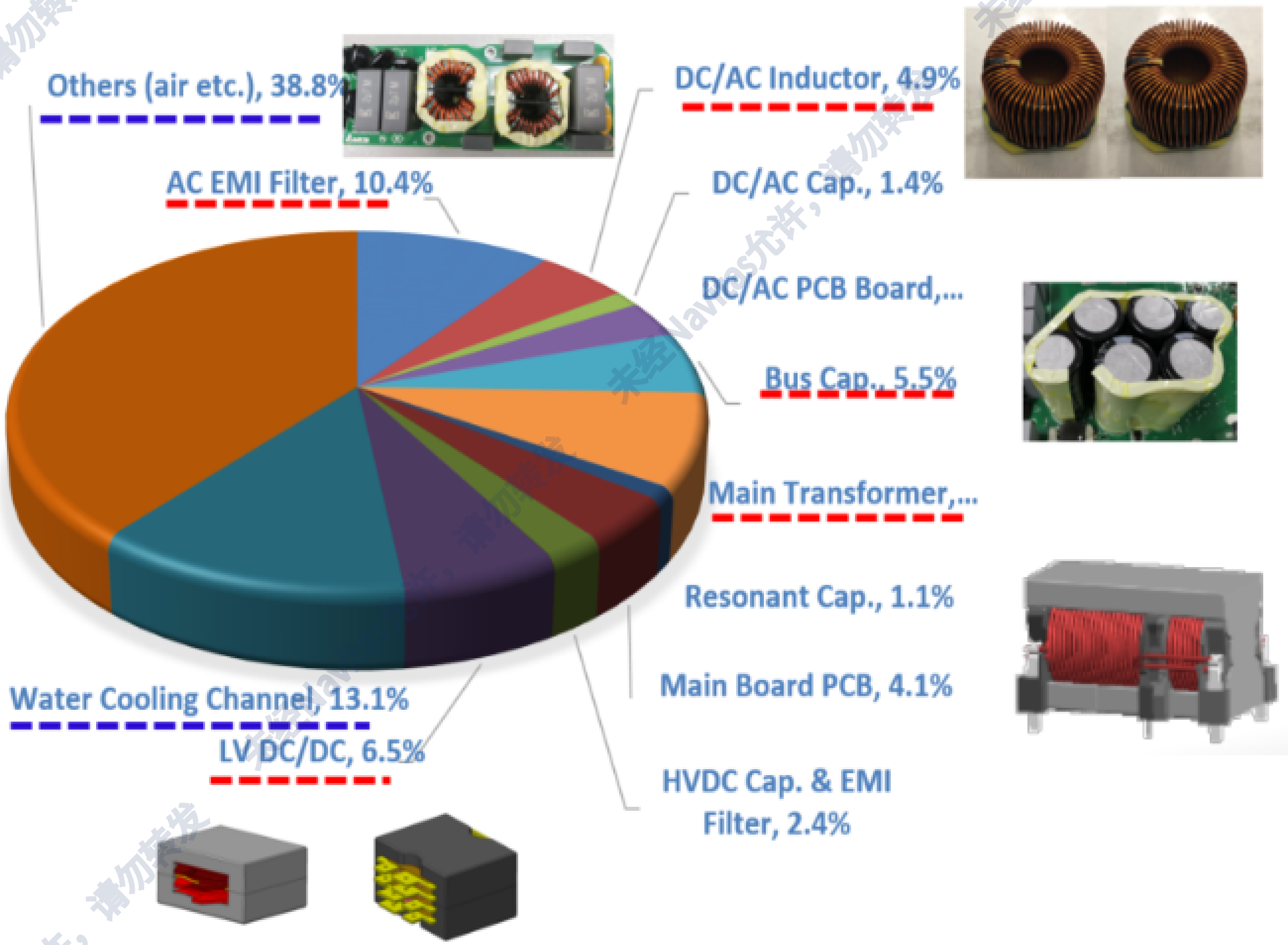
■ **Typical 2 in 1 Integrated PEU for example**



- Magnetic components account for 30% of the total volume；
- Bus cap. account for 5.5% of the total volume；
- Almost 50% of the volume is taken up by the structures and the waterway.

■ **The proportion of magnetic parts**



Design Challenges for EV Power

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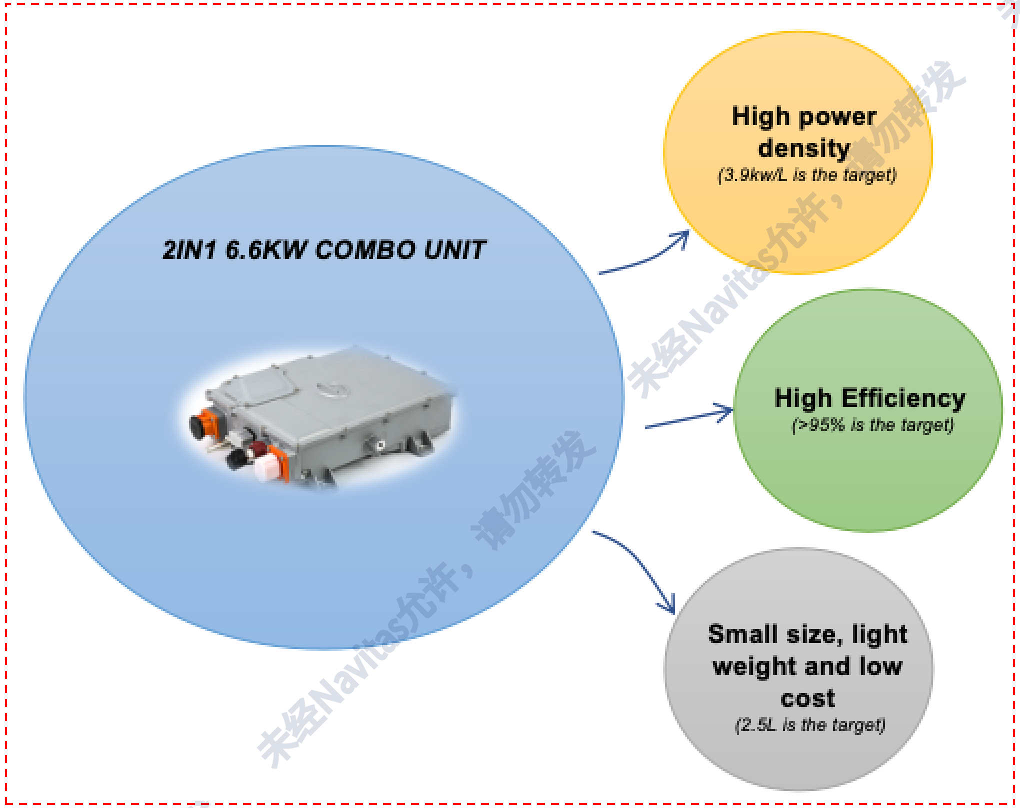

	Components (Volume%)	Solution
Electronic design with WBG device	EMI Filter (10.4%)	High frequency
	PFC choke (5%)	High frequency and integration
	Main TR.(8.4%)	High frequency and integration
	LVDC TR.+LO(6.5%)	High frequency and integration
	Bus Cap. (5.5%)	Active filter or new topology
	Film Cap.(3%)	High frequency
Mechanical design	Water cooling channel (13%)	Low power loss and simple water cooling channel
	Others (38%)	Power module solution

High power density is the key and most challenge target to achieve

WBG device like GaN and SiC is the key to solve this challenge!

Characters Comparison of Si， GaN and SiC

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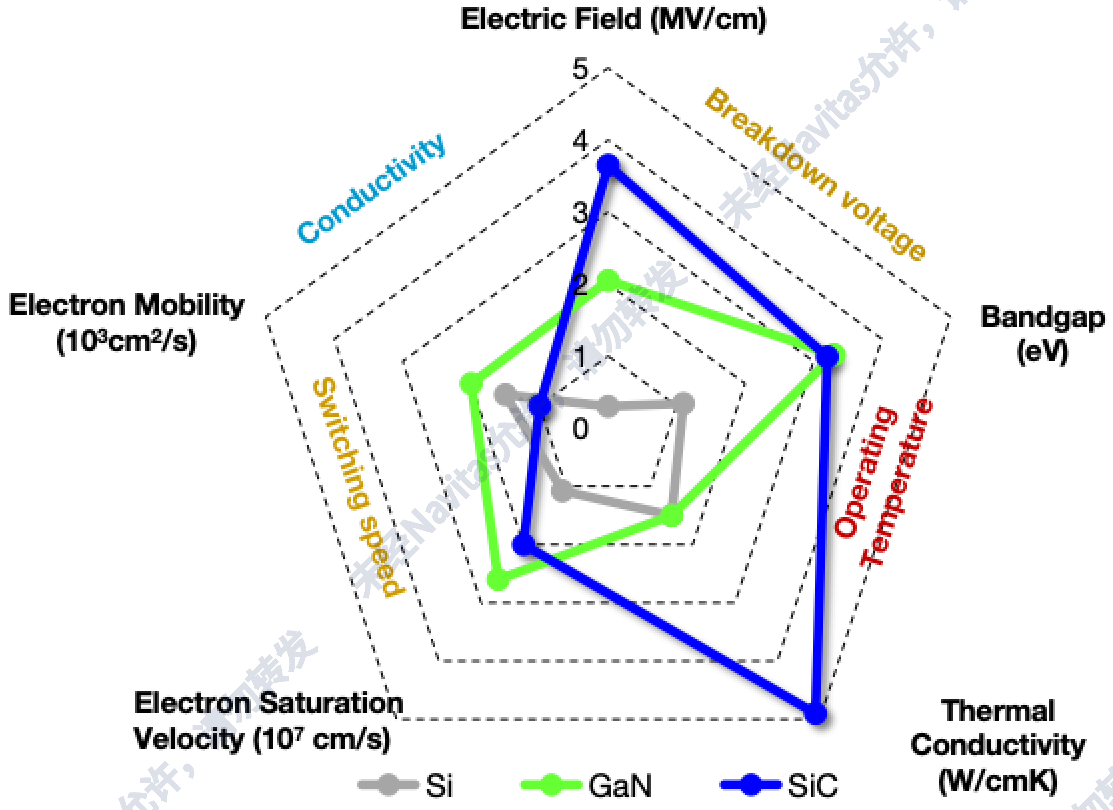
- Physical property comparison



	Si	GaN	SiC
Band gap energy (eV)	1.12	3.45	3.26
Melting point (×1000°C)	0.15	0.8	0.76
Thermal conductivity (W/m.K)	1.5	1.3	4.9
Ctritical electric field (MV/cm)	0.3	3.5	3.2
Electron saturation velocity (10^7cm/s)	1	2.5	2
Electron mobility (×1000 cm^2/Vs)	1.4	1.8	0.9

- SiC and GaN taken as the 3rd WBG device;
- 3rd WBG device had a huge advantage in switching speed, FOM, and thermal capability;

GaN Feature Compare with SiC

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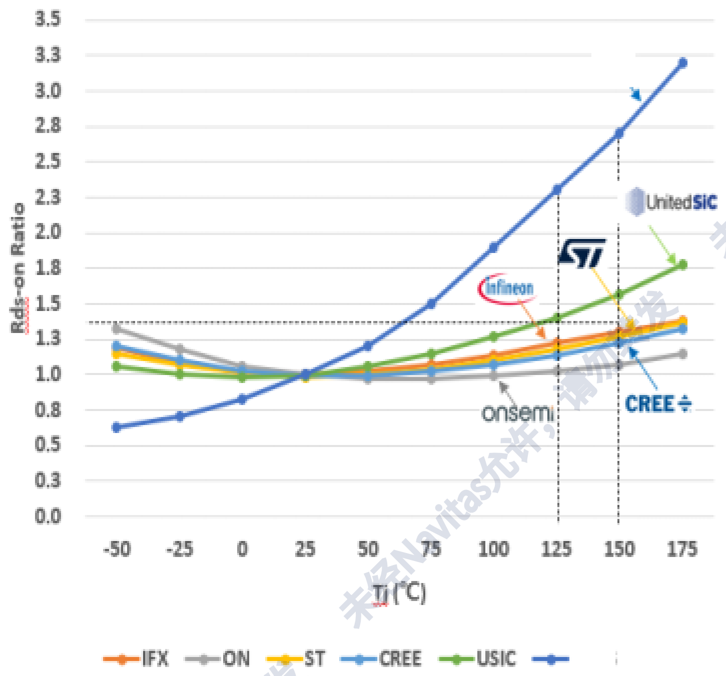
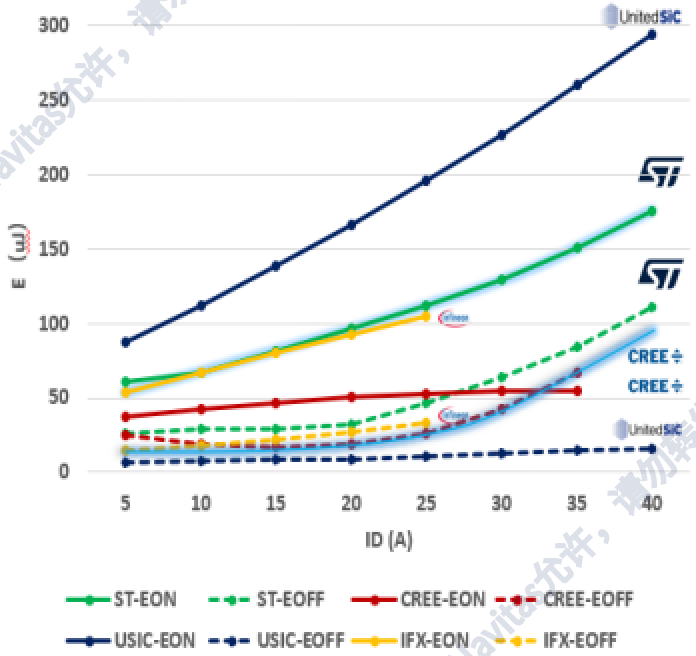
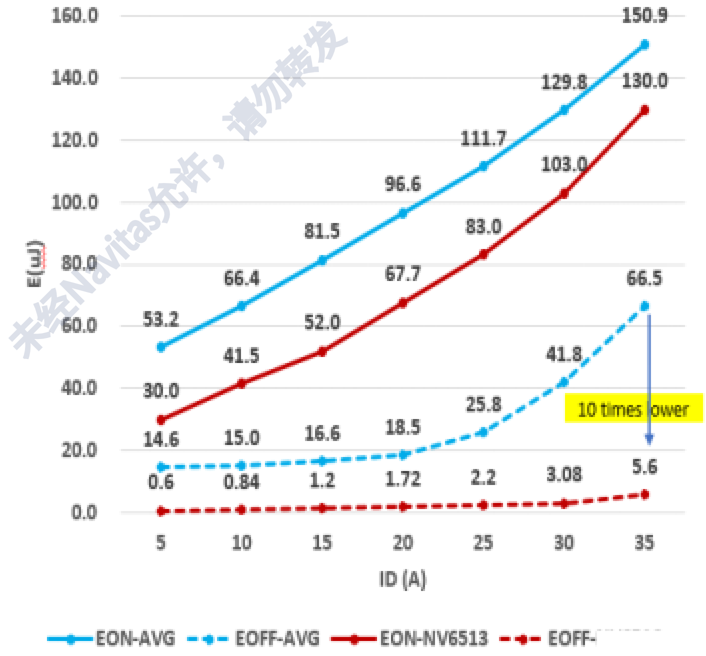
- **Rds-on ratio VS Tj for Sic and GaN devices**



- **EON and EOFF comparison between different SiC vendor**



- **EON and EOFF comparison between SIC and GaN**



- SiC MOS had much better Rdson increase ratio related to junction temperature features than GaN;
- GaN has a little better turn on performance with SiC MOS;
- GaN has much better turn off performance than SiC MOS;

GaN Feature Compare with SiC

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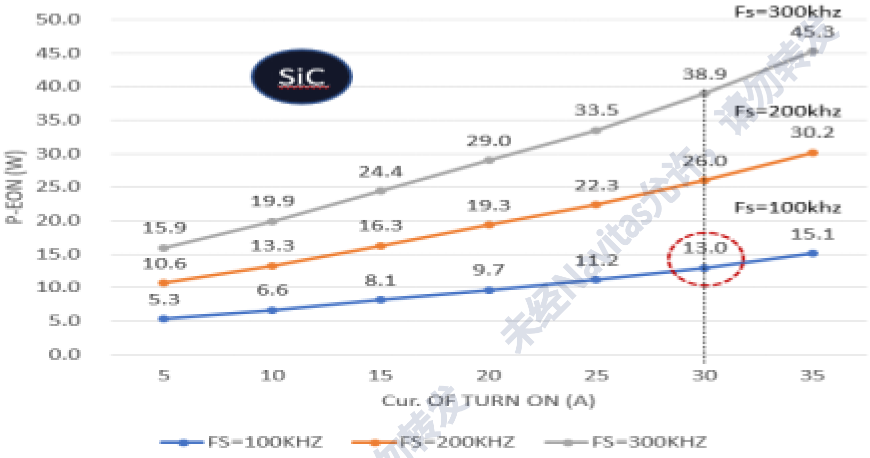
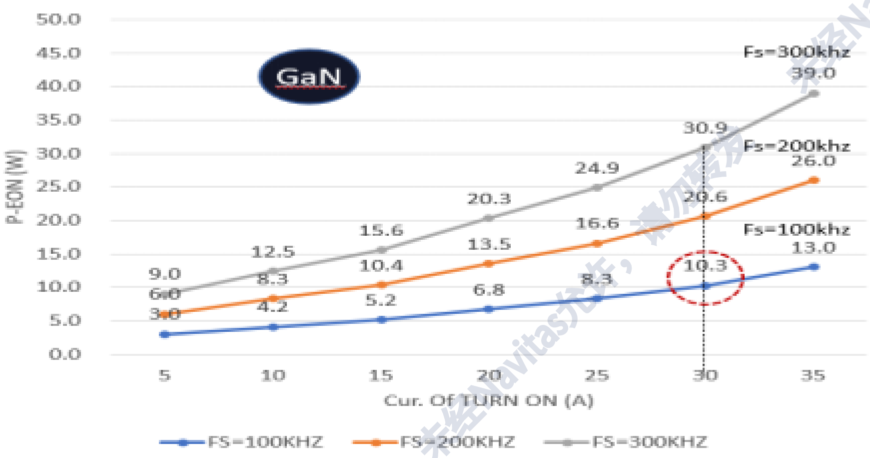
- EON LOSS VS switching frequency for SiC

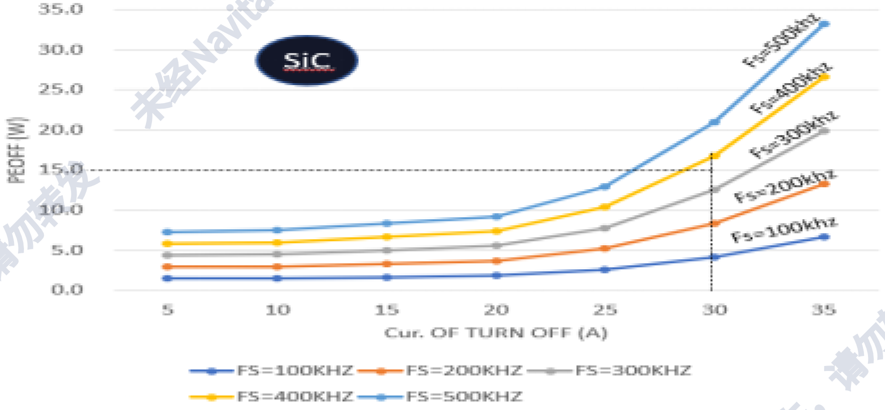


- EON LOSS VS switching frequency for GaN

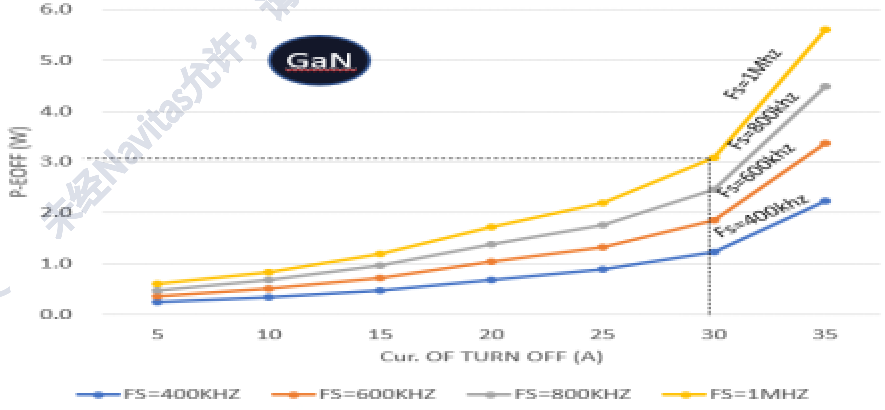


- If the max. Eon loss is 15W@30A, the max. switching frequency can be designed at about 100khz.

- EOFF LOSS VS switching frequency for SiC



- EOFF LOSS VS switching frequency for GaN



- EOFF loss is 15W@30A, the max. switching frequency can be designed at 300khz for SiC and above 500khz for GaN.

Benefit of GaN & SiC for High Power Density OBC

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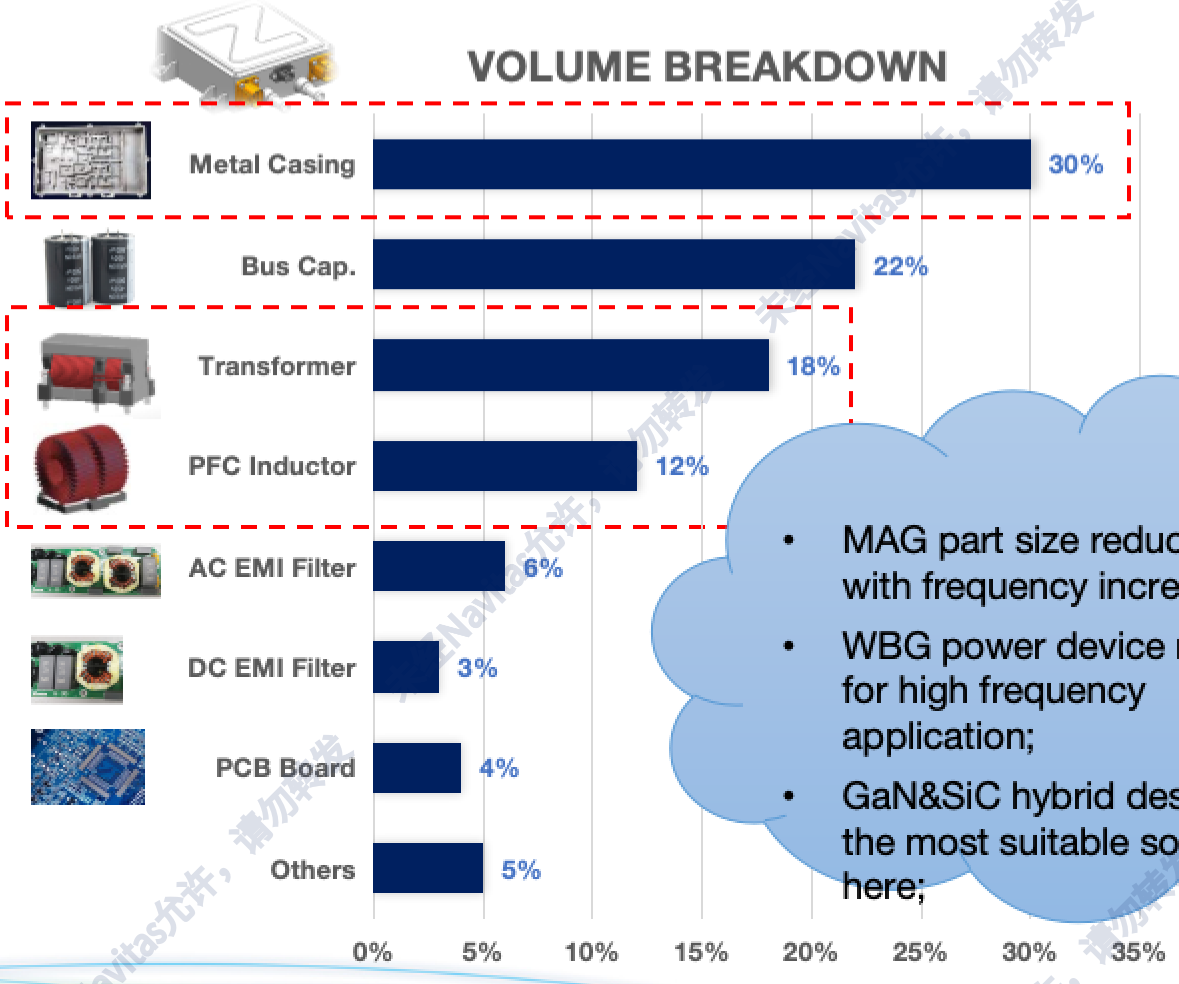
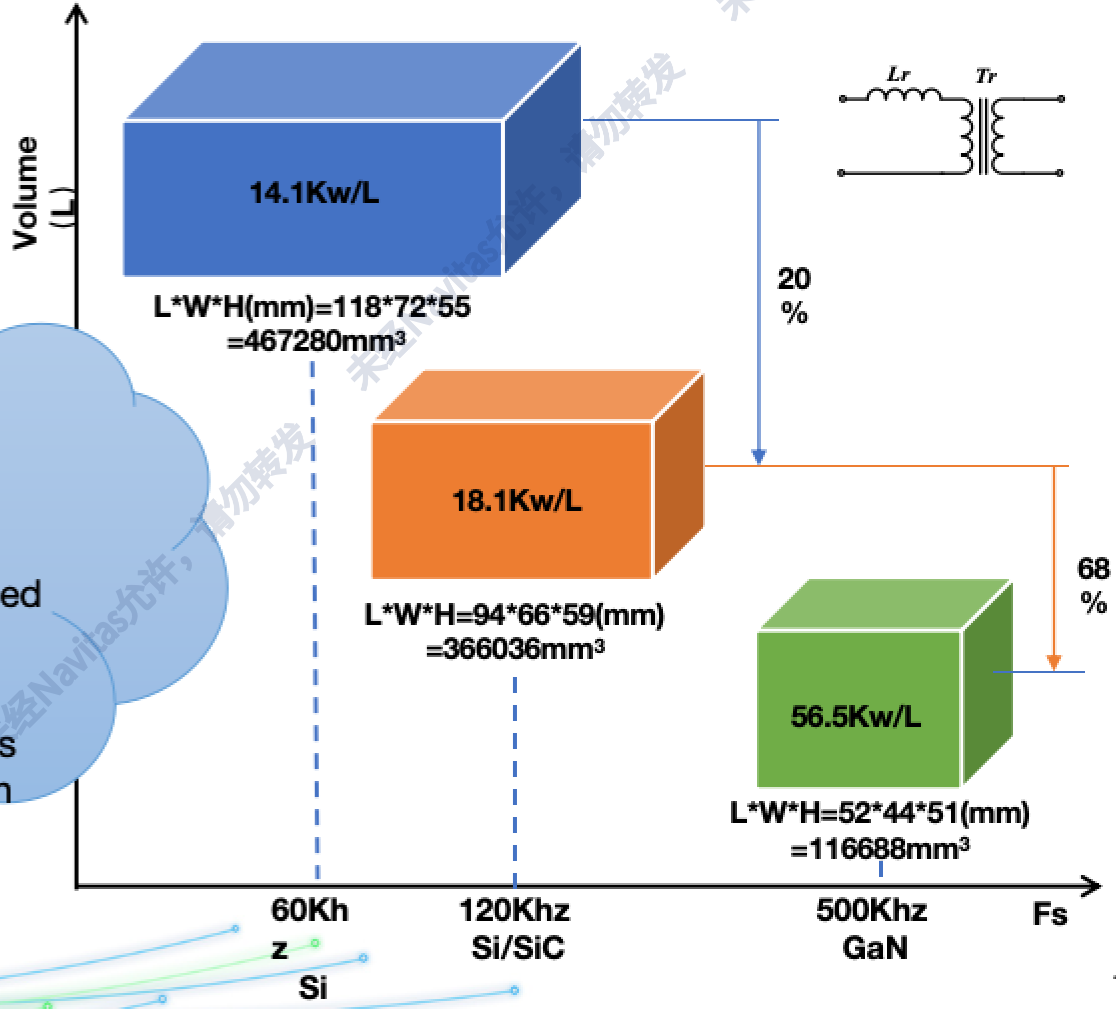
■ 6.6kW OBCM for Example



- MAG part size reduction with frequency increase;
- WBG power device needed for high frequency application;
- GaN&SiC hybrid design is the most suitable solution here;

■ 6.6kW OBC transformer for Example



Technical Challenge for GaN&SiC in EV

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Gate voltage limited

- Typically, GaN devices have VGS of under 10V, compared to 20V for silicon and SiC devices.
- Gate sensitive to overvoltage, better to be lower than 7V
- Small Vth around 1V, sensitive to noise
- Negative drive voltage needed in SiC for safe drive

High switching speed

- Too fast turn-off speed about 100v/ns dv/dt;
- Switching noise may impact other circuit;
- EMC issue maybe caused by fast switching;

GaN & SiC Device in EV

Weak avalanche breakdown capability

- VDS not allowed to be overstress;
- No avalanche capability;
- Weak short current withstand capability;

Package standardization

- Each supplier has its own GaN package to be reduce the package parasitic parameter as small as possible;
- Different GaN technology has its own package;
- Multi-source difficulty for customer;

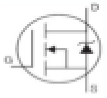
Reliability evaluation

- AECQ for automotive component qualification standard but not dedicate for GaN&SiC;
- JEDEC standard for GaN&SiC reliability test;
- Lack of reliability model;

August 15th, 2022: Navitas Semiconductor, industry-leader in gallium nitride power ICs, acquired GeneSiC Semiconductor, silicon carbide pioneer and industry leader

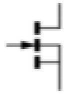
Navitas GaNFast™ Features

Si MOSFET GaN



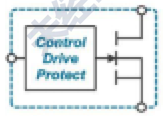
- Old, slow
- High Q_g
- High C_{OSS}
- F_{SW} < 100 kHz

Discrete



- dV/dt sensitivity
- Layout sensitivity
- ESD sensitivity
- Unknown reliability

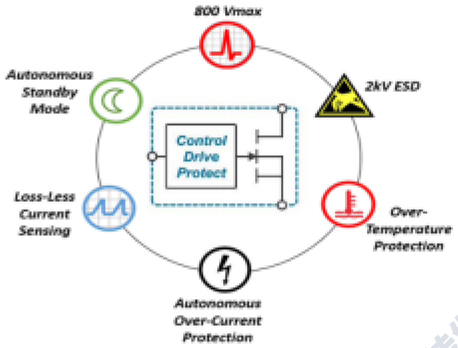
GaNFast™



GaNFast:

- ✓ Internal Gate
- ✓ Integrated Gate Drive
- ✓ dV/dt Immunity
- ✓ Layout Insensitive
- ✓ 2 kV ESD rating
- ✓ Proven Reliability
- ✓ Proven Robustness

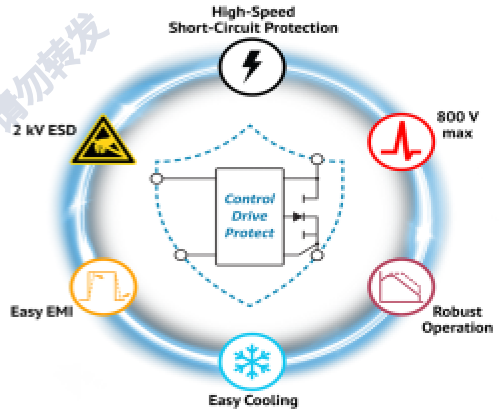
GaNSense™



GaNFast plus:

- ✓ Autonomous Standby
- ✓ Autonomous Protection
- ✓ Loss-less Current Sensing
- ✓ High Precision
- ✓ High Efficiency

GaNSafe™



GaNSense plus:

- ✓ Desat detect Short Circuit Protection with ultra-fast 300ns latency
- ✓ Robust, thermally enhanced packaging: ultra-low $R_{\theta\_JUNC\text{-}AMB}$ and BLTC Reliability
- ✓ 4th Gen integrated GaN gate drive with positive TempCo V_{GS} regulation
- ✓ Integrated Miller Clamp (no negative gate bias, higher 3rd quadrant efficiency)

Efficiency

Reliability

Speed

Integration

Navitas GeneSiC™ Features

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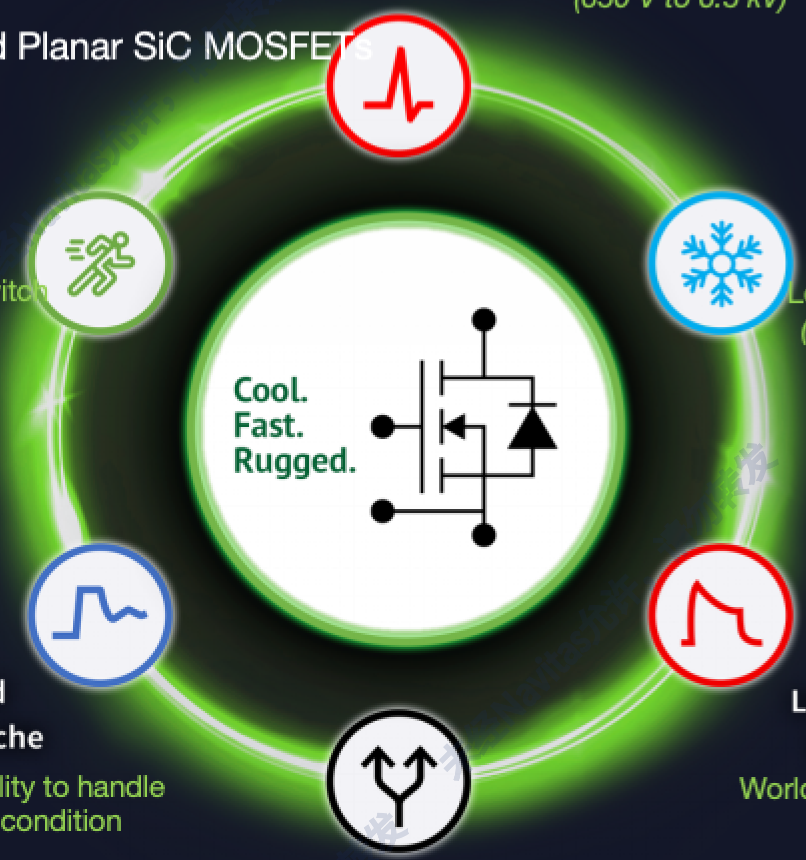
GeneSiC™

Patented Trench-Assisted Planar SiC MOSFETs



Up to 6.5 kV
Largest range of SiC FETs & diodes
(650 V to 6.5 kV)

Fast Switching
Highest efficiency hard-switch, soft-switch
(Lowest E_{ON}, E_{OFF}, E_{ZVS} losses)

Cool Operation
Lowest $R_{DS(ON)}$ at high temperature
(25% lower than industry typical)

100%-Tested Robust Avalanche
Highest published capability to handle excess energy in fault condition

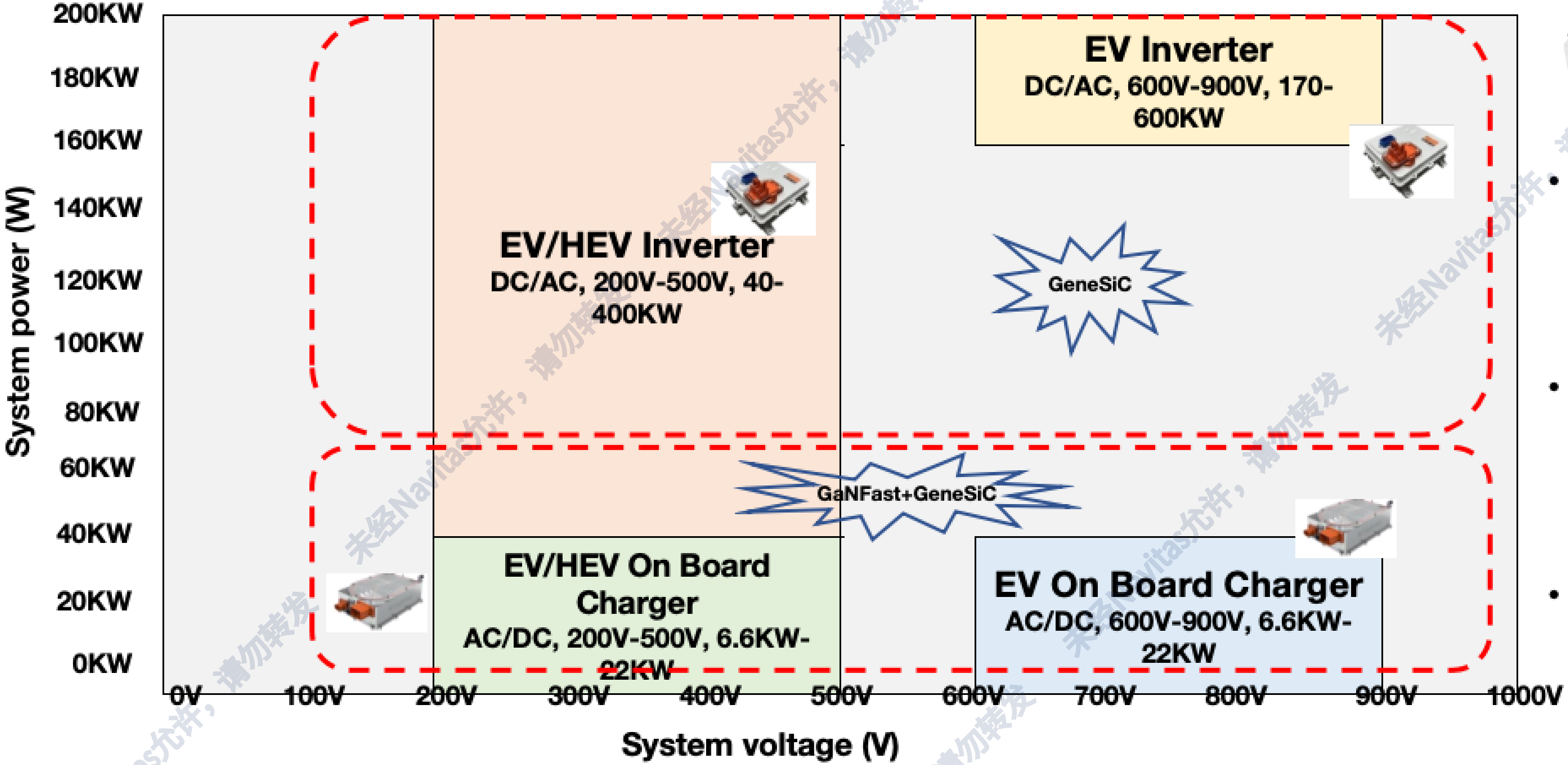
Long Short-Circuit Withstand Time
World-class survival duration in fault condition

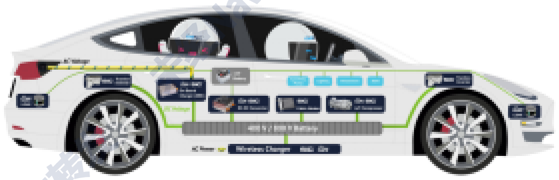
High-Power Paralleling
Matching currents
(Stable V_{TH})

Based on Navitas testing of 1200V SiC MOSFETs vs. competitor products

Navitas WBG Power Device Application in EV

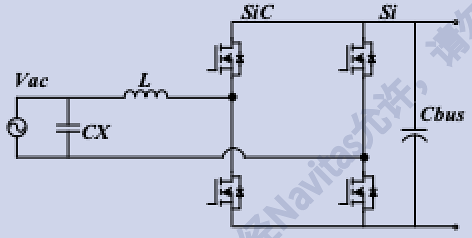
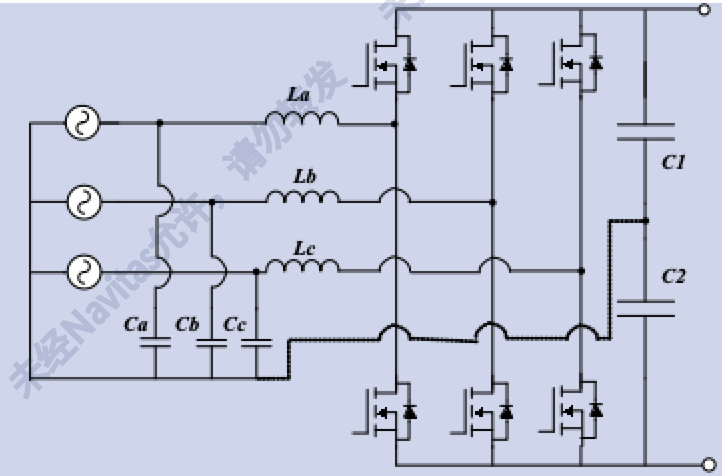
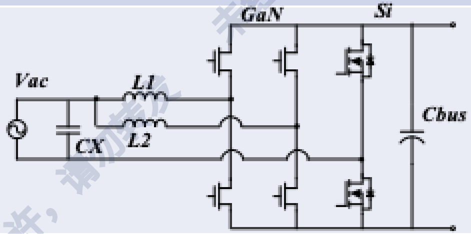
- GaN and SiC power device application in EV





- For GaN, mainly focus on the 400V BAT system for OBC and DCDC application;
- For SiC, mainly focus on the 800V BAT system for OBC and DCDC application;
- In EV inverter area especially in 800V BAT system, SiC will dominate this area with its high voltage performance;

Navitas GaNFast™ and GeneSiC™ Application in OBC

<table>
<tr><th>Name</th><th>Bi-directional DC/DC （400V）</th><th>Name</th><th>Bi-directional DC/DC （800V）</th></tr>
<tr><td>1ф 6.6kw Bidirectional AC/DC-SiC based</td><td>
</td><td rowspan="2">3ф rectifier Bidirectional AC/DC 1200V SiC based</td><td rowspan="2">
</td></tr>
<tr><td>1ф 6.6kw Bidirectional AC/DC-GaN based</td><td>
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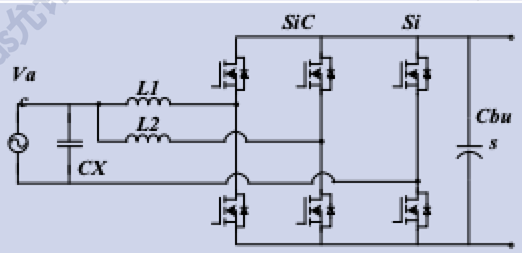
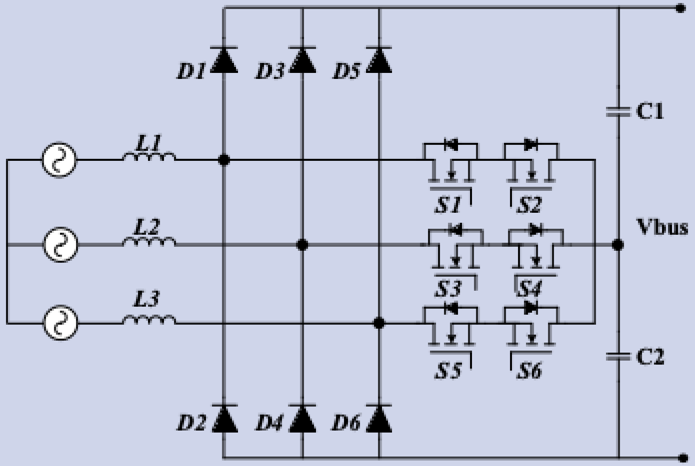
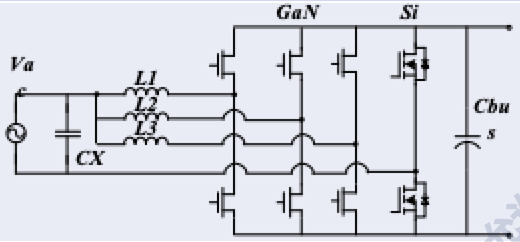
<tr><td>1ф 11kw Bidirectional AC/DC-SiC based</td><td>
</td><td rowspan="2">3Ø “T” Type unidirectional AC-DC converter 650V GaN or SiC based</td><td rowspan="2">
</td></tr>
<tr><td>1ф 11kw Bidirectional AC/DC-GaN based</td><td>
</td></tr>
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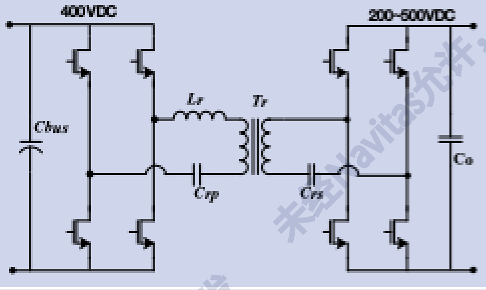
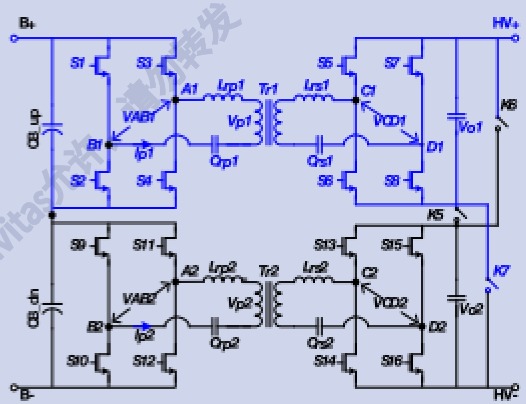
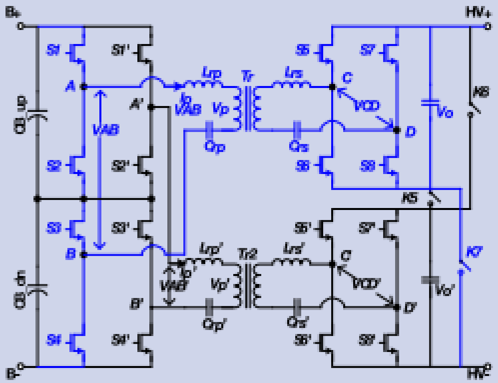
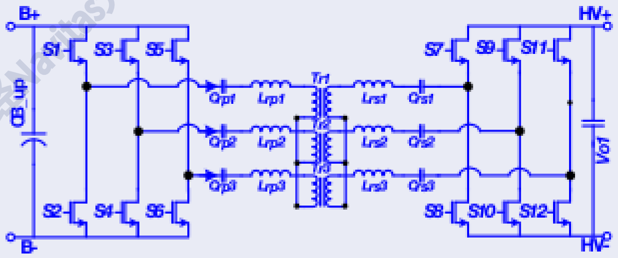
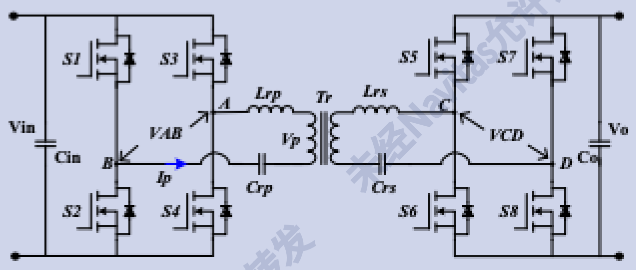
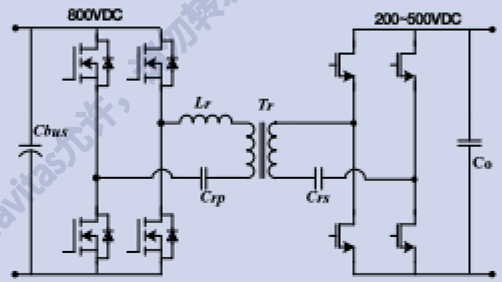
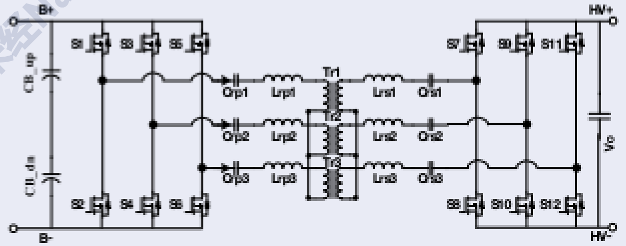
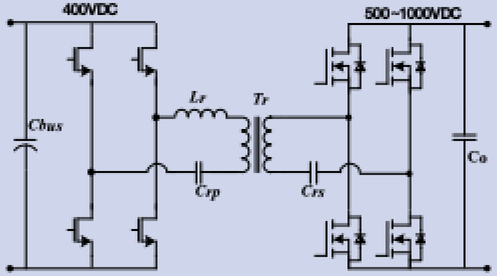
Navitas GaNFast™ and GeneSiC™ Application in OBC

Name	Bi-directional DC/DC (400VBUS)	Name	Bi-directional DC/DC (800V BUS)
6.6kW Bidirectional DC/DC 650V GaN or SiC based		11kW/22kwBidirectional DC/DC 650V GaN or SiC based	 
11kW Bidirectional DC/DC 650V GaN or SiC based			

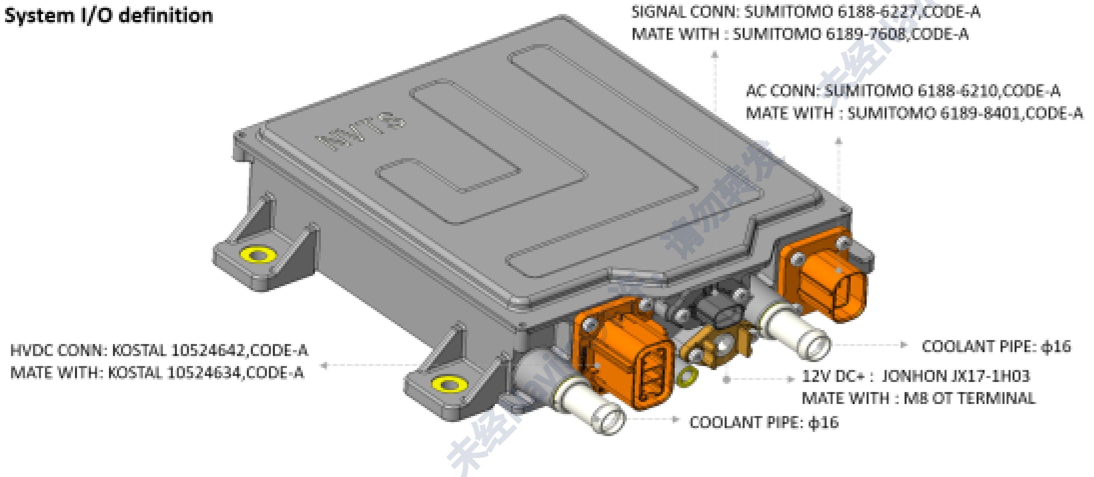
Navitas GaNFast™ and GeneSiC™ Application in OBC

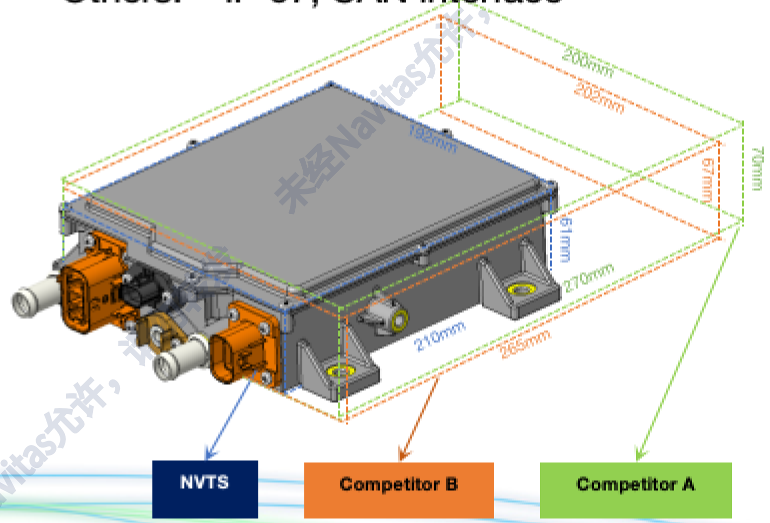
Name	Bi-directional DC/DC （800V）	Name	Bi-directional DC/DC （800V+400V）
11kWBidirectional DC/DC 1200V SiC based		6.6kW/11kwBidirectional DC/DC SiC+GaN based	
22kW Bidirectional DC/DC 1200V SiC based			

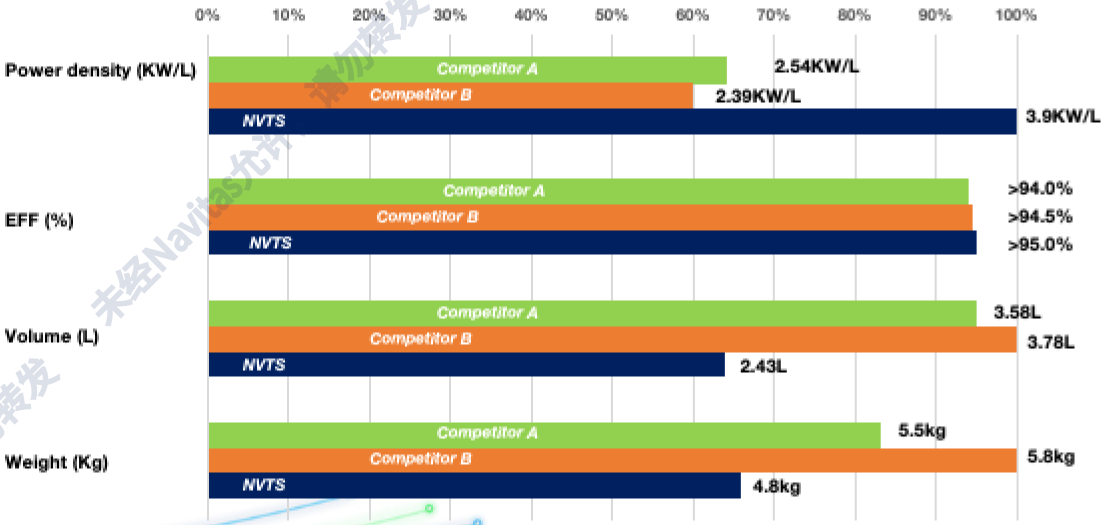
Navitas High Performance 6.6kw OBC 2in1 Combo

Navitas

- ✓ Bi-6.6KW OBC
- AC Voltage: 90 ~ 265Vac / up to 32A
- DC Voltage-400V version: 250~500V
- DC Voltage-800V version: 480~950V
- Power: 6.6kW for charging/6.0kVA for discharging
- Efficiency : > 95.0% @ full load
- ✓ 3.0KW DC/DC
- LV DC Voltage: 9~16V
- ✓ Dimension: 210mm x192mm x 61mm(<2.5L)
- ✓ Cooling: -40degC~65degC @ Liquid Cooling
- ✓ Others: IP 67, CAN interface



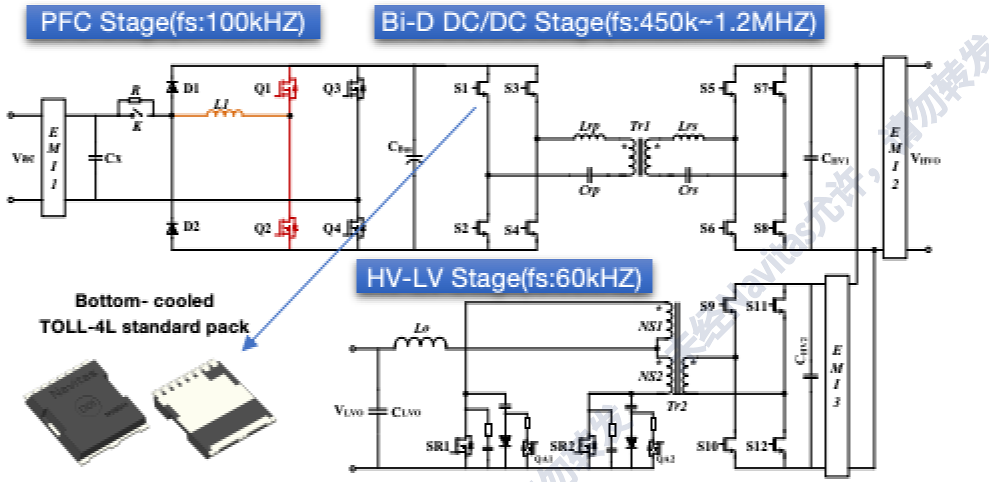




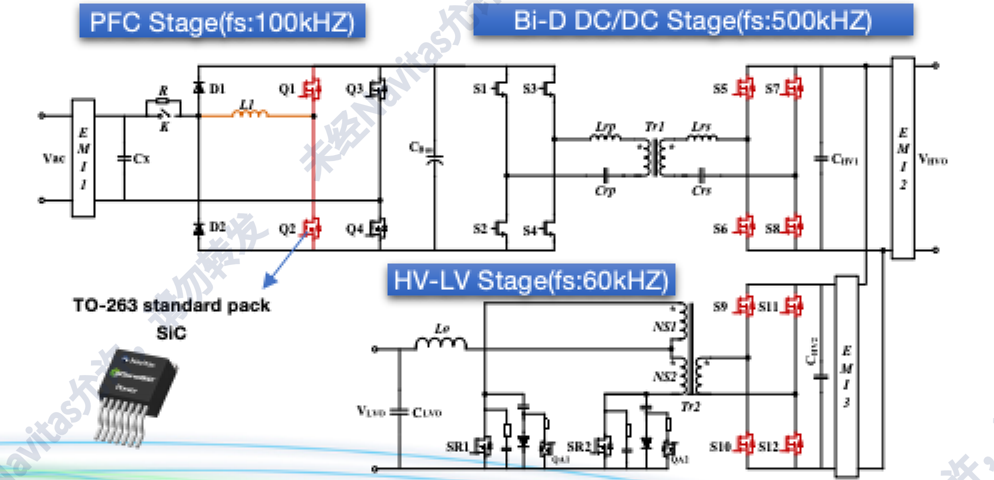
Navitas High Performance 6.6kw OBC 2in1 Combo

Navitas

400V SiC+ GaN Hybrid Solution



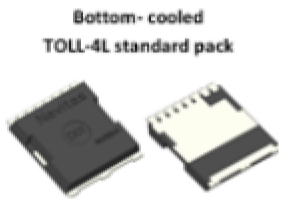
800V SiC+ GaN Hybrid Solution



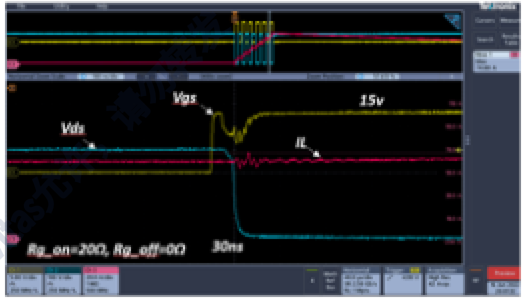
GaNFast™

Features:

- ✓ TOLL, 35mΩ MAX Rds_on @25C
- ✓ 12~18V for DRIVE to SK
- ✓ Integrated 5v power supply unit, typical 15v drive voltage need 30ns for stable
- ✓ Integrated Level shift and deglitch circuit for Improve anti-interference performance



GaN Power IC Control Block

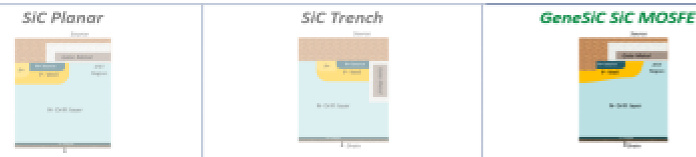


Typical drive waveform

\+

GeneSiC™

1.2kv/75mohm

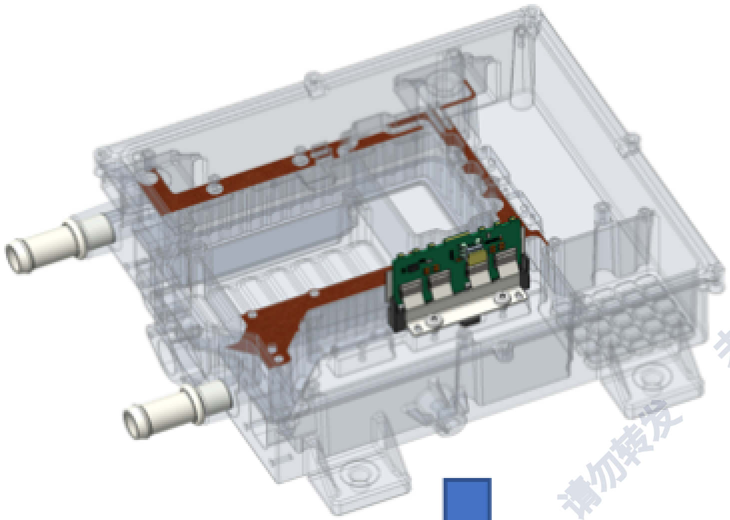


	SiC Planar	SiC Trench	GeneSiC SiC MOSFET
Manufacturability	➢ Repeatable ➢ High yield ➢ Low cost	➢ Inconsistent trench-etch profile ➢ Lower yields ➢ High cost	✓ Repeatable ✓ High yield ✓ Low cost
Performance	➢ High $R_{DS(ON)}$ / area ➢ Slower switching FoM	➢ Lower $R_{DS(ON)}$ / area ➢ Faster switching FoM ➢ High $R_{DS(ON)}$ / Δ temp	✓ Lower $R_{DS(ON)}$ / area ✓ Fastest switching FoM ✓ Lowest $R_{DS(ON)}$ / Δ temp
Reliability	➢ Rugged gate oxide (stable V_{TH})	➢ Non-uniform gate oxide	✓ Rugged Gate oxide (stable V_{TH}) ✓ Highest 100% tested avalanche ✓ Long short-circuit withstand time

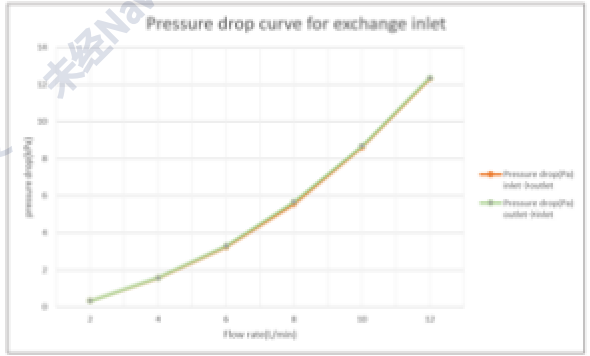
Trench-Assist Planar Gate SiC MOSFET

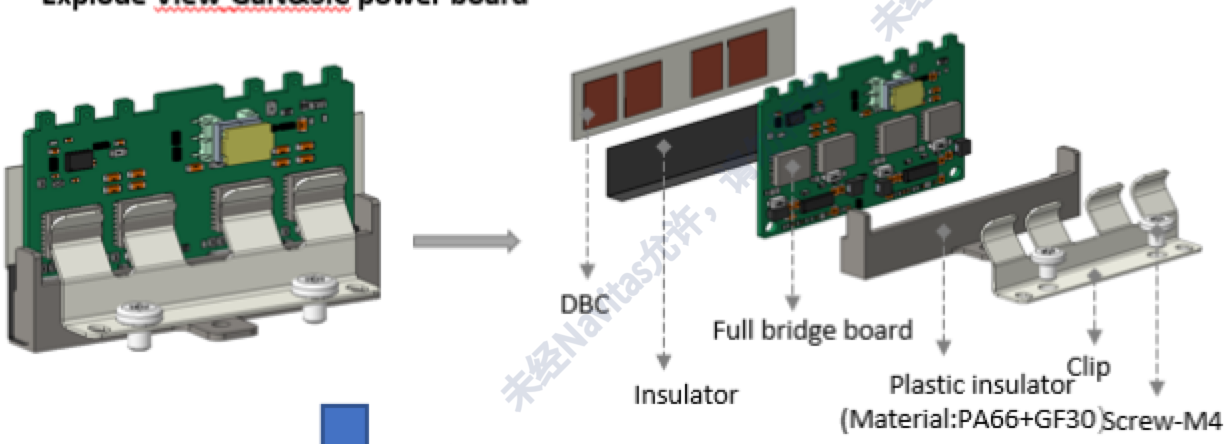
Navitas High Performance 6.6kw OBC 2in1 Combo

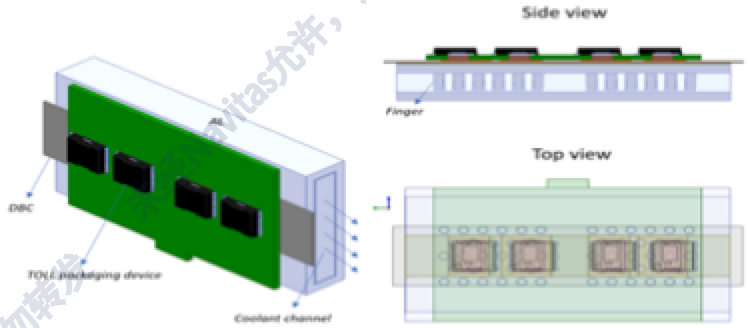
Navitas



Flow rate (L/min)	Pressure drop (kPa) Inlet → outlet PFC side	Pressure drop (kPa) Outlet → inlet D2D side
2	0.33	0.34
4	1.56	1.57
6	3.24	3.30
8	5.55	5.67
10	8.61	8.69
12	12.32	12.36





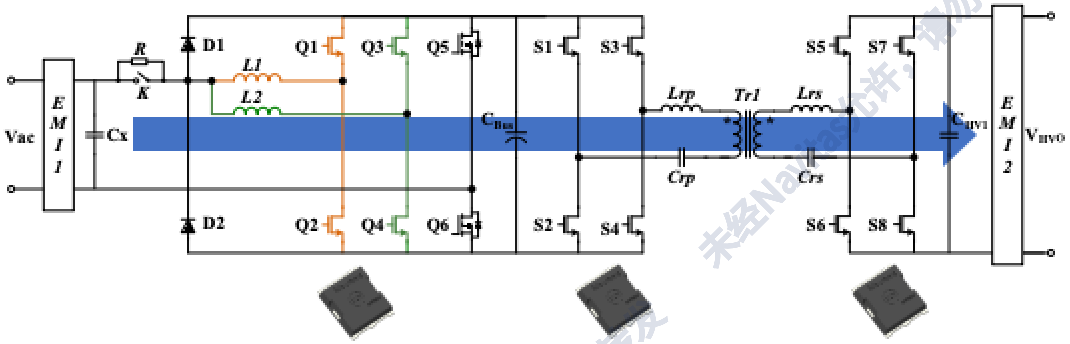


- PCB with copper inlay;
- DBC used to support the isolated thermal interface;
- Junction to coolant thermal resistance can be optimized to 1.48℃/W;

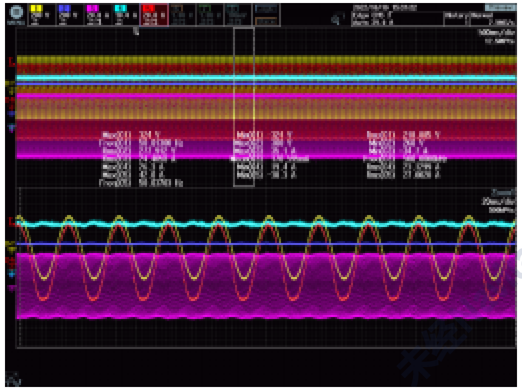
Navitas High Performance 6.6kw OBC 2in1 Combo-Charge

Navitas

- Typical Waveform (220Vac/6.6kW/CV Load)



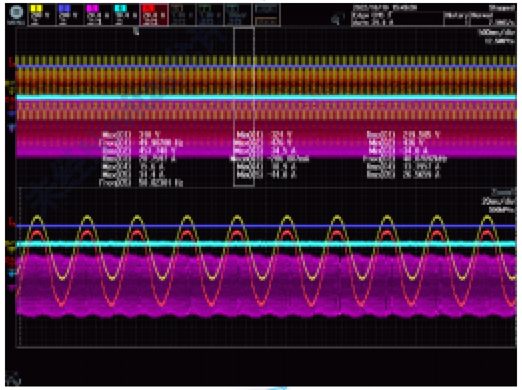
220Vac input, 280Vbat output, ***fs_AC/DC*** =100kHz, ***fs_D2D*** =490kHz



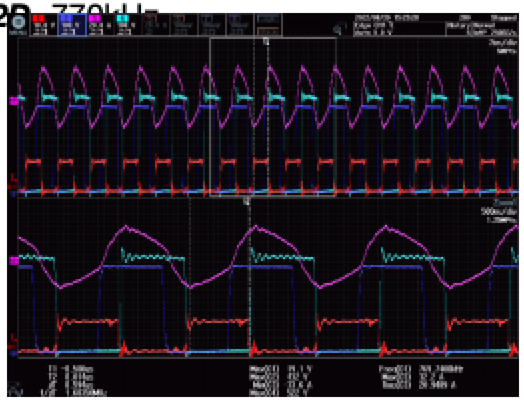
CH1: Vac, CH2: Vbat, CH3: ILr, CH4:Ibat, CH5:Iac

CH1: Vgs_Q8, CH2: Vds_Q2, CH3: IL, CH4: Vds_Q8

220Vac input, 460Vbat output, ***fs_AC/DC*** =100kHz, ***fs_D2D*** =770kHz



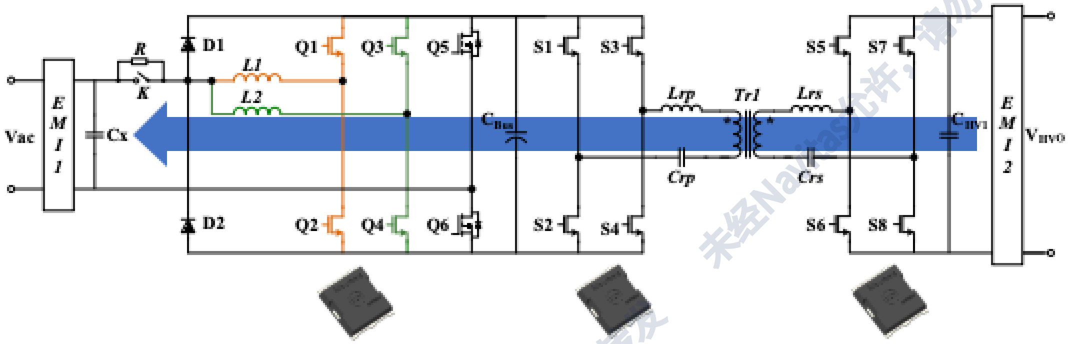
CH1: Vac, CH2: Vbat, CH3: Iac, CH4:Ibat, CH5:Iac



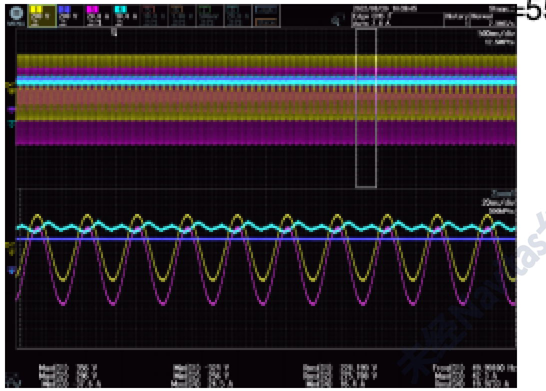
CH1: Vgs_Q8, CH2: Vds_Q2, CH3: IL, CH4: Vds_Q8

Navitas High Performance 6.6kw OBC 2in1 Combo-Discharge

- Typical Waveform (220Vac/6.0kW/R Load)



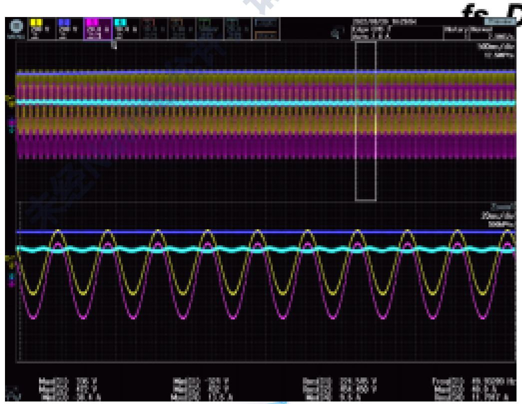
280Vbat input,220Vac output, ***fs_DC/AC*** =100kHz, ***fs_D2D*** =550kHz



CH1: Vac, CH2: Vbat, CH3: Iac, CH4:Ibat

CH2: Vds_Q8, CH3: IL, CH4: Vds_Q2, CH4: Vgs_Q2

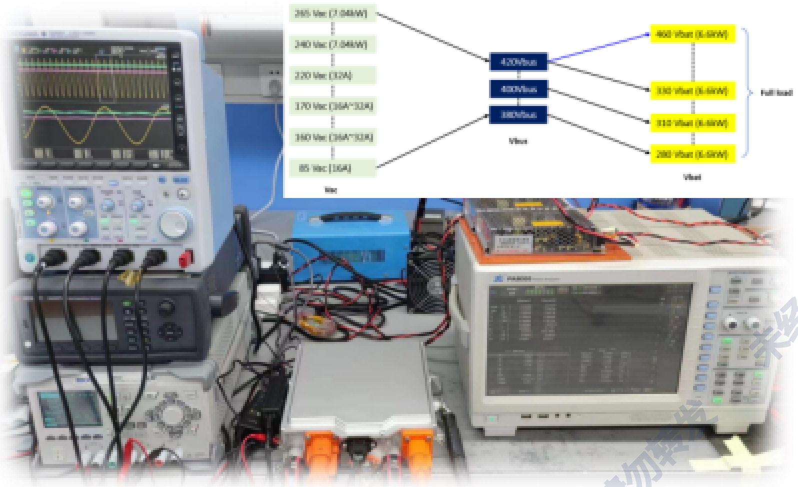
460Vbat input, 220Vac output, ***fs_DC/AC*** =100kHz, ***fs_D2D***=900kHz



CH1: Vac, CH2: Vbat, CH3: Iac, CH4:Ibat

CH2: Vds_Q8, CH3: IL, CH4: Vds_Q2, CH4: Vgs_Q2

Navitas High Performance 6.6kw OBC 2in1 Combo

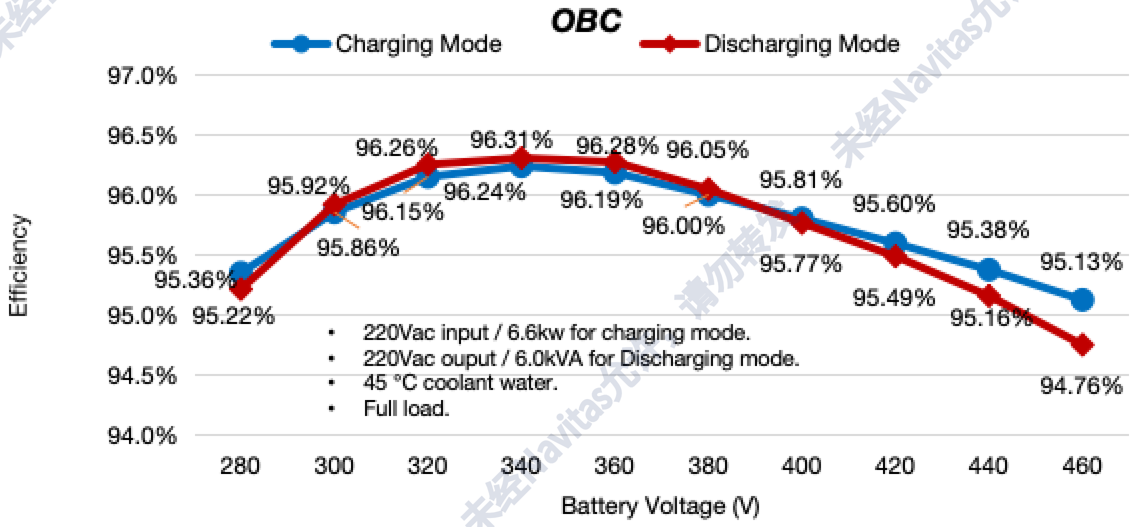


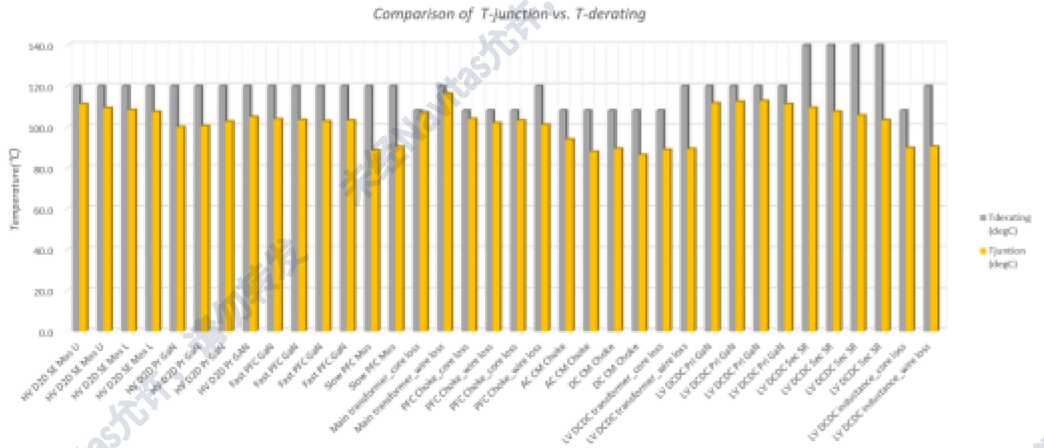
- AC Source:IT7800

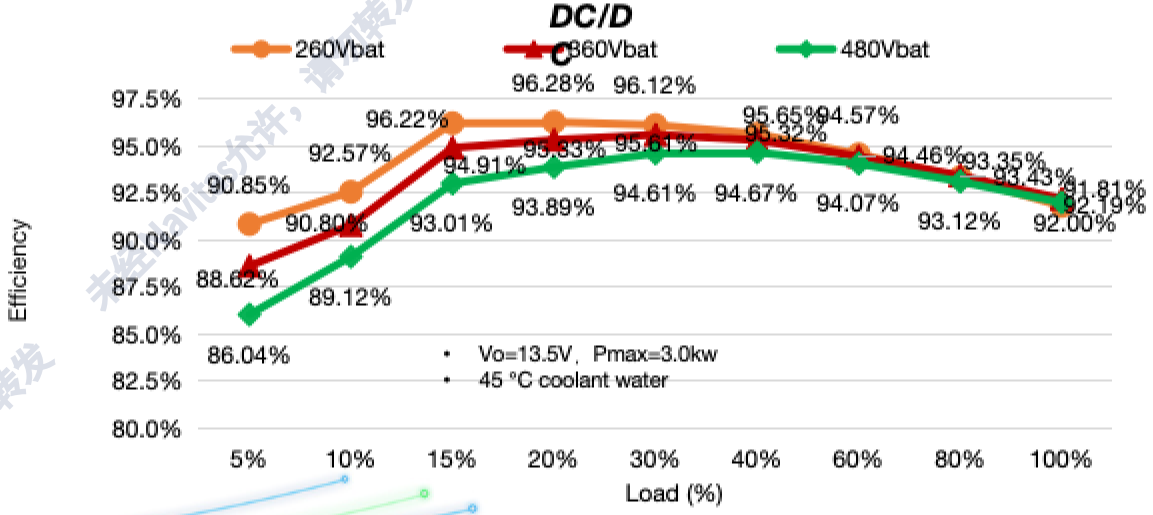
- DC Source:IT6018D

- AC Load:IT8625

- DC Load:IT8918A







Summary

Navitas

- EV market continuous explosion brings many opportunities for GaNFast™ and GeneSiC™ applications.
- Next generation power semiconductor device fast and low switching loss can improve the switching frequency, reduce the volume of passive components and improve the power density of products.
- Navitas will focus on high-power applications in the future.
- GaN and SiC hybrid design proposal for automotive power can achieve leading technical advantage compare to traditional ones.
- GaN and SiC double engines drive Navitas future fast growth in EV.

What’s the next OBC coming?

NVTS Next Generation BID 6.6KW OBC 2IN1

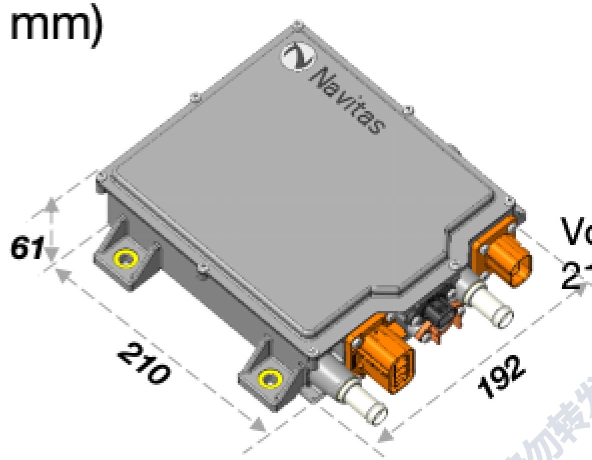
Navitas

	1st version-Existing sample	2nd version-Planned version	Remark
PFC topology	2 phase interleaved totem-pole PFC	1 phase totem-pole PFC	Cost down to save driver and sensor circuit;
PFC power device	4*NV6514	2*G3R33MT06K—TOLT package (TBD)	Need to check Junction temperature variation based on most update datasheet;
CLLC power device	8*NV6514	8*NV6525—TOLT package	TOLT package to save PCB cost;
DCDC power device	4*NV6514	4*NV6525—TOLT package	TOLT package to save PCB cost;
Control DSP	3*'F280039CPZQ1	'F280039CPZQ1+'F280025CPZQ1	Simplify control circuit design to save cost;
Aux power	Separate supply voltage with 5pcs drive transformer;	Integrated supply voltage with 1 flyback transformer;	Simplify supply voltage circuit design to save cost;
Size	210mm x192mm x 61mm(<2.5L)	200mm x147mm x 65mm(<2L)--TBD	
Efficiency	Full load>95% Peak load>96%	Full load>95% Peak load>96%	

- Target to reduce 20% system cost with new design concept;
- New platform plan to be kicked off in Q4;

G1 vs G2

- Size Comparison (Unit: mm)

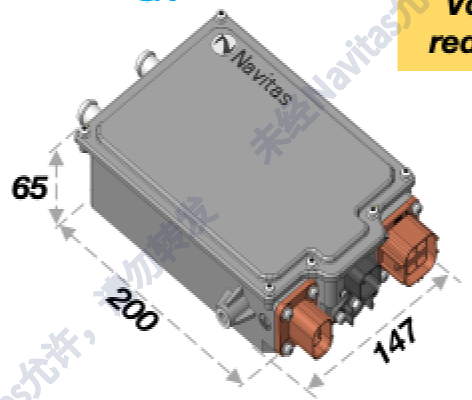


Volume:
210*192*61=2.46L

NVTS Demo G1

22% Volume reduction

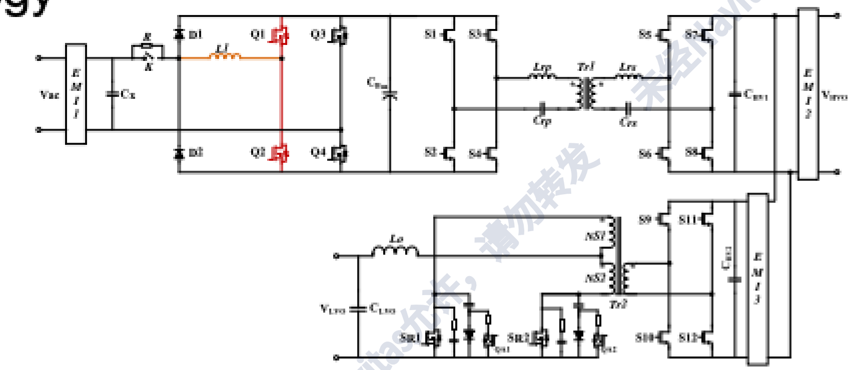
28% Power density improve

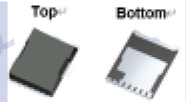
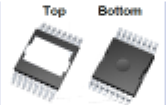


Volume:
200*147*65=1.92L

NVTS Demo G2

- Topology



	G1 NV6514C	G2 NV6524C
Packaging		
$R_{SD(ON)}$	Typ=18mΩ (25mΩ max)@25°C , 37mΩ @125°C	Typ=18mΩ (25mΩ max)@25°C , 37mΩ @125°C
$I_{DS(CONT)}$	85A@25°C, 60A@150°C	85A@25°C, 60A@150°C
C_{OSS}	183pF	183pF
V_{DRIVE}	-0.6~20V	
V_{SD}	3.2V	
RJC	0.28° C/W	0.28° C/W

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