Refection of LFN Perception on an Auditory Model

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Introduction

Low-frequency noise (LFN) is a growing problem and there may be different reasons for this:

Houses are better insulated today than in the past, but the acoustical effect is concentrated on the higher frequency range conditioned by physics. Certainly, the occupants have in most cases only a low-level noise (mostly measured in dB[A]) in their flat now, but this noise becomes an emphasized LFN, which can be extremely annoying for some people even if the levels are lower than the limits given in the relevant rules. Figure 1 shows the third-octave-spectrum of a LFN and the course of the $L_{Ceq,30s}$ measured in a flat over three days. This LFN is caused by a power-heat-station located near to the flat [1-7].

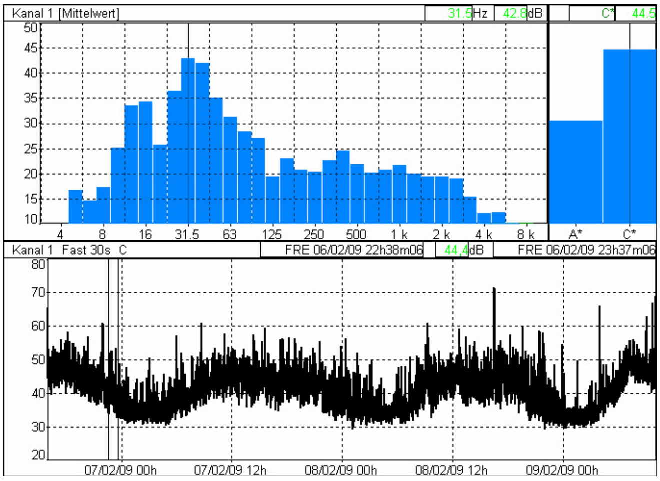


Figure 1: Measured third-octave-spectrum and the course of $L_{Ceq,30s}$ over three days of a LFN in a flat caused by a power-heat-station nearby

Another reason may be A-weighting itself. Since most of the limits in rules are defined on the basis of dB(A), which is combined with a stronger attenuation down to low frequencies, so fulfilment of these limits is sometimes easier to be done by a shift of e.g. a resonance to lower frequencies than by an attenuation.

All this can lead to a LFN having a spectrum with a marked emphasis at low frequencies like in Figure 1 and from which sufferers say, it is more annoying than a noise containing higher frequency components additionally. Sometimes this results in the reaction, sufferers open the windows, in order to have this additional noise e.g. by traffic [8]. It remains the question: "Why is this LFN so annoying and can an auditory model help to understand this more thorough?" [9] An answer is not only interesting in a scientific way but has also practical relevance in definition of rules and the construction of noise protection for instance.

Aim of the Investigation

The investigation, done mainly by simulating physiological processes, aimed at a better understanding of the effect described before, but more in a qualitative than in a quantitative way. Therefore, the term reflection is used in the title.

The stimuli used for this have different spectra to the effect that one is limited in the frequency range by a steep edge and the other by flat edge. Both spectra are shown in Fig. 2.

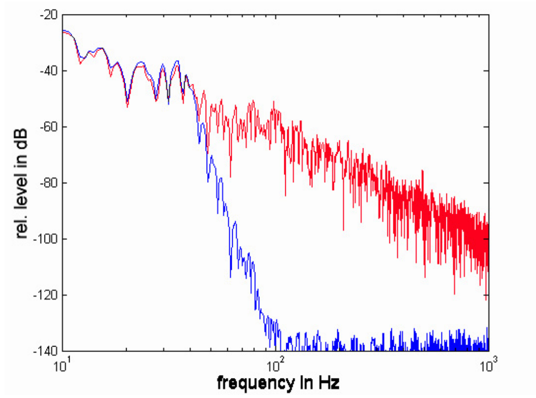


Figure 2: Spectra of the both used stimuli

The reaction of auditory modelling software on these two different stimuli should illustrate, why LFN with a steeply limited frequency range could be more annoying than other ones.

Possible Special LFN Effects in Hearing

One explanation for the special effect of LFN causing not only annoyance but also a mental strain in some cases [10,11] is given in the opinion in [12] by the fact, that a connection between the cochlear and the semicircular channels exits (ductus reunions) and therefore sound wave can irritate the sense of balance. [12] says, that this effect is not restricted to very low frequencies (infrasound), it can reach up to 70 Hz decreasing more and more. May be, there is such an effect and it should be mentioned here, but it is not usable to explain the different reaction on the both stimuli, because the LF content is unchanged.

In the following, three effects should be discussed being possibly able to bring some explanation into the phenomenon considered here. These are:

- on-effect
- synchronism
- special binaural conditions.

On-Effect

The on-effect can have different causes and is the result of one or more adaptation processes. It can be observed in the spiking pattern on a nerve fibre, when a stimulus is switched on or its level jumps up. Figure 3 shows an interval histogram of the spiking activity, when a stimulus is switched on.

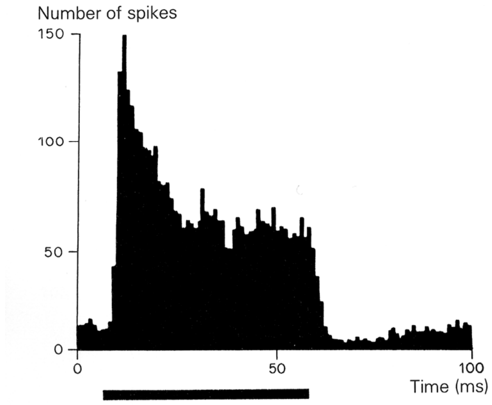


Figure 3: Interval histogram of a spiking activity on a nerve fibre of a cat caused by an on/off-switched stimulus (duration marked by the bar); Reference [13]

In the moment of switching on the stimulus, the activity jumps on a measure, which is here about three times higher than about 20 ms later. Regardless of the fact, that Figure 3 shows the reaction by a cat, a similar reaction can be also observed in the human sense and is implemented in all sophisticated auditory models, e.g.[14].

In combination with the both stimuli used here, it is expected that the steeply edged stimulus leads to a stronger reaction, because it results in a larger fluctuation (low-frequency modulation) also at higher frequencies, as it is shown later in Figures [5]. This means, the variation of the level is large, sometimes sudden, but in all slow enough, that the on-effect works.

In order to illustrate this, both signals were band limited around 300 Hz (based on ERG-filter bank) and then processed by an adaptive stage realizing the on-effect in a way oriented by [14]. Figure 4 shows the results, which are to interpret only qualitatively.

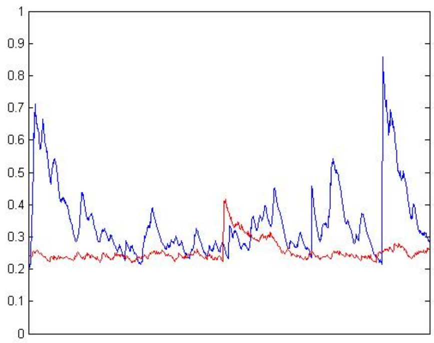


Figure 4: Demonstration of the on-effect processing a part of the both stimuli (blue: steep edge , red: flat edge)

The steeply edged stimulus brings about the stronger reaction here, but it should be mentioned, that the results depend on the parameters of the model in a sensitive way. The on-effect may be one explanation, why this stimulus is more annoying, for many listeners, but not for all. Perhaps, there is some "parameter sensitivity" in the nature too. But fluctuation is a strong indicator for LFN annoyance. Therefore, some national LFN rules, e.g. the Danish, use the L_5/L_{95}-differnce as an additional measure.

Synchronism

In the case of the steeply edged stimulus, all the nerve fibres having their best frequency above about 50 Hz are stimulated more by the signal content below 50 Hz caused by the much larger spectral density in this range and the limited frequency resolution of the spectral analysis. This produces nearly identical stimulations, what means they are strongly correlated and synchronised.

In simulation, the ERB-filter-bank models this effect. Both stimuli were processed by such a filter bank splitting the frequency range from 50 Hz to 500 Hz in 10 channels. Figure 5 shows the results in a form of courses of 10 band pass signals over the time of 5 seconds.

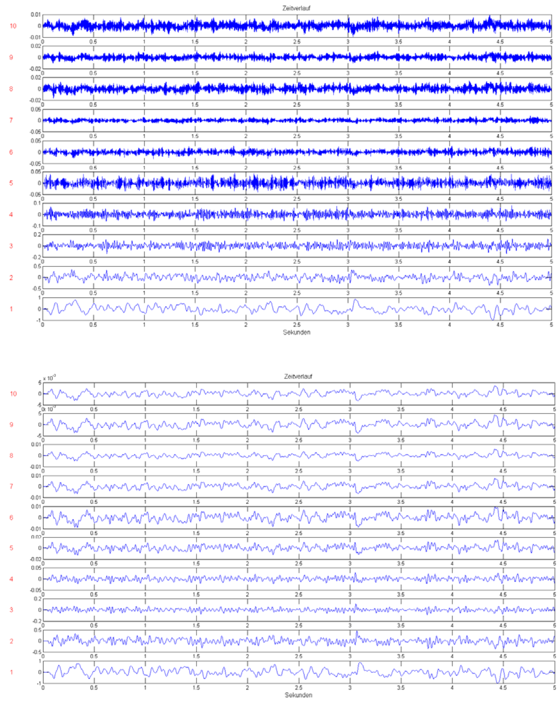


Figure 5: Stimuli processed by an ERB-filter-bank splitting the signals in 10 band-pass signals between 50 Hz and 500 Hz, duration 5 seconds (top: flat edge, down: steep edge)

Comparing the both plots in Figure 5 the correlation between the band-pass signals in the lower part is obvious, while such an observation cannot be made in the upper part.

As consequence of this correlation, respectively synchronisation, and probably supported by the on-effect, the spike activities on the nerve fibres are clearly synchronised with common concentrations at different times, if the stimulus is steeply edged. In the other case, this is not given.

Figure 6 shows the spike activities on fibre nerves spanning the range from 50 to 500 Hz (ordinate) over 5 seconds (abscissa) in form a qualitative pattern. This is the result of a simulation made by the program MAP1_6 developed by Ray Meddis [15].

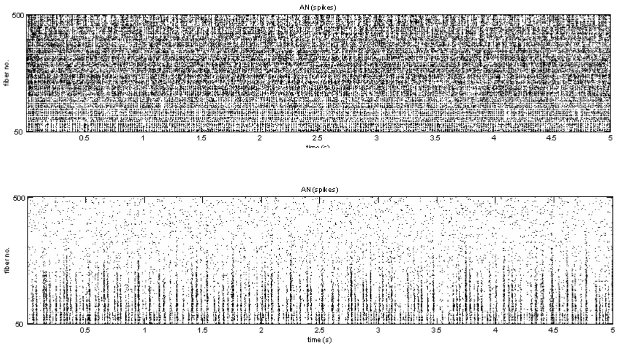


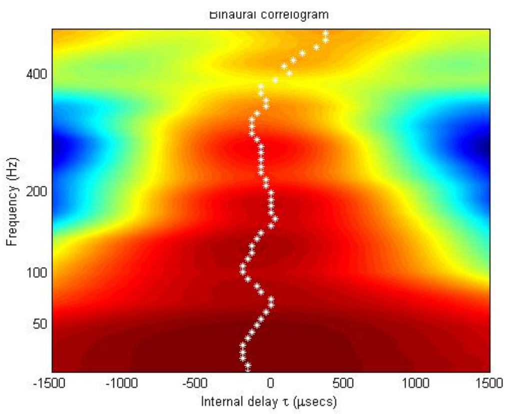
Figure 6: Patterns of spike activities spanning the range from 50 Hz to 500 Hz (ordinate)over 5 seconds (abscissa), (top: flat edge, down: steep edge), analyzed by the program MAP1_6 [15]

The correlation of the signals in figure 5 is transformed to a synchrony of the spike activities in Figure 6 now. Like before this is restricted to the lower part of the figure, so for the stimulus with the steep edge.

It is not clear in the moment, if synchronism is combined with an enhanced annoyance, but some phenomena are known, for instance that synchronism can lower the threshold for noticeable stimuli [16,17]. Generally it is a fact that synchronism is one of the most important functional concepts in our brain. It can bring more attention to a sound or parts of a sound, but it can bring also irritation and others strains [18,19]. This is more known about visual effects, but between the visual and aural sense is a close interaction [20,21].

Special Binaural Conditions

A further operation based on correlation exits in binaural hearing. Utilizing the level difference and the time / phase shift between both ear signals the source of sound can be localized. However, in the low-frequency range there is only a very small level difference caused by the good diffraction condition around the head as well a very small phase difference and so both ear signals are very well correlated in this frequency range. To show this, both stimuli were recorded by an artificial head with no direct sound propagation path from the loudspeaker to the head. Then both recorded signals were analyzed by the program Binaural Cross-correlogram made available by Michael A. Akeroyd [22]. The results are presented in Figure 7 in form of a correlogram.



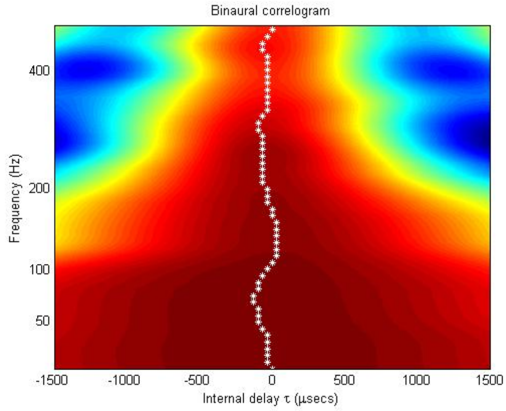


Figure 8: Binaural correlogram by the program [10] ©MRC, dark red: high correlation, dark blue: low correlation, (top: flat edge, down: steep edge)

Again, the stimulus with the steep edge reaches higher correlation values up to a higher frequency and it can conclude from this a stronger synchrony of the activities, for instances in the corpus trapezoideum, where a first cross-connection exists between the nerve fibres coming from the left and right ear.

It is not clear, if this kind of synchrony influences the extent of annoyance, but it can be observed, that stimuli of kind "steep edge" are perceived in another way, when the presentation by headphone is changed from diotic to dichotic with stochastically identical but independent signals.

Listening Experiments

Preliminary listening experiments were done, which give clues, that LFN with a strong emphasis at low frequencies like the stimulus of kind "steep edge" here, can be extremely annoying. However, the statistical analysis of assessment of about 20 persons brought not significant results. What can be the reason(s)? The physical conditions during hearing were controlled, so that an influence in this direction can be excluded. However, other influences are assumed.

The effect of the LFN investigated here may be more a mental one. At first, it was observed that some of the persons reacted extremely strained and other ones more relaxed, when they heard the noise for a first short time, which supports the assumption that the persons are preconditioned differently. Because the used stimuli lasted only 10 seconds in each assessment, this might have an influence. At second, it was observed, that people reacting in a moderate way initially were more and more annoyed, in particular hearing the stimulus with the steep edge for a longer time (2-3 minutes). Possibly, it takes this time for a first mental reaction, if there is no precondition before. Considering this in all, a careful strategy is to develop for a listening experiment aiming at clearer answers, if a special kind of LFN is more annoying or even straining.

Conclusion

LFN with a strong emphasis at low frequency seems to be annoying in a special way. Two stimuli, one steeply limited in frequency range and another one flat limited, were used in simulations based on hearing models. The results of these simulations are showing clearly different reactions.

According to this, the on-effect, synchronism and special conditions in binaural hearing may play a role, one of them or more in combination. Under this consideration, auditory models are very helpful to get a better understanding, what happens in hearing LFN and why is some LFN extremely straining for some people?

However, the models can give only clues in the moment. More investigations are required, probably having to be interdisciplinary. For instance, there is no clarity, if synchronism can force a mental stress and, given that, if aural stimulation can cause such a kind of synchronism.

Also further listening experiments are needed and will be done, asking more for a mental reaction than a simple perception.

All these tasks should be done, in order to avoid a further increasing LFN problem, because the reasons and the connections are not understood in a sufficient measure.

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