Wide Band Gap Materials: Revolution in Automotive Power Electronics

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IEEE forum

Torino Sept 16, 2015

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Who we are

- A global semiconductor leader
- The largest European semiconductor company
- 2014 revenues of **$7.40B**
- Approximately **43,600** employees worldwide
- Approximately **8,700** people working in R&D
- **11** manufacturing sites
- Listed on New York Stock Exchange, Euronext Paris and Borsa Italiana, Milano

As of December 31, 2014

Strategy & Growth Driver

Sense & Power and Automotive Products

Embedded Processing Solutions

addressing a ~140B$ market globally
~26B$ market for Automotive worldwide

Automotive

Smart Power

MEMS & Sensors

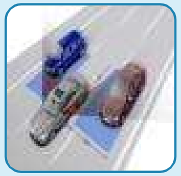
Microcontrollers

Application Processors & Digital Consumer

Innovation:
from Active Safety to Autonomous Driving

From Active Safety

3.9 %



Blind Spot Detection

5.2 %

Lane Departure Warning

Obstacle Detection

4.4 %

Emergency Braking

2013: Semi-autonomous driving is a standard option in $30K cars

Radar

Vision Processing

CMOS Camera

High precision GNSS Multiple-core MCU

Sensor Fusion

Functional safety

To Autonomous Car

Auto Steering

Self-adaptive speed control

Traffic Light Detection

Adaptive Braking

202x: Full-autonomous driving will become a standard equipment

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2013 penetration rate

Source: Strategy Analytics, Jan 2014

ST Solution for Infotainment & Telematics

Driving the Move from Car radio to a Connected Car

Infotainment

Terrestrial Radio

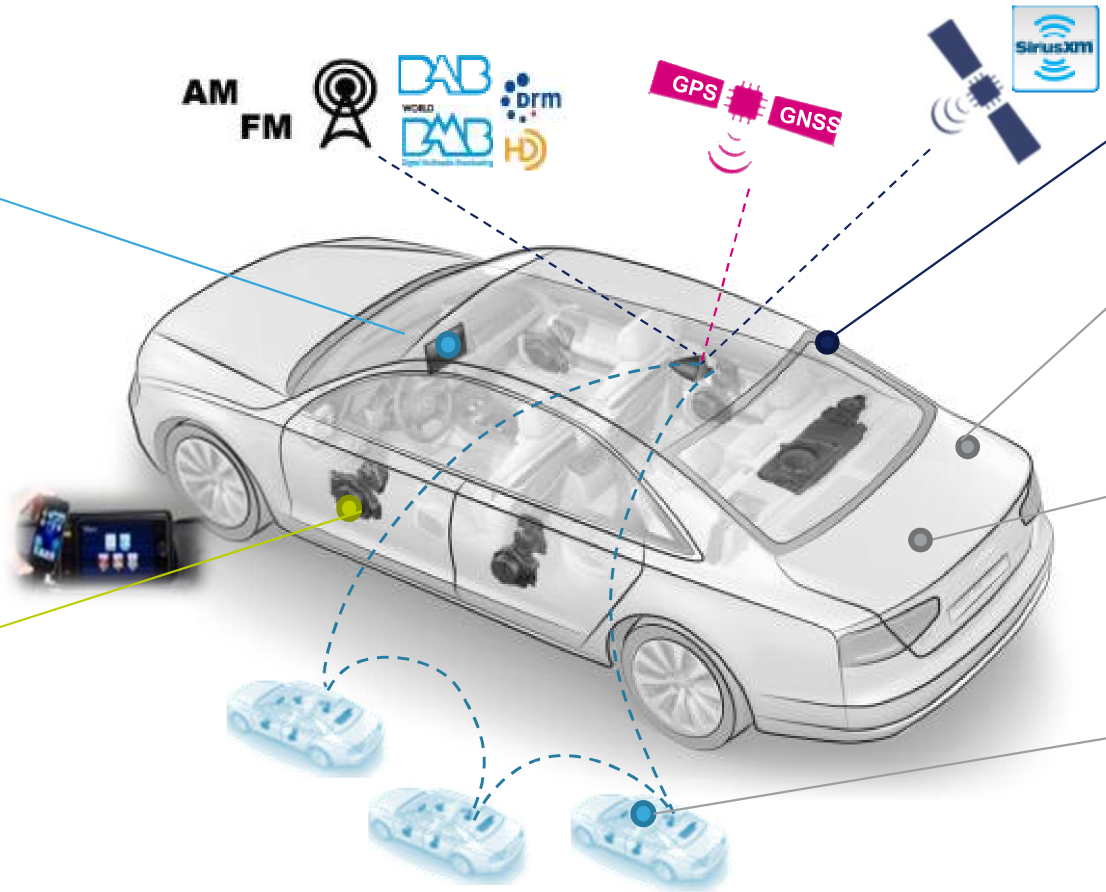
- AM/FM Receivers
- Digital Receivers for DAB/DMB/HD

Car Infotainment Processors

- Processors with Phone Connectivity, Media-player & Display control

Premium Audio

- High Fidelity Amplifiers
- Multichannel Class D Amplifiers



Connectivity

Satellite Radio

- Sirius XM Receivers (ASICS)

Positioning & Telematics

- Multi-Constellation Positioning
- Telematics Processor

Telematics – Insurance Box

- Tolling
- Insurance Trading
- Car Rescue

Vehicle to Vehicle

- Wi-Fi 11-P for Car to Car communication

Positioning
Teseo2 & 3
Enable Beidou with Teseo family positioning accuracy

Processing
Accordo & Telemaco
The highest performing and cost effective solution for Entry Infotainment

Tuners
STAR & DOT
OEM performance, scalability and multi-standards

Amplifiers
ClassAB / D
Leading innovation, robustness

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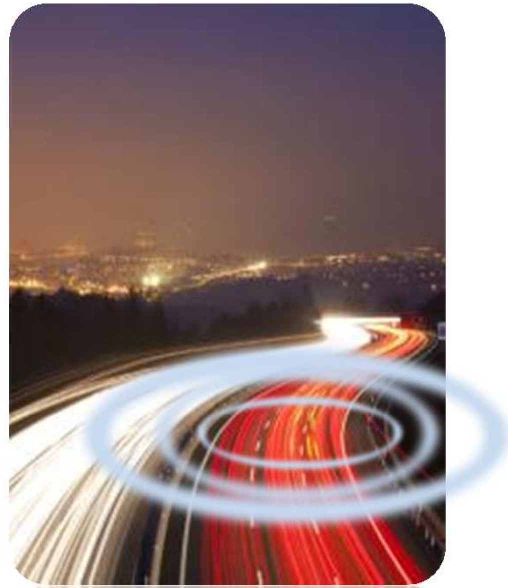
- Unmatched V2X system solution co-development combining
  - Autotalks V2X technology lead and
  - ST Automotive and Telematics Expertise with Global Infrastructure and services
- First ISO26262 ASIL-B grade V2X Processor integrating
  - WiFi modem
  - Security
  - Vehicle network connectivity
  - Multi-Core CPU processing
- Leveraging best-in-class Multi-GNSS positioning of Teseo Family Receivers

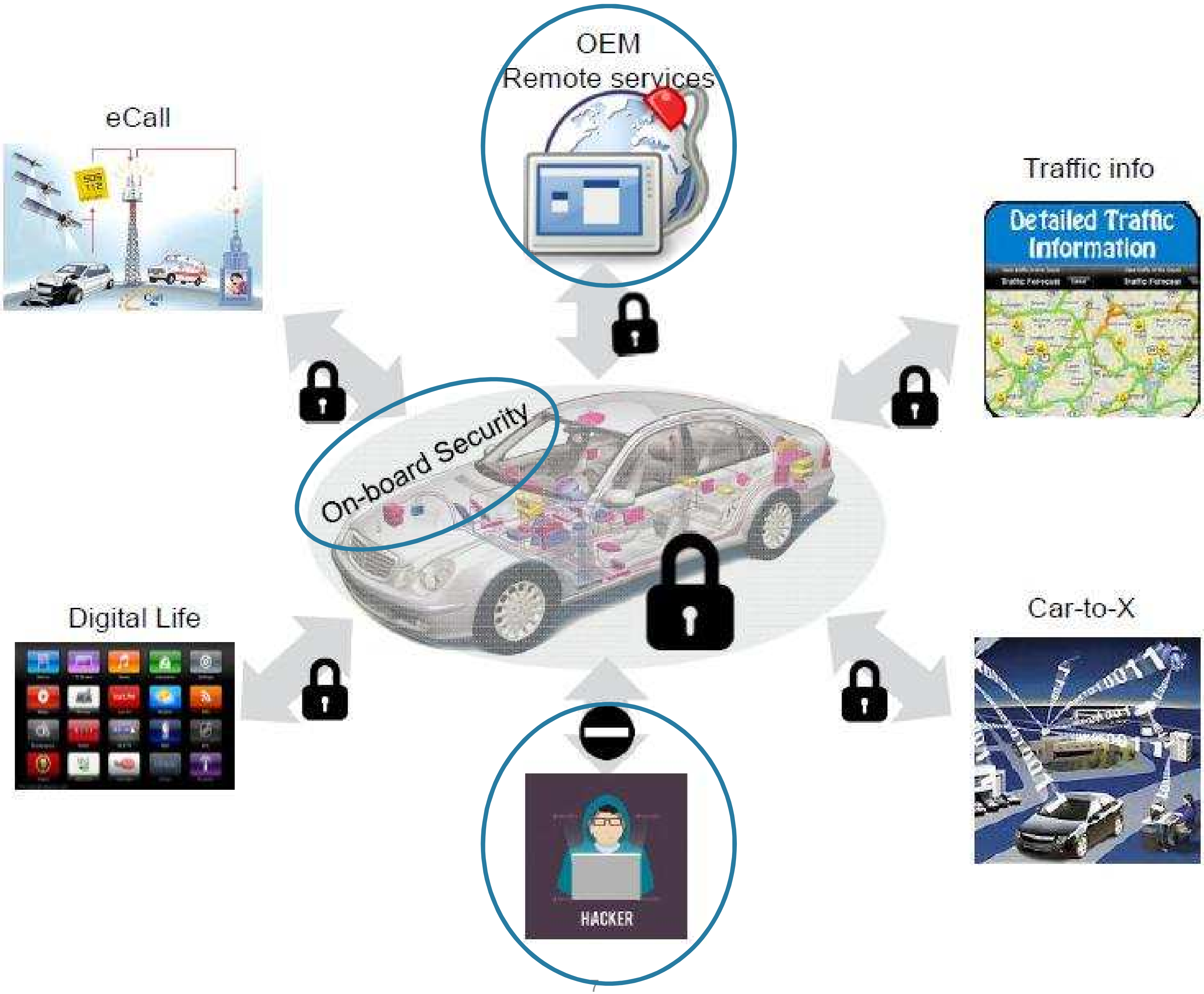


In partnership with Autotalks

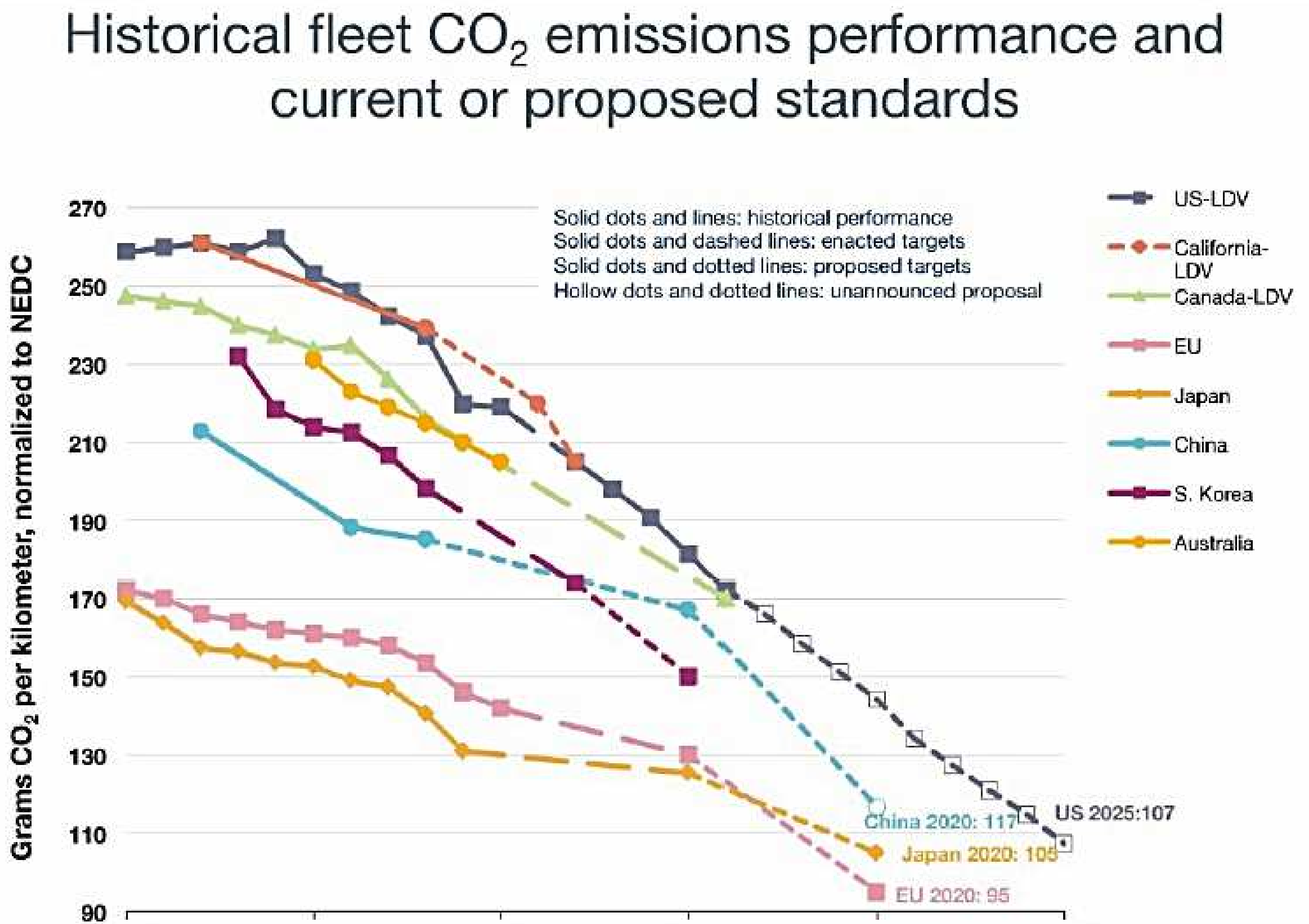
IHS 2014 report forecasts worldwide V2X communication sales will amount to nearly 700,000 units in 2017, rising to 55 million in 2025

From Telematics → **To Connected Car**

Connected cars need security



CO2 reduction mandate



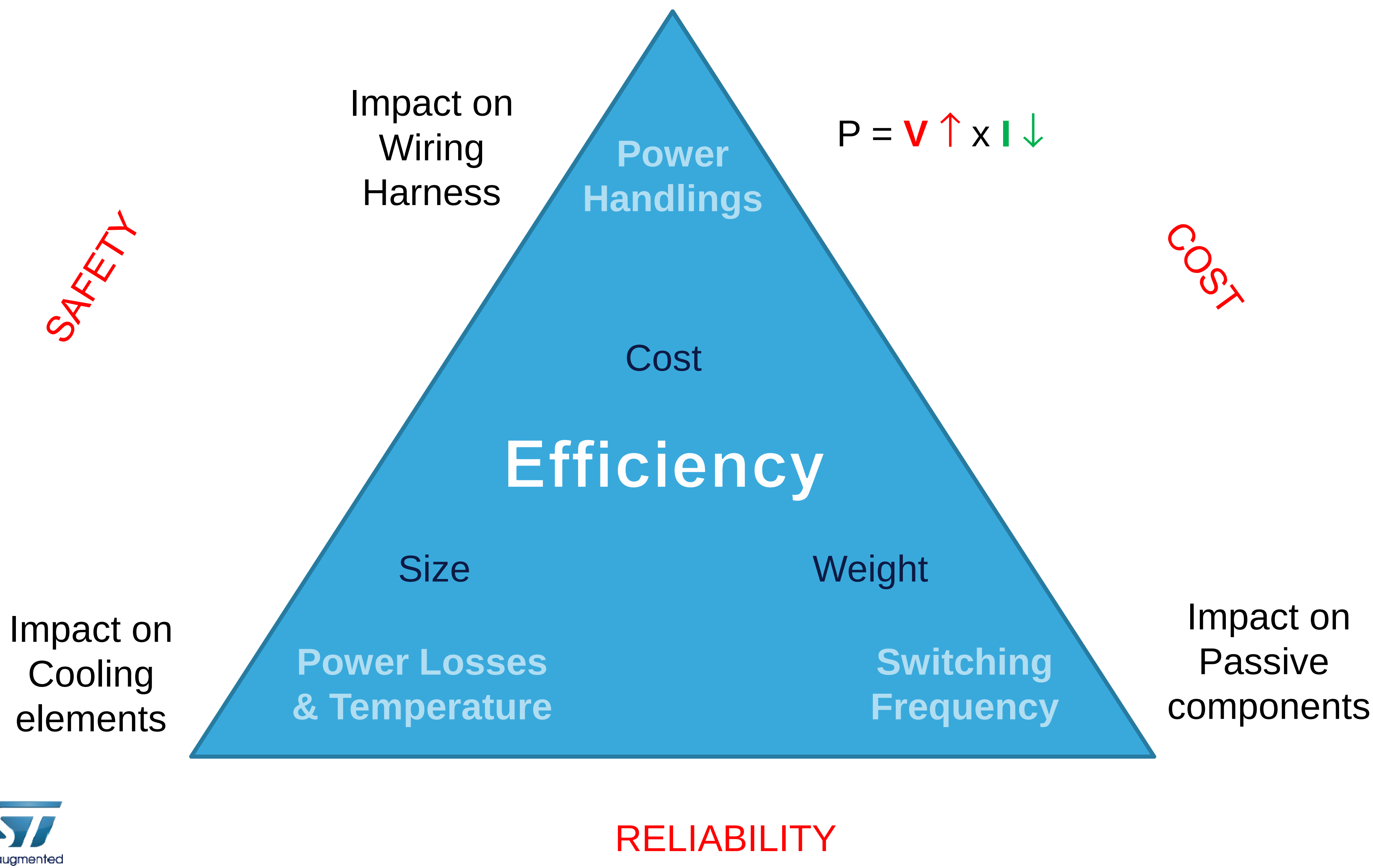
[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
[2] US and Canada light-duty vehicles include light-commercial vehicles.

In EV/HEV car, dealing with......

- New voltage classes never seen before in a car, up to 1,200 Volts !!!
- Power of 100's of Kilowatts
- High temperature environment and huge thermal power cycling stresses
- Mechatronics integration complexity requiring new cooling techniques
- New functional safety boundaries, not really covered by previous mission profiles
- and all of this, keeping it within an affordable cost……

THIS IS CALLED REVOLUTION !

The power semiconductors in the center of the challenges



Wide Band Gap Materials
Breaking the paradigm

	Si	GaN	4H-SiC
E_g (eV) – Band gap	1.1	3.4	3.3
V_s (cm/s) – Electron saturation velocity	$1x10^7$	$2.2x10^7$	$2x10^7$
ε_r – dielectric constant	11.8	10	9.7
E_c (V/cm) – Critical electric field	$3x10^5$	$2.2x10^6$	$3x10^6$
k (W/cm K) thermal conductivity	1.5	1.7	5

E_c → **low on resistance**

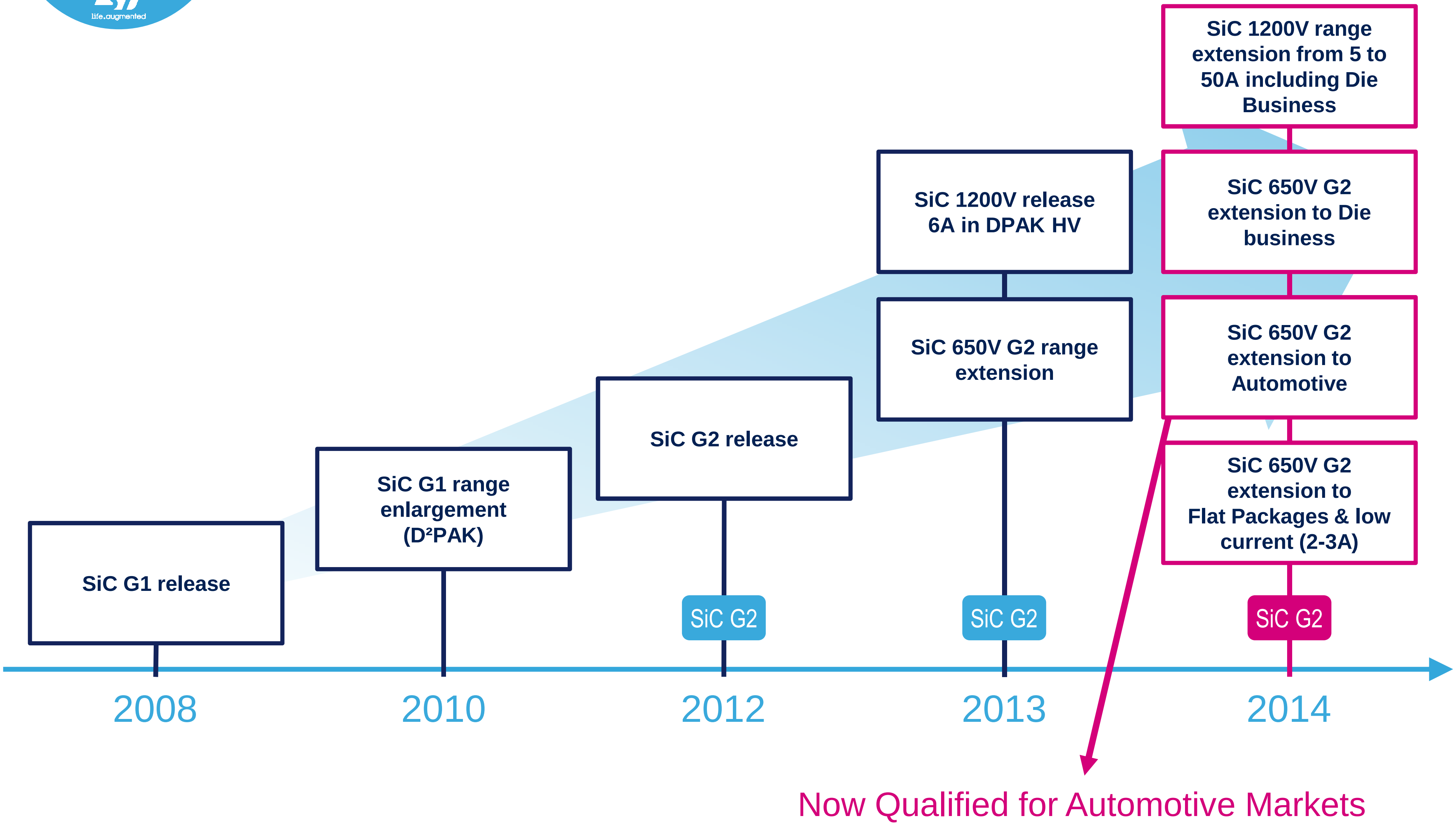
E_g → **low leakage, high Tj**

k → **Operation > 200 ˚C**
Reduced Cooling Requirements

V_s → **Higher switching frequency**
Lower switching losses

SiC
Rectifiers

ST’s long History on the SiC market



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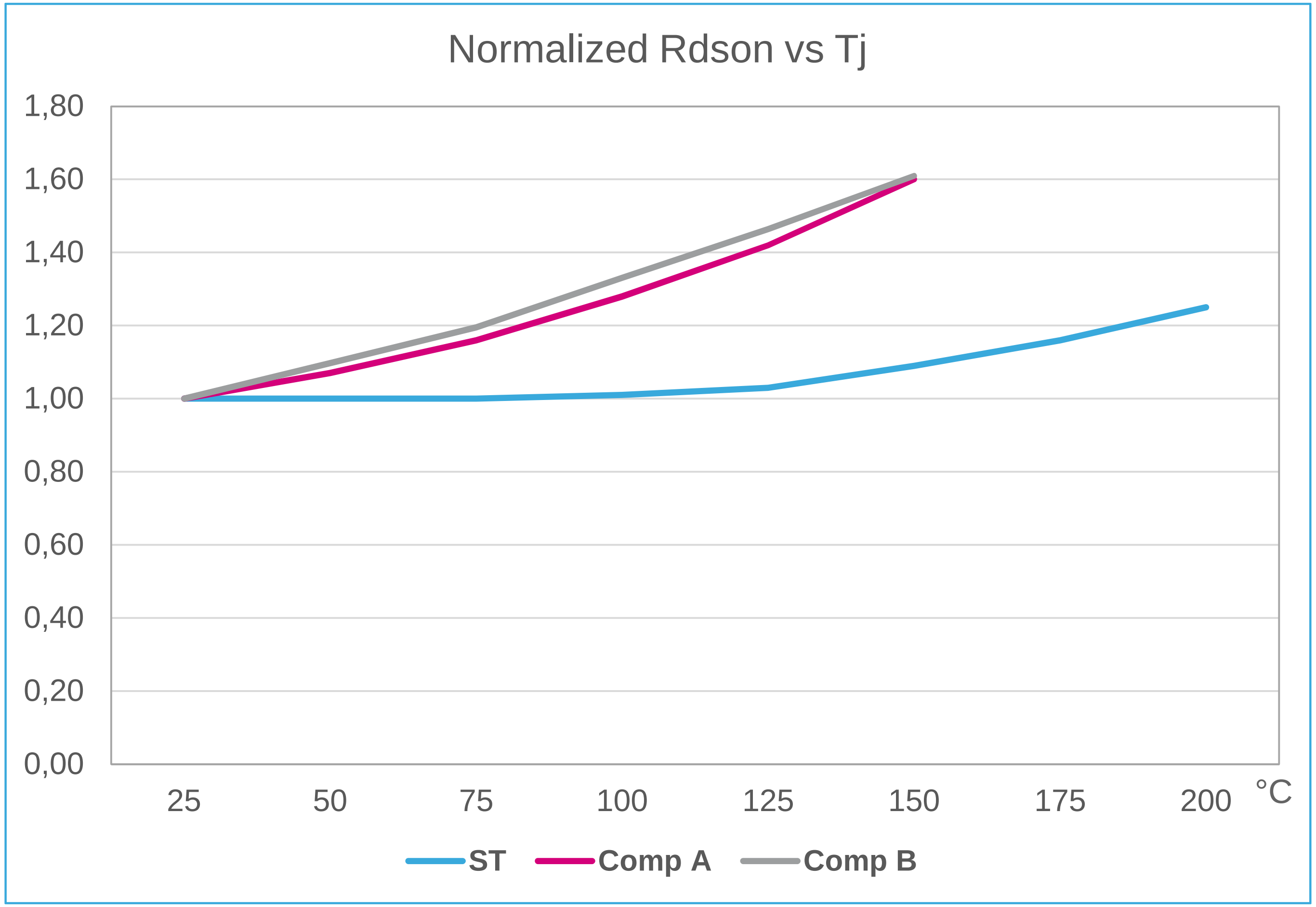
And now Power MOSFET…..

1200V SiC MOSFET	SCT20N120	SCT30N120	SCT50N120
In	20 A	45 A	65 A
$R_{on(typ)}$	< 240 mΩ	< 90 mΩ	< 70 mΩ
$Q_{g(typ)}$	< 45nC	< 105nC	< 130nC

Gate Driving Voltage = 20 V

HiP247 Package : **Tjmax=200 °C**

On-resistance Variation vs. Temperature

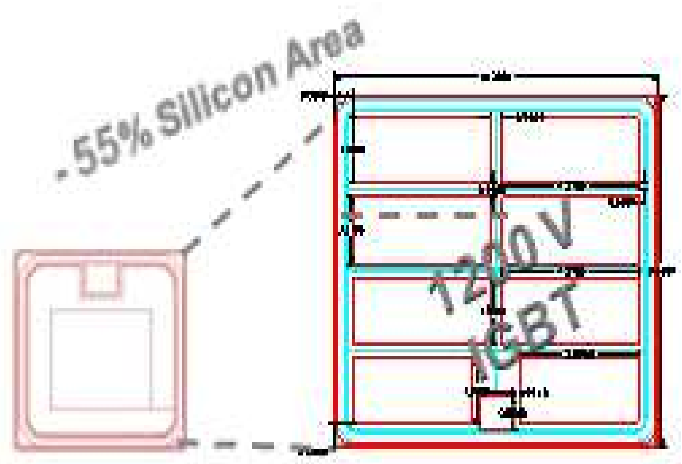


ST SiC MOSFET specified in Rdson at 200°C with only 25% increase vs 25°C

Unmatched switching losses vs IGBT

ST SiC MOSFET vs. best in class IGBT						
	Chip size (Normalized)	V_{on} typ (V) (25°C, 20A)	V_{on} typ (V) (175°C, 20A)	E_{on} (µJ) (20A, 900V) 25°C / 175°C	E_{off} (µJ) (20A, 900V) 25°C / 175°C	E_{off} 25°C / 175°C difference (%)
SCT30N120 (SiC MOSFET)	0.45	2	2.4	725 / 965*	245 / 307	+25%
IGBT (competition)	1.00	1.95	2.35	2140 / 3100	980 / 1850	+90%

* Measured by using the SiC intrinsic body diode



- **Switching losses significantly lower**
  - **Eon 3x lower, Eoff 4x lower**
- **Moderate dependancy on temperature variations**
  - **Valid for $R_{DS(ON)}$ and Switching Losses**

ST SiC MOSFET vs. best in class IGBT

Full SiC-MOSFET vs Si-IGBT
simulation for 60kW inverter

Simulation Results at Vdc = 900V, 200A_{pk}, f_{sw} = 20kHz

Loss Energy	Si-IGBTs Solution	Full-SiC Solution	SiC vs Si
Total chip-area	300 mm²	168 mm²	
Conduction losses (W)	125	55	> 2x lower
Turn-on losses (W)	280	90	> 3x lower
Turn-off losses (W)	246	40	> 6x lower
Body diode conduction losses (W)	NA	12.3	2x higher, but **no external diode**
Diode conduction losses (W)	5	NA	
Diode's Q_{rr} losses (W)	260	5.3	50 x lower
Total losses (W)	**916**	**203**	

Total Power Dissipation about 75% lower by using Full SiC-Solution

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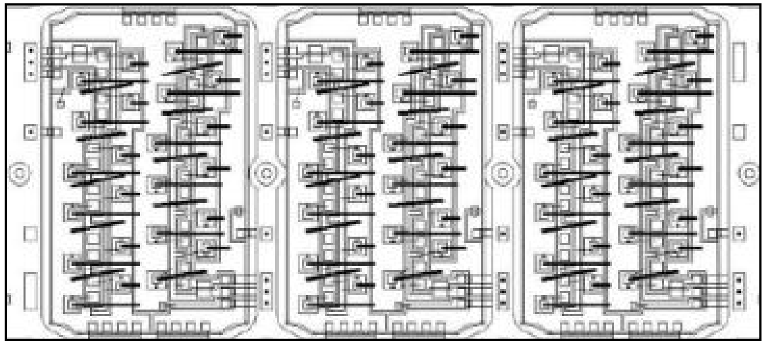
Full-SiC Power Module
Case-study



Main Module Specs
- Full SiC Power Module
- Topology: 3-ph, full-bridge
- Nominal Power = 60kW
- Bus Voltage = 900V
- Current capability = 200A peak

Description & Purpose:

Custom Power Module for 3-ϕ inverter to drive an electric turbo 1200V, 300A

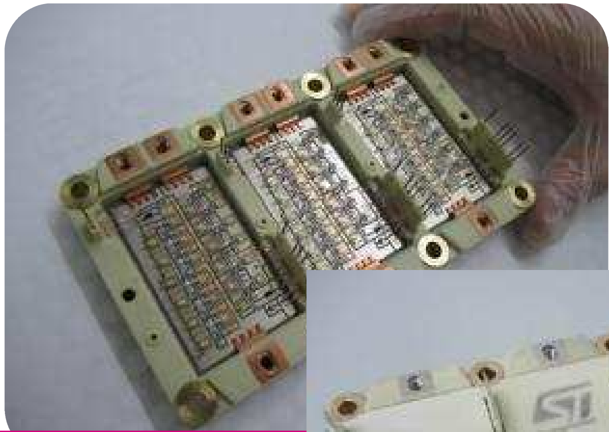
Liquid cooling (baseplate with fins)

Key Products:

x 72 1200V/80mΩ SiC MOSFET (12 x switch)

No freewheeling diode

Gate resistors embedded



20% smaller vs. previous IGBT based Module

Can be further improve thanks to:
- larger die size (with less die to be put in parallel)
- By integration of Rg into SiC structure

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SiC Value Proposition in EV/HEV Main Inverter

>1% efficiency improvement (75% lower loss)

→ Longer battery life

75% cooling system downsize on Inverter side

→ Smaller and Lighter Power Unit

Up to 50% module size reduction

→ Smaller and Lighter Power Unit

A deeper look on Boost converters and on-board chargers

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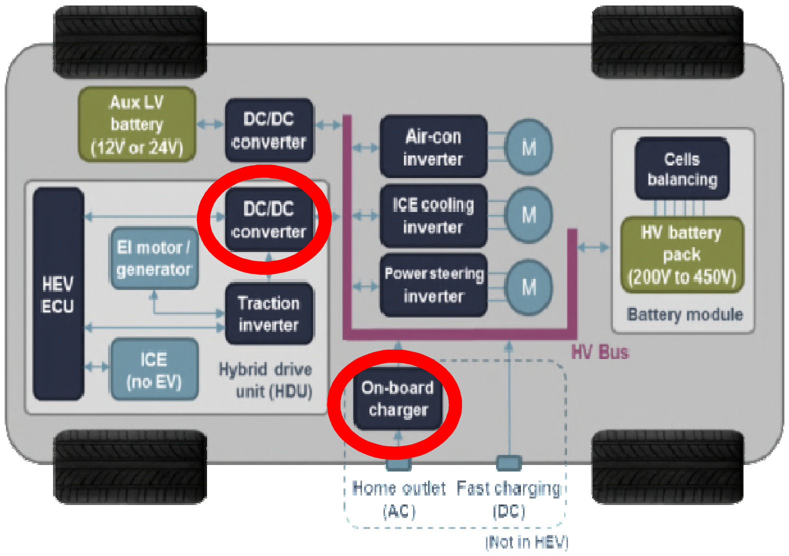
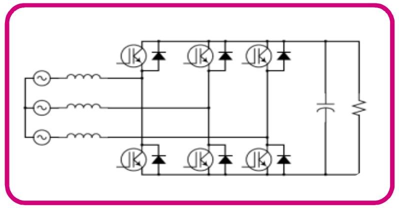
Various Switching Topologies

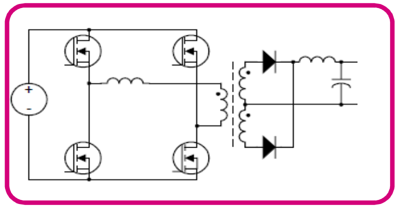


3 phase fast charger

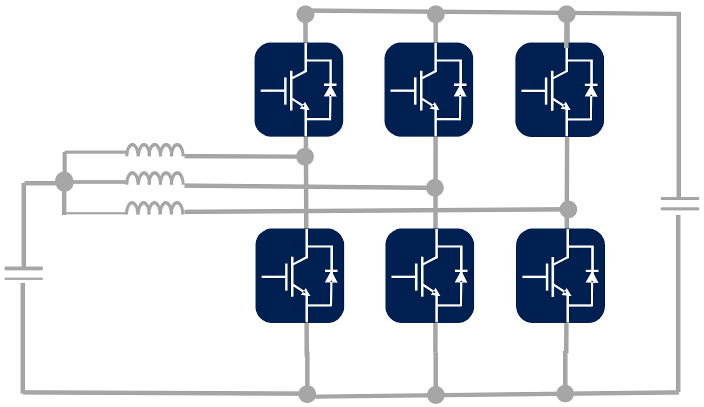


PFC block

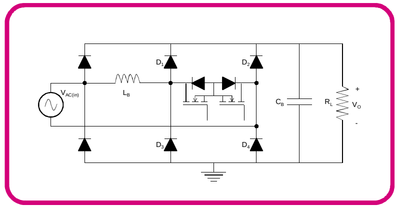
DC/DC block



HV DC/DC converter

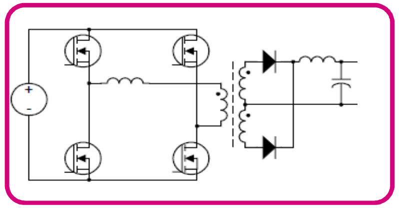


1 phase charger



PFC block

DC/DC block



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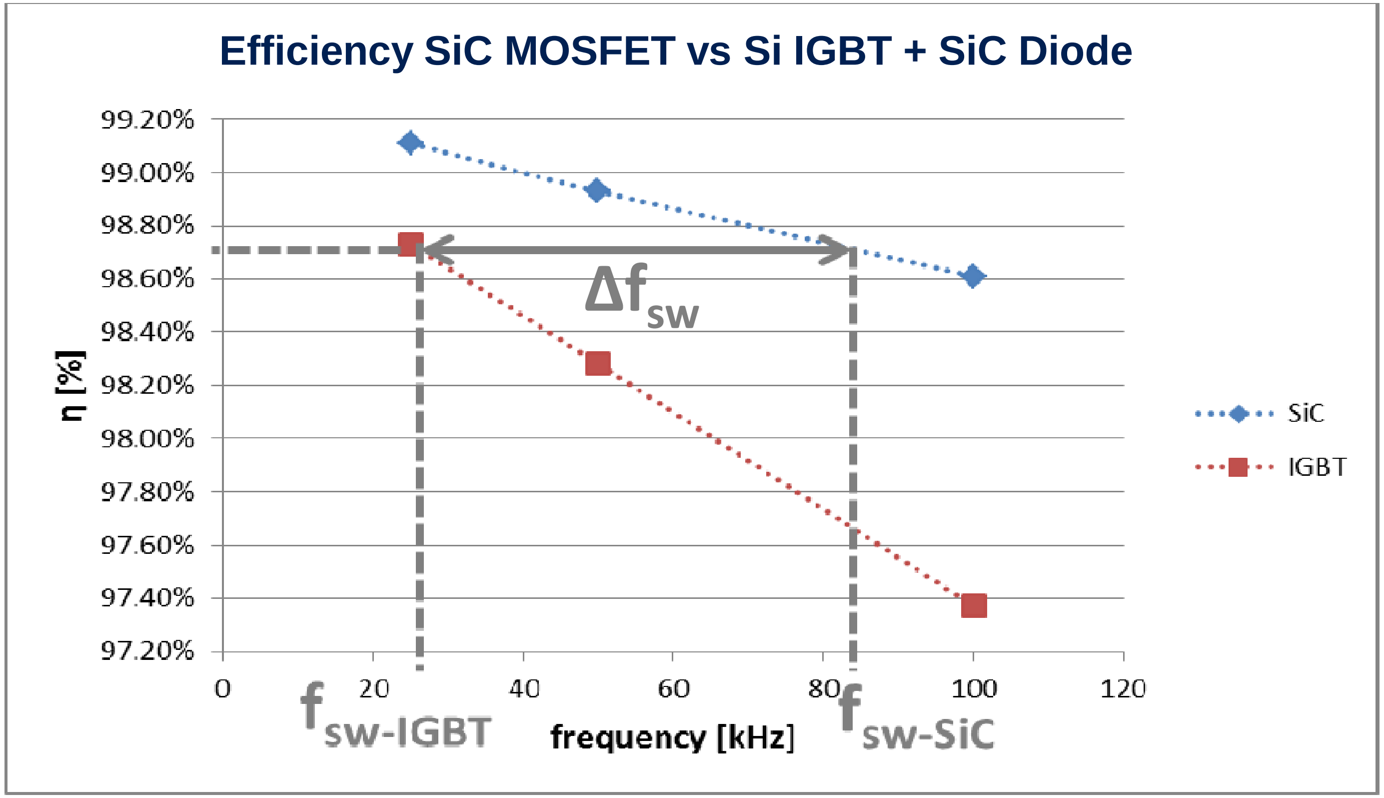
System benefit for
HV DC-DC & chargers

SiC enables new ‘Efficiency-switching frequency’ vs Silicon technology

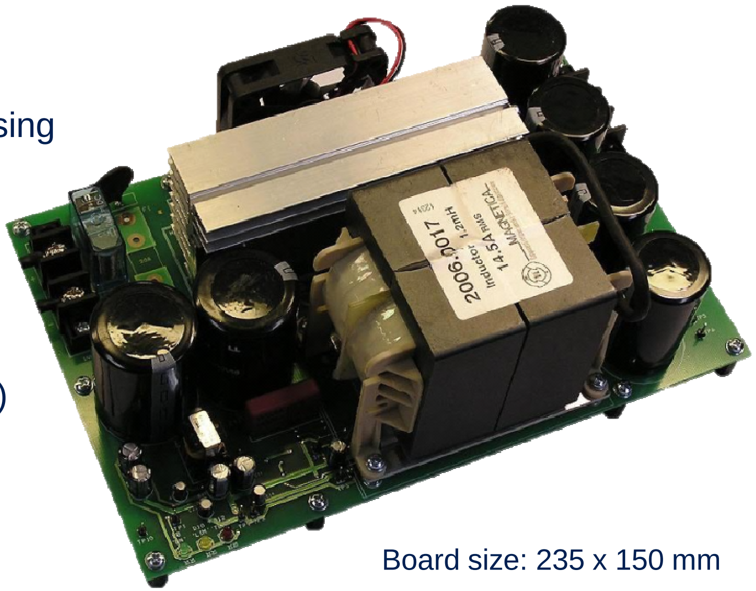


1200V SiC MOSFET guarantees similar efficiency at 100 kHz compared to a 1200V Si IGBT (+ SiC boost diode) at 25 kHz… And…..

Exercise done on 4kW solution
based on SiC technology

Boost Inverter in detail

- Fully integrated and compact solution:
  - Power stage, aux. SMPS, controller, signal processing
- Main ST products:
  - **SCT30N120** (1200V / 45A SiC MOSFET)
  - **STPSC6H12B** (1200V / 6A SiC Diode)
  - **TD350ED** (GapDrive also tested with equal results)
  - **L5991D** (current mode PWM controller)
- Optimized for 100kHz switching
- Board available to selected Customers



Board size: 235 x 150 mm

Performance				
Input Voltage (VDC)	Output Power (W)	Heatsink Temperature (°C)	Total efficiency including AUX (%)	Total efficiency without AUX* (%)
600	2094	57.5	99.11	**99.29**

* Efficiency of boost inverter itself (SiC MOSFET, SiC diodes and main choke)

And…..space/cost saving

impact on inductor

1.2mH
@25kHz
ferrite core

0.3mH
@100kHz
ferrite core

Almost 50% less volume *

30% lower Losses on Magnetic *

60% lower Weight *

Cost halved!! *

(*) Study conducted by **F.E.EM Sas,** Italian company which manufactures Electric and Electromagnetic components on a 5kW Boost converter. Report available.

Overall System cost cheaper with SiC

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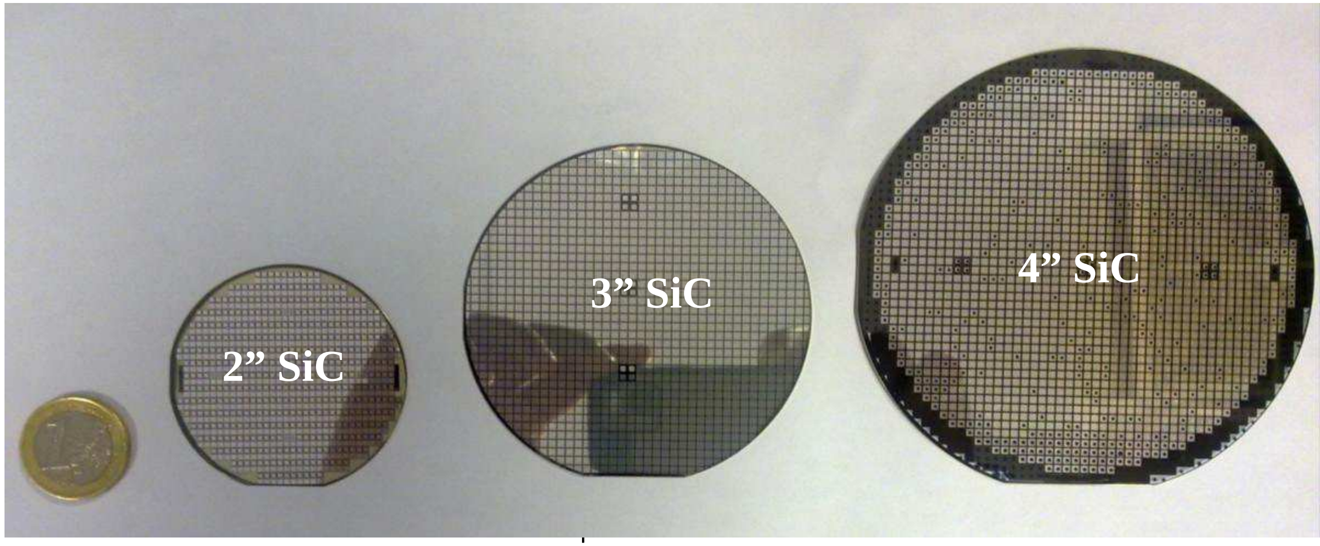
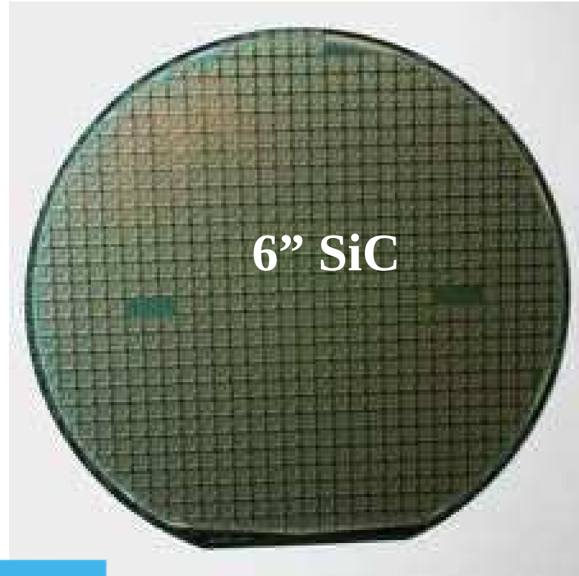
SiC Wafer Size Evolution

ST has Well-established Expertise on SiC Material & Devices

2003 – 2” line startup → 2006 – 3” line startup → 2011 – 4” line startup → 2015 – 6” line startup



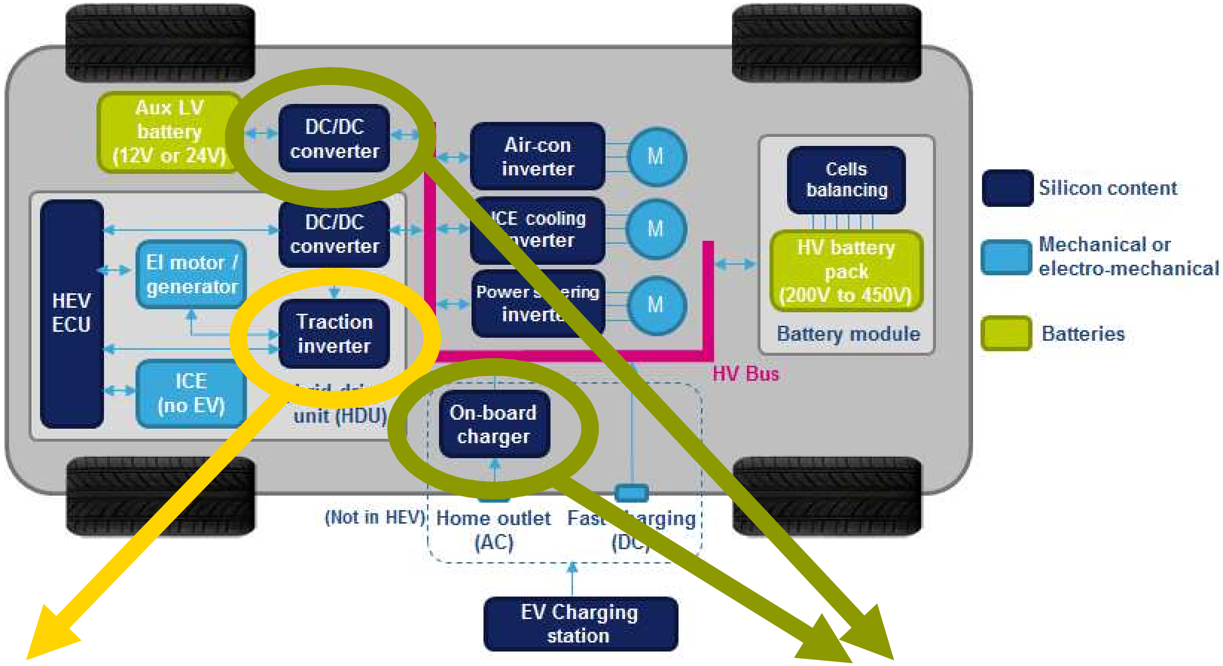


SiC MOSFET price roadmap keeps improving year after year thanks to:

- Industrial maturity
- More competition among wafer suppliers
- 6” wafer
- Epi in house
- New techno generations

Epi in house

Conclusion:
Application areas of WBG in cars



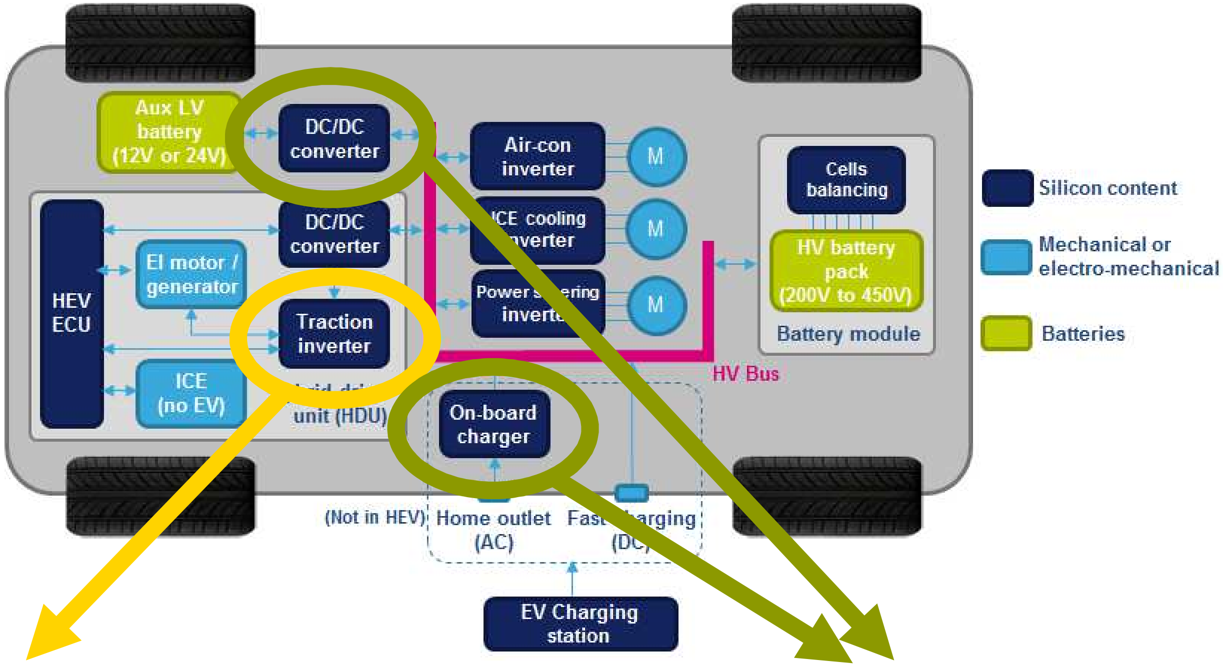
Traction inverter

Low Frequency Operation
High Power
High Thermal environment

DC/DC Converters
On board Chargers

High Frequency
High Passive Content
Compactness

Conclusion:
Application areas of WBG in cars



Traction inverter

Low Frequency Operation
High Power
High Thermal environment

Smaller cooling systems
Smaller Power Modules

DC/DC Converters
On board Chargers

High Frequency
High Passive Content
Compactness

Smaller Passive components
Light & compact systems

Merci Grazzie Thank you!

ST stands for

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