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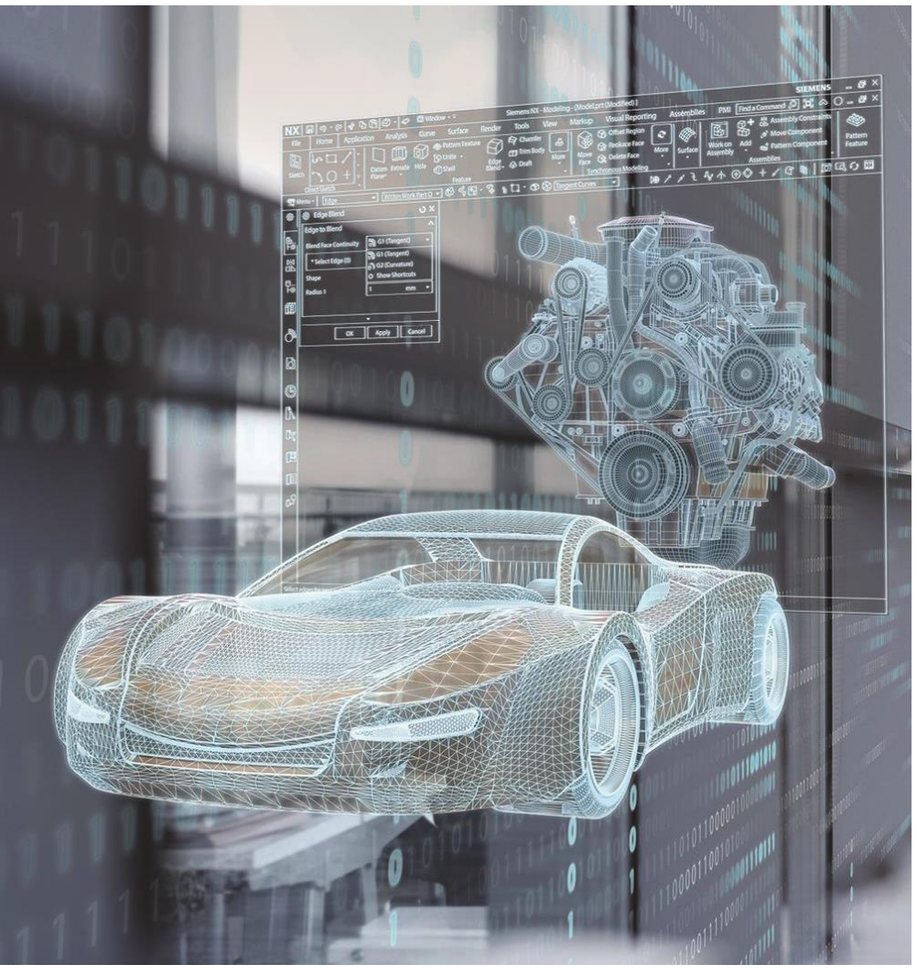
Ingenuity for life

Vibro-acoustic engineering challenges in (hybrid and) electric vehicles

Agenda



Introduction

Interior noise

- Receiver perspective
- Source perspective
- Noise transfer

Exterior noise

Conclusion

Legislation and Regulation
Pushing engineering to the limit

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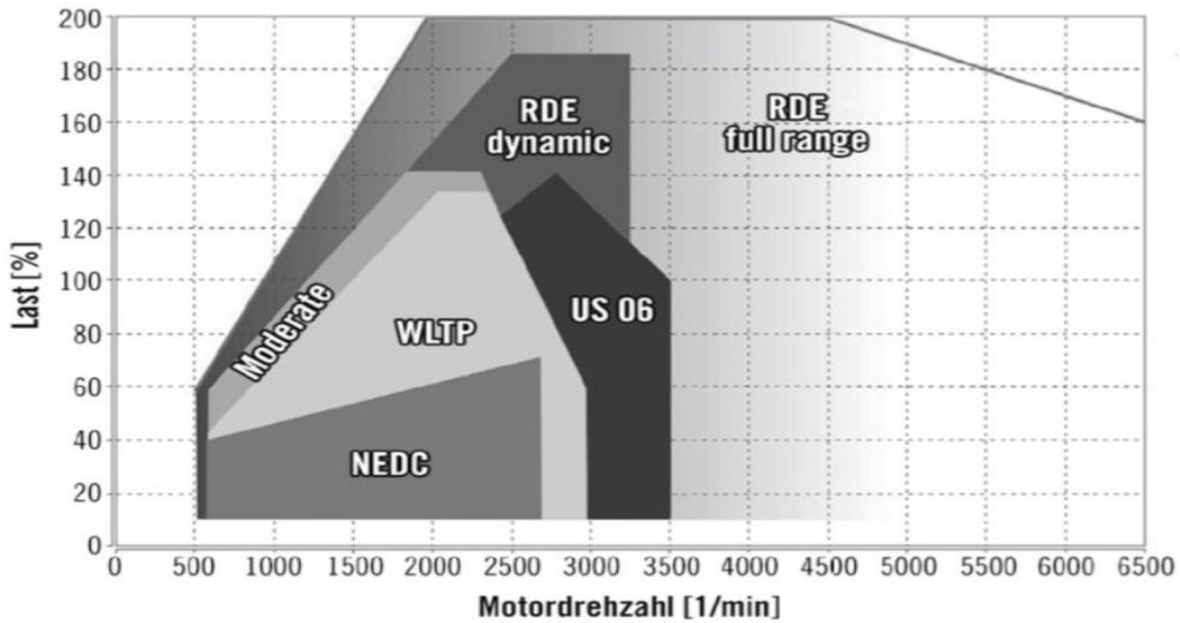
Legislation tightening

Pollutants remain a major area of focus
- Taking into account particle number (PN) in EU
- Mass of particle matter is divided by two in US

Particle emissions becoming an issue for both Diesel and GDI engine

New regulations - with harmonized WLTP and **Real Driving Emissions** (RDE) will stress the operating conditions with significant contributions of high loads and speeds

For diesel engines, urea consumption will become a challenge, requesting optimization in control strategies



Driving cycles in engine map

		GDI PC-PDV PARTICLE MATTER REGULATION TREND									
		2013	2014	2015	2016	2017	2018	2019	2020	2021...	... 2025
Europe	Level	Euro 5		Euro 6b			Euro6c				Euro 7 ?
	PM	5 mg/km		4.5 mg/km							
	PN	-		6×10^{12} #/km			6×10^{11} #/km				
		CO2 140 g/km					CO2 120 g/km			CO2 95	
	Cycle	NEDC TEST CYCLE					WLTC + RDE TEST CYCLE				
USA	Level	LEV 2		LEV 3			LEV 3			LEV 3	LEV 3
	PM	10 mg/mile		6 mg/mile			3 mg/mile				1 mg/mile
	Cycle	FTP									

European and US legislation, particle emission

Market Introduction New Powertrain Architectures
Alternative Fuel Vehicles & Hybrid Electrical Vehicles

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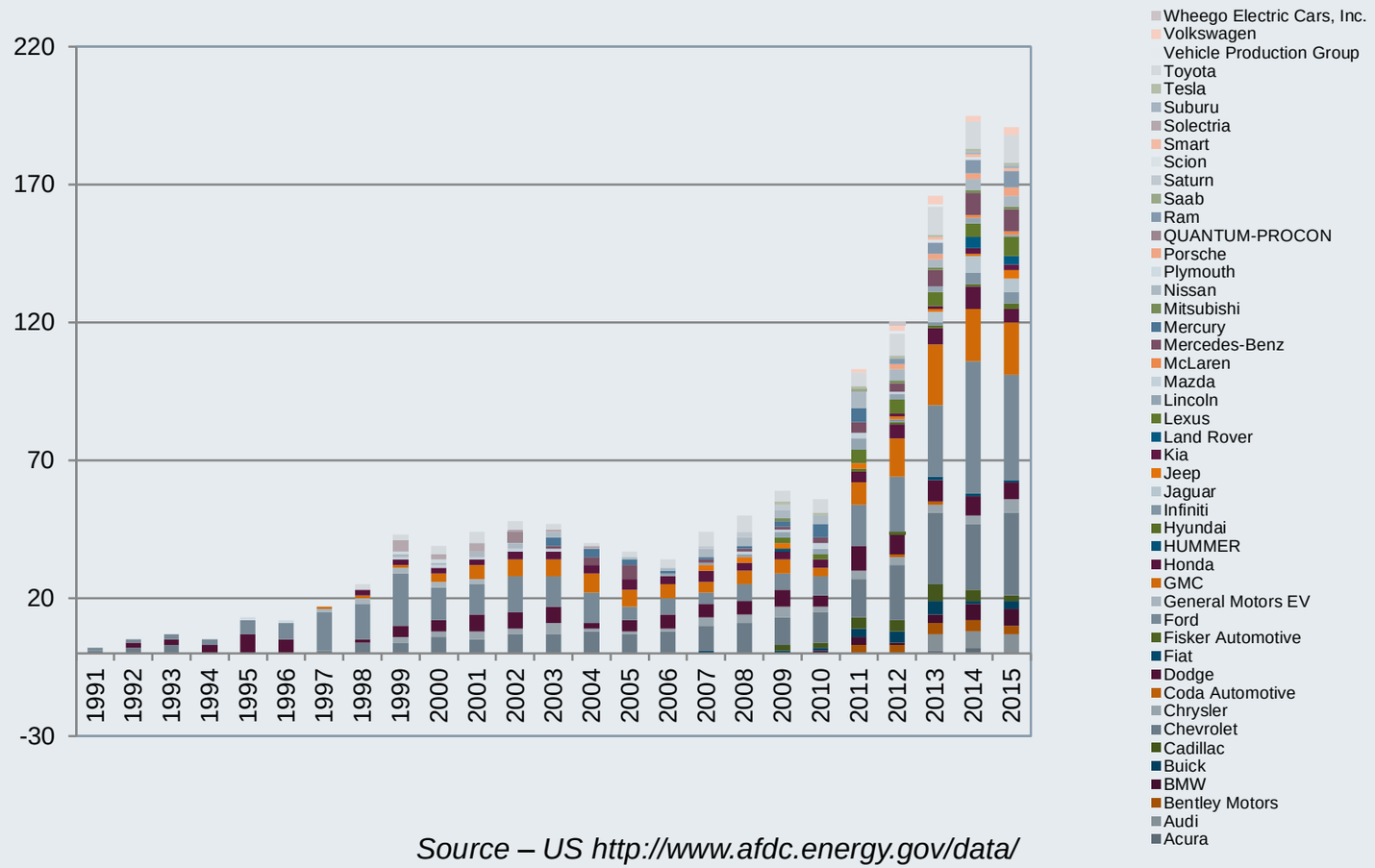
Increase of model variants
~ 200 model market introductions yearly

Increased complexity
- Neighbourhood Electric Vehicles (NEV)
- Battery Electric Vehicles (BEV)
- Extended-range EVs (E-REV)
- Plug-in Hybrid Electric Vehicles (PHEV)
- Alternative fuels
- …



Source – US http://www.afdc.energy.gov/data/

Constant Pressure on Weight Reduction
Driving Innovations in Vehicle Engineering

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Pressure on weight reduction

- fuel economy of a vehicle is generally considered to increase by 6-8 % for every 10% reduction in body weight

Technical & architectural complexity

- Introduction new materials
- Impact battery weight & alternative powertrains
- Balancing vehicle performance vs. weight reduction …

Ford, DowAksa jointly to develop carbon fiber for high-volume automotive light-weighting applications

Carbon Core of next-gen BMW 7 Series helps reduce sedan's weight by up to 130 kg

New Opel Astra up to 200 kg lighter than predecessor with a slimmer body and all-aluminum engines.

GM applies Gen 3 advanced high-strength steel in new vehicle for China; 1,200 MPa Q&P steel

Continental Structural Plastics and Mitsubishi Rayon exploring joint venture for carbon fiber automotive structural components

http://www.greencarcongress.com/

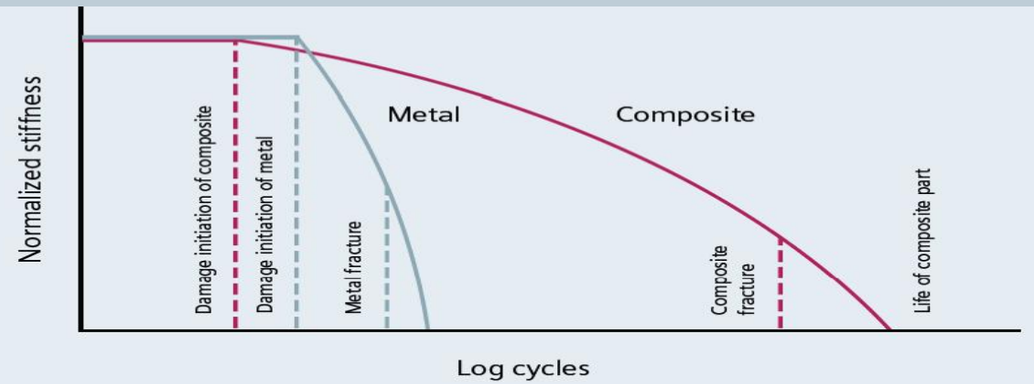
Implications

Continued focus on fuel economy & emissions

NVH & driving pleasure impacted by fuel economy

Multitude of options to be evaluated

New Materials – new engineering challenges



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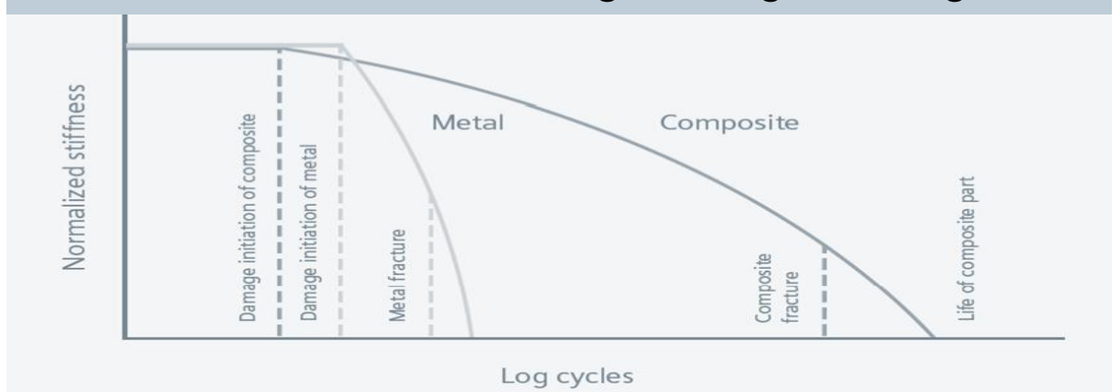
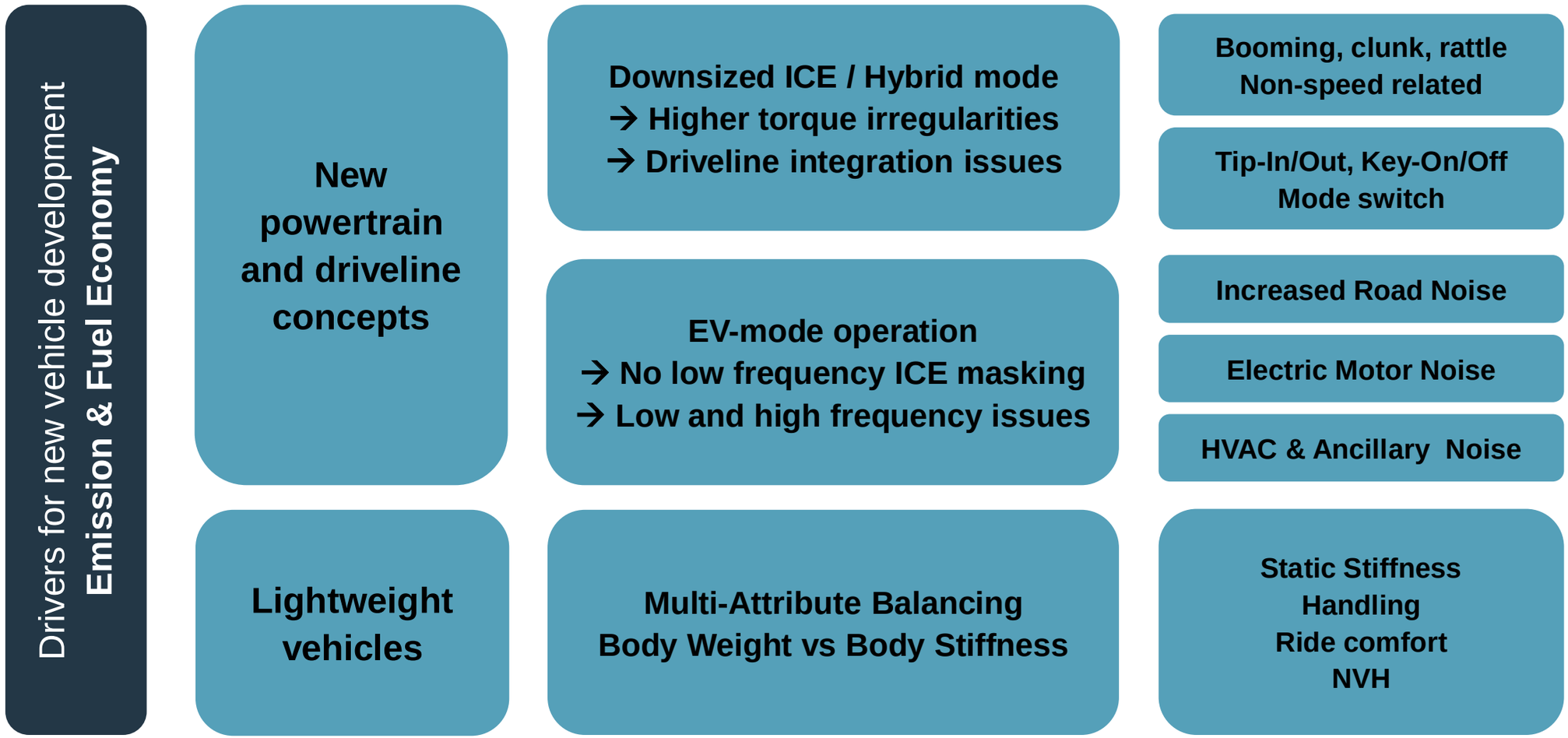


Reducing CO_2, at the price of NVH?



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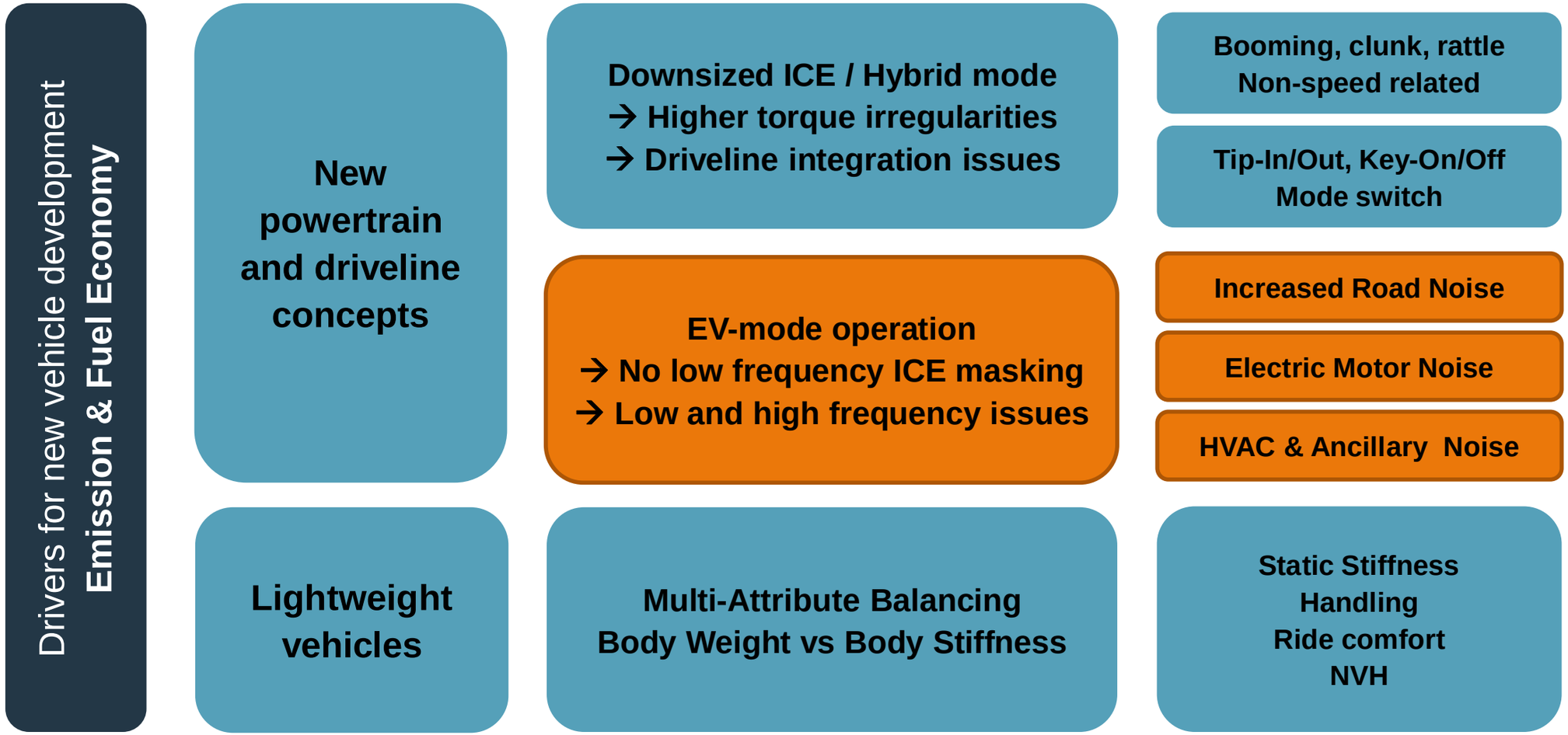
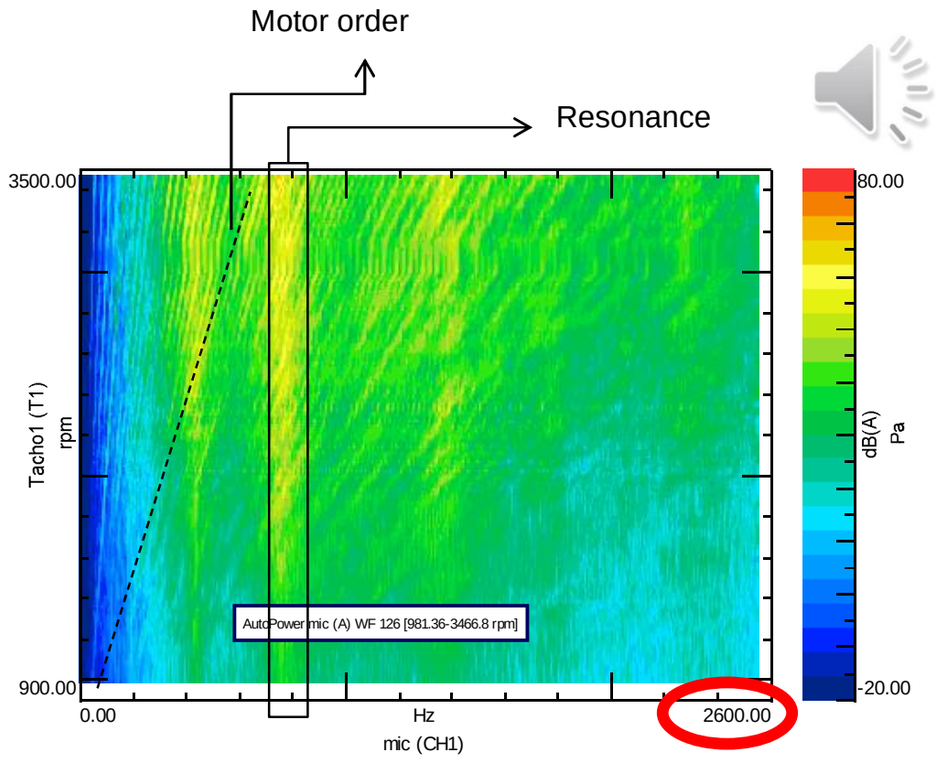
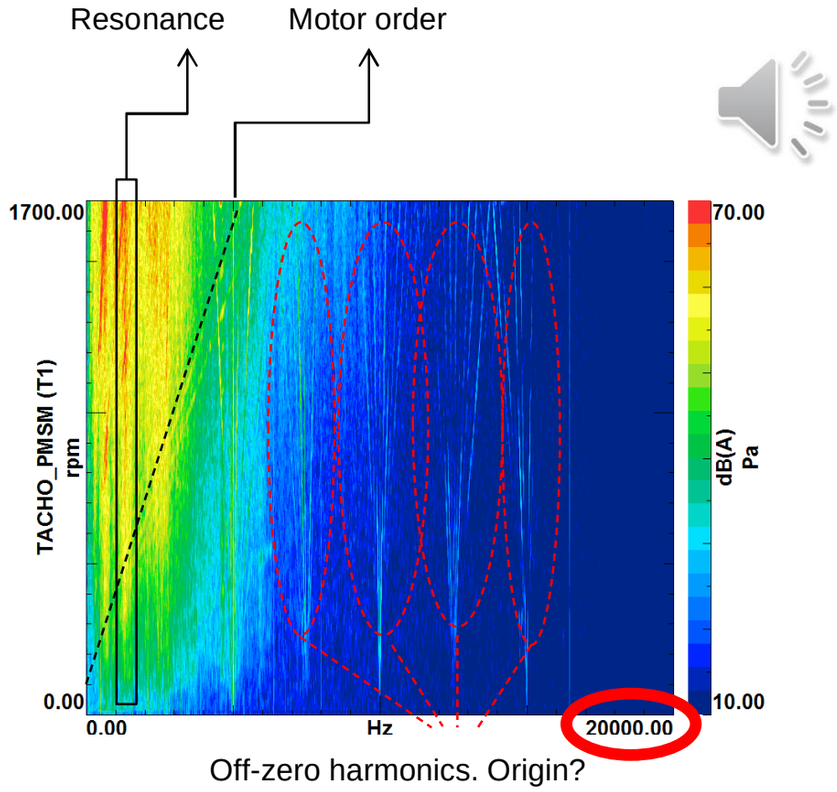


ICE versus EV



ICE driven



Off-zero harmonics. Origin?

Electric driven

Hybrid - Electrical Vehicle
Frequency ranges of interest

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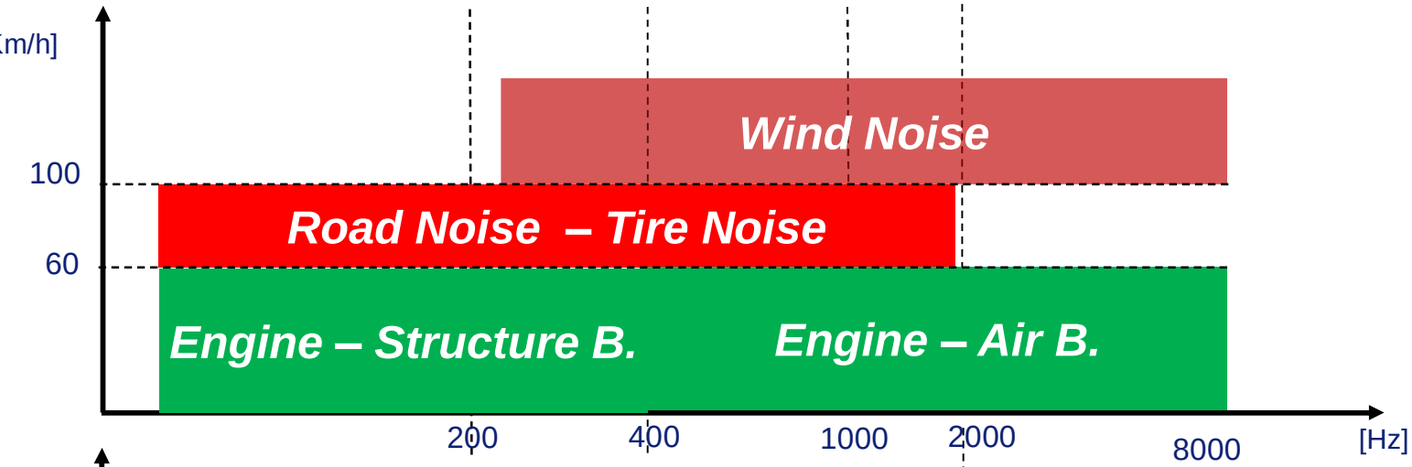
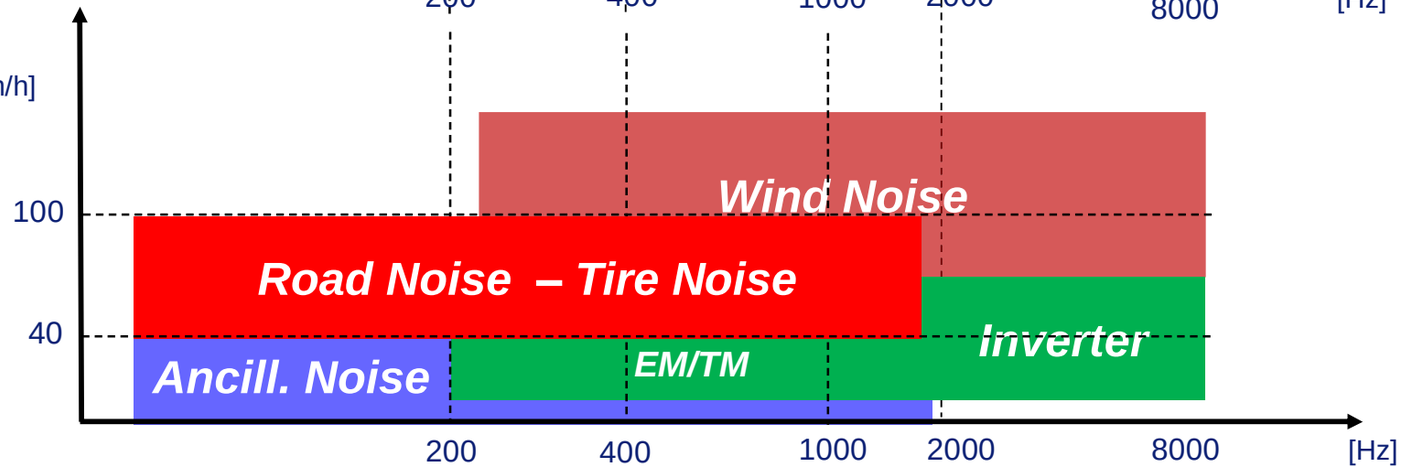
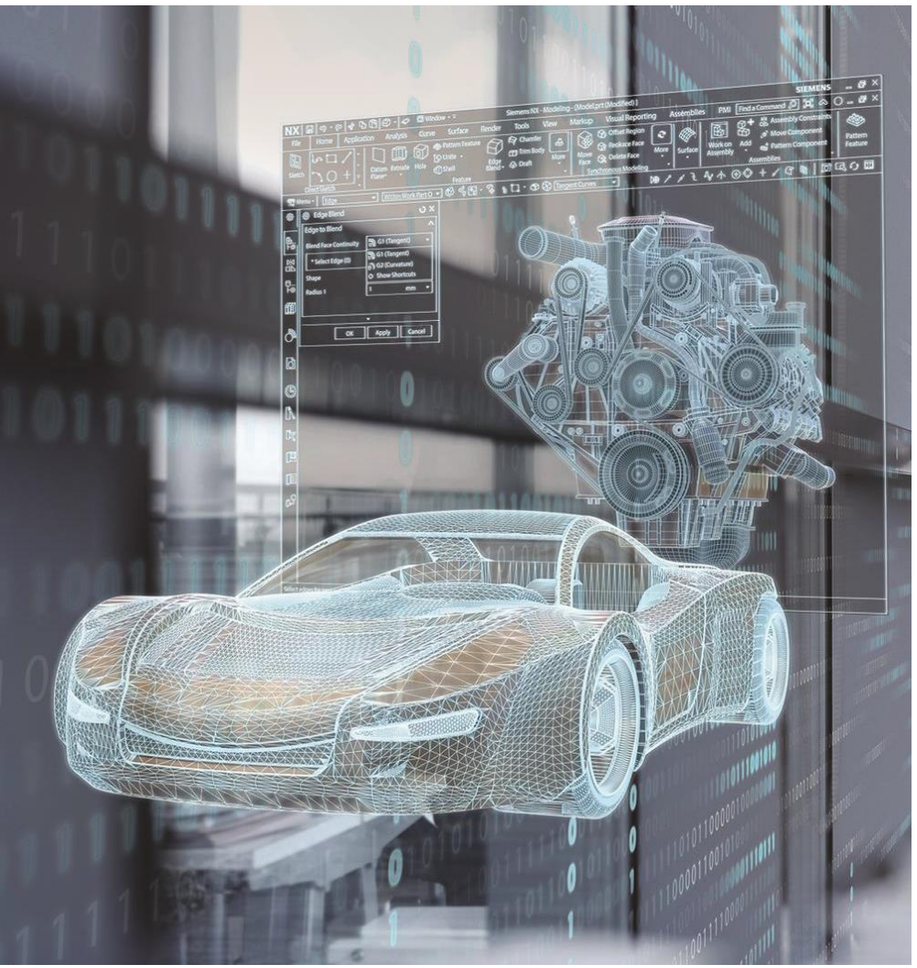
ICE



EV



Webinar agenda



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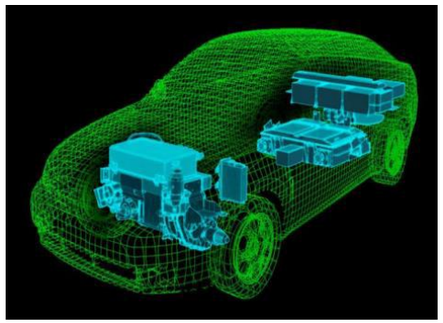
Interior noise

- Receiver perspective
- Source perspective
- Noise transfer

Exterior noise

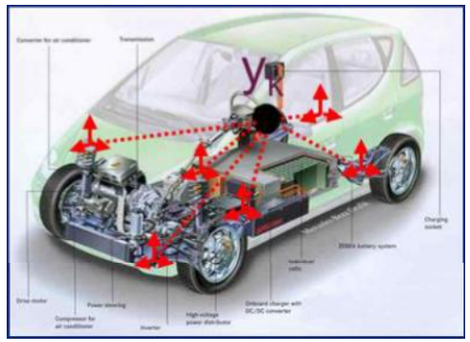
Conclusion

Interior noise
The Source – Transfer – Receiver model



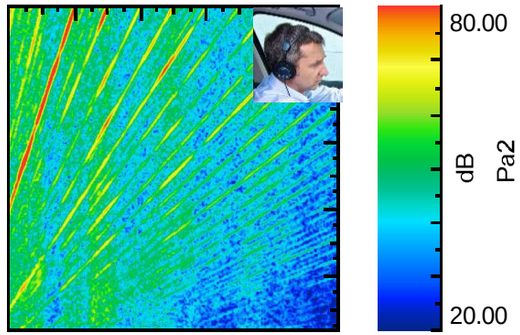
Source (F_i,Q_j)

X



Transfer (NTF)

=



Receiver (y_k)

Structural and acoustic lLoad Identification

Noise source mechanisms

Source modeling and engineering

System concepts and layout engineering

System modeling and engineering

Noise transfer mechanisms

TPA, Modal Analysis, FEM/BEM modeling…

Materials, architectures, system design engineering

Assessing customer value (annoyance, quality, message)

Setting targets

Design engineering towards the right targets

Relevant validation of targets

Interior noise
HEV Receiver Considerations: Level ↔ Perception

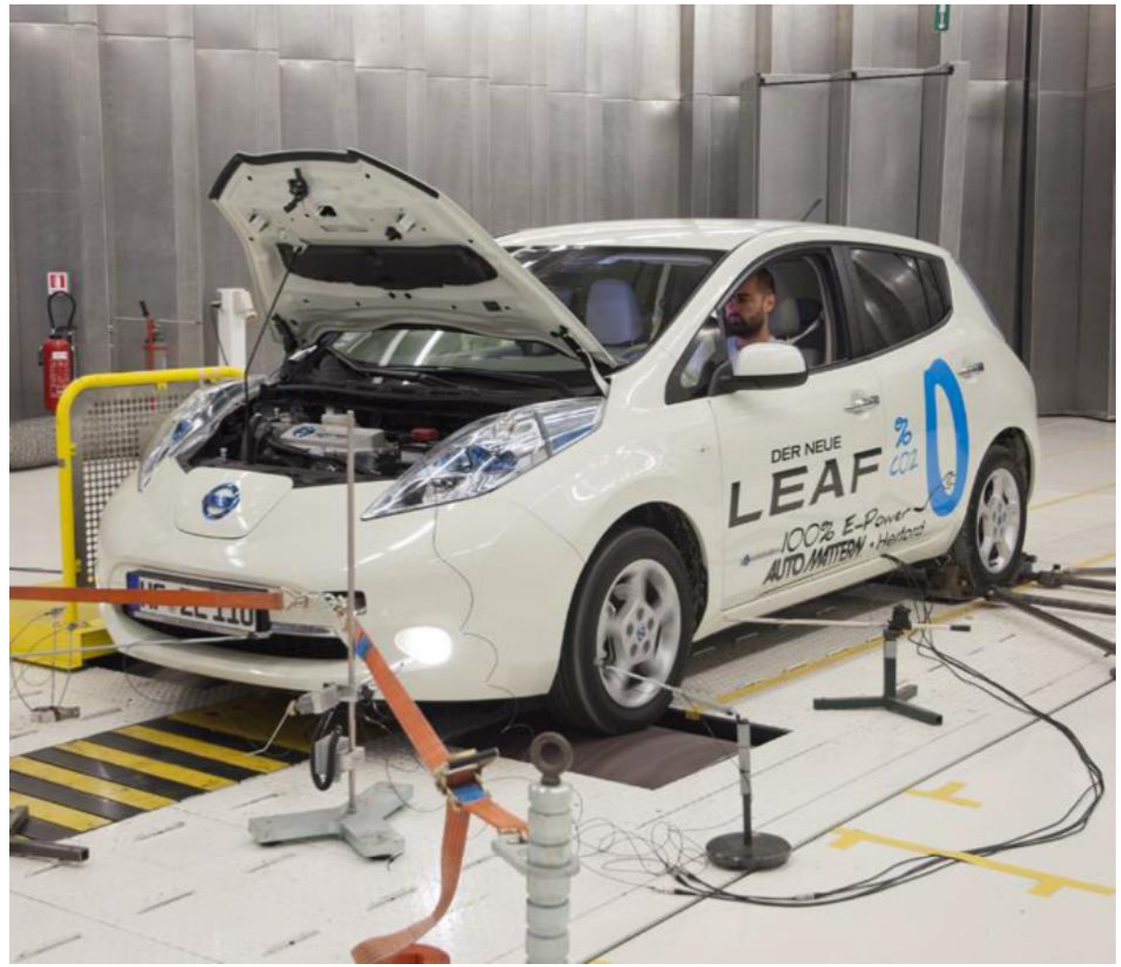
SIEMENS

EV: Low overall noise levels

- No low-order ICE noise
- Reduced masking of wind and tire noise
  => cruising noise
- Reduced masking of noise from ancillaries
  => idle and low-speed noise

New NVH types

- Tonal, high frequency noise of complex harmonic nature
- Broadband high-frequency noise not linked to operating condition
- Hybrid mode switching
  => Transient phenomena
- Less dependency of the interior noise on the load
  => less dynamic

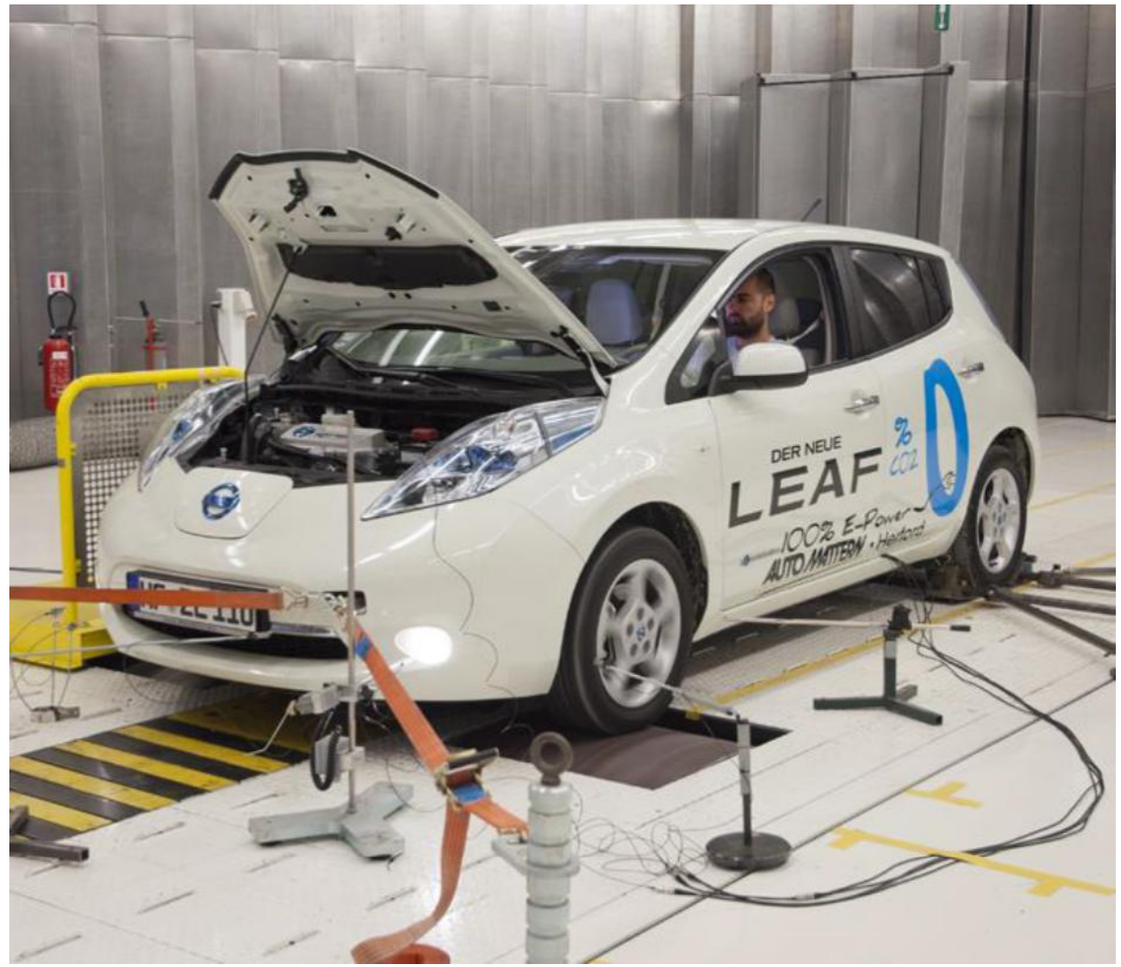


Interior noise
HEV Receiver Considerations: Level ↔ Perception

SIEMENS

New demands for describing sounds and setting targets

- Loudness: accounting for high-frequency effects (<> dBA…)
- Sharpness: shift of noises to higher frequencies
- Tonality, Tone-to-Noise, Prominence…
- Modulation effects other than roughness



WorldAutoSteel

Reducing body structure weight by 35 percent and achieve NVH targets

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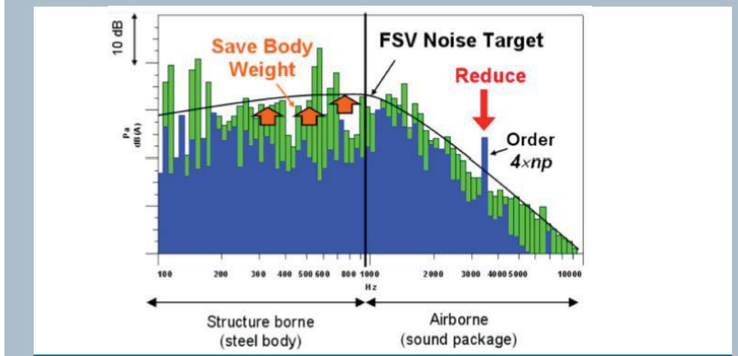
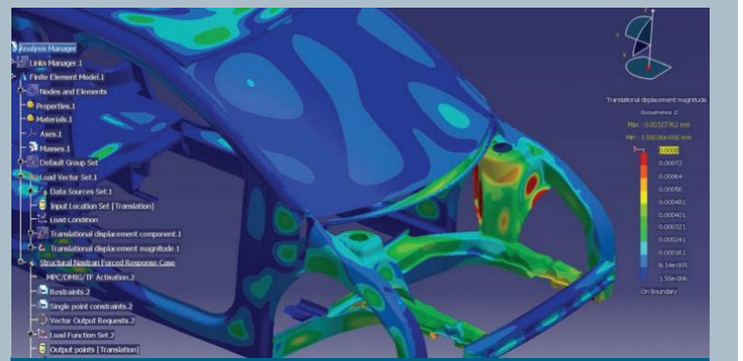
- **Enhanced NVH performance**
- **Helped achieve a 35 percent reduction in body structure weight**
- **Enabled engineers to identify and analyze specific NVH problem areas**

Pursuing seemingly contradictory objectives



A comparison of EV- and ICE-powered class A/B car concept to enable target setting



Clever body design that balances low mass and acceptable NVH performance

- Use LMS Engineering capabilities to balance multiple performance attributes in parallel
- Use LMS Virtual.Lab early in concept design

LMS Engineering services carried out the NVH simulation studies on the FSV project in close collaboration with the consortium performing the crash and rigidity studies.

Interior noise
HEV Receiver Considerations

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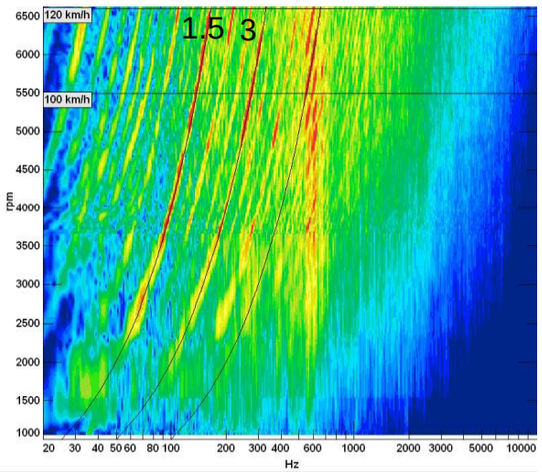
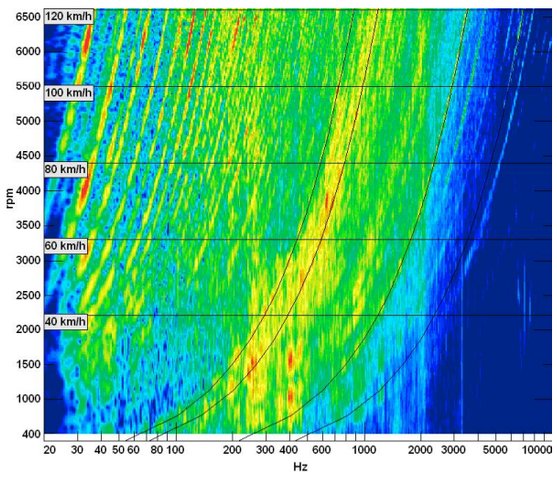
Case: WorldAutoSteel FSV concept study
Benchmark Small Vehicle ICE (3-cyl.) vs. EV PWT – Acceleration WOT

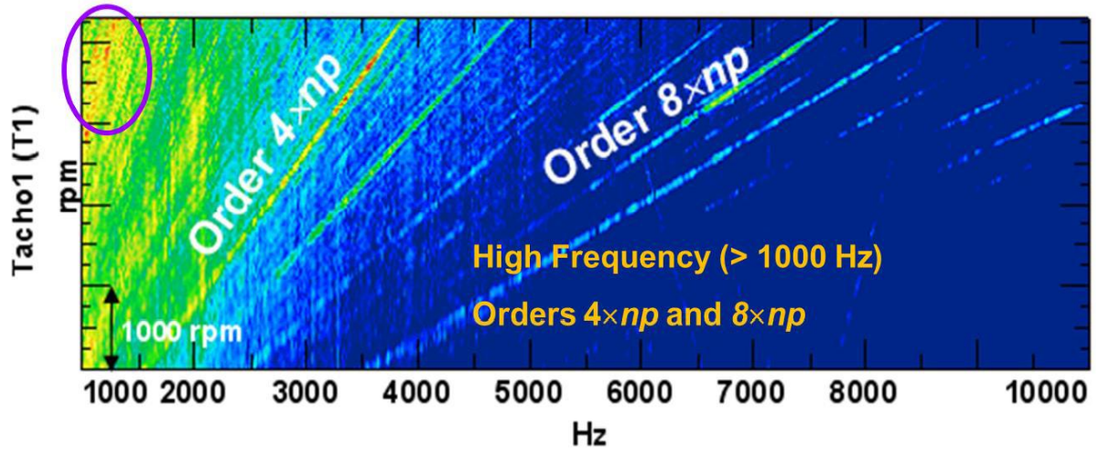
ICE



EV



Case: WorldAutoSteel FSV concept study
Benchmark Vehicle EV PWT – Acceleration WOT

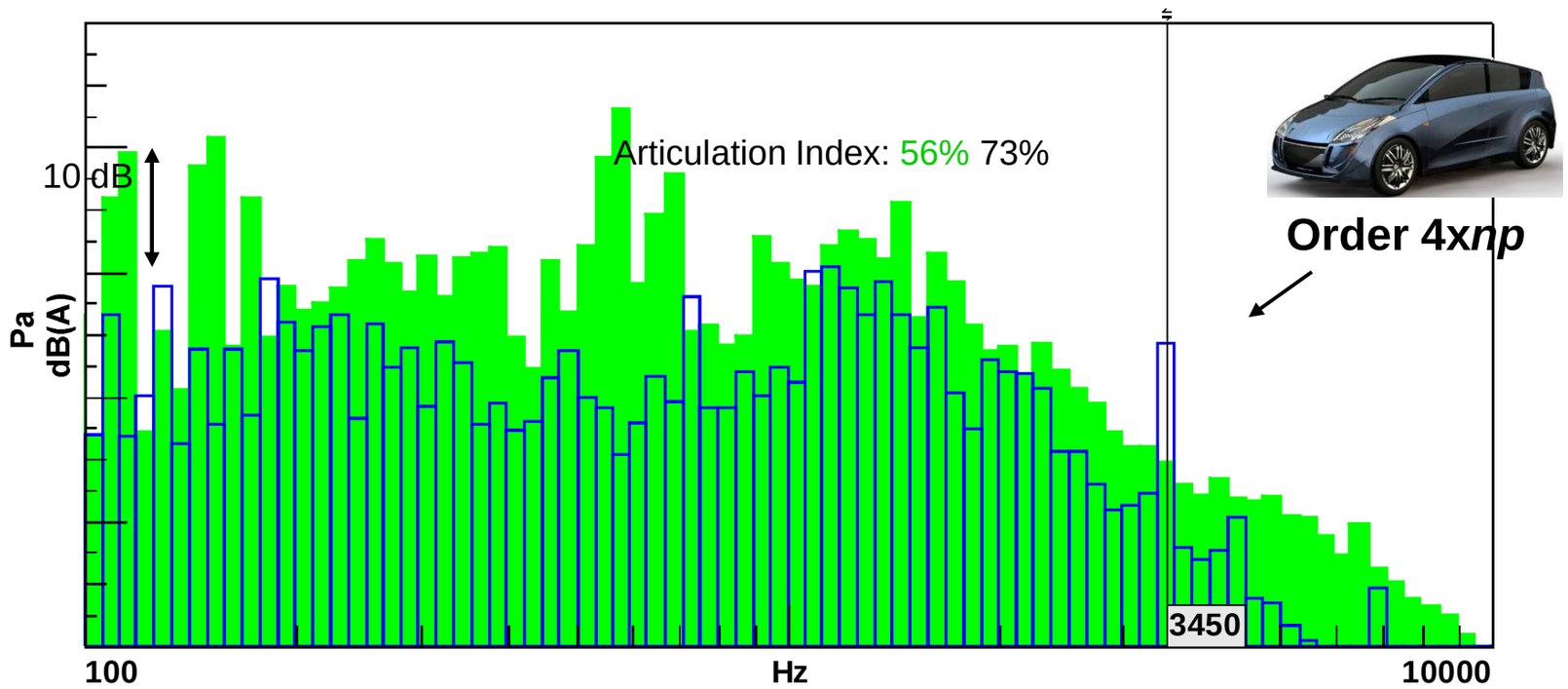


- Low Frequency (< 200 Hz): Low orders up to *np/2*
- Mid Frequency (200 – 1000 Hz): Order *np*… quiet range

Interior noise
HEV Receiver Considerations

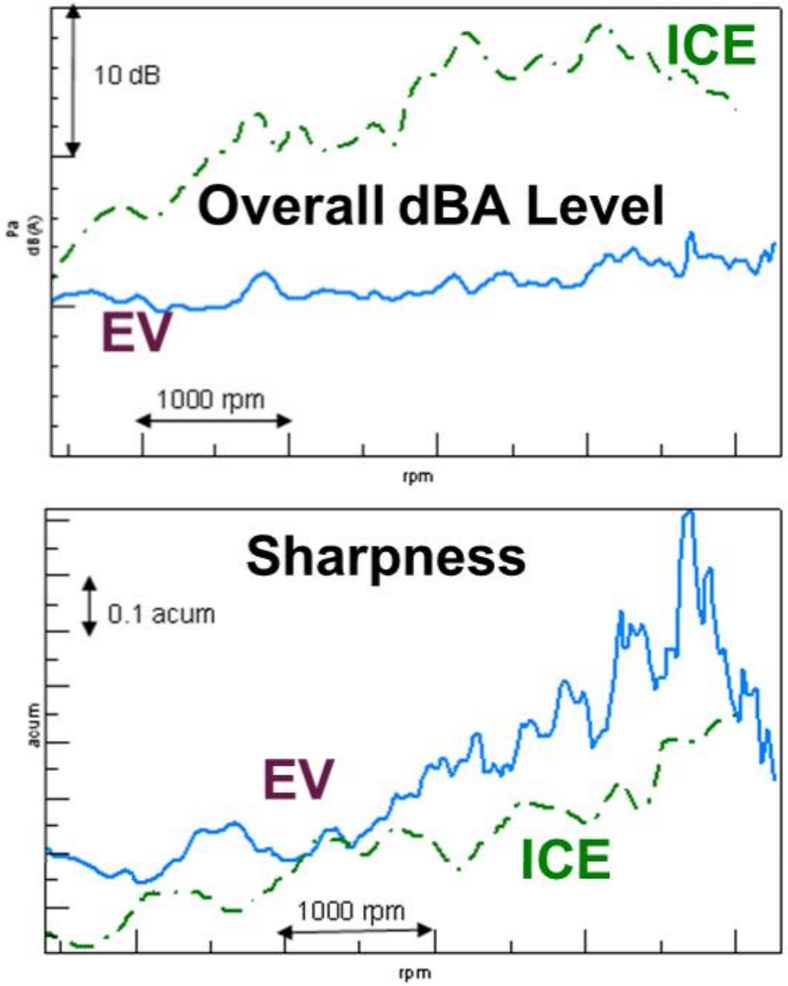
SIEMENS

Case: WorldAutoSteel FSV concept study
Benchmark Vehicle ICE vs. EV PWT – Constant speed 120kph, drivers ear



LF: road noise

Interior noise
HEV Receiver Considerations



Case: WorldAutoSteel FSV concept study
Benchmark Vehicle EV PWT – Acceleration WOT

Sound Indicators for EV Noise

Articulation Index	ICE 56% EV 73%
Prominence Ratio	EV order *4×np* 9.27 dB *> 9 dB threshold*
Tone to Noise Ratio	EV order *4×np* 11.03 dB *> 8 dB threshold*

Prominence ratio and tone-to-tone ratio
are suitable for target setting

Interior noise
The Source – Transfer – Receiver model

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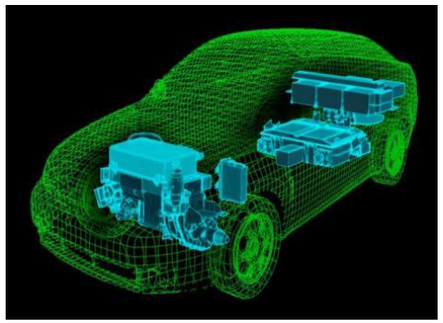
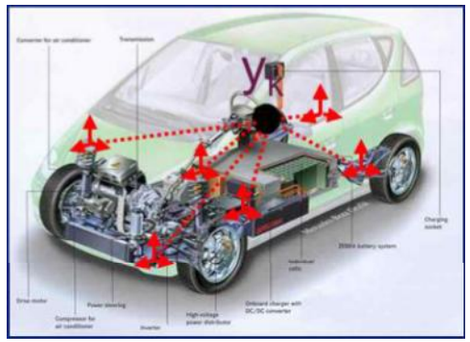


Source (F_i,Q_j)

X



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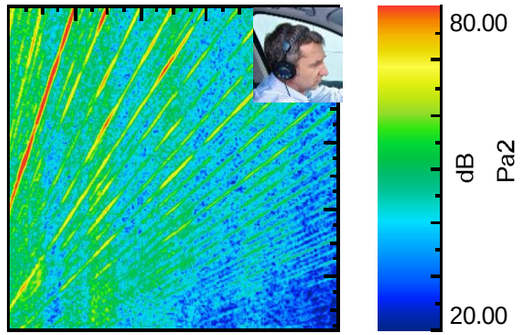

Receiver (y_k)

Structural and acoustic Load Identification

Noise source mechanisms

Source modeling and engineering

System concepts and layout engineering

System modeling and engineering

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TPA, Modal Analysis, FEM/BEM modeling…

Materials, architectures, system design engineering

Assessing customer value (annoyance, quality, message)

Setting targets

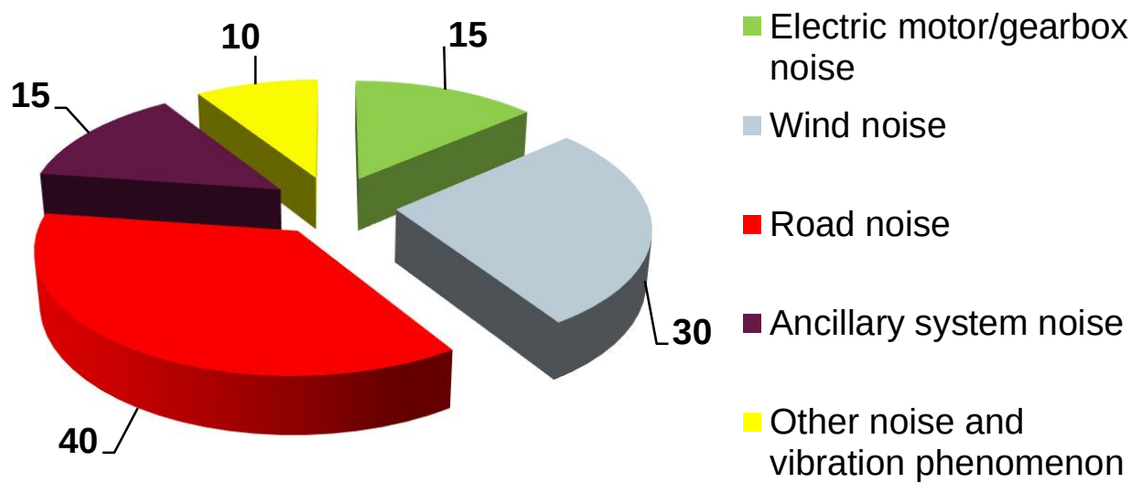
Design engineering towards the right targets

Relevant validation of targets

Interior noise
HEV Source Considerations

New noise sources

- Electric powertrain components
  - Electric Motor
  - Invertor
  - Current-control strategy
- New secondary sources
  - Battery cooling
  - Complex gears in HEV



Greg Goetchius – opinion in Sound &Vibration, April 2011

Interior noise
HEV Source Considerations

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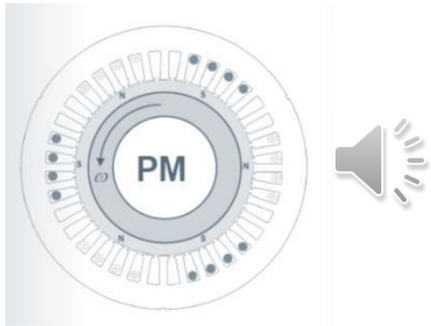
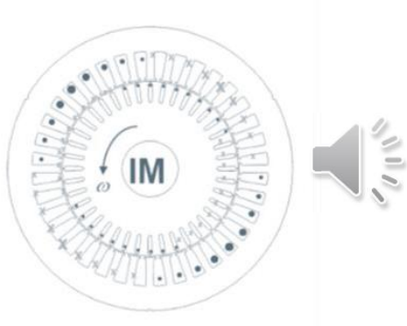
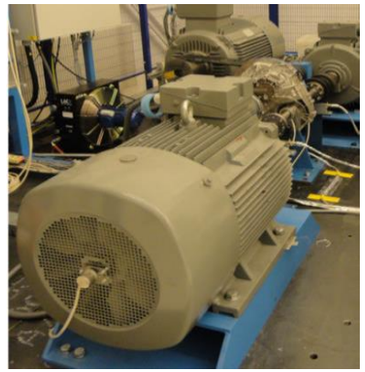
Permanent Magnet Motors
Magnets embedded in the steel rotor

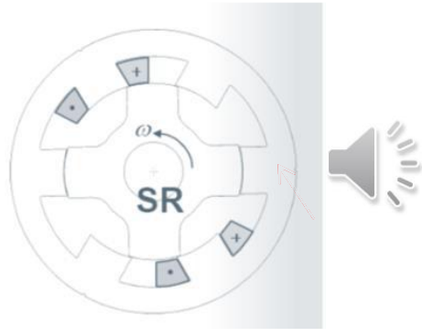


Induction Motors
Cylinder of steel with aluminum or copper conductors





Switched Reluctance Motor
Soft magnetic steel material



Interior noise
HEV Source Considerations

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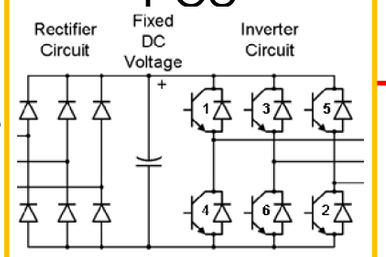
Noise produced by the Electromechanical Control System

DC Power

PCU

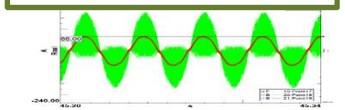


PWM Switching Frequency

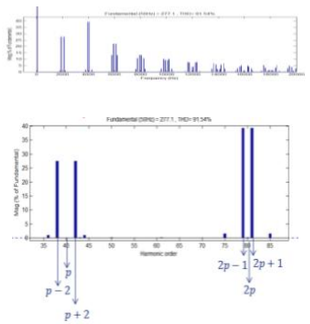
Voltage/Current control

- Sinusoidal
- Space vector
- Hysteresis

Motor voltage and current (harmonics)



Current and voltage harmonics



Motor cables

Electromotor

Permanent Magnet DC

PM Synchronous

Induction Motors

Switched Reluctance

Vibrations

Internal forces

Interior noise
HEV Source Considerations

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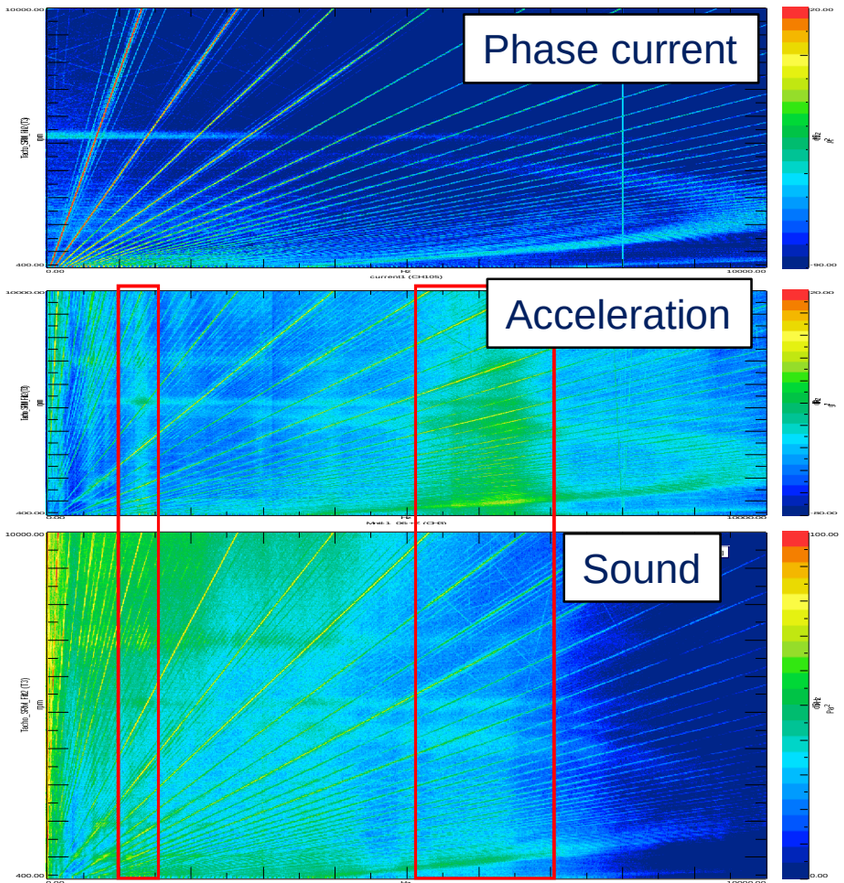
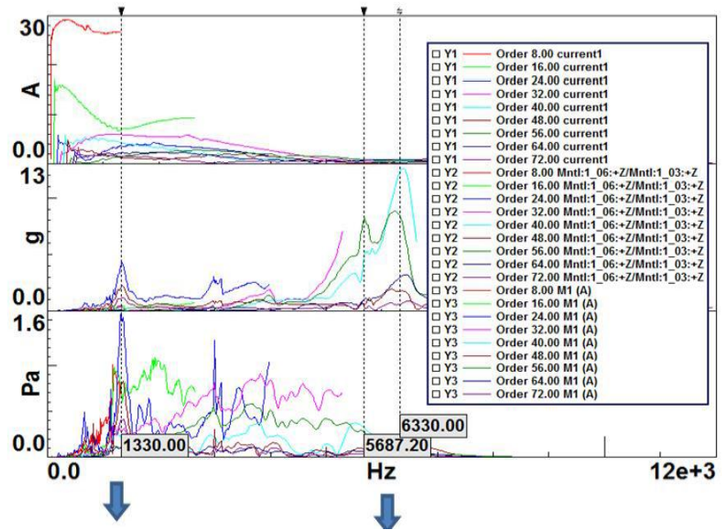
SRM Spectrum of current, acceleration and sound - ODS





1330 Hz: **6330 Hz:**

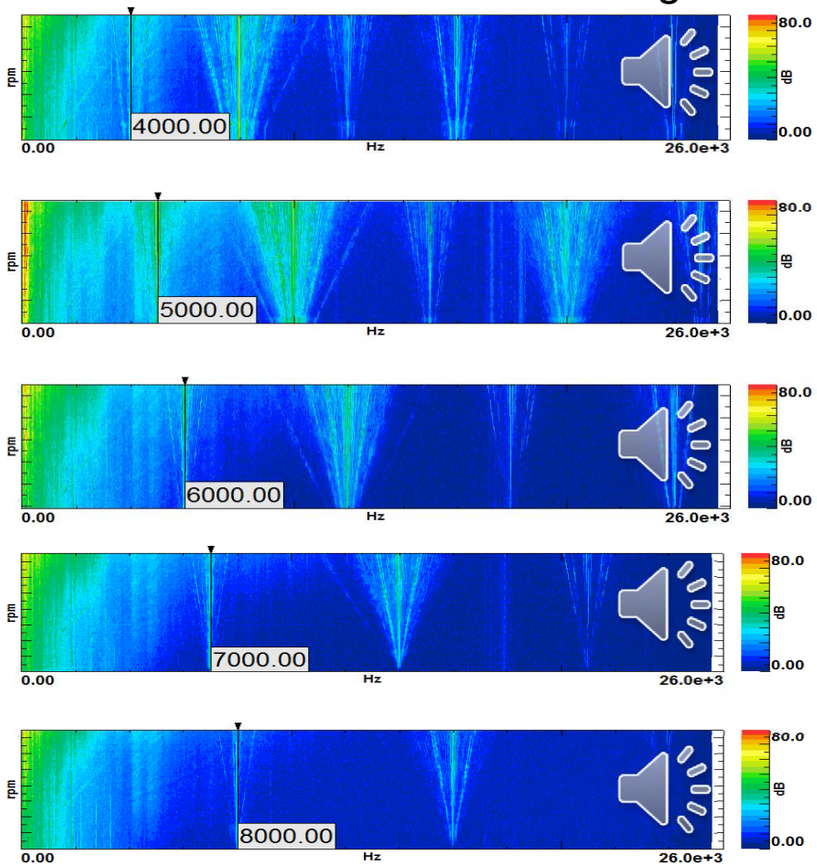
Both square and ovalation modes are excited!

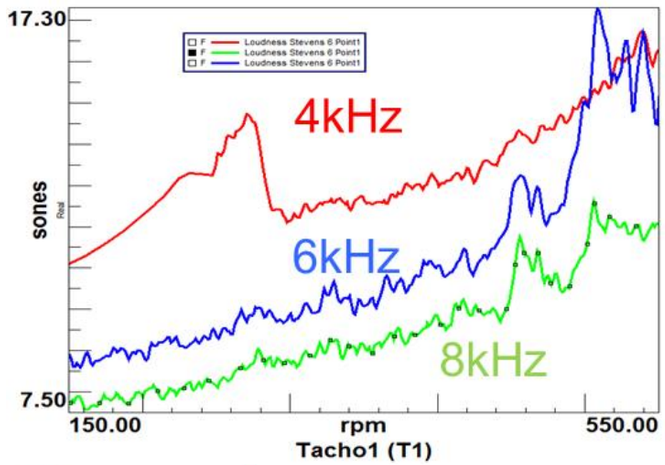
Interior noise
HEV Source Considerations

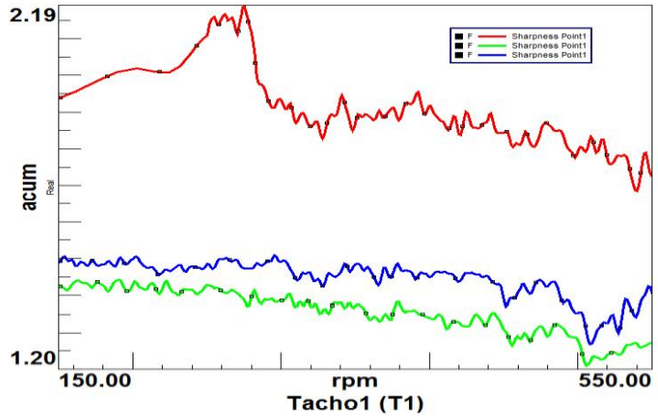
SIEMENS

Noise produced by the Electromechanical Control System: PWM Control

IM-drive: Increasing the switching frequency -> lower vibration speeds







Punch Powertrain

Using LMS Engineering services and tools to cut development time by a factor of 2

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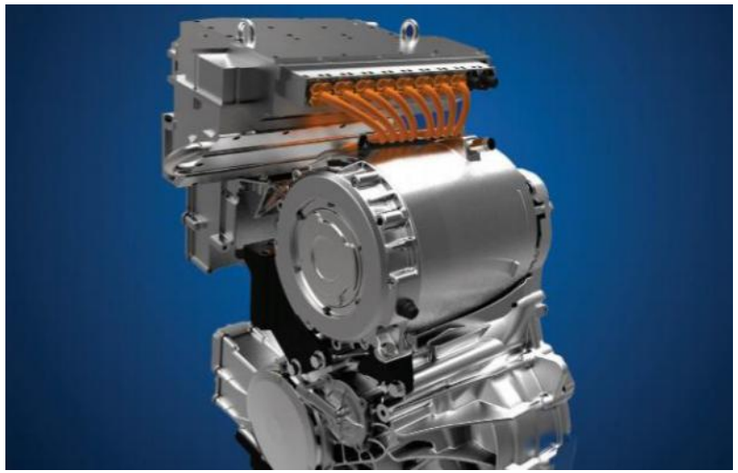


- **Reduced total development time by at least 50 percent**
- **Developed new generation of motors with better NVH performance**
- **Implemented a new simulation-based process with knowledge transfer**

New motors generation for automotive propulsion

Switched reluctance motors challenge NVH performance

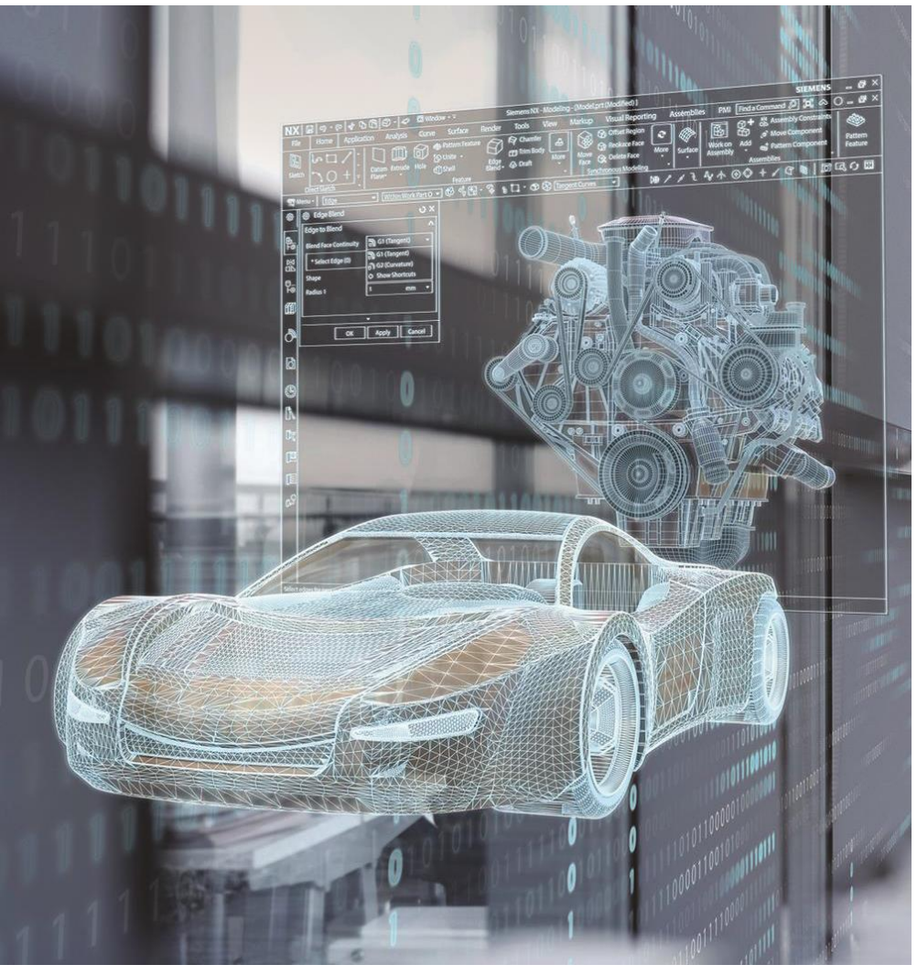
Developing a powerful partnership

- Couple the vibro-acoustic model with the electromagnetic model
- Combine test and simulation for the creation of validated simulation models

“Thanks to LMS Engineering and the optimization process they used with LMS Virtual.Lab, we are now working on a new generation of commercially competitive switched reluctance motors for automotive propulsion.”

Diederik Brems, Mechanical Engineer

Webinar agenda



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- Receiver perspective
- Source perspective
- **Noise transfer**

Exterior noise

Conclusion

Interior noise
The Source – Transfer – Receiver model

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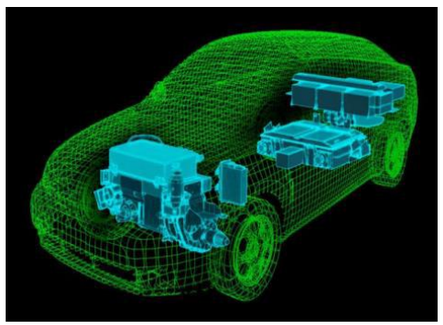
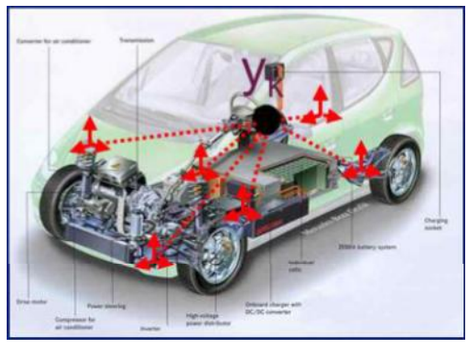
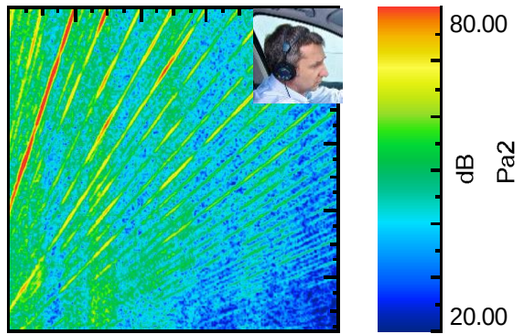






Source (F_i,Q_j) X Transfer (NTF) = Receiver (y_k)

- Structural and acoustic Load Identification
- Noise source mechanisms
- Source modeling and engineering
- System concepts and layout engineering

- System modeling and engineering
- Noise transfer mechanisms
- TPA, Modal Analysis, FEM/BEM modeling…
- Materials, architectures, system design engineering

- Assessing customer value (annoyance, quality, message)
- Setting targets
- Design engineering towards the right targets
- Relevant validation of targets

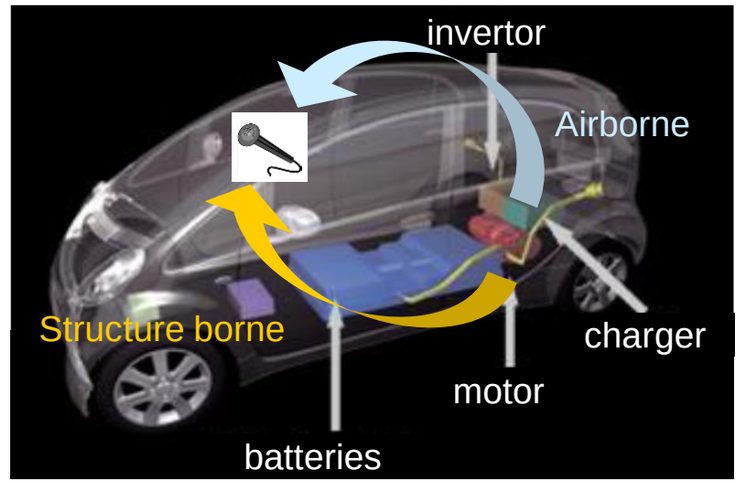
Interior noise
HEV Transfer System Engineering

SIEMENS

Experimental approach: Transfer Path Analysis

- Energetic methods: higher frequencies
- Time domain TPA: Transients & Auralization
- TPA for exterior acoustics

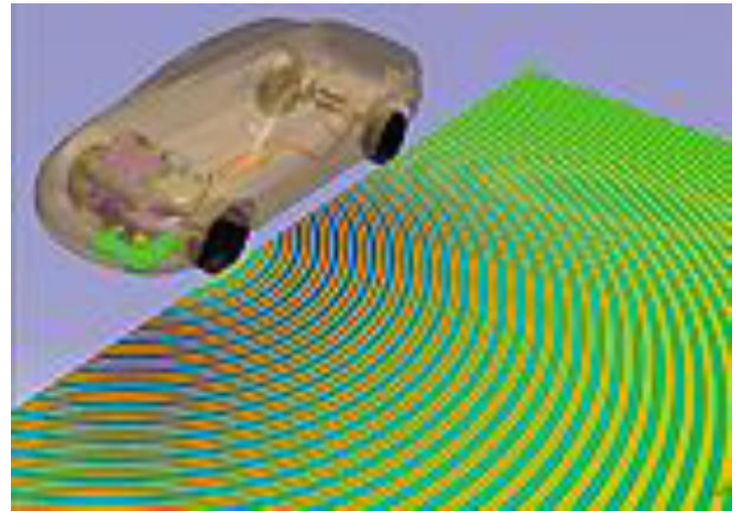
TPA



Numerical approach

- Full audible frequency range
- Fast Multi-pole BEM
- Hybrid approach: HF method (Ray Tracing) + LF techniques (FEM-BEM)

Fast multipole BEM



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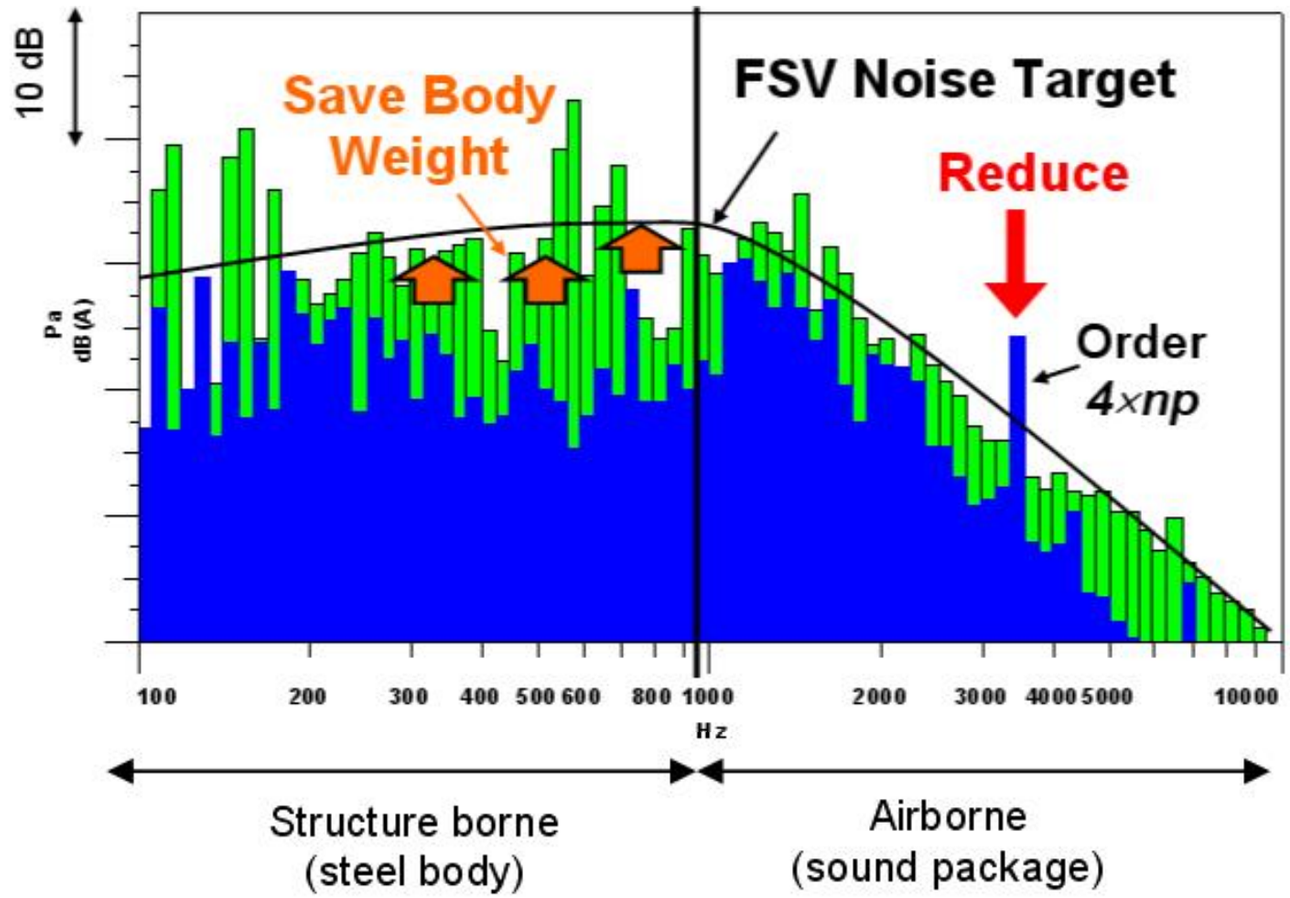
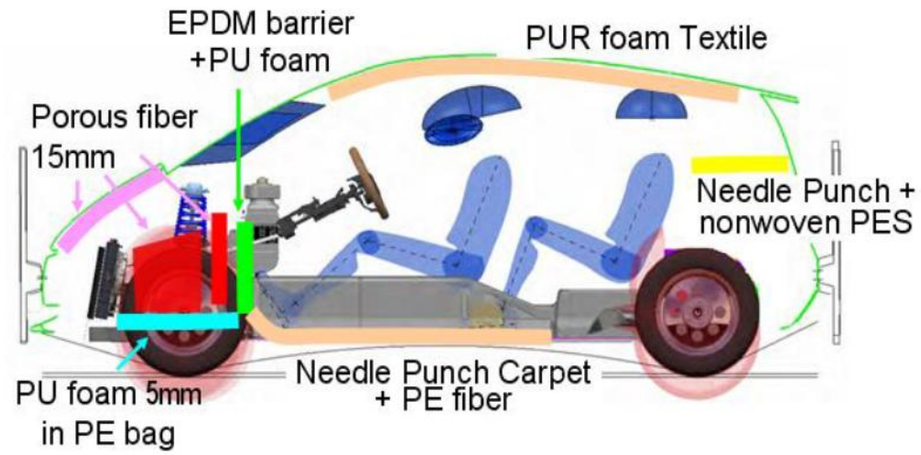
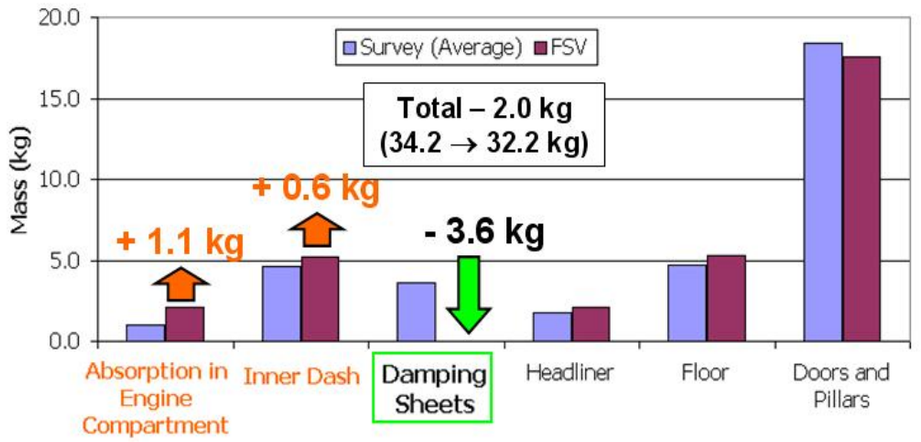
Can weakening NTF target gain weight?



Interior noise
HEV Transfer System Engineering





EV less low-frequency noise

=> gain mass in structural design by reducing steel sheet thickness and using of vibration damping steel

EV high-frequency tonal components

=> increased HF isolation and absorption

=> specific sound pack design

Body weight target

=> 35% mass reduction

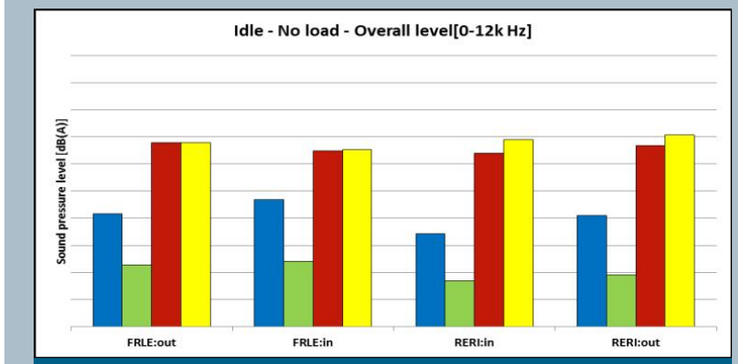
=> 190 kg body structure

BYD Auto Company Limited
Boosting NVH performance of plug-in hybrid vehicle fleet

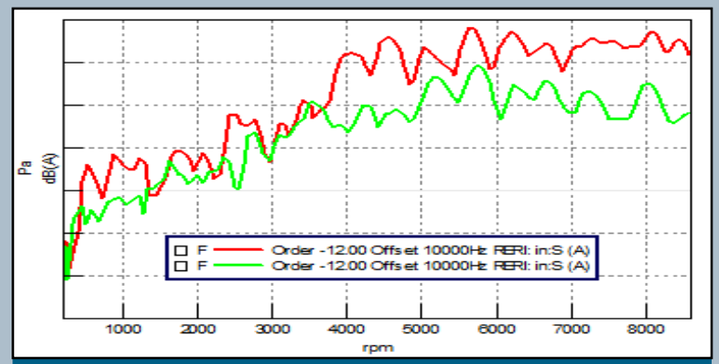
SIEMENS

- **Reduced noise and vibration levels in hybrid vehicles and other NVH-related problems, such as wind and cooling pump noise**
- **Optimized overall hybrid vehicle structure for NVH performance without compromising other quality parameters, such as drivability and handling**

Improving the NVH development and control process



Target setting and benchmarking



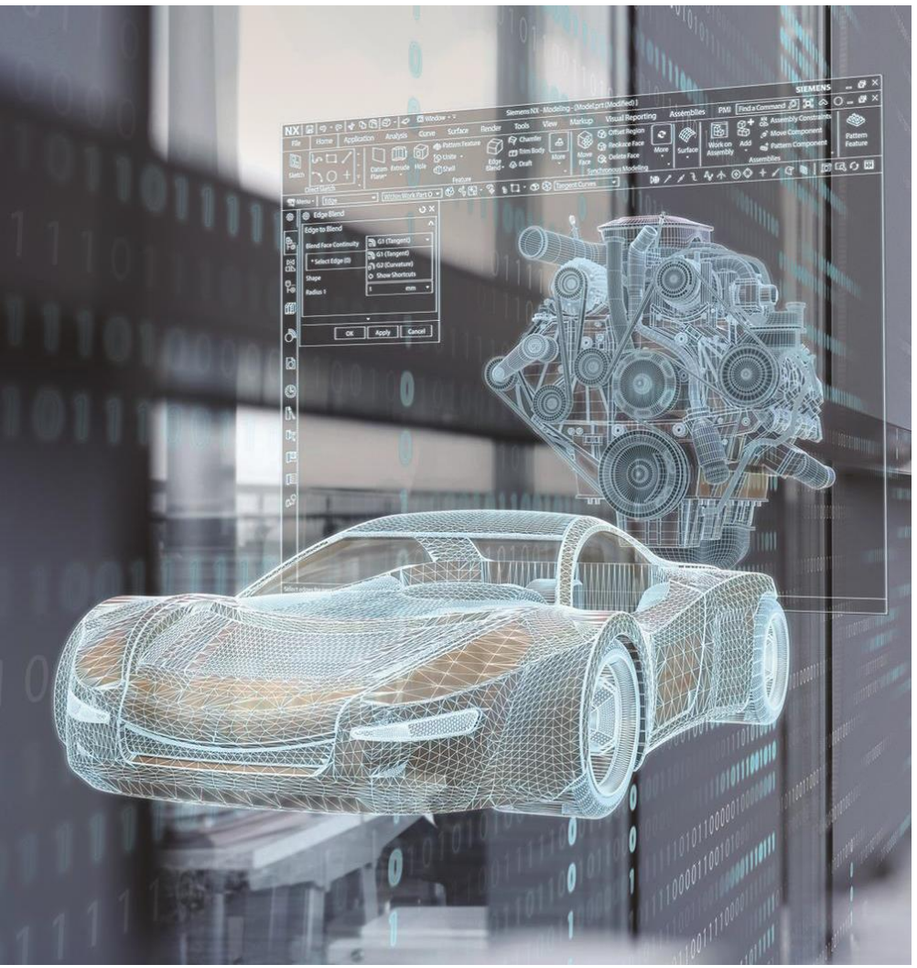
NVH optimization

- Dedicated and comprehensive troubleshooting methodology
- Integrated simulation and testing to determine and resolve the root causes of problems

"15 versions of the Qin were praised for NVH performance by our customers. Working together with LMS Engineering for NVH optimization has helped us position ourselves as the top seller in plug-in new energy vehicles"

Zhang Rongrong, Manager NVH performance research division

Webinar agenda



Introduction

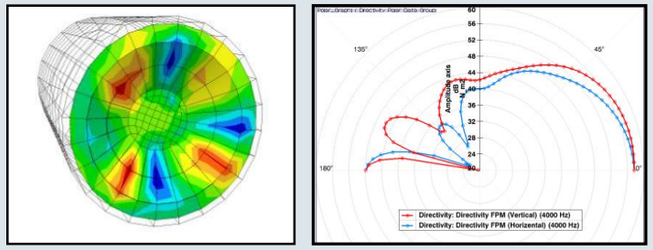
Interior noise

- Receiver perspective
- Source perspective
- Noise transfer

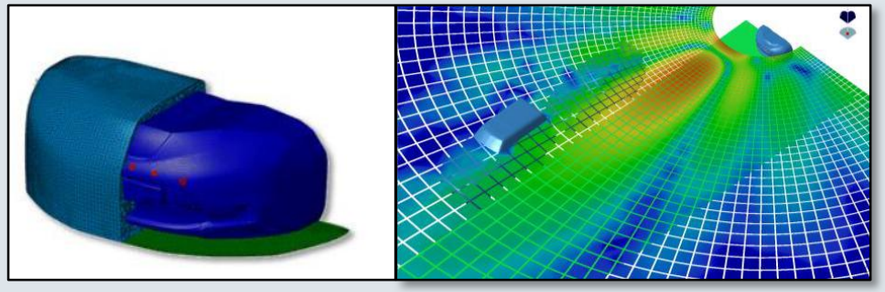
Exterior noise

Conclusion

eVADER – Exterior sound of EV (EU Project)
System engineering approach - Sound Synthesis and Propagation



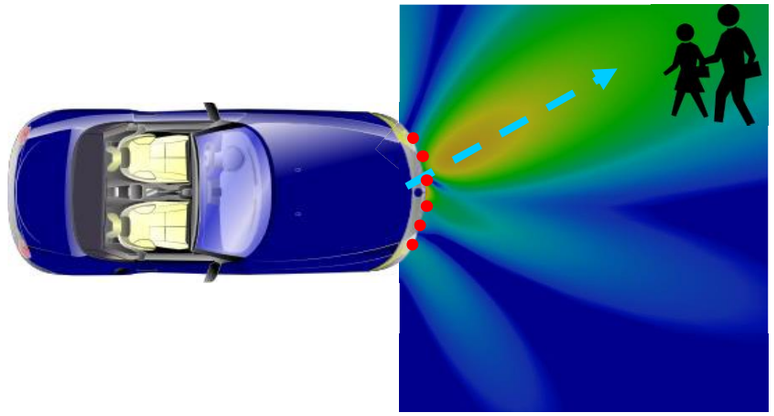
Speaker Directivity



Sound Reflection and Propagation

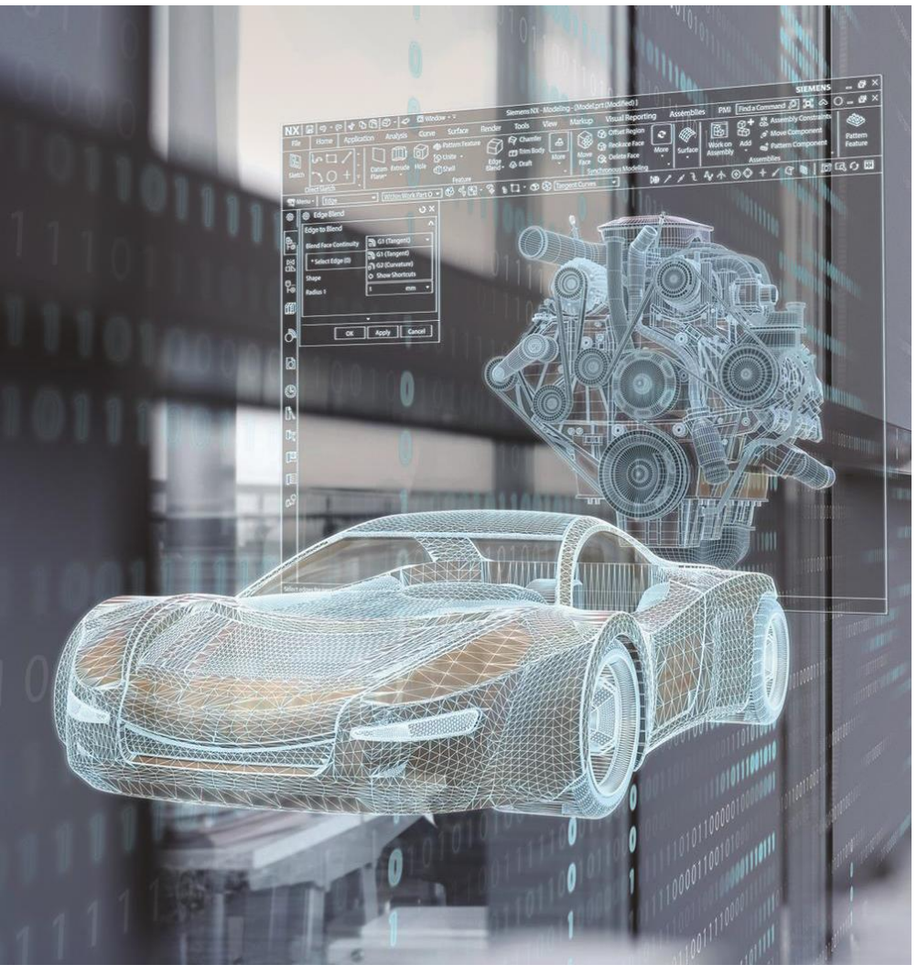
Multiple speakers in bumper
Combined with sound environment
And Beam-forming (phase shift)

=> Directional warning sound field



EC Project eVADER - SCP1-GA-2011-285095
Electric Vehicle Alert for Detection and Emergency Response

Webinar agenda



Introduction

Interior noise

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- Source perspective
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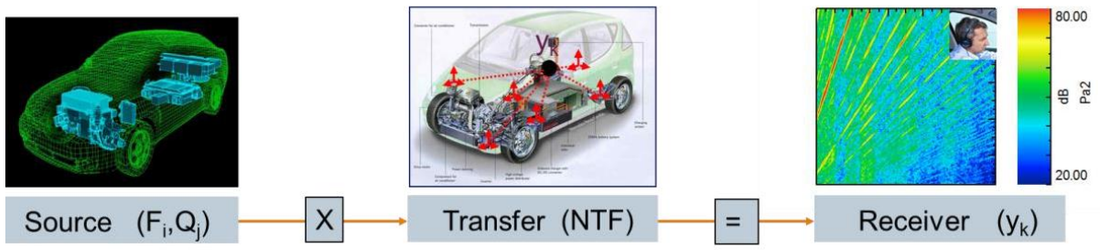
Exterior noise

Conclusion

Conclusion: EV and HEV have a specific NVH behavior

Source-Transfer-Receiver approach

- **Sources**: Motor/invertor, gear, specific appliances and support systems
- **Receiver**: Absence of masking, tonal components of complex nature, warning sounds
- **Transfer**: High-frequencies predominant, lightweight design



Revisit engineering methods and tools

- Signal capturing
- Signal analysis
- Sound quality indices
- Experimental system modeling (TPA) extension to HF & auralization
- Numerical system modeling extension to HF
- Active sound generation more prominent

New research and skills challenges emerge

- Multi- & interdisciplinary
- Not just an “add-on” or “variant” problem.
- Systems approach is required
- From architecture evaluation to system integration and validation

Simcenter solutions for Automotive NVH & Acoustics

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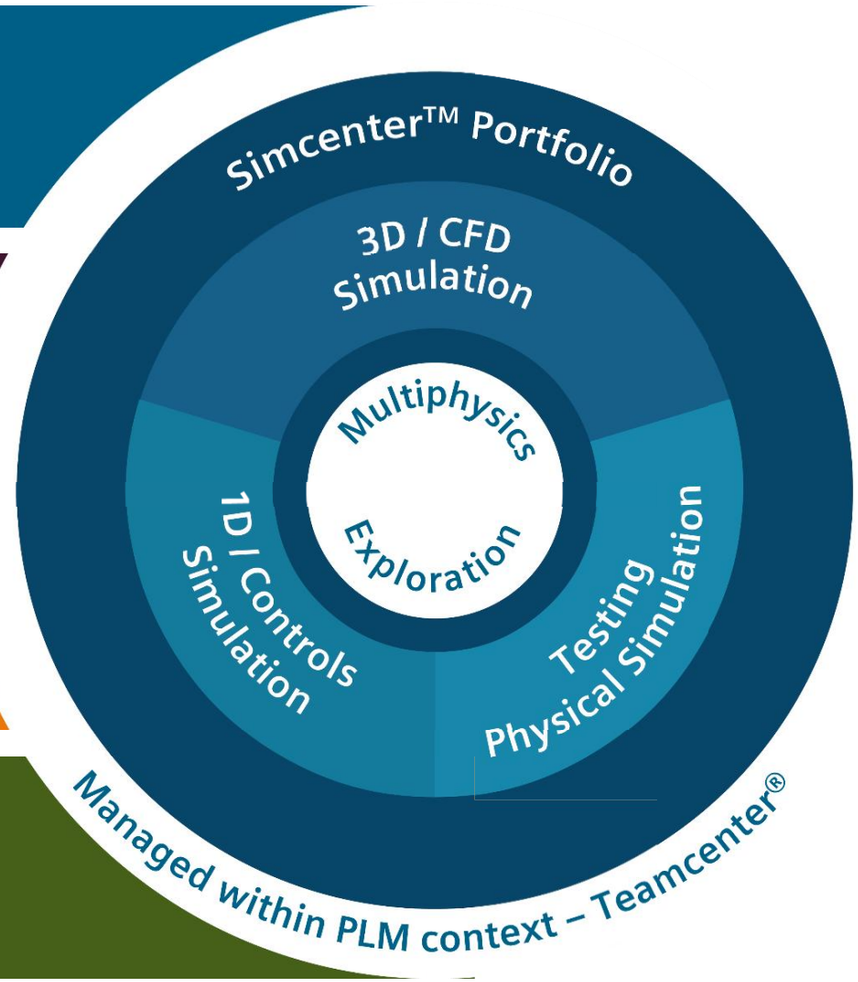
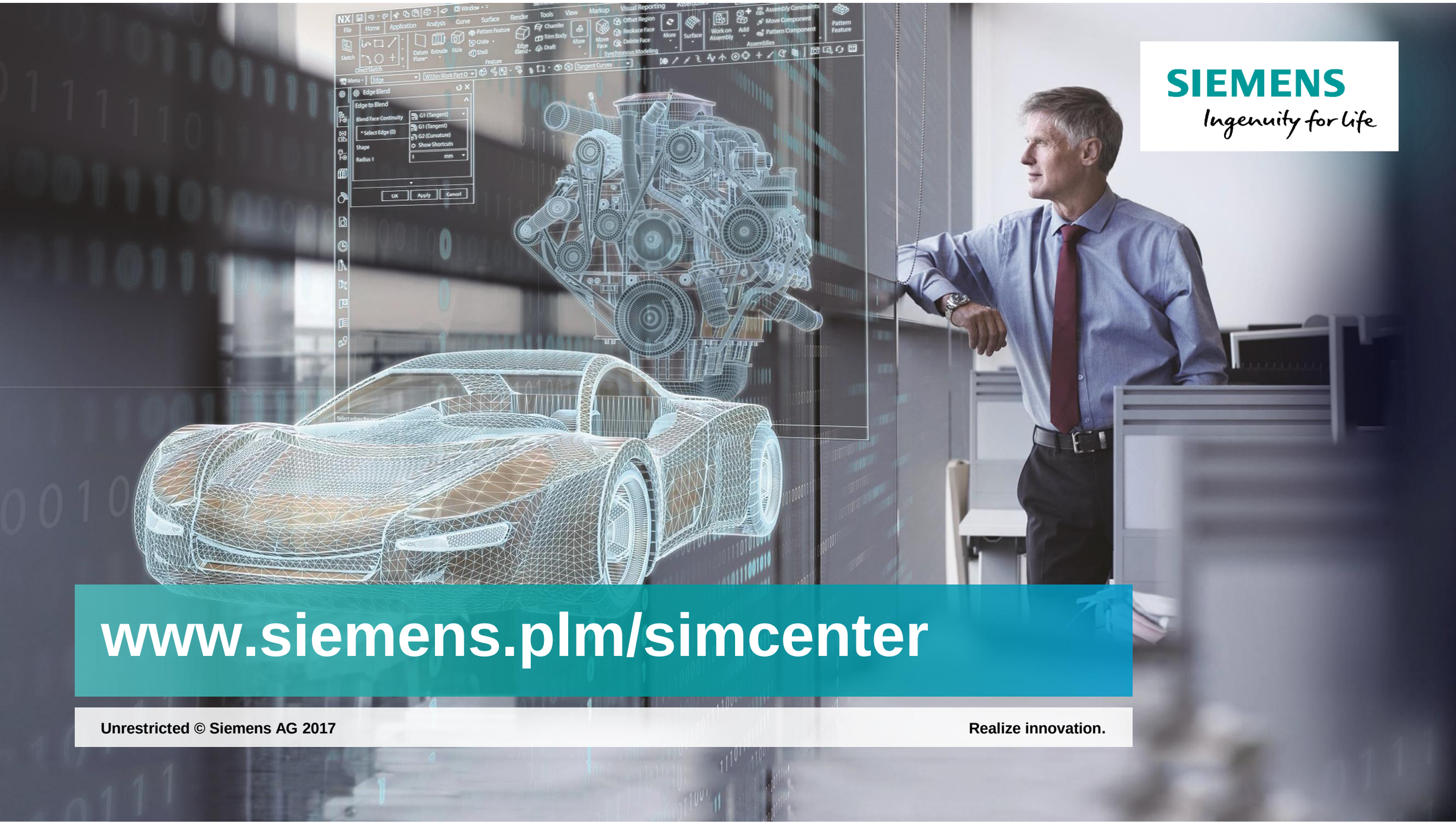
- Legislation and regulation
- New powertrain concepts
- Lightweight structures
- Increase vehicle performance





Realize innovation.