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Annoyance of Noise in the Infrasound Range; Study design and acoustic presentation

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ABSTRACT

An increasing number of infrasound sources and the success in decreasing the acoustical emission and immission caused by noise sources at higher frequencies let the noise below 20 Hz come more in the focus. Many investigations concerning infrasound are done in the past, e.g. regarding the threshold of perception. However, none of the results gives a sufficient answer, which can essentially explain the number of infrasound complaints and can give a reliable recommendation for a limitation of the exposure to infrasound. Therefore, in a special laboratory study on behalf of the Federal Environmental Agency an interdisciplinary team of experts tried to answer this question. The test persons should hear several noise scenarios in a living room atmosphere in a very silent house for a scenario period of 30 minutes. They should hear the sound in an accustomed way, that means by loudspeaker, where the driver has to have low distortions in order to be sure, the reaction is exclusively caused by infrasound. The actions and organization to create these conditions for the investigation are described in this paper. In the papers of Müller et. al. and Schreckenberg et al, the physiological and psychological effects of infrasound in this study are described.

Keywords: Infrasound, Annoyance, Perception

1. INTRODUCTION

Although infrasound is an ubiquitous phenomenon, and although it is commonly made responsible for many different symptoms, only little scientific knowledge exists about its potential effects on human perception and response. A result is an increasing public debate about systems and equipment that emit infrasound (< 20 Hz). These include, for example, power plants and biogas plants, pumping stations, heating plants and wind turbines. However, the levels in the infrasound range are sometimes well below the hearing threshold, e.g. (1). However, if complaints are reported, this may be caused by an increased sensitivity due to prolonged exposure. However, noise components above 20 Hz in the so-called low-frequency range (up to approx. 100 Hz) could also be the cause of the annoyance. This is because many of the sources mentioned above also emit noise in this frequency range, where hearing thresholds are more likely to be reached. As a rule, those affected persons can not differentiate between these different components. So the questions arose: How do people react under realistic conditions to pure infrasound with a level close to the hearing threshold? Does a pre-exposure play a role in this? In the period from 2015 to 2019, the Federal Environment Agency commissioned a research project (FKZ 3714 51 100 0) to investigate the acute effects of infrasound immissions under controlled conditions. The investigation has been carried out oriented towards these questions.

A number of 42 people took part in the investigation. Of less than half of them were known to have already had problems with low-frequency sounds. The corresponding test persons were specifically selected in order to have an approach to investigate the possible influence of a pre-pollution. The investigation was made in an outlying, very quiet house, where the test persons heard the generated infrasound in a room with living room atmosphere. So they should have a feeling comparable to their situation at home.

The main part of the test execution consisted for each test person of the presentation of five scenarios. Four one with infrasound with different frequencies and levels near the hearing threshold and silence as fifth one. The infrasound was generated with the TRW-17 rotary subwoofer supplemented with an active sound control system. In this way, the non-linear distortion could be successfully minimized. Each scenario lasted 30 minutes and the sequence was chanced for each test person. During each hearing session, test persons had to answer a range of psychologically designed questions and a number of their physiological reactions were measured.

This article gives details on the structural and acoustical conditions as well as on the acoustical set-up and solutions. The psychological and physiological methods used in the investigation are briefly described in an overview. For further details please refer to the contributions by Schreckenberg et al. (2) and Müller et al. (3).

2. STRUCTRAL AND ACOUSTICAL CONDITIONS

The listening conditions near the hearing threshold and by a loudspeaker system demanded to avoid any kind of acoustical disturbances. Therefore, a house was rented in a very quiet environment on a former naval airport and prepared for the investigation. This house offered the advantage of being able to prevent all noises in the house during the hearing test, running noises from persons or installations. The latter ones could simply be switched off. Preliminary tests in buildings of the University of Wuppertal had shown that even with massive building fabric (former barracks) movements in the building or e.g. the humming of transformers were clearly measurable and could have led to irritation in the perception. Figure 1 shows the house in isolated position between some shelters. The layout of the house shows Figure 2 with the two main rooms, the listening room and the control room.

Figure 1 – The test house

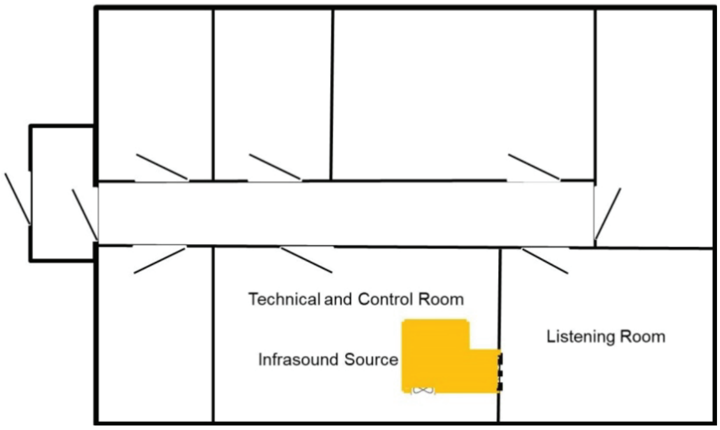

Figure 2 – Layout of the test house

In the control room the infrasound source was located, which sounded through an opening in the wall the listening room. Figure 3 (right) shows the part of the technical and control room, which was occupied for the generation and measurement of the infrasound. Another part of the room contained devices for the acquisition and storage of EEG signals. Figure 3 (left) shows the enclosure of the infrasound source with the mounted TRW-17. The enclosure was fixed to the wall common with the listening room.

The listening room (Fig. 4) was designed in such a way that it had a certain living room character in terms of both acoustics and appearance. The test persons had e.g. the possibility to see out of the window. This environment was specifically aimed at so that the test persons were as far as possible not impressed and negatively influenced by an unusual environment (laboratory or e.g. bunker) in the psychologically oriented investigations. The opening to the infrasound source was located behind the shelf to avoid possible irritations caused by the supposed location of the source. All objects were fixed in such a way that they could not move - stimulated by the infrasound. Looking at the shelf, the test person sat at the table to fill in the questionnaires during the listening test. During the examination there was a microphone close to the head which was used to record and control the sound. In order to be able to control local dependencies of the sound field, a second microphone was positioned elsewhere. Due to the large wavelength of the sounds used, this was minimal, so that head movements of the test persons could not result in any noticeable level changes.

Figure 3 – Infrasound source with the TRW-17 (left) and the control / measurement devices (right)

Figure 4 – Furniture of the listening room

The background noise that could be achieved in the listening room was extremely low at 15.6 dB(A). The spectrum of background noise in Figure 5 during the scenario “silence” was clearly below the hearing threshold.

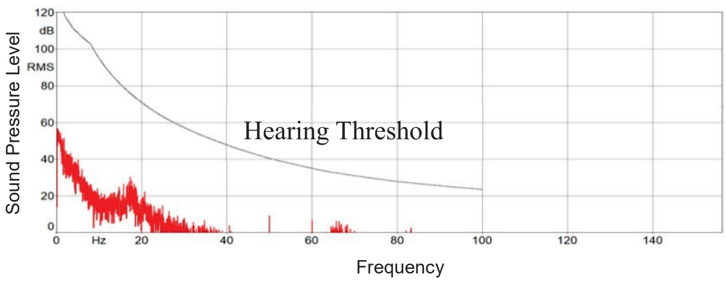

Figure 5 – Spectrum of the background noise

3. ACOUSTICAL SET-UP

The aim of the infrasound source design was – at sound pressure levels around the hearing threshold – to achieve sound generation with low operating noise and as little non-linear distortion as possible.

3.1 Rotary Subwoofer TRW-17 and Passive Components

An essential component of the infrasound source was the Rotary Subwoofer TRW-17 from Eminent Technology, in principle a fan, which can change its blade position by means of a signal and thus move the air back and forth. The volume speed and consequently the sound pressure level depend on the constant speed and the maximum steepness of the wing position, which is determined by the audio signal. In this way, sound pressure levels of up to 115 dB can be generated at frequencies down to 1 Hz. In order to avoid an acoustic short circuit and to dampen operating noises of the engine as well as higher-frequency air turbulence, the manufacturer proposes a design of an enclosure, in which the TRW-17 induced the air movement. Figure 6 (left) shows how the TRW-17 is positioned at the construction and the construction, how it is recommended by the manufacturer. In addition to the covering the enclosure inside with sound-absorbing material, the structure should be reinforced by a number of cross struts.

In order to improve the signal-to-noise ratio, further materials were incorporated into the structure. The open-pored materials marked with (a) dampened the higher-frequency noises caused by air turbulence and those of the electronic control when passing through this barrier. As a further passive measure a larger volume with absorbing material for damping arising resonances was inserted marked with (b). This resonance was not caused by the walls of the structure, as measurements showed, but by a blowing of the enclosed air volume (Helmholtz resonator), as a calculation revealed. If the thickness of the walls is sufficient, stiffening with cross struts did not bring any additional improvement. It was therefore omitted, making it possible to integrate two active loudspeakers into the housing, which were used to actively reduce distortion products (Figure 6 - right).

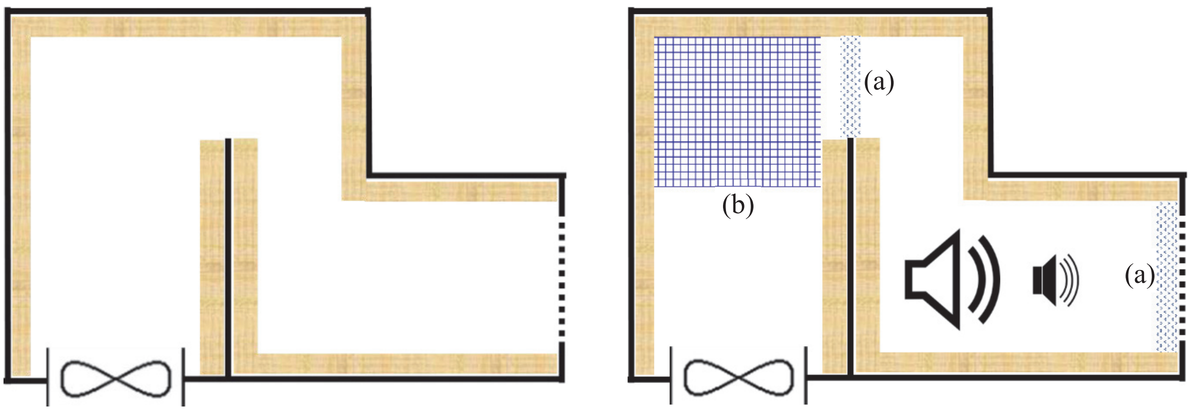

Figure 6 – Construction of the enclosure as recommended by manufacturer (left) and supplemented by additional absorbing material and a loudspeakers of an ADC system

3.2 Active Distortion Control (ADC)

The ADC system is designed to significantly lower the levels of harmonics and discrete components in the form of mixed products by means of destructive interference and thus to control non-linear distortion. Its function is therefore referred to in the following as Active Distortion Control (ADC). Table 1 compares the three sound reinforcement components used; Figure 7 shows the conceptual structure of the ADC system.

As preliminary experiments had shown, there is a strict correlation between the target signal, the harmonics and the mixed products, which indicates an almost deterministic behavior. Thus, the undesired components were reduced very effectively by superimposing destructive interfering components, which were derived from the target signal in a very stable way.

The core of the ADC system was a signal processor kit (DSK) TI C6713. Before each presentation of the noise scenario, the target signal was loaded into the DSP with the frequency f_0 and the distortion signal with the known distortion products (components with the frequencies f_1 to f_N). The fact that both signals were equally clocked meant that the strict synchronicity of both signals supports effective cancelling of the distortion signals.

The KH870 as opposed sound loudspeaker was supplied only with the distortion signal. The superposition of both signals was controlled close to the test person by a microphone whose signal is looped through a measuring system that logs everything and transmits the signal to the signal processor. There it is processed according to the FX-LMS algorithm. This adjusts the magnitude and phase of each component of the distortion signal so that the cross-correlation between the microphone signal and the distortion signal is minimized. This is achieved when the microphone signal contains only the components with the frequency f_0.

The KH120 was used as control source, when the KH 870 took the roll of the TRW-17. This was done at a target signal just below 20 Hz.

Table 1 – The used speakers

Rotary Subwoofer Eminent Technology TRW-17 1 Hz – 30 Hz	Active Subwoofer Neumann KH 870 18 Hz – 250 Hz	Active Monitor Neumann KH 120 50 Hz – 25 kHz

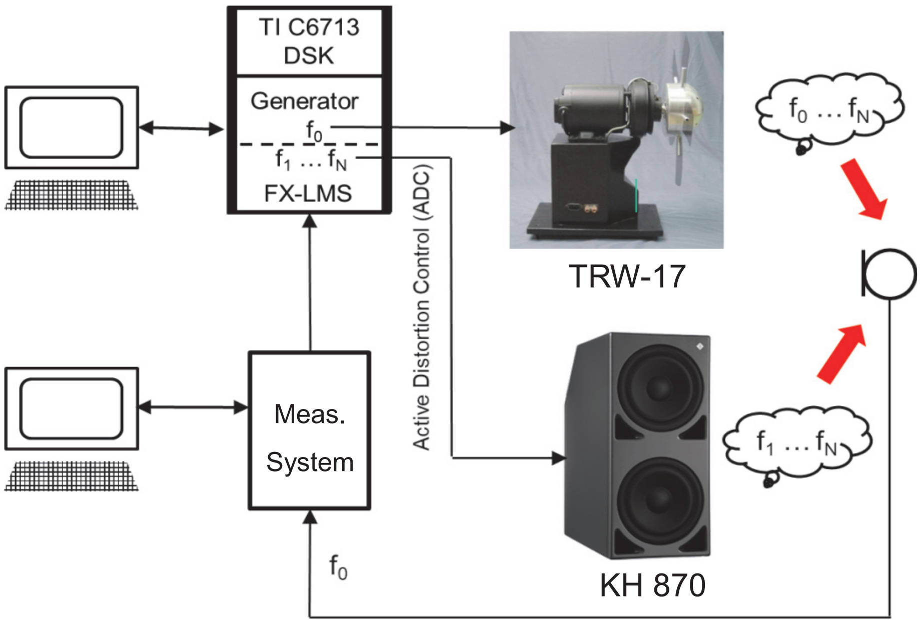

Figure 7 – Conceptual structure and operation of the ADC system

4. ACOUSTICAL SCENARIOS

4.1 Used Scenarios

The selection of the noise scenarios was determined, among other things, by the objectives of being able to vary the infrasound to a certain extent on the one hand and to be able to observe the reactions to a longer exposure time on the other in which the test persons were constantly exposed to sound. In addition, there were boundary conditions such as the time-limited resilience of the test persons, a very extensive preparation time and a post-processing time on each test day. In the end, the available timeframe allowed five runs of 30 minutes each. The scenarios were defined:

1. sinus 3 Hz, 100 % amplitude-modulated by Sinus 1 Hz,
   level 105 dB (unweighted)
2. sinus 5 Hz, level 105 dB (unweighted)
3. sinus 10 Hz, level 95 dB (unweighted)
4. sinus 18 Hz, level 85 dB (unweighted)
5. silence

The choice of frequencies covered the infrasound over a wide range. The levels were selected so that scenario no. 4 with a level of 85 dB was above the hearing threshold according to DIN 45680 (4) and scenario no. 3 with a level of 95 dB was at the hearing threshold. The scenarios no.1 and no.2 were below the hearing threshold according to an investigation of Møller and Pedersen (1) for this frequency range, which was below the range defined in DIN 45680. The choice of scenario no. 4 was done to have an observable reaction of the test persons with great certainty and thus to have a so-called anchor. The other scenarios, which were towards lower frequencies increasingly reduced in level relative to the hearing threshold, were intended to gain knowledge, if - as is frequently claimed - annoyance by infrasound can also exist below the hearing threshold. To set the levels even lower here would have been interesting, but would have been associated with the danger of no longer being able to observe any reactions from the test persons. Further comprehensive investigations will be required to determine the limit for this depending on various signal parameters. Scenario no. 1 was also intended to investigate the effect of modulation, which can be assumed to increase annoyance. The scenario of silence, defined here as scenario no. 5, serves control purposes.

4.2 Results of Active Distortion Control

Figure 8 shows the spectra of scenarios 1 to 4, left without ADC, right with ADC.

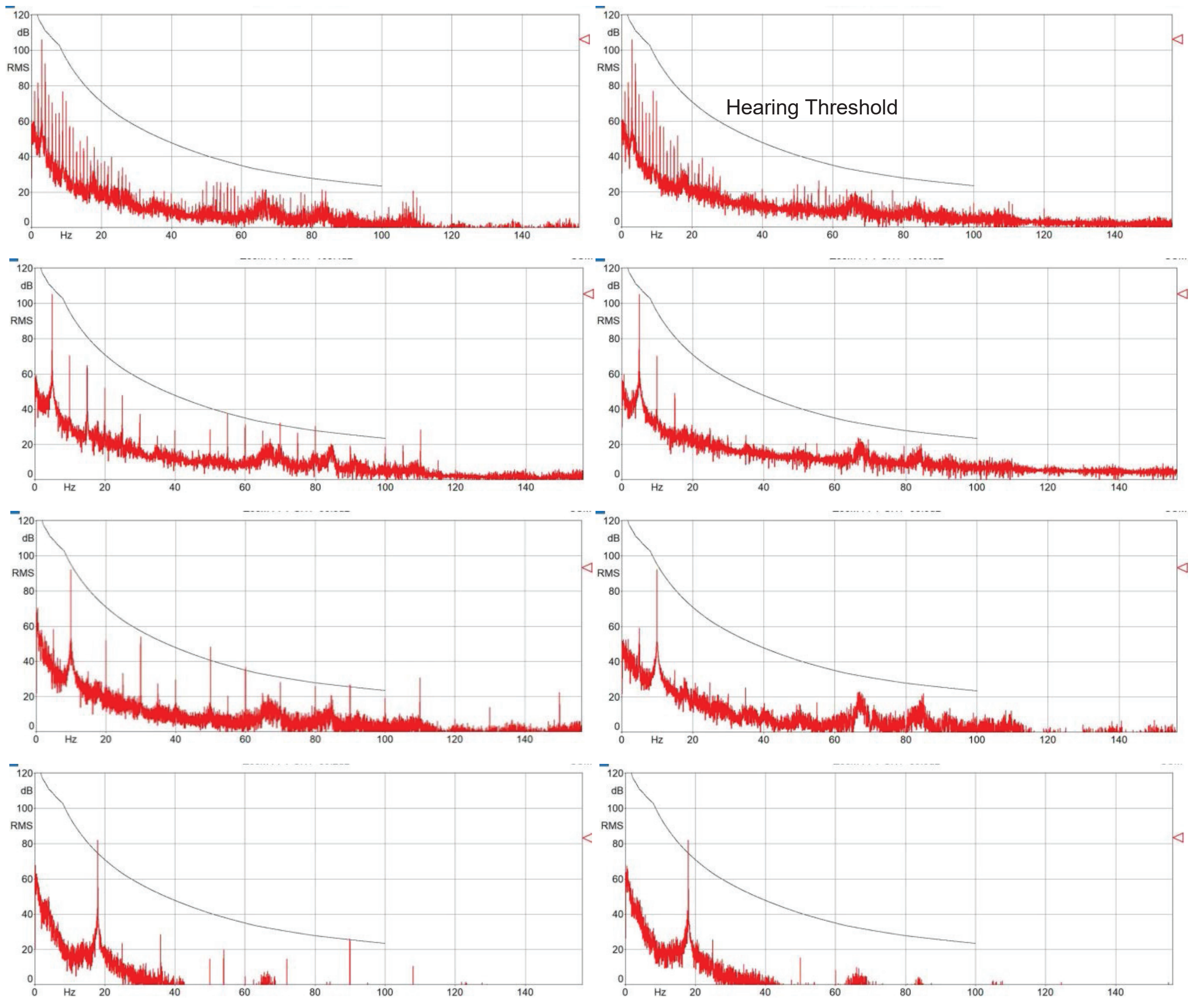

Figure 8 – Spectrum of the sound pressure of the scenarios 1 to 4 (top down) without (left) and with (right) ADC

A comparison of the spectra shows a significant reduction in distortion in the form of discrete frequency components by the ADC system, especially in those components, which were close to or even exceed the hearing threshold. Scenario no. 1 differed here from the others. The modulated signal theoretically contains only the components with the frequencies 2 Hz, 3 Hz and 4 Hz. Due to the non-linearities of the TRW-17, however, the radiated sound had a whole series of harmonics in a 1Hz grid. Their compensation would had been difficult in some cases, which, however, was deliberately dispensed with. In the range up to approx. 30 Hz, the spectrum was not dissimilar to that of a wind turbine (WTG), where the 1 Hz raster is created when the three wings rotate fully in three seconds (wing frequency). Thus, the counter sound was concentrated only on reducing the level of the components by 100 Hz. Scenario no. 1 thus reproduced a sound that is often said to be more annoying. The distortion in scenario no. 4 without ADC is significantly lower than in the otherones, but this is not surprising with a high-quality studio subwoofer like the KH 870. It was used in scenario no. 4 for the radiation of the target signal. Nevertheless, ADC could also significantly reduce the distortion components here. The slight increases in the spectra of scenarios no.1 to 3 between approx. 60 Hz and 85 Hz are to mention still. These were due to the resonance effect mentioned above.

5. MEASUREMENT OF IMPACT ON THE TEST PERSONS

Here only a very short view on the psychological and physiological investigations can be given. The Table 2 shows the course of the examination during one day with one test person.

Table 2 – Time table of one examination

Arrival of the test person (welcome and short tour through the lab)	30 min
Introduction to the physiological measurement + questionnaires, audiometry, applying the EEG electrodes, measuring blood pressure (three times) + equilibrium (resting measurement)	120 min
Noise exposure (4 noise exposures + noiseless + lunch break) Each exposure: Free view (3 min), Fixing point (3 min), Eyes closed (3 min), Free view (1 min) Measurement of blood pressure + balance (10 min), Questionnaires (10 min), Measurement of blood pressure + balance (10 min), Break (noise free) (20 min)	300 min
Final questionnaire, leave-taking + formalities	30 min
Sum	8 h

The evaluation and assessment of the noise scenarios by the test persons were recorded on a tablet PC by means of a questionnaire inventory. In addition to sociodemography, general noise-related questions were asked, including general noise nuisance from various sources, as well as some general questions about housing and satisfaction of participants. Other questions addressed individual hearing and environmental concerns. In the last part of the questionnaire the general understanding of low-frequency sound and infrasound was asked, as well as the reasonableness of the overall experiment and health and risk factors (smoking, alcohol consumption and sport).

The physiological reactions were determined by means of established methods, e.g.

- Electrocardiogram (ECG)
- Electroencephalogram (EEG)
- Blood pressure measurement (2x per scenario)
- Nystagmus measurement using Frenzel glasses

The responses und reactions were interviewed respectively measured during the presentation of the sounds. The details of the psychological investigation are subject in the contribution (2), those of the physiological investigation in the contribution (3). However, some remarks to physiological measurements should already be made here:

- The results of the physiological measurements will show the acute reactions of the human organism to the presented 30-minute noise exposure scenarios.
- In the case of little or no change in the physiological parameters on the noise scenarios compared to the reference situation, it can not be concluded that a health risk can be excluded. A possible sensitization can certainly also take place after prolonged exposure to

noise.

- If a clear change in the physiological parameters to the noise scenarios compared to the reference situation is found, the hypothesis is plausible that long-term exposure can lead to the genesis of diseases.
- However, a review of this hypothesis is only possible by means of epidemiological follow-up studies, whose implementation for methodological reasons should be difficult, especially in the case of infrasound.

6. CONCLUSION AND OUTLOCK

The TRW-17 can generate sound down to 1 Hz with a sound pressure level of more than 110 dB, which is, however, associated with significant distortion products due to the principle of sound conversion. Active compensation allows the distortion products to be reduced to a level well below the hearing threshold.

In addition to hearing experiments with sinusoidal signals in the infrasound range, those with more complex signals that do not have to be limited to the infrasound range but have their focus in the infrasound range are also interesting. Furthermore, it would be desirable to shape the spectrum in the infrasound range as desired, i.e. not only to suppress unwanted components as far as possible. This is to be achieved with one or more more powerful signal processor systems and a more complex algorithm.

The signals do not necessarily have to be (strictly) periodic, but can also be stochastic in nature. Nevertheless, the algorithm can still work according to the feed-forward principle, since the target signal can be determined and therefore apparent non-causal solutions can also be implemented. However, the more stable solution has to be "paid" with a higher processor performance.

The signal processor kit TI C 6713 used here is considered outdated, but in combination with a daughter card it offers a certain comfortable functionality. Newer DSP solutions - mostly multiprocessor systems - offer higher clock rates and larger memory. This not only significantly increases the number of components to be modified, but also the spectral resolution. This means that the components could occupy the frequency range very densely.

Further investigations with such approaches would be useful in order to gain more knowledge about the perception and effect of sound in the infrasonic range. The main advantage of using this infrasound source is that the generated infrasound has defined properties and is reproducible.

7. ACKNOWLEDGMENT

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