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# THE BINAURAL ANALYSIS AND EVALUATION OF NOISE WITH CONSIDERATION OF THE HUMAN HEARING

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## INTRODUCTION

At several acoustical situations the sound or the noise is not only a result of one sound source but a complex mixing of different sound sources at different spatial positions and different structures in the time and frequency domain. The objective judgement of the annoyance of noise by means of measuring methods, e.g. in the form of the A-weighted sound pressure level, the third octave spectrum or the equivalent sound level, is often not clearly correlated to the subjective impression /3/, /4/. This is caused by the complex evaluation of sound events by the receiving end 'human hearing', which does not only register the level, but also the amplitude density, the spectral composition as well as the time structure of the signal.

## SIGNIFICANCE OF THE HUMAN HEARING

The human hearing differs from the conventional measuring method in three fundamental respects:
1) The outer ear is a directional filter, that weights the sound pressure level in a range of +15 to -30 dB, depending on the direction of sound incidence and frequency /3/.
2) The signal processing in the hearing process cannot be compared to the physical measuring method with regard to its frequency and time resolution as well as its dependence on signal properties. The noise impression, particularly the annoyance of noise is determined by psychoacoustic attributes like loudness, sharpness, roughness and tonality /4/.
3) The hearing has two auditory canals, which enables a binaural signal processing in connection with directional hearing, selectivity and noise reduction /1/.

The transmission characteristics of the outer ear are very important for the further signal processing and pattern recognition in the receiving end 'human hearing' for the selectivity and sound quality. As a result of the thus completely different masking effects, there is a totally different impression of complex tones and sound in comparison to conventional microphone recording.

### Psychoacoustics

When judging noise, not only does the sound pressure level play an important part, but also the loudness. The measurement procedure of loudness according to ZWICKER /6/ considers the critical band spectrum in the human hearing. Thus, the masking properties and the tonal components of the sound can be better registered. On the one hand, the loudness of a sound stimulus is determined by the sound pressure level, on the other hand by the frequency spectrum. Further parameters influencing the auditory sensation are the roughness (modulation of tones) /2/, the sharpness (proportion of high frequency spectral components to low-frequency ones) as well as harmony (proportion of tonal components to each other). The sharpness depends on the spectral envelope and is calculated as a weighted first moment of the distribution of critical band rates of the specific loudness. The roughness is caused by sound signals with a strong time structure as a result of amplitude and frequency modulation. In particular in the case of modulation frequencies between 20 Hz and 250 Hz audible roughness of the noise can clearly be perceived. Apart from the modulation frequency, the level difference, too, determines the roughness, i.e. the roughness is proportional to the modulation frequency. As the level difference decreases with increasing modulation frequency due to the post-masking in the hearing, the roughness diminishes with increasing modulation frequency. For the subjective judgement of sounds, also the tone colour and pitch are of importance /5/. This is determined by means of a procedure that ascertains and adds up the audible tonal and narrow-band components of a sound, considering frequency, level difference and bandwidth.

Binaural signal processing

The hitherto known measuring methods of loudness, do, however, not consider the binaural signal processing in the hearing. Due to the evaluation of aural signals of two sound pick-ups at a stereophonic distance, the human hearing can select with the help of the binaural signal processing and specific pattern recognitions individual sounds from various signals and discriminate others. This shows that the described psychoacoustic sizes cannot easily be applied to real sounds if the sound situation consists of a complex overlying of various sound sources in spatial distributed positions of sound sources. Depending on the structure of the signal-to-noise ratio of the hearing, e.g. the loudness can increase or decrease because of the binaural noise reduction. This effect can be illustrated with the aid of binaural noise reduction in case of speaking in a reverberating environment. By closing one ear, the speech intelligibility decreases although the signal-to-noise ratio does not change. At the same time the acoustic situation is judged louder, although the total power has been reduced.

## BINAURAL SOUND DIAGNOSIS

As the objective acoustic measurement procedure available up to now has not led to satisfactory results and especially does not provide for sufficiently functioning algorithmus for the selection of individual sound sources from several sounds, the idea suggested itself to judge and analyse sounds with the help of the measuring method by the artificial head by using the receiving end 'human hearing'. The artificial-head-measuring-system shows transmission characteristics that are measurable and comparable to the human hearing and compatible to the conventional measuring method /3/. An essential part is the sound diagnosis, i.e. the artificial-head signals are manipulated with the help of digital-signal-processsing aiming at the subjective minimization of the annoyance of noise (see fig. 1). The adjustment of the filter parameters usually supplies information on those components which, from the acoustic point of view, need to be improved. Especially these examinations have often shown that not always the spectral components with the highest power density in the spectrum are responsible for an unsatisfactory acoustic comfort, i.e. annoyance of noise. On the contrary, that when reducing certain spectral components, an unfavourable judgement can be the result, due to the thus reduced masking properties of the sound.

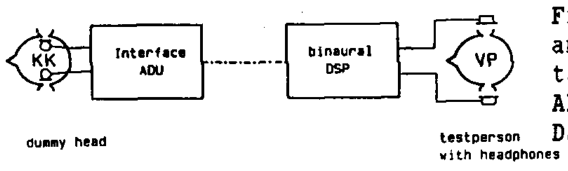


Fig. 1 Subjective noise diagnosis and analysis using binaural digital signal processing
ADU: analog to digital converter
DSP: digital signal processor

## Application example: tyre noise

Fig.2 shows the measurement result of a tyre sound in the interior of a motorcar at a speed of 66 mph in an anechoic chamber on a roller test stand. The sound is mainly determined by a wide-band sound about 1,200 Hz and 2 tonal components about 2,000 Hz and 3,000 Hz. At the same time, loudness, sharpness and the linear A-, B- and C-weighted sound pressure level are indicated. This sound was judged to be very annoying, although the A-weighted sound pressure level is not different to that measured at other tyres. By means of the digital signal processing, the signals in real time can be manipulated in order to auditively judge, which components are responsible for the annoyance of the sound. The tonal component about 3,000 Hz can clearly be correlated to the subjective impression. It is remarkable that the subjective impression is considerably better than the calculated values were expected to leave. When eliminating the other components respectively, there were also similar reductions of values without a corresponding subjective improvement of the sound quality (see table I).

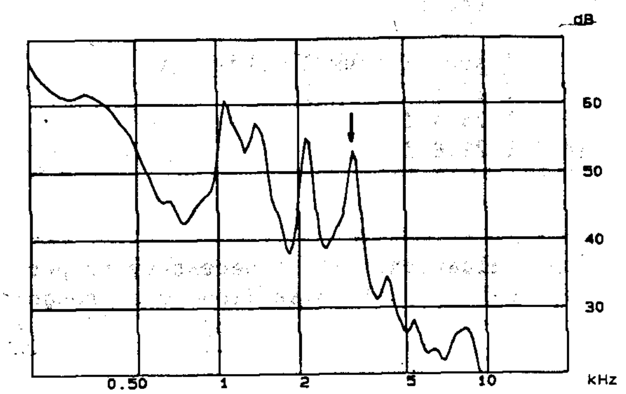


Fig. 2 Noise caused by tires measured indoors, 66 mph, amplitude spectrum, roller test stand, front wheels, arrow points to the spectral component which has been subjectively evaluated as annoying.

| Table I | lin | A | B | C | sone | acum | subjectiv |
|---|---|---|---|---|---|---|---|
| Original | 79.1 | 57.8 | 64.5 | 75.6 | 9.6 | 0.8 | - - |
| - 1200Hz | 79.1 | 56.0 | 64.3 | 75.5 | 8.3 | 0.7 | - |
| - 2000Hz | 79.1 | 55.8 | 64.3 | 75.5 | 8.8 | 0.7 | o |
| - 3000Hz | 79.1 | 54.9 | 64.2 | 75.5 | 8.7 | 0.6 | + |

## Application example: Aircraft cockpit

A comparative judgement of the noises measured inside of two different cockpits A and B, using aircrafts of the same brand and flown by the same pilots, revealed that cockpit A was rated significantly more annoying and louder than cockpit B by all pilots. The vents of the airducts were suspected to be the reason for the disadvantageous noise excitation. Modifications of these air-conditioning vents did not change the overall subjective judgement, although the A-weighted sound pressure level was reduced thereby. In the following a comparative study of noise measurements inside cockpit A before and after the air-conditioning was modified is described with respect to the results obtained from cockpit B (see fig.3). Comparing type B with type A reveals an almost unchanged A-weighted sound pressure level. But the linearly weighted sound-pressure level and especially loudness and sharpness are significantly in favour of the type-B cockpit.

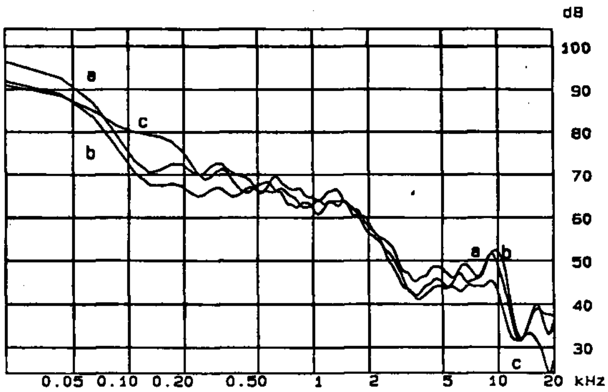


Fig. 3 Noise inside cockpit
height 24000 feet
indicated airspeed 325, 0.758 mach
a) type A
b) type A with modification
c) type B

**A hearing-adapted investigation using** artificial-head measurement technique in connection with objective analysis (see table II for results) and subjective hearing tests yielded the following results:

1. The sound pressure level of the cockpit indoor noises is approximately the same for the two different types of aircrafts.
2. The psycho-acoustical value of loudness is insignificantly smaller for the type-B cockpit as compared to the cockpit of type A.
3. A subjective hearing test proved that the indoor noise of cockpit A mod was judged significantly louder than the type-B cockpit.
4. The indoor noise of cockpit A is clearly characterized not only by hissing and tones of higher frequencies, which are considered to be subjectively annoying, but also by strong low-frequency beat-oscillations, causing a feeling of pressure onto the ears. Low-frequency flutter can give rise to distinct stress symptoms up to nausea.

| Table II | lin | A | B | C | sone | acum | subjectiv |
|---|---|---|---|---|---|---|---|
| A | 79.8 | 75.5 | 76.9 | 78.6 | 29.6 | 1.8 | - |
| A mod | 77.5 | 73.2 | 74.0 | 76.1 | 25.4 | 1.8 | -- |
| B | 78.7 | 69.5 | 75.2 | 78.1 | 21.8 | 1.2 | o |

## CONCLUSIONS

To arrive at an effective noise evaluation, it is necessary to perform a binaural analysis of the agreeability of noise (loudness, roughness, sharpness, tonality) for each selectable sound component from a mixture of noises. Due to the dependence of binaural signal processing and pattern recognition processes on the relationship and condition of the signal and noise levels, the results of a just monaural analysis of agreeability cannot be transferred to binaural hearing. There are many sound situations where noise trouble is not only caused by just one sound source alone, but rather by a multitude of sometimes even spatially distributed sound sources. The sources usually differ with respect to their temporal and frequency characteristics. Hearing-adapted acoustical measurement technique does not only mean recording sound events in accordance to the human hearing, as can be realize by the newly developed artificial-head-measurement-technique. It also stands for signal processing capabilities adequate to the ultimate receiver 'human hearing', which is provided by a proper computing system programmed for that task.

## LITERATURE

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