Moderators of Sound Quality of complex sounds with multiple tonal components

Markus Bodden*, Ralf Heinrichs**

* Ingenieurbuero Dr. Bodden, Ursulastr. 21, D-45131 Essen, Germany, email: db@product-sound.com
** Ford Werke AG, Acoustic Centre Cologne, Spessartstraße, D-50725 Köln, Germany, email: rheinri1@ford.com

Tonal components play an important role in the context of Sound Quality for interior vehicle noise. In contrast to basic psychoacoustic data which are based on experiments with single components embedded in a broadband masker, vehicle sounds are composed of a variety of tonal components. The component to be investigated and the background noise do not form clearly different sound sensations any more, and we observed that different subjects focused their attention towards different tonal components while rating the Sound Quality. The results derived from experiments with single tonal components can thus not be transferred to the case of multiple tonal components, and special attention has to be paid to the method to evaluate Sound Quality of these signals.

INTERIOR VEHICLE SOUND

The evaluation of the Sound Quality of interior vehicle sounds is a complex task. First, the sound is composed of a variety of different components, and second, the perception of Sound Quality by humans is a complex process. This process is not only based on the pure physical signal, but also on other modalities like visual or tactile information and even non-sensory moderators (e.g., [1]).

In general, a product sound consist of two different groups of features, undesired and desired features. The first group comprises the sound features which have to be avoided (e.g., squeak and rattle), the second group comprises the sound features which form a „good“ sound (e.g., pleasant, sporty, noble).

The undesired features play an important role, because they can significantly degrade a good sound and spoil the effort spent to create it. They have to be reduced to that level where they do not degrade the overall sound (acceptance level).

But, this task is complicated by the fact that the classification of specific components might change. Today for example the characteristic sound of a turbo charger is not classified as undesired, because it gives the feedback that the car is equipped with this non-standard feature. But in the future, when nearly all vehicles with a diesel engine will be equipped with a turbo charger, this feedback information will loose its importance, and the sound might be classified as undesired.

Interior vehicle sound is composed of the major components from engine, road, and wind, plus contributions from various components. Since the overall level and undesired sounds like squeak and rattle have been significantly reduced in the past, now other sound components turn out to be undesired. One important class are tonal components, which are caused by various vehicle components:

- the engine sound consists of multiples of the engine order
- road noise might include tonal components from tires or road surfaces
- the transmission often creates tonal components
- automatic steering, oil and fuel pumps, chains, and all kind of electric motors cause further contributions.

Fig. 1 shows that an interior vehicle sound is composed of multiple tonal components covering a broad frequency range. It is important to note that the components often do not show ideal sinusoidal character, but can be much broader.

TONAL COMPONENTS

It is obvious that the evaluation of the influence of the various tonal components is a difficult task, although the investigations on the perception of tonal components have a long tradition. Basic psychoacoustic research data is available from literature with respect to detection and masking (e.g., [2]), but they basically all consider either the case of a single tonal component in a broadband, non-tonal masker, or the relation of two tonal components without any masker. The description above shows that these data can thus not directly be applied to interior vehicle sounds.

Furthermore, in the context of Sound Quality not the detection of tonal components is important, but their acceptance level. We thus planned several experiments to investigate the frequency-dependency, the role of the width of a component, and the influence of multiple tonal components.

All experiments have been conducted in a sound-

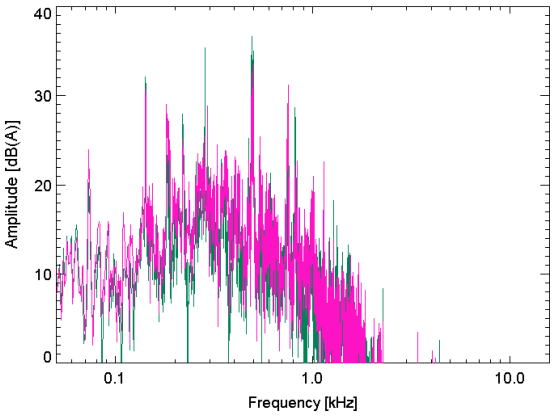

Fig. 1 Typical narrowband spectrum of an interior vehicle sound (idle at 1200 rpm, red=right, green=left chan.)

proofed chamber using headphone representation and applying the individual test [3]. They have been based on real interior vehicle recordings of several vehicles where the existing tonal components have been modified by filtering or synthetic sounds have been added. Psychoacoustical investigations have been conducted for the following parameter variations:

- frequency variation of a single tonal component
- combination of two tonal components
- combination of three tonal components
- a synthetic ideal sinusoidal tonal component
- a real broad tonal component (bandwidth 80 Hz around 800 Hz).

A group of experts and a group of non-experts participated in the tests and determined the detection and acceptance thresholds and rated the strength of the whine. The findings can only be summarized here:

- the expected frequency-dependency is reproduced: higher frequency components are more annoying than lower frequency components (e.g., [2])
- the difference between detection and acceptance threshold depends on frequency and is about 6 dB at low frequencies and 3 dB at high frequencies
- experts render reproducible and stable results
- non-experts have problems to rate whine in a reproducible manner. The rating of a subset of stimuli rated two times depended on the other stimuli presented in the respective test (context effect)
- broader components also causes tonal sensations comparable to sinusoidal components, but the spectral peak level is not the appropriate descriptor
- the presence of multiple tonal components influences the whine rating. It seems that contributions of several components are combined to produce a whine rating.

A very important and critical finding turned out in an experiment where gear whine was investigated. There the sounds of different vehicles once were rated when only the condition with whine was presented, and in another test with a direct comparison of the situations with and without whine (clutch engaged and disengaged). Differences in the ratings could be observed: it turned out that in the first case the overall whine was rated, while in the latter case the attention of the listener was automatically focused to the gear whine, so that only that whine component was rated.

But, even the rating of the overall whine impression was not stringent for all subjects. In a discussion it turned out that a kind of global tonal impression arises, but that in addition usually one prominent tone was perceived caused by a single tonal component. But, different subjects detected different tones when listening to the same stimuli. Furthermore, if this prominent tonal component was eliminated, in a first instance the whine impression was reduced, but after listening to it for some time, another tone seemed to „pop out“ of the background noise and could be heard as a single component.

The perception of tonal components in these complex stimuli thus does not only depend on pure physical parameters - it also depends on cognitive aspects, here in the form of attention. The attention of a subject is focused on one of the components present in the stimuli.

This finding showed that most of the results of basic perceptual investigations of tonal components can not directly be applied to interior vehicle sound. In most basic experiments the level of one tonal component was systematically varied, so that the attention of the subjects was automatically focused to that component and the contribution of other components was suppressed by the listener. In a complex sound like the interior vehicle noise the perceptual process is different, since the attention of the subjects is not automatically focused.

SUMMARY

The approach to adopt basic psychoacoustic data derived from experiments with single tonal components by superposition of the effects can not be applied to the perception of multiple tonal components. In this complex condition non-acoustic moderators influence the perception of humans.

LITERATURE

1. Bodden, M., “Perceptual Sound Quality Evaluation“, in Proc. Internoise 2000, Nice, France, 2000.
2. Zwicker, E., and Fastl, H., Psychoacoustics -Facts and Models, Springer Verlag, 1990.
3. Bodden, M., and Heinrichs, R., “Evaluation of interior vehicle noise using an efficient psychoacoustic method“, in Proc. of the Euronoise 98, 1998.