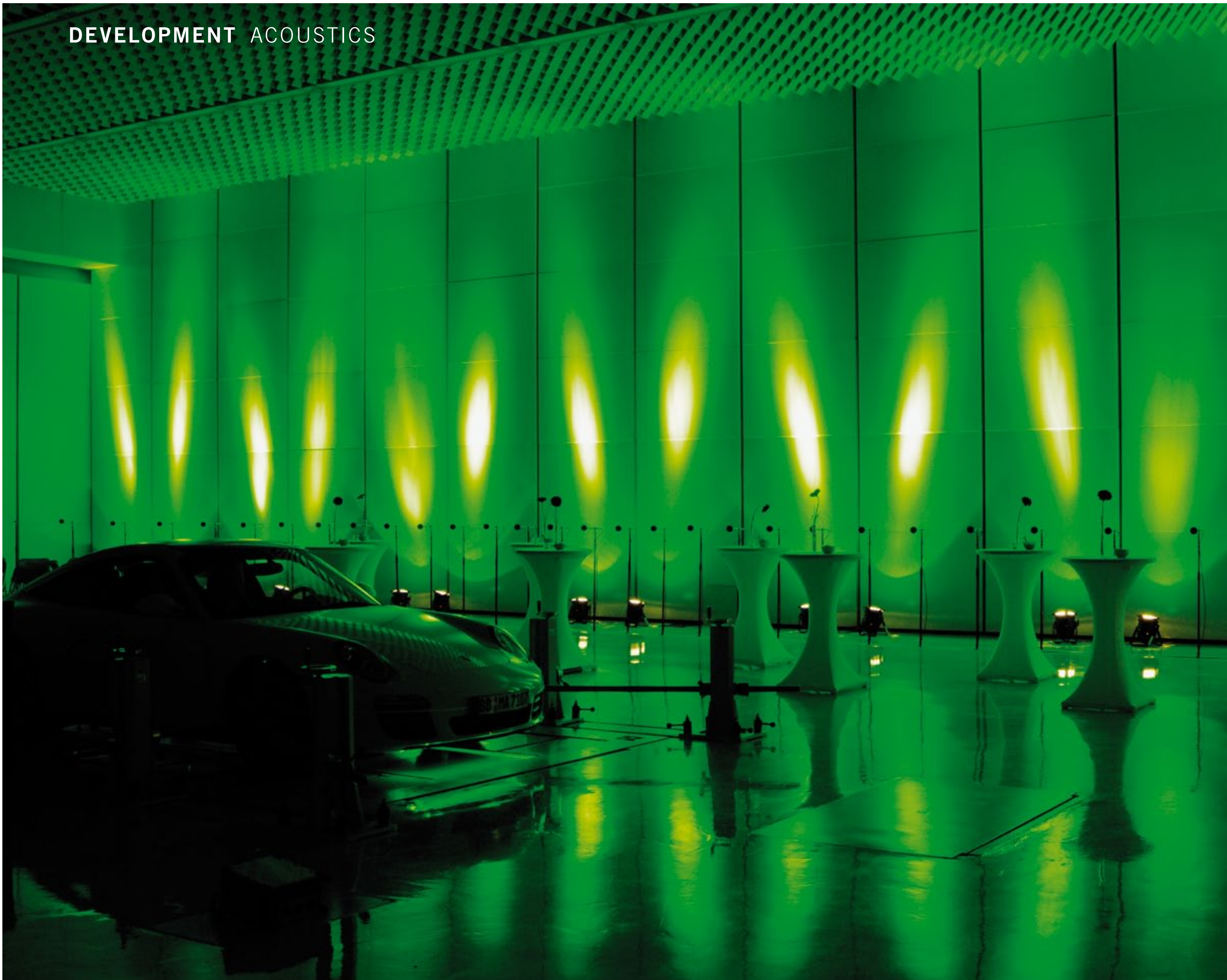

OPTIMISED VEHICLE ACOUSTICS WITH AN INNOVATIVE 4WD ROLLER TEST BENCH

The acoustics in the interior and noise emitted to the outside have become essential factors in developing vehicles. Due to the energy transition and the related promotion of electric vehicles completely new tasks and challenges arise. With a new 4WD roller test bench, where both fields can be equally investigated, the Fraunhofer Institute for Building Physics (IBP) answers to these requirements and is working on a sound-absorbing wheel house or absorbers in the tyre cavity.

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NEW VERSION OF VALID REGULATIONS FOR MEASUREMENT

Vehicle acoustics is widely discussed, if it is associated with the sound design of engine noise or exhaust systems. Due to the energy transition and the related promotion of electric vehicles acoustics engineers are faced with completely new tasks and challenges [1].

Vehicles, however, have to comply with a limit value of exterior noise required by law, which is determined on pass-by test tracks. Due to the new version of valid regulations for measurement [2] as well as the expected lowering of limit values, vehicle designers are faced with great challenges. In this context, tyre-road noise is becoming more and more important, since the noise emitted by the powertrain was already strongly reduced. On the other hand, additional noise generation at low velocities is taken into consideration in case of electric vehicles, which are assessed to be very quiet, for the safety of pedestrians by means of an additional acoustic signal. Yet, concerning these vehicles tyre noise is already dominant at a speed of 40 to 50 km/h.

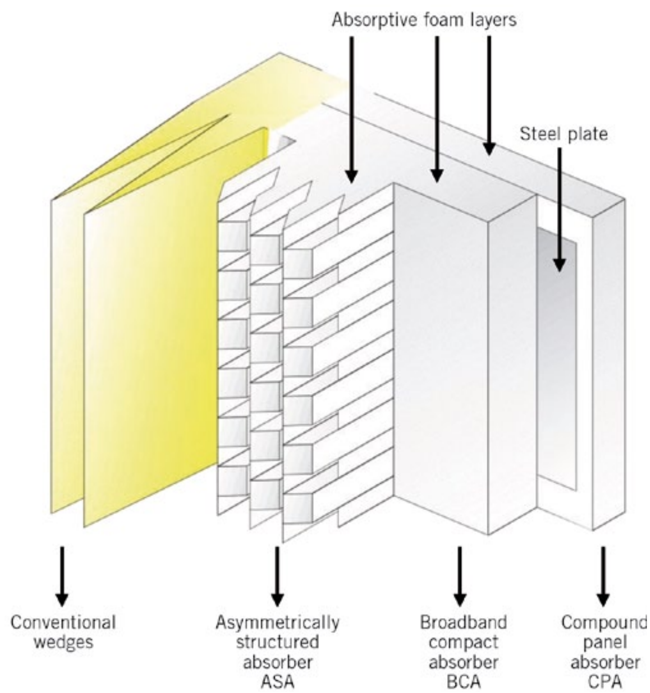
The resulting various research topics, which include the vehicle and its components as well as investigations of traffic scenarios, noise pollution and subjective criteria of perception, may be treated at a new four-wheel roller test bench for vehicle acoustics of Fraunhofer IBP, including simulated pass-by measurements.

TEST BENCH CONCEPT AND ITS COMPONENTS

The 4WD roller test bench in the measurement hall for exterior noise has four rollers with a diameter of 1.9 m, which can be individually actuated. The drive power of four times 300 kW and a force of 7500 N per wheel allow high accelerations and velocities up to 320 km/h.

The roller test bench was equipped with exchangeable coverings in form of pallets, which can be moved by means of air cushions. This allows the transport of completely equipped vehicles from each of the two preparation rooms to the test bench, ❶, as well as an efficient test bench handling. The floor has a hard-wall plastic coating. By means of 32 microphones on each side of the measurement hall, the signals of which are simulta-

❶ Pallet with air cushions to transport prepared vehicles



❷ Three absorber systems and comparison of their structure

neously recorded and analysed, simulated pass-by measurements can be conducted independent of weather conditions [3].

SOUND-ABSORBING LINING OF THE TEST ROOM

The ceiling, walls, doors and gates of the measurement hall with clear dimensions of approximately 25 × 19 × 6 m³ (length × width × height; clear inner finished size) are lined with Asymmetrically Structured Absorbers (ASA) and Broadband Compact Absorbers (BCA) that have been developed by Fraunhofer IBP. The lining is made in such a way that a semi-anechoic field is present in the measurement hall with 40 Hz lower cut-off frequency for pure tones and assessment according to [4]. ❷ shows the structure of these two absorber systems together with their common basis, the Compound Panel Absorber (CPA).

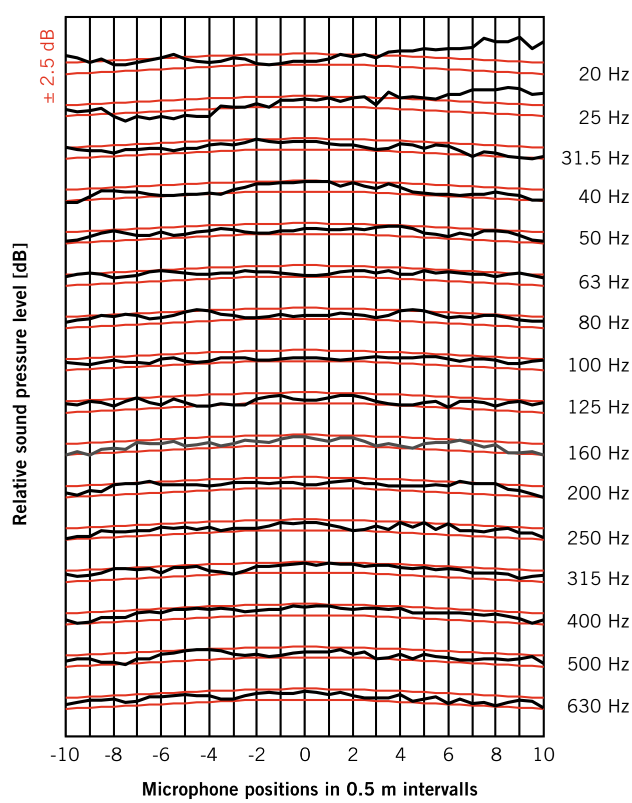
The absorption capacity of the BCA with a depth of 35 cm and of the ASA with a depth of 65 cm is based, simply spoken, on three well-known principles. The first is a spring-mass resonator, where a metal plate acts as mass and the passive absorber as spring. The second is generated by free vibrations of the plate, producing elastic bending deformations due to the incident sound. Both resonators operate in the low-frequency range. The third is produced by an additional absorber layer, which is arranged on the spring-mass resonator and serves as passive absorber for medium and high frequencies. Single- or multi-layer absorbers as with BCA or structured arrangements as with ASA can be used.

Broadband linings can be realised by this combination of coordinated resonators and passive absorbers. ❸ presents as an example of the free-field conditions achieved the level decay along one of the two microphone arrays for the simulated pass-by together with tolerance bands defined according to [4]. These are only exceeded in the frequencies below 40 Hz.

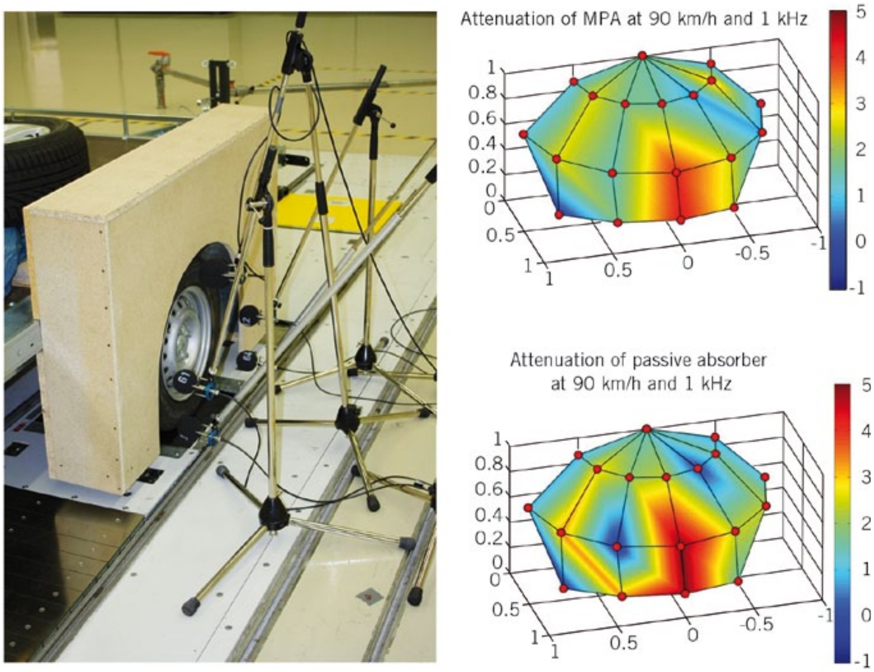
DEVELOPMENT EXAMPLE: SOUND-ABSORBING WHEEL HOUSE

The acoustic treatment of the wheel house is a possible passive measure to reduce the tyre-road noise. The acoustic level reduction to be expected in the far field is within the range of a few decibels, but these can gain significant importance. Moreover, the airborne sound transmission path to the driver as well as the subjective auditory impression especially at high speeds can be influenced.

In contrast to the otherwise commonly used passive absorbers, for example mineral fibres or foams, a micro-perforated absorber (MPA) as wheel house



❸ Verification of free-field conditions along a pass-by microphone array



❹ Mock-up of wheel house on the test bench and level reduction of lining with micro-perforated (top) and passive (bottom) absorber

shell was examined by Fraunhofer IBP in the test bench. This absorber consists of a thin panel with regular holes with a diameter smaller than 1 mm, whereby the perforation ratio is less than 1 %. This panel is installed in front of a closed air volume and thus has the effect of a distributed Helmholtz resonator that exhibits a high share of inherent attenuation due to the small holes and can do without any fibrous material [5]. The absorption behaviour is determined by the holes geometry, the holes distance and the volume in the back cavity. The absorber is tuned well by these parameters to the frequency range of highest excitation levels between 1 and 2 kHz.

The efficiency of the micro-perforation was determined by comparison with a passive absorber layer of the same thickness as well as without any acoustic measure in the wheel house at a mock-up according to ❹. The sound pressure levels on a quarter-sphere around the wheel house were measured in the near field for this purpose. The level reduction due to these measures is represented in the diagrams on the right side of ④ for the third-octave band 1 kHz. Both absorbers show a similar effect, absolutely as well as in spatial distribution. The highest level reduction between 3 and 4 dB is achieved at the axis perpendicular to the wheel. Further directional measurements were performed at the pass-by microphones resulting in a far field reduction for the overall level of 1 to 2 dB.

DEVELOPMENT EXAMPLE: ABSORBER IN THE TYRE CAVITY

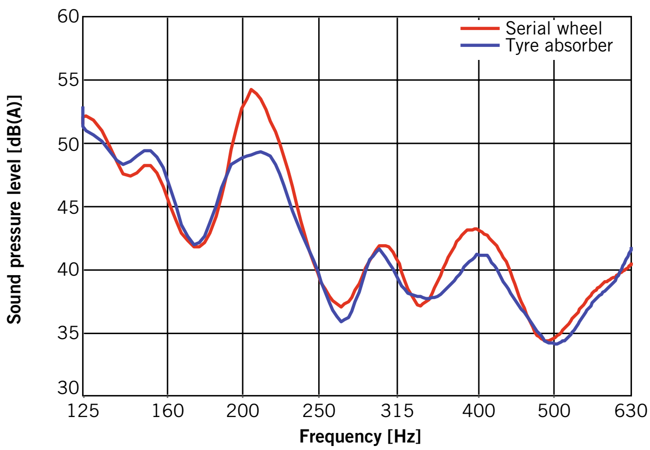
Besides the wheel house shell also the tyre cavity can serve for absorber integration. The focus now is on the attenuation of the standing wave occurring in the circumferential cavity of the tyre, which is also known as torus mode. The wavelength of this first torus mode is determined by the mean perimeter in the air volume. Usually, a frequency of approximately 200 Hz is achieved for normal tyre sizes, at which a measurable level increase in the vehicle interior may be detected. This noise transmitted by air- and structure-borne sound is perceived as unpleasant.

Up to now, the application of fibrous materials in the tyre cavity failed, primarily due to the handling for tyre changes in the car workshop, which these materials do not withstand on the long run. The solution presented here follows the approach to integrate a micro-perforated absorber in the rim [6]. The micro-perforated rim surface, ❺ (left), is directly realised over the rim by drilling the necessary holes in the well-base rim. A separately manufactured chamber, ⑤ (right), necessary for the air back volume and the sealing of the wheel is integrated in the inner diameter of the rim and air-tightly bonded.

A complete tyre set of the type 255/40 R18 95 W was manufactured as a prototype for the measurements in the vehicle interior. The measurements were conducted on the road as well as on the acoustic roller test bench of Fraunhofer IBP with mounted shells to simulate rough textured asphalt with higher noise excitation. The sound levels were recorded by means of an artificial head on the front passenger seat. ❻ shows the A-weighted sound pressure level for a vehicle with series wheel and with the micro-perforated tyre absorber determined in the test bench. A level reduction of the torus mode of 5 dB could be achieved in the test bench as well as on the road.

The drilling of rims for micro-perforation, however, is neither practical nor profitable for a serial product. Therefore, a solution with the integration in the rim is pursued, and with a comparable


❺ Rim with micro-perforation, cross-section with absorber chamber and completed wheel



❻ Sound pressure levels in the vehicle interior with a serial wheel and the micro-perforated tyre absorber

acoustic efficiency has already achieved the stage of close-to-production testing.

CONCLUSION AND OUTLOOK

The test laboratory for vehicle acoustics at the Fraunhofer Institute for Building Physics (IBP) has a high-performance and modern four-wheel roller test bench which is used for vehicle development independent of weather conditions in many industrial projects. Research projects within the traditional key competences of the IBP, the development of absorbers and silencers, result in new applications and products, for example the presented micro-perforated tyre absorber.

At present, comparative investigations of pass-by simulation are performed on different test tracks and test facilities aimed at allowing future type testing in this kind of test facilities. Data gained in this process are incorporated in the effort of the standardisation workgroup ISO TC 43/SC 1 WG, preparing the appropriate draft under ISO 362-3.

Furthermore, first psycho-acoustic investigations on user acceptance of electric vehicles and their perceptibility, for example when nearing crosswalks, were conducted within the framework of the project “Fraunhofer System Research Electro-Mobility” promoted by the Federal Ministry for Education and Research. Electro-mobility, in particular, raises many new questions with regard to acoustics and is a research focus for the future.

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