
# CONFERENCE REPORT

Across three days this September the third international conference on automotive audio took place. The event was sited in San Francisco, an area that is currently experiencing an influx of automotive OEMs, start-ups, and suppliers in response to the rapidly evolving automotive market. The theme evident at the conference was that the traditional automotive customer, and the established image of mobility, is changing. "ACES" (Autonomous Connected Electric & Shared Vehicles) are causing shifts in the industry, and continued development of business practices will be required to ensure products and services are developed to remain attractive and relevant to these new types of consumer, to what they do, what they want, and what they own.

To this end, the conference was packed full of innovative exhibits, demonstrating interactively how new and established technologies can be applied to automotive. A diverse set of disciplines were represented, broadening out from automotive into broadcast, simulation, and measurement technology.

The conference has seen good growth since the inaugural event in 2009, this year boasting over 150 registrations, with delegates from automotive OEMs, tier one suppliers, acoustics and software companies, hi-fi, navigation, and metadata organizations.

Across the three days, attendees enjoyed 14 paper sessions and were also able to experience five demonstration vehicles brought into the venue. Interactive exhibits from measurement, electronics, and DSP software companies were open across the whole weekend to allow demonstrations of their latest products. Each day was bracketed by a keynote speech at the start, to put the concepts presented into context, and a social reception at the end, to allow delegates to network with one another and discuss the day's topics. At one of these there was the chance to enjoy some music from a Bay Area jazz trio The Bartron Tyler Group, while also critiquing the time alignment of the in-ceiling PA.

## OPENING

Opening proceedings, Armin Prommersberger and Chris Ludwig of Harman spoke about their vision for next generation automotive audio, and how the traditional image

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of hi-fi may need to change, to retain younger consumers trained to expect new features and updates in their technology with high regularity. Sound quality in cars has become an expectation, not a differentiator, and Harman has been investigating ways to create new experiences by doing such things as adding microphones to the cabin to synthesize the acoustics of a theatrical experience, and even exploring the replacement of all door speakers with a single phased array in the IP.

**New automotive usage models**

On the topic of new automotive usage models, Martin Kreißig of Sony discussed how system architecture for autonomous vehicles requires some rethinking, describing the use of individual speakers in the seats, loudspeaker arrays throughout the cabin, and the considerations in design choices when moving from monolithic to distributed amplification. Jeffrey Read of Perfect Surround and Andy Wehmeyer of Audio Frog described a configurable driving environment where occupants may switch from forward- to rear-facing, or where multiple occupants may be undertaking different activities. They presented their concept of a center speaker sited at the center of the vehicle cabin for meetings, but that can be reconfigured to the traditional front-of-cabin location for a shared movie experience. In support of this, they presented a new phaseless up-mixer that focused on extracting a stable center channel that would be resilient to being moved around the cabin as usage changes. At their vehicle demonstration they explained that this is accomplished by extracting the center channel first, isolating it, and then applying the up-mixer to the remaining content, allowing the center to be moved around in the cabin for different seating positions, with minimal bleed of center channel into the LR signal.


Sebastian Scharrer of Fraunhofer IIS elaborated further on varied uses in a modern vehicle. For business commuters a permanent VPN connection to enable office work was suggested, and Sebastian demonstrated Enhanced Voice Services (EVS), a new communications codec available in current phones, featuring improved audio bandwidth suitable for transmitting mixed content in addition to speech. The improvements in audio quality were demonstrated against GSM and AMR Wideband, with EVS extending to 16 kHz without an increase in bit rate over the competing codecs.

Also outlined were codecs for audio and video streaming; some 37% of music consumption is streamed and 55% is streamed while mobile, with fluctuating bandwidth. Fraunhofer IIS's Extended High Efficiency AAC was proposed as a suitable codec for mobile streamed audio, to contend with costly bandwidth and rural connection dropouts. The challenges of Hybrid Radio, where a vehicle must synchronize both the radio broadcast and internet stream while in transit, were outlined. For immersive sound, MPEG-H 3D Audio was suggested for its support of object-based audio codings and channels combined with metadata. This codec is already in use in some regions for television broadcast.

In the exhibits, Proactivaudio was demonstrating their echo canceler technology, using machine learning to adjust the canceler in response to changes in the signal, all delivered in a lightweight algorithm that runs client-side.

Harman was seen to be embracing new usage models, exhibiting their Smart Audio Solutions vehicle first shown at CES 2017, featuring Ambisonics Escape to transform the cabin into a relaxation space, Dynamic Sound Stage for excitement when a vehicle is being driven, and In-Car Conferencing to spatially separate telephone calls for meetings.

From entertainment audio inside the vehicle to engine and road noise outside, Joel Douek and Brian Scherman of Man Made Music discussed the importance of cohesive sound design across a product when creating electric vehicle sound, and the conundrum of matching a brand identity while also meeting electric vehicle regulations.

Juergen Zollner from Harman demonstrated the challenges in bringing an Active Road Noise Cancellation (ARNC) module to market. With electric vehicles there is less overall noise but, since the human auditory system is adaptive, the remaining noise increases in annoyance. While some may enjoy the roar of a V8 engine, when the masking it provides is removed the occupants will have an increased perception of wind and road noise. Addressing this through active sound design to restore the masking effect of an internal combustion engine in an electric vehicle is a challenge from a brand identity and authenticity perspective. An alternative approach is to use ARNC, wherein microphones, accelerometers, and the vehicle's audio system are recruited to create a quiet zone. Juergen outlined the two primary noise types, airborne noise from tire tread snap-in and snap-out, and structure-borne noise transmitted through the suspension system. He then presented a practical solution to structure borne noise: A feed-forward ARNC system, relying on accelerometers in the suspension system, with feedback microphones in the cabin for iterative noise reduction.


Major obstacles in implementing such a system were enumerated. These included latency, where a 1–3 ms acoustic path from noise source to the occupant's ear consumes much of the 6 ms of tolerable latency, leaving little for the electrical side comprising a digital accelerometer and ARNC ECU. Also, for good performance, the vehicle will need well established woofers covering the 20–350 Hz range. Poorly planned speaker geometry may result in notches in the operating range, and addressing these with peaking EQs will consume precious latency.

Juergen then presented an off-the-shelf ECU implementation at A-sample level using automotive-grade hardware, and provided some spectrograph examples of ARNC working, offering performance improvements in several vehicle types.

**The infrastructure to support modern vehicle infotainment**

With the need for careful woofer placement for ARNC established, Mads Herring Jensen of Comsol presented a Virtual Acoustics tutorial, demonstrating the means by which one could use simulation of woofer placement to predict audio and ARNC performance. Mads began by explaining how simulation can reduce the number of physical prototypes required, and even provide virtual measurements or sound field visualizations to justify engineering decisions early in the design process. He then went on to give an overview of car cabin acoustics, a complex space with porous elastic structures that must be attacked with different methods to account for modal, medium, and high-frequency behavior. A summary of simulation methods with some guidance on selecting the appropriate method was provided, covering full-field finite and boundary element methods, high-frequency ray tracing, and lumped methods for loudspeakers. Approaches for preprocessing mesh geometry to reduce the number of boundary elements were discussed, and it was highlighted that good-quality boundary conditions dictate the quality of the results. For absolute simulations, Mads recommended controlling for temperature, humidity, and pressure. Where the goal is to visualize and understand what is happening in the cabin across the audio range, one will typically have to combine methods to succeed and, as always, the quality of the output depends upon the quality of the input.



Another aspect of the audio system that can benefit from simulation is the loudspeaker grille. Closely tied to the cabin visual aesthetic, and a tool of brand differentiation, what in essence is simply a perforated surface can be subject to some acoustic constraints to satisfy styling. If those constraints are not well understood then the grille can have deleterious effects upon the audio system. Martin Olsen of Harman spoke about the acoustic modeling and validation of loudspeaker grilles and their placement in the cabin, to understand which parameters will impact audio in advance. Simulating what is happening in the nearfield of the grille can reveal lobing effects and nulls at certain off-axis angles that may be missed with component-level 2π measurements. Martin explained how carefully simplifying the complex grille surface to a boundary impedance can reduce complexity and was able to share some validation of his tweeter grille simulations showing good correlation to measurements. He also isolated the effect of the grille in simulation and measurement, to reveal a high-level "fingerprint" of the of the grille behavior. Martin surmised that the impact of tweeter placement in a complex environment is not to be underestimated and warned that one cannot use 2π measurements to judge tweeter grille performance once the part is fitted to a vehicle geometry.

Integration of ARNC isn't only dependent upon well planned vehicle acoustics, but due to the low latency requirements it must be designed into the infotainment system with care. Rolf Schirmacher of Müller-BBM gave an introduction to his company, who find themselves increasingly partnering with tier-one suppliers and OEMs to deliver software in support of active acoustic technologies. Rolf presented an overview of the requirements and pitfalls of implementing ARNC on an infotainment system and aimed to help guide designers in ensuring that active acoustic technologies are integrated properly on IVI systems found in modern vehicles. Echoing Juergen's comments, he explained that ARNC systems do not fit on mainstream established audio frameworks due to their stringent latency requirements. On the one hand, traditional infotainment systems seem well suited, being fully digital, flexible, highly integrated with the vehicle and having low start-up times and many audio outputs. However, being implemented increasingly on standard processors with an operating system and middleware, they may even be running virtualization to separate the vehicle and customer domain for security, and this all leads to large latencies. With entertainment content this is typically undetectable to the user, but this does not meet the prerequisites for ARNC application.

For ARNC, Rolf recommended exposing the ARNC ECU to the raw vehicle data, avoiding gateways or tunneling through other protocols. For microphones this leads to MEMS being the preferred choice. They have fewer wires, fewer pins, and do not require HPF DC removal filters, saving latency again.

With a control-theory approach, he described an ARNC system that combines engine RPM with an error signal from a microphone, to generate antiphase noise in the speakers. However, he warned that a reduction in engine noise will be matched with an increase in noise over a broad set of frequencies in-between the engine orders, and if these are not adequately controlled they may lead to instability.

**Test and measurement**

Audio playback, driver and pedestrian warnings, ARNC, engine sound enhancement, connectivity, natural language processing, personal sound zones … with such complex and multilayered infotainment systems there is a need to go beyond end-to-end testing in diagnosing problems. Jayant Datta and Dan Foley of Audio Precision warned that without being able to follow the signal path to look for problems, diagnosis of issues could be akin to "unscrambling an egg." They advised a multitiered testing strategy covering designs and components in the lab, followed by verification of integration of these subassemblies, before finally testing performance in-vehicle. Dan shared a formidable set of pitfalls to be cognizant of, drawing from his broad career experience. The selection of suitable audio test equipment was covered, with examples of when a HATS is appropriate for use, and raising awareness of the correct energy dispersion when testing voice systems. For ARNC testing, Dan advised selecting a noise source with adequate low-frequency response and SPL with low distortion, remembering

that door slams can go down to 2 Hz, where audio equipment rolls off at 20 Hz. In day-to-day testing, he recommended always having a live FFT running to quickly detect measurement issues early on, and reminded us not to scrimp on a good-quality bench PSU. For Bluetooth testing Dan covered correct application of a BT sniffer, correct use of speech signals for voice codecs, and some basic tips such as unpairing all devices except the one under test. He recommended, where possible, planning in I²S or TDM header pins on evaluation boards to make troubleshooting painless. Finally, there were reminders to avoid long cable runs that can cause clocking problems through capacitance and to always properly terminate cables to avoid reflections.

In the exhibits, Audio Precision demonstrated their APx585 connected to an A²B system via the Mentor analyzer platform, for multichannel audio measurement analysis. Alongside, Head Acoustics exhibited their 3PASS system, a new approach for multipoint noise simulation that captures multimic positions, with phase. This level of capture and playback is required to meet the new ITU P1100 and P1110 standards for measurement methods and quality requirements for automotive hands-free operation.


## Engine order cancellation and sound synthesis

Alongside ARNC, in a traditional internal combustion vehicle, engine order cancellation may also be required for a quiet or refined cabin experience. Such a system would use microphones in the cabin, an audio processing unit, and woofer speakers to cancel the engine harmonics at the occupants' ear. Victor Kalinichenko from ASK Industries warned that, in such a closed-loop system, stability is of utmost importance because feedback could be extremely dangerous. Victor listed a litany of factors that could impact the stability of engine order cancellation, including loaded trunks, a large number of occupants, interference with microphones, aging components, damage from accidents, and improper speaker mounting, and then talked through an automated test environment designed to catch these edge cases. His hardware-in-the-loop system was shown to be testing for basic functionality, artifacts, stability, and performance.


Once road and engine noise have been dealt with, there may be sounds that we want to accentuate, those that stir emotions in drivers. Shunsuke Ishimitsu of Hiroshima City University and Suzuki Motor Corporation discussed how active noise control can reduce the fun of driving. Active sound quality control, the mixing of the intake sound from the engine with the original interior noise, can combat this. He presented an algorithm that boosts selected harmonics, while suppressing others. He then detailed a paired-comparison listening trial that was conducted to select the preferred combination of harmonics. His results indicated that different populations may prefer individualized engine noises.

## System architecture and processing

John Whitecar of DSP Concepts shared some insights into the relocation of audio processing from dedicated DSPs to a more general purpose CPU or SoC (system on a chip). Citing that home computers underwent this change around 15 years ago, John sees this as an inevitable change in automotive and a good way to save cost and simplify software upgrades. SoCs are growing in power and, while they may be multiple-application processors, they still include dedicated audio DSPs, with all the comforts one would expect such as sample rate converters and interfaces to audio hardware or RS232.

To demonstrate the point, John shared SoC benchmarks for low-memory tasks such as biquad filtering and medium- to high-memory FFT filter processing tasks. He concluded that multicore SoCs can take on audio processing and, with the right L2 cache architecture and task prioritization, can be trusted to manage concurrent audio streams.

Expanding beyond the architecture of the components to the whole system architecture, Martin Kessler of Analog Devices provided an introduction to their automotive audio bus, dubbed A²B. With more microphones and loudspeakers in vehicles than ever before, and vehicle weight under scrutiny to meet government imposed fuel-efficiency standards, a new approach to audio harnesses is necessary.

A²B running on a single UTP cable reduces the harness weight and uses fewer connectors, leading to improved fuel efficiency and reduced part cost. Martin demonstrated how phantom power on the bus allows simple daisy-chain addition of MEMS digital output microphones, Bluetooth modules, ADCs, and DACs. The bus was shown to be bidirectional, multichannel, and to provide clock and control. This was supported by an Analog Devices exhibit demonstrating the placement of an antenna module on the roof and passing audio to the head unit over A²B. If active speakers are provisioned, it is even possible to create a scalable audio system, reducing complexity in harness variants. Finally, he highlighted the low 50 µs latency and the support of automotive diagnostic standards. To allow testing on the A²B bus, where the audio is typically scrambled data, Mentor exhibited their A²B analyzer system for audio playback, command and control, and GPIO. They also had on show an A²B sniffer that can be put onto the bus silently to observe traffic.

## Audio stream preprocessing

Several presentations at the conference were related to preprocessing the audio stream before it is played back in the cabin in one way or another. In his opening comments on the third day, Wol-

fram Jähn of Audi was calling for quality metadata-aware upmixers. And Fraunhofer IIS, among a number of technologies in a vehicle they were exhibiting, showed a frequency-domain upmixer by the name of Symphoria 3D that they were offering, along with tuning services for unbranded application in vehicles. Alongside this was their fully automated Sonamic loudness normalization algorithm, designed to smooth out differences in program material level while preserving music's dynamics. Peter Poers of Jünger Audio GmbH also showed an adaptive multichannel loudness control for the car environment, bringing to automotive Jünger's know-how as an established name in the broadcast industry. Peter gave an overview of how loudness is perceived and measured, and gave examples of how in broadcast there are standards and recommendations for consistent loudness measured in Loudness Units Full Scale (LUFS). With a modern vehicle infotainment system being able to aggregate content from such a wide array of sources, some form of loudness control is necessary. Peter's recommended approach is to autolevel first, since that is a very fast process, before applying a short-term transient processor operating at 0–2 ms latency, and then following with LUFS auto loudness matching operating in a 400-ms timeframe.


As well as contending with wildly varying program loudness coming to the vehicle, low-bandwidth sources are now prevalent through satellite radio or internet streams, so much discussion occurred around low bit-rate enhancement. Low bit-rate content must be detected without the use of metadata because metadata cannot be trusted if the content has been transcoded. Fraunhofer IIS demonstrated Sonamic low bit-rate enhancement technology in their vehicle. It offered blind restoration of degraded audio portions as often seen with streamed content, with no impact to high-quality audio, across speech, music, and mixed content.

For spectral restoration of older codecs Patrick Gampp of Fraunhofer IIS described a method of separating out and treating independently the transients and sustained components of low bit-rate content. His method used a copy-up of the spectral coefficients with appropriate attenuation derived by extrapolating the spectral tilt of the original material. He also described the audibility of spectral islands and gap artifacts, named "birdies" due to their similarity in sound to tweeting birds, and described generating a fill signal using all-pass filtering of the input signal to remove these. Listening tests were carried out and, due to the nature of the copy-up and island-filling process, the tested material was loudness normalized to compensate for the naturally increased SPL.

Christian Uhle of Fraunhofer IIS demonstrated how at low bit rates the stereo image is reduced due to an increase in left-to-right correlation. He was able to improve spatial quality by applying artificial decorrelation to the background signal components, the intensity of which was controlled with a perceptual model of reverberance.

Another demonstration vehicle at the show was provided by Orban, a broadcast industry veteran with some new technology targeting low-bandwidth streams in automotive. Their vehicle was showing high-frequency restoration, low-frequency resynthesis, stereo widening, and adaptive dynamics and EQ.

**End-of-line and in-the-field testing**

In automotive, quality is paramount, and field rejects are costly to brands. Stefan Irrgang of Klippel described some typical issues that may befall the unwary manufacturer: nonlinear distortion, air noise from leaks, and rattling trim panels are traditionally difficult to diagnose and differentiate once a vehicle is in the field. A misdiagnosis of a faulty loudspeaker can lead to false warranty returns on drive units, delays, and customer frustration. Stefan then introduced a method of reliably testing vehicles at the dealership using music stimulus instead of stationary signals. Using the automotive built-in microphone and an audio signal from the head unit, the system was able to take a recording of the issue in the field, before repair, and assess severity. An adaptive model of each speaker in linear operation was stored within the vehicle itself, and this allowed the algorithm to excite the speaker with music, identify the modeled signal in the recording from the microphone, remove said signal, and leave the residual distortion for identification or auralization.

Of course it's preferable to detect issues before a vehicle is sold, and Stefan also put in a nutshell the tools available to OEMs to facilitate this. While every loudspeaker supplier will conduct their own end of line test, and every OEM will have diagnostics to detect poor connections, the foremost critical defect is parasitic vibration that will not be detected by either of these methods. Human detection does not work well here due to the high SPL required to cause the vibration and the need for training and time to reliably identify and root cause issues, but automated systems need to be robust against noise found in manufacturing. Stefan covered using statistics and clustering to generate limits and determine golden samples, and also for determining golden defects that allow engineers to understand a problem. Finally, he talked about the auralization of defects and the need to improve objective criteria for what is perceived as annoying.

In a continuation of her paper presented at AES Berlin 2017, University De Palma's Maria Costanza Bellini has been seeking to improve the quality of the loudspeaker manufacturing process by determining if it is component or assembly variances that are the primary cause of loudspeaker performance differences. By measuring the frequency response of loudspeakers constructed using parts at tolerance limits and comparing against those constructed using parts at the center of tolerance but assembled at the edge of

tolerance, Maria Constanza demonstrated that the differences are primarily caused by component variances.

Steve Temme from Listen was exhibiting their SoundCheck software, with some impressive demonstrations in a noisy environment. Long established as an end-of-line measurement system for production, SoundCheck has grown in recent years to be feature rich enough for use in R&D also.

**Directivity**

Toby Gifford of Monash University examined how the near-field of a circular piston in an infinite baffle is well understood, but its polar pattern of particle velocity direction is not well studied. He presented a piece of work wherein he correlated the tangential particle velocity at certain angles to dips in sound pressure level in the directivity pattern. Toby then replaced the piston with an array of point sources having phase delays determined by a quadratic residue diffuser pattern, and was able to demonstrate improved uniformity in both particle velocity direction and directivity. While there is a need for subjective trials to validate if tangential particle velocity is tied to listener preference, a 2.1 Emergence AS8 system was among the exhibits at the conference for attendees to hear for themselves.

Also available to listen to was Panasonic's ELS Studio system in the 2017 Acura NSX, a production vehicle featuring nine speakers, two-way channels in the doors, a rear center surround, and an acoustic motion control subwoofer using back-EMF motional feedback to reduce distortion.

**Panel discussions**

Among the paper sessions were two panels where topics were discussed and questions fielded from the audience. First, Greg Sikora of Harman moderated a session on system design and tuning process, reviewing the history of system engineering, summarizing the state of the art, and discussing the likelihood of moving to fully automated tuning in the future. The general consensus was that a fully automated tuning system is still far beyond reach, but an assisted system where the more basic tasks are completed automatically before a human begins tuning was seen as a good compromise between speed and quality.

With so many audio system variants in a modern car, it is not possible to build all combinations before mass production. A need for virtual tuning and auralization was discussed, but to be successful it is dependent upon good quality models from the ground up. Also mooted were head-tracked VR representations to increase immersion.

The panel was questioned about their preferred subwoofer locations and what makes for good bass. A minimum of five woofers was felt to give the best protection against seat-to-seat variance, and it was agreed across the board that resonance-free and time-aligned bass performance remains a high-priority feature in OEMs. Also raised was the enduring rumor of regional differences in desired bass balance. Harman discussed finding no significant regional differences in preference on headphones between the U.S. and Europe, and reported that new trained listener programs in China and Japan are currently being set up that may allow this to be debunked with greater authority.

The final topic for this panel was the question of where the center image should be placed in a traditional vehicle cabin. Between the attendees there were differing opinions, with some preferring a center-of-car arrangement to better reproduce a live music event, and to have greater resilience against component variances and occupant height causing the image to stray in production. Others preferred a phantom center above the steering wheel to bring the sound out of the loudspeakers and add more spatial dynamics.

The second panel, moderated by Rafael Kassier from Harman, addressed the health implications of high sound pressure levels in vehicles, and questioned if proactive steps should or could be taken to protect customers from harm and allow them to continue to enjoy life-long audio. This was a lively discussion with some attendees challenged by the moral questions. Where the headphone and live-event industries have recently had strict regulations placed upon them, the panel considered if taking preemptive steps as an industry to protect users might be preferable to waiting for outside legislation to do the same. In this way, as audio experts, limits could be devised that succeed in protecting users while also permitting the dynamics that a high-quality audio system depends upon.

**Conclusion**

Thanks must go to Alfred Svobodnik, Roger Shively, and Bjarke Pihl Bovbjerg for their extended planning of the event over the last two years, and thanks also to the other members of the organizing committee, Wolfram Jähn and Timo Esser, for their coordination efforts at the event, and Angelo Farina and Martin Kreißig for chairing the papers sessions. A thank you is also extended to the keynote speakers, panelists, authors, sponsors, AES, exhibitors, and visiting delegates.

The automotive audio landscape has dramatically changed in the five years since the last conference. This year's event was considered a great success by all present and, with talk already underway to decide when and where to hold the next, it will be interesting to watch which companies successfully adapt and which new faces will be joining from other industries when it comes round again.

Editor's note: the papers from this conference can be downloaded from the AES E-Library at http://www.aes.org/publications/conferences/?confNum=ID-169. AES members get free access to the E-Library. A number of the presentations have also been made available at: http://www.aes.org/conferences/2017/automotive/presentations.cfm