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HOW BINAURAL MEASUREMENT TECHNOLOGY AND PSYCHOACOUSTICS HAVE CHANGED ACOUSTIC MEASUREMENT TECHNOLOGY

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ABSTRACT

In the 80s of the last century, the automotive industry developed an interest not only to measure the interior noise level of a vehicle, but also to determine the acoustic sound quality. The annoyance of a noise or the attributes of good sound could not be described by the A-weighted sound pressure level. The desire arose to include human hearing into the analysis. However, artificial head stereophony, which was used in the broadcasting sector, proved to be unsuitable for enabling a faithful reproduction of vehicle interior noise. An improved, calibratable and free-field equalized artificial head measurement technology was developed with technical properties comparable to human hearing combined with headphone playback to generate same hearing events as in the original. Furthermore, based on digital signal processing, possibilities were created to change signals in the time and frequency domain in real time to audibly assess which signal characteristics influence the sound quality. With the help of psychoacoustics, calculation methods could quantitatively describe the sound impressions perceived by hearing. Meanwhile, the ISO 12913 Soundscape standard defines the recording and assessment of an acoustic environment in context, whereby binaural measurement technology is normatively requested, and the use of psychoacoustic parameters is recommended.

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1. INTRODUCTION

At the beginning of the 80s, the acoustics engineers at a large German automobile manufacturer recognized the problem that noises were perceived differently, but they could not be analyzed and quantitatively measured in a differentiated way. This gave rise to the idea of including human hearing in the analysis process. This means that the sound situation should be recorded and reproduced true to the original. However, the artificial head systems available at the time were not qualitatively able to guarantee a faithful reproduction of ear signals.

2. BINAURAL RECORDING

The human hearing has two input channels that enable binaural signal processing to recognize the direction of sound sources, to select single sound source among several different sources (selectivity), and to suppress noise and reverberation and thus lead to different results than conventional measurement methods in the presence of several spatially distributed sound sources. In addition, the outer ear is a direction-dependent filter, which modifies the sound pressure level in the range between -15 dB and +30 dB depending on frequency and angle of sound incidence. This means that it does make a difference in human hearing whether several sound sources come from the same direction of incidence or from different directions. In addition to the proper recording, the artificial head technology offers the following advantages in the sound reproduction:

- clearly defined noise
- can be repeated as often as desired
- direct A/B comparison
- can be stored indefinitely
- no distraction from the environment
- spatial impression

These advantages have led to the fact that the artificial head measurement and analysis technology is not only used in the automotive industry, but in addition to traditional sound measurement technology in a wide variety of industrial sectors, especially for the design of sounds. Hearing is a highly sensitive measuring system, but it does not have sufficient long-term memory. This means that if the human ear has classified a sound event unpleasant and annoying, this parameter is retained even if this noise has been reduced by 2 dB or 3 dB or even more. This means that once the human ear has become more sensitized to a specific sound event, the hearing is hardly able to reliably assess whether the sound quality or the noise exposure as a whole has changed. If the sound event consists not only of a single sound source, but of several sound sources, which are also spatially distributed, binaural signal processing is required for the correct assessment of a sound event. The binaural technology means the recording of sound with an artificial head measuring system and the inclusion of an evaluation algorithm comparable to human hearing. The simple physical measurands such as A-weighted sound pressure level and third octave spectrum do not provide complete information about the sound event.

The principle of head-related stereophony consists in the distortion-free measurement, transmission, and reproduction of sound pressure signals on the human eardrums. The directional pattern of the artificial head must correspond to the average directional pattern of the human being. The self-noise should be imperceptible in order to allow listening in the area of the hearing threshold. The dynamics should reach up to the pain threshold in accordance with the human ear in order to be able to detect all level peaks in a distorted manner. The system must be calibratable and compatible with conventional sound measurement technology.

Such a measurement system was developed based on the cooperation of an automobile manufacturer with the Institute of Electrical Communications Engineering at RWTH Aachen University, see Fig.1.

Figure 1. First calibratable, freefield equalized artificial head (Aachen Head) which was compatible to a measurement microphone [1].

In 1981, the first artificial head measuring system was developed with properties comparable to those of the human ear in terms of directivity, frequency transmission range and dynamics, which was also free-field equalized and calibratable for use in acoustic measurement technology [1]. It is primarily used for recording and analysis in the field of noise quality and sound design. Sound events are faithfully recorded and evaluated via headphones. On the one hand, it is possible to make easily audible comparisons of different products (benchmarking) or the acoustic effects of modifications to the product. On the other hand, signal processing can be used to manipulate individual components in the time or frequency domain in order to identify which properties lead to an annoying sound impression and how a desired sound can be achieved. In conjunction with psychoacoustic analyses, different noise situations can also be better documented with objectively describable quantities adapted to the auditory assessments.

The field of application of this improved artificial head measurement technology initially focused on the automotive sector, manufacturers as well as suppliers. Soon, however, also in the field of determining the sound quality of office and household appliances. In the meantime, the application has also been established in

room and building acoustics as well as for recording acoustic environmental pollution. The international standard ISO 12913 "Soundscape" requires the use of binaural measurement technology.
Very quickly, the advantages of a faithful reproduction of sound events became apparent during the application of binaural measurement technology: a direct comparison of different driving situations or of different vehicles or modifications was now very quickly possible even for inexperienced persons. Measures taken could be impressively demonstrated to the management without resorting to diagrams and measurement data evaluations that are difficult to understand.

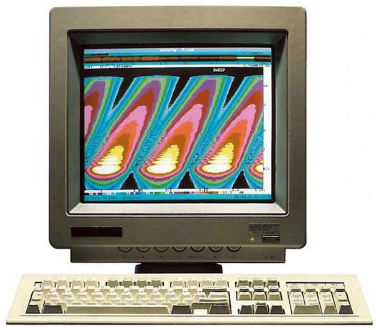

Figure 2. PC-system with DSP-board to analyze sound like the human hearing combined with interactively manipulation of sound and psychoacoustic analysis [2].

Now that true-to-the-original sound recordings were available in digitized form, the idea and the desire soon developed to manipulate them with the help of digital signal processing in the time and/or frequency domain in order to be able to judge which features in the signal make the noise seem unpleasant or annoying (troubleshooting) or how the sound should be designed in order to be able to achieve the sound suitable for the product (sound design).

3. PSYCHOACOUSTICS

The psychoacoustic properties of human hearing like loudness, sharpness, roughness, fluctuation strength, pre-, post- and simultan masking determine the auditory sound impression. There was interest in using new parameters to make the audible sounds comparable with numerical values. This led to the integration of psychoacoustic calculation variables and thus the BAS - Binaural Analysis System, see Fig. 2- was born, which enabled the comparative reproduction of artificial head recordings, their manipulation, and their calculation with DSP boards for online analysis and interactive manipulations in real time with a PC [3].
This combination of hardware artificial head recording and calibrated, equalized headphone playback system, DSP boards and software led to the founding of HEAD acoustics GmbH in 1986, which further developed this innovative approach to noise assessment and design worldwide and made it available to a wide range of applications. The practical applications led to consistent further developments: if it was now possible to quickly find out which signal components in the noise are responsible for annoyance and quality, the desire arose to recognize their sources and transmission paths in airborne as well as structure-borne sound. This led to the expansion of the previously two-channel measurement technology for binaural signals to a multi-channel measurement technology (SQlab) in order to record sources and transmission paths with microphones in the near field and with acceleration sensors at the force application points, see Fig. 3. In addition, other variables such as speed and engine speed were recorded [4].

Figure 3. Mobile portable multi-channel recording system to record not only the sound but nearfield microphones and accelerometer signals, too, including information about speed and rotation.

4. SIMULATION

The next evolutionary step lies in predicting how modifications to transmission paths will affect perceptible acoustics. In 1992, as part of a European-funded research project AQUSTA [5], binaural transfer path analysis and synthesis (Pro(g)noise) was developed in order to be able to interactively auralize changes in airborne sound transmission paths and/or altered impedances and stiffnesses binaurally. As early as 1996, the first sound car was introduced, which could simulate not only binaural signals, but also the vibrations perceptible in the seat and steering [6], see Fig. 4.

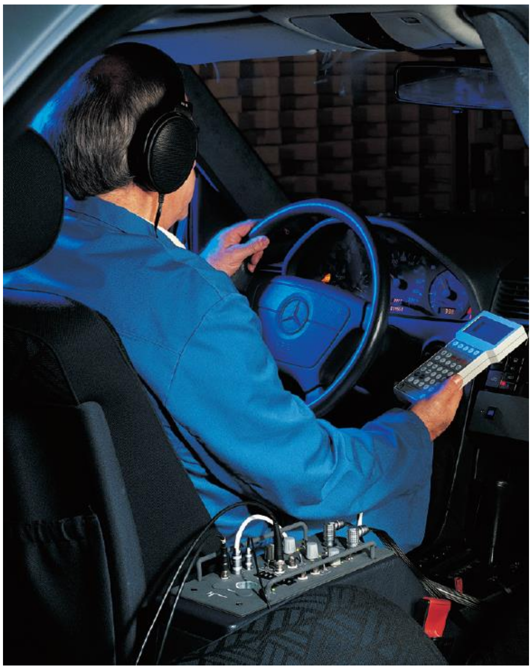

Figure 4. First acoustical driving simulator with vibration at seat and steering and iteractively sound simulation based on transfer-path-analysis [7].

With over 450 employees, HEAD acoustics GmbH, with its headquarters in Herzogenrath and 8 subsidiaries worldwide, not only has its own hardware and software development, but also a large research and service area with several measuring rooms (four-wheel roller, 3-D anechoic room, etc.). HEAD acoustics is working intensively within several standardization committees such as DIN, ISO, ETSI, EMAC, ITU, CCITT.

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