ISVR Institute of Sound and Vibration Research

University of Southampton

WORKSHOP ON THE ACOUSTICS OF AUTOMOTIVE INTERIORS

2nd – 3rd March 2023

Chilworth Manor Best Western Hotel

University of Southampton Science Park, Southampton, UK

Timetable

2nd March

8:30	Arrival & Reception			
9:00	Introduction	Phil Nelson	ISVR	
9:30	Session I	Davide Caprioli	Autoneum	**Evolution of vehicle NVH requirements and solutions in the era of sustainability and electrification**
10:00	Session I	Dave Thurgood	Pritex	**The low carbon future and its effects on automotive acoustic design**
10:30	Coffee Break			
11:00	Session II	Mehregan Bagherpour	TEEVA	**Battery electric truck noise and vibration challenges**
11:30	Session II	Etienne Parizet	INSA Lyon	**Low-frequency enhancement of a car radio through vibratory stimulation**
12:00	Discussion	Panel		**New challenges on NVH**
12:30	Lunch			
13:30	Session III	Steve Elliott	ISVR	**Active sound control in cars**
14:00	Session III	Lorenzo Ebri	ASK	**The interior active noise and sound control challenges**
14:30	Session III	Simon Roberts	ISVR Consulting	**Lessons learned in application of ANC to broadband noise control in vehicles**
15:00	Coffee Break			
15:30	Session IV	Abhishek Singhal Matt Marchese	Tymphany	**Audio Foundry**
16:00	Session IV	Filippo Fazi	ISVR	**Multi-zone audio delivery in cars: fundamental theory and recent advances**
16:30	Session IV	Martin Møller	Bang and Olufsen	**Automotive Sound Zones: On the Influence of Ambient Temperature and Reflecting Boundaries**
17:00	Discussion	Panel		**Sound field control (ANC and multi-zone)**

HUAWEI

3rd March

9:30	Session V	Michael Cousins	Meridian	**Immersive Audio Experiences in the Car**
10:00	Session V	Marcos Simon	Audioscenic	**User Tracked Audio for Automotive Applications**
10:30	Session V	Phil Nelson	ISVR	**Optimal source distribution for multiple listener virtual sound imaging**
11:00	Discussion	Panel		**Spatial audio in car**
12:00	Lunch			

SESSIONS

I	The acoustical challenges faced in designing vehicles for a low carbon economy
II	The internal noise and vibration environment in new generations of electric and hybrid vehicles
III	The active control of interior noise and vibration
IV	The generation of private sound zones for vehicle occupants
V	The delivery of spatial audio (3D sound) to vehicle occupants

	Chair	Panels
Session I & II	Phil Nelson	**New challenges on NVH** Simon Roberts (chair) Davide Caprioli, Dave Thurgood, Mehregan Bagherpour
Session III & IV	Simon Roberts	**Sound field control (ANC and multi-zone)** Phil Nelson (chair) Steve Elliott, Lorenzo Ebri, Filippo Fazi, Abhishek Singhal, Martin Møller
Session V	Filippo Fazi	**Spatial audio in car** Filippo Fazi (chair) Michael Cousins, Marcos Simon, Phil Nelson, Etienne Parizet

HUAWEI

List of Presentations

Davide Caprioli Autoneum Management AG

Davide leads acoustic and thermal management department at the Autoneum Research and Technology Center in Switzerland, supporting the release of novel products within Autoneum portfolio and leading the development of advanced CAE and testing based analysis and design methods for NVH and Thermal management, and their application in joint pre-development projects with key OEMs.

Davide holds a PhD in Mechanical Engineering from the University of Florence.

He joined Rieter Automotive in 2001 as mechanical engineer, along his 20 years of experience within Rieter Automotive and later with Autoneum, he's been gathering relevant experience in NVH simulation methods for low and high frequencies, NVH methods for vehicle troubleshooting and benchmarking, Product engineering comprising acoustic, mechanical and thermal requirements, and program management.

In his current function he's supporting the automotive trend analysis and establishment of the Autoneum innovation roadmap capable to cope with future NVH and Thermal Challenges driven by incoming legislation scenario.

Evolution of vehicle NVH requirements and solutions in the era of sustainability and electrification

Marco Cardillo - Engineer Vehicle Testing and Benchmarking
Théophane Courtois - Principal Engineer R&T Methods
Philippe Godano - Global Product Manager Interior & Product Marketing Manager

With the Paris agreement, we have all committed to reduce our CO2 emissions.

On one side with a clear cut of ICE based powertrains from 2035, thus dictating the increase of adoption and development efforts of new BEV vehicles. While the first generations of Battery Electric Vehicles were based on combustion engine vehicle platforms, European car manufacturers are now developing models based on native BEV platforms. For what concerns NVH, this is obviously the opportunity to rethink dedicated body design, NVH parts, as well as weight and cost allocation adapted to new vehicle architectures, new acoustic sources, and new customer expectations.

On the other side, as the CO2 emission of the use phase of the BEV cars is approaching the neutrality with the adoption of green electricity, the impact of the CO2 emissions of the whole "life" of cars from the phase of the extraction of raw materials to the End-of-Life one, where the vehicles are partially recycled, is getting more and more important, thus pushing for higher sustainable content in the material and processes used to realize vehicle components.

In this context the Life Cycle Analysis (LCA) methodology, which allows calculating the CO2 emissions at every stage of a product life using precise rules (ISO 14040), is becoming and essential tool to be used along

with the conceptual process of any component of a car, in order to match the increasing pressure and expectations on sustainability targets.

In this paper, we present an analysis of the NVH challenges and solutions trend, based on an existing acoustic benchmarking database of more than 25 BEVs. A particular focus is given to the BEV tire noise trend, thanks to the comparison of vehicle acoustic transfer function, and the description of adopted NVH treatments.

In parallel thanks to the comparison of the sustainability potential of different technologies, by means of LCA of a given NVH component, and of their impact on engineering and on NVH performance, an outlook of the likely DNA of future NVH sustainable optimized products answering the specific needs of BEVs will be presented.

Dave Thurgood Pritex Ltd

A childhood curiosity of the mechanics of sound generation and propagation led David to pursue academic study at the University of Salford. After attaining a degree in ElectroAcoustics, David began his career with roles in NVH engineering consultancy at MIRA. David then moved into the automotive supply chain, where he has held a number of application engineering and management roles.

With 30 years of experience in the industry of automotive acoustics, David is currently technical director of Pritex Ltd, an SME specialising is automotive acoustic and thermal insulation based in SW England. When not engaged in the world of automotive acoustics David enjoys cycling, music and exploring.

The low carbon future and its effects on automotive acoustic design

The low carbon automotive future is a future which will enforce change.

There will be changes to the acoustic challenges which our industry will face, changes to the supply landscape brought about through the embodiment of sustainable manufacturing practices, and finally changes in the way consumers use and interact with transport itself with the evolution of intelligent mobility.

This paper provides insight into some approaches to the unique acoustic challenges which are emerging as transport becomes electrified, as well as an overview into the changes of component technologies and how these can support sustainable manufacturing for the future.

Some novel laboratory acoustic characterisation approaches are firstly described. These ensure a resilient component level acoustic understanding can be generated as soon as possible in the vehicle design cycle. Furthermore, these lab characterisation techniques may be used to validate the efficacy of alternative acoustic media that has an enhanced sustainability footprint.

Finally, the paper aims to offer an insight into some of the challenges that the industry at large will face concerning the minimisation of carbon footprint.

Mehregan Bagherpour TEEVA Motors Ltd

Mehregan is a Lead NVH Attribute Engineer at Tevva Electric Trucks. He was formerly Lead Principal Powertrain Integration NVH Engineer at the Changan UK R&D Centre, where he has gained over 10 years' experience in training teams and developing new hybrid CAE & testing technique to characterise noise and vibration sources on the new powertrain & vehicle NVH development projects.

Battery Electric Truck Noise and Vibration Challenges

The challenge of reducing Carbon footprint through freight transport is real. Based on International Energy Agency (IEA) publication on 2018, 75% of transport emissions come from road vehicles and 29% of them are from Freight transportation. The proposal offered by Tevva Electric Trucks is to first bridge the gap between ICE and BEV truck through a platform integration process first. Tevva is using a familiar and proven platform to build the first electric truck for general use, this would allow the users and operators to develop their processes in terms of delivery scheduling, maintenance, route mapping etc… as well as getting the drivers used to drive Electric trucks.

There are some fundamental differences in power delivery of BEV Vs ICE trucks and also there is the customer anxiety about range that will disappear as they use the trucks more.

Replacing the traditional powertrain (ICE) with Electric drive on a platform that was developed for ICE has its unique challenges, both terms of design criterions and the ranking of attributes. I will be sharing with you the challenges faced and you can see the fruit of our labour in our first trucks within coming months.

Etienne Parizet INSA Lyon

Etienne Parizet is professor at Insa Lyon, which he joined in 2000. He is a member of Laboratoire Vibrations Acoustique and his research focuses on sound and vibration perception, contribution of sound and vibration to discomfort in transportation, sound quality and noise annoyance in open-plan offices. Before 2000, he was employed by the car manufacturer Renault, mainly in acoustics (in the research acoustic team, which he led for some years).

Low-frequency enhancement of a car radio through vibratory stimulation

It has been shown that vibrotactile stimulation can increase the perceived quality of audio reproduction (Merchel 2018). Can this be useful in a car? The low-frequency efficiency of standard car radio is far from perfect. This can be improved thanks to a subwoofer – which is expensive and takes up a lot of space (for example in the trunk). The question addressed in this presentation is whether a vibrotactile stimulation, limited to the low-frequency content of the signals, can be used instead of an additional subwoofer in a car. In a semi-anechoic room, a car seat was placed in front of a pair of stereo speakers. It was equipped with 8 vibrators powered by the low-frequency content of the car radio signal. 25 participants had to compare this set-up with the reference one (speakers only). The use of additional subwoofers was also evaluated. The evaluation was made according to three criteria: bass sensation, immersion and overall quality. Results show that using the vibrators really enhance the listening experience, in a more effective way than subwoofers.

Steve Elliott ISVR

Steve Elliott graduated with first class joint honours in physics and electronics from the University of London, in 1976, and received his PhD from the University of Surrey in 1979 for a dissertation on musical acoustics.

He was appointed Lecturer at the Institute of Sound and Vibration Research (ISVR), University of Southampton, in 1982, was made Senior Lecturer in 1988, Professor in 1994, and served as Director of the ISVR from 2005 to 2010. His research interests have been mostly concerned with the connections between the physical world, signal processing and control, mainly in relation the active control of sound using adaptive filters and the active feedback control of vibration. This work has resulted in the practical demonstration of active control in propeller aircraft, cars and helicopters. His current research interests include modular systems for active feedback control and modelling the active processes within the cochlear.

Professor Elliott has published over 300 papers in refereed journals and 600 conference papers and is co-author of Active Control of Sound (with P A Nelson 1992), Active Control of Vibration (with C R Fuller and P A Nelson 1996) and author of Signal Processing for Active Control (2001). He is a Fellow of the Acoustical Society of America, was jointly awarded the Tyndall Medal from the Institute of Acoustics in 1992 and the Kenneth Harris James Prize from the Institution of Mechanical Engineers in 2000.

He was made a Fellow of the Royal Academy of Engineering in 2009.

Active sound control in cars

The physical principles and historical development of active sound control of engine noise and road noise in ICE cars is briefly outlined, before describing some of the current commercial applications. The development of “active sound design” is emphasised, with the combination of active cancellation of unwanted sound and the reproduction of noise signatures that provide brand identity. Some of the issues associated with the active control of sound in electric vehicles are then discussed, particularly the emphasis on the attenuation of road noise and the increased importance of generating sounds to give the driver feedback or to mask distracting noises. Finally, recent work on the local active control of sound is discussed, significantly extending the frequency range of global systems particularly if combined with virtual sensing and head tracking.

Lorenzo Ebri ASK Industries S.p.A.

Lorenzo Ebri graduated from the University of Parma in 2013 with first class honour in Mechanical Engineering with a dissertation on 3-D spatial acoustics (Design, construction and test of a cylindrical microphone array). From 2014 to 2016, he worked in a car maker company as NVH engineer. In 2020, he completed a Ph.D. program in Industrial Engineering at the University of Parma with a dissertation on “Methods for assessing and controlling the spatial sound field inside a car”. Since 2016, he is employed in ASK Industries S.p.A. as Noise & Vibration System engineer

The interior active noise and sound control challenges

A brief review of active noise and sound control systems in 2020s cars. Quite well known ANC and Sound Enhancement features have now to interact together within modern vehicle powertrain architectures. Road

noise control systems has been discussed in scientific literature for more than 40 years now, but only in the current years it was possible to implement them in the real world. With a never ending trend of increased refinement from the final customer, the interaction and integration of these features is challenging like never before.

Simon Roberts ISVR Consulting

A mechanical engineering graduate, I obtained my MSc from the ISVR in 1987. I worked for Jaguar cars on engine refinement before moving to MIRA in 1992 to work on whole vehicle NVH and the development of hybrid modelling methods for vehicle NVH development. Following a period working on various noise and vibration projects I then joined ISVR Consulting in 2011 and have worked primarily in the automotive and marine areas since, including the development of ANC systems for these platforms. I am currently the manager of the unit.

Lessons learned in application of ANC to broadband noise control in vehicles

In recent years ISVR Consulting have worked on the application of active noise control to a number of vehicles, including road vehicles and high-speed trains. During the course of these projects the practicalities of reference selection, speaker location, and hardware performance have been a major area of investigation. The presentation will try to convey the issues we have encountered and approaches to improve the system performance.

Abhishek Singhal & Matt Marchese Tymphany Acoustic Technology Ltd

Abhishek's professional journey jump started with a stint at Renault-Nissan as a Production Engineer and later as a Quality Engineer. With a strong foundation in manufacturing and quality management, Abhishek pursued his MBA to help facilitate a career path towards the business end of automotive and worked with an advanced automotive product planning consulting firm, The CARLAB. Through various research & consulting projects, Abhishek took on Tymphany's initial challenge for setting up its automotive strategy and since joined Tymphany's journey into the automotive industry as its Automotive Strategy Lead.

Matt began his career in automotive with "in-vehicle electronics" product planning and business development while at Ford/Visteon. In the following years, Matt became the Director of Marketing at the CARLAB, an automotive product planning consulting firm, which has served nearly every global OEM with product design and planning research. He also was head of sales for THX, supporting audio/video certification and licensing. Today, Matt is Tymphany's Automotive Business Unit leader for the newly formed vertical within the company.

Audio Foundry

Tymphany is a globally diversified design & manufacturing company with nearly 30 nationalities and locations spanning Asia, North America and Europe. Our roots date back to 1926 when Peerless was founded, and we have a long history of innovation since. We work with brand partners to develop the

world's most innovative audio/video products. For the automotive industry we are bringing new types of hardware, technologies, and tools to support Automotive Audio 2.0.

In this presentation we talk about the purpose-built Maker's Space for developing advanced automotive audio solutions and/or experiences that spark collaboration and innovation.

Filippo Fazi ISVR

Prof Fazi is Professor of Acoustics and Signal Processing at the Institute of Sound and Vibration Research (ISVR) of the University of Southampton, where he is Head of the Acoustics Group and leads the Virtual Acoustics and Audio Engineering Team. He also served as Director of Research of the Institute and sits on the Intellectual Property panel of the Faculty of Engineering of Physical Sciences. He is an internationally recognised expert in audio technologies, electroacoustics and digital signal processing, with special focus on 3D audio, acoustical inverse problems, multi-channel systems, and acoustic arrays. He is the author of more than 160 scientific publications and co-inventor of various patented or patent-pending technologies. Prof Fazi graduated in Mechanical Engineering from the University of Brescia (Italy) in 2005, with a master thesis on room acoustics. He obtained his PhD in acoustics from the Institute of Sound and Vibration Research in 2010, with a thesis on sound field reproduction. Prof Fazi was awarded a research fellowship by the Royal Academy of Engineering in 2010 and the Tyndall Medal by the Institute of Acoustics in 2018. He is a fellow of the Audio Engineering Society, a member of the Institute of Acoustics and is co-founder and chief scientist of Audioscenic, a start-up company that commercialises loudspeaker array technologies developed by Prof Fazi and his team.

Multi-zone audio delivery in cars: fundamental theory and recent advances

This technical lecture will cover the theory of multi-zone audio delivery. Well-established techniques will be reviewed, including pressure-matching, acoustic contrast maximisation, and energy difference maximisation. Some of the key performance metrics will also be introduced. In the second part of the talk, some of the most recent advances in multi-zone audio delivery will be briefly presented, with focus on technologies that adapt to the condition of the acoustical environments and to the listeners' position.

Martin Møller Bang and Olufsen

Martin Bo Møller received the M.Sc. degree in engineering acoustics from the Technical University of Denmark in 2011 and the Ph.D. in signal processing and acoustics from Aalborg University in 2020, both in Denmark. Since 2011, he has been employed by the Danish consumer electronics company Bang & Olufsen, where his research interests include sound field control, loudspeaker array processing, and loudspeaker-room interaction.

Automotive Sound Zones: On the Influence of Ambient Temperature and Reflecting Boundaries

The goal of sound zones is to reproduce different personal audio signals to multiple people occupying different spatially confined zones in the same acoustic environment, e.g., an automotive cabin. To reproduce the intended audio content in the separate zones and reduce undesired leakage between them, the output sound of a given set of loudspeakers is controlled. However, due to the acoustically reflective environment, the available knowledge of the environment heavily influences the degree to which the sound field can be controlled. In this talk, the focus will be how imperfect knowledge about the acoustic environment influences the accuracy of the reproduced sound field, or more specifically, the acoustic leakage between the sound zones.

Michael Cousins Meridian

Dr. Michael Cousins is a senior automotive engineer at Meridian Audio. He has been involved in delivering branded audio systems for the likes of Jaguar Land Rover, Rivian, Human Horizons and Kia. After completing the Tonmeister Sound recording degree at the University of Surrey, he gained a PhD (supervised by Filippo Fazi) at Southampton University. His PhD thesis, titled “The Diffuse Sound Object”, investigated the perception of diffuse sound fields (e.g. reverberation and rain) for reproduction as part of an object-based audio system. This work, partly funded by the BBC, led to a postdoc at Surrey as part of the S3A project looking how best to decorrelate and render diffuse sound fields for object-based audio. Since working at Meridian Audio, he has helped develop new technologies (Perfect Balance (loudness), Horizon (upmixer), Re-Q (tuning processes) and Vibrohaptic Audio (tactile bass enhancement)). With the use of software technologies, system design and “Golden Ears” system tuning, Michael has delivered several world-leading branded audio systems which--according to one review--“Truly, undeniably, bangs”.

Immersive Audio Experiences in the Car

Meridian Audio develops some of the best sound systems in the world. The automotive cabin is a unique environment with unique opportunities and challenges. We will present; what is required to deliver an immersive audio experience in the car; how innovation in automotive will allow a more immersive experience than ever before; and discuss some of the technologies and experiences coming soon to the car.

Marcos Simon Audioscenic

Marcos Simón graduated in 2010 from the Technical University of Madrid with a B.Sc. in telecommunications. In 2011, he joined the Institute of Sound and Vibration Research, where he worked with loudspeaker arrays for sound field control and 3D audio rendering and also in the modelling of cochlear mechanics. He obtained his Ph.D. title in 2014, and between 2014 and 2019 he was part of the S3A Research Programme “Future Spatial Audio for an Immersive Listening Experience at Home”. In 2019 he co-founded Audioscenic for the commercialisation of innovative listener-adaptive audio technologies, where he currently works as Chief Technical Officer. Since the creation of the company, Marcos has been leading the

vision of Audioscenic and established himself as a nexus between the commercial and technical world for the start up; making sure that the technology is continually evolving and that the customers understand exactly what the technology makes possible.

User Tracked Audio for Automotive Applications

This presentation introduces the concept of user-tracked cross-talk cancellation and presents some results of its application to the car environment.

Head-tracked cross-talk cancellation allows for the creation of “virtual headphones” that are locked to the user position. This technique can be used to deliver binaural audio and give a very convincing spatial image that is robust to user movements, something very important for typical consumer environment, i.e., desktop applications or living rooms.

The same techniques can be applied in the car cabin, giving for a more robust delivery of binaural signals to the occupants of a vehicle. In this case, head-tracked is employed to enlarge the sweet spot of the two front occupants of a vehicle for the delivery of independent binaural content in a multiset configuration

Phil Nelson ISVR

Philip Nelson holds the post of Professor of Acoustics in the Institute of Sound and Vibration Research at the University of Southampton. He has personal research interests in the fields of acoustics, vibrations, signal processing, control systems and fluid dynamics. He served from 2005-2013 as Pro Vice-Chancellor of the University of Southampton, with particular responsibility for Research and Enterprise. From 2014-2018 he served Chief Executive of the Engineering and Physical Sciences Research Council. He is a Fellow of the Royal Academy of Engineering and was made a Commander of the Order of the British Empire in the 2018 New Year Honours for his services to UK Engineering and Science.

Optimal source distribution for multiple listener virtual sound imaging

Advances in technology have made it possible to use loudspeakers to generate the perception in a listener of a “virtual” image of a source of sound that appears to be at a position other than that of the loudspeakers. This paper deals with the challenge of simultaneously generating the perception of the same virtual sound image at the ears of multiple listeners. The basis of the analysis is the so-called Optimal Source Distribution (OSD) that enables well-conditioned crosstalk cancellation at the ears of a single listener. This consists of a hypothetically continuous distribution of monopole acoustic strength which has a remarkable frequency independent radiation pattern. This directivity pattern enables crosstalk cancellation at a series of defined listener positions in the far field. However, in any practical application using current technology, the sources will be discrete loudspeaker elements. Previous work already shows the promise of this technique and the work described here aims to evaluate a number of methods for determining the strength of such discrete sources while still ensuring crosstalk cancellation at a number of listener positions. Whilst the analysis presented assumes a free field environment, a longer-term aim might be to have the capability to generate virtual images for multiple occupants of a vehicle interior. The practical challenges in doing so will be discussed