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AIRBORNE SOUND INSULATION AND ITS SUBJECTIVE PERCEPTION – HOW MUCH MAKES A DIFFERENCE IN LOUDNESS

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Abstract

The airborne sound insulation between dwellings describes in general the quality of the indoor living environment. It is common practice to use the current standard method of predicting airborne sound insulation according to EN ISO 12354-1. But one also knows, that by using this method the psycho-acoustical standard parameter (especially loudness) cannot be deduced in an adequate way. A well-defined increase in airborne sound insulation might not be "felt" or subjectively recognised as such. However, in specific sound insulation requirements e.g. in the German Standard DIN 4109 a raised weighted sound reduction index of one and two decibels is supposed to indicate an increased sound insulation. The problem is if such small increases in R_w lead to a noticeable difference in "acoustic quality"? The question whether an airborne sound insulation is judged as sufficient or not cannot be answered in a simple way. After the transformation from the sound descriptor into a hearing descriptor such as loudness, it might be possible to predict an increasing sound insulation in a more realistic manner. This research work was therefore primarily focused on how much the sound insulation has to be increased to realize a significant difference. As a starting point pink noise was used as noise source replacing a raised spoken voice. The sound insulation used in this investigation, which included two different structures, i.e. a heavy and a lightweight construction, were calculated according to EN ISO 12354-1. The sound level in the receiving room was calculated. The computed results were loudness and loudness level, which were more appropriate values indicating subjectively judged increase of different airborne sound insulation depending on background noise level. The results show that in a very quiet environment, i.e. with a background noise level below about 15 dB(A), a necessary increment in R'_w leading to a halving in loudness is of about $\Delta R'_w = 3\ dB$. An increase of background noise leads to a dramatic increase of needed increment in R'_w. An average background noise of about 18 dB(A) was found yielding a needed 5 dB increase of sound insulation.

INTRODUCTION

The Weighted Sound Reduction Index (R_w) is a single-number rating of the sound reduction through a wall or other building element. Since the sound reduction may be different at different frequencies, tests are subjected to a standard procedure, which yields a single number that approximates the average sound reduction in the midrange of the human hearing spectrum. The Weighted Sound Reduction Index (R_w) classifies partitions according to their ability to isolate against speech and other similar sounds dominated by mid- and high-frequency content. Defined in ISO 717 [1], the rating has also acquired several descriptors that rank performance for other frequency ranges of interest. The airborne sound insulation between dwellings is supposed to describe generally the quality of the indoor living environment. In cases where the sound insulation between dwellings is claimed to be insufficient and should therefore be improved, one wants to rely on a subjectively recognised sufficient/improved sound insulation as a design-criteria. For that case legal regulations usually fail. For example, in Germany the Standard DIN 4109:1989 defines the legal requirement for a certain limit in sound insulation. The supplement two of DIN 4109 provides additional recommendations of an improved sound insulation. The airborne sound insulation for a partition wall between dwellings, for example, has to be at least 53 dB (R'_w) and the recommended improved sound insulation is 55 dB. Another example is exemplarily a separating floor between dwellings, with a required sound insulation limit of 54 dB. The recommended improved sound insulation is 55 dB. This is a difference of 2 dB in the former case and of 1 dB in the latter case. Due to raised comfort demands concerning the airborne sound insulation in dwellings, as well as in flats and houses etc., it is very important to know how much the sound insulation should be increased in order to cope with certain expectations. To introduce in a more distinct way the subjective related assessment of sound insulation in buildings it was already shown in [2], and [3] that a subjective related measure like the loudness and the loudness level, respectively, yield a more realistic measure to the standard rating of sound insulation. In this paper a further initial step toward an improvement of a more subjectively related judgment of the sound insulation is proposed. To start off it is primarily investigated, how much the sound insulation has to be increased to make a difference. Due to the complexity of the issues involved in determining the right sound insulation performance, it is proposed in this paper a first investigation of the subjective estimation of various sound insulations between dwellings depending upon background noise level for two different structures. The sound insulation used in this investigation is a heavy weight and a lightweight construction, all with heavy weight flanking structures. Both constructions are chosen in that way, that the legal regulation of DIN 4109 for separating structures is fulfilled, i.e. $R'_w = 53\ dB$. The calculated resulting sound insulation was performed according to EN ISO 12354-1 [4]. Pink noise was used as noise source replacing a raised spoken voice of $L_{AF,eq} = 70\ dB$. The sound level in the receiving room was calculated. The computed results were loudness and loudness level, which were more appropriate values indicating subjectively judged increase of different airborne sound insulation depending on background noise level.

AUDIBILITY OF SOUNDS AND BACKGROUND NOISE

The acoustic comfort in dwellings, as well as in flats and houses etc., is strongly related to the sound transmission coming from outside or from adjacent dwellings etc. The threshold-in-quite indicates as a function of frequency the sound pressure level of a pure tone that is just audible. The threshold of hearing under diffuse-field listening conditions is specified in ISO 389-7:2003(E). Figure 1 shows the minimum audible sound level, i.e. the hearing threshold, under diffuse-field listening conditions as provided by the International Standard ISO 389-7.

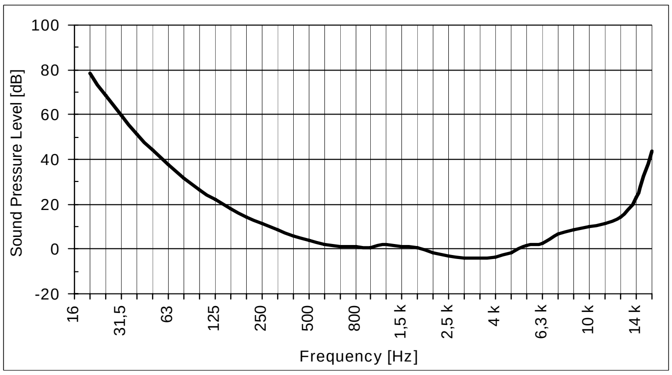

Figure 1 – The minimum audible sound level plotted as a function of frequency

The absolute threshold of a sound is the minimum detectable level of that sound in the absence of any other external sounds. In real rooms, however, a certain background of noise is observed. This noise acts as a masking sound in the room. In order to assess the magnitude and frequency dependency of typical background noise numerous field-measurements of background noise levels were investigated. These background noise levels were obtained during measurements according to ISO 140-3:1995 of airborne sound insulation measurements in building acoustics. The analysis of the measured data was performed based on a set of 157 measured noise level in a frequency range from 50 Hz up to 5 kHz. The median was calculated corresponding to a cumulative percentage of 50%, revealing a noise level as a function of frequency as shown in Figure 2.

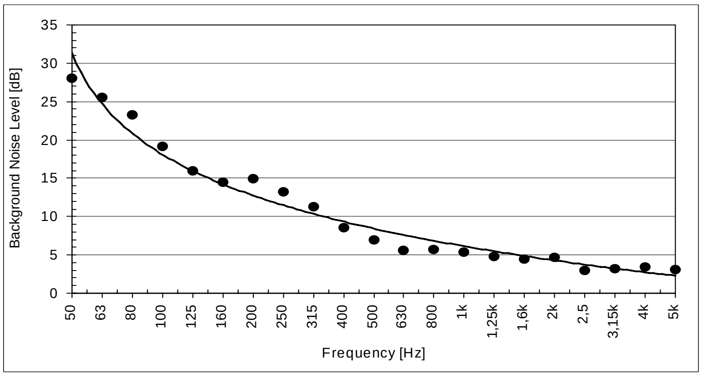

Figure 2 – Background noise level (L_{eq} = 31,7 dB, n = 41)

Background noise as a function of frequency often shows a typical falling slope towards higher frequencies, very similar to Figure 2. A generated random noise was used instead the measured In analogy to pink noise which is defined as having equal power in each octave band (corresponding more closely to the response of the ear than white noise) red noise will be used here for an assessment of background noise, because it correspond more to the measured noise spectrum with the observed major low frequency component. Thus the power varies inversely with frequency - for this reason red noise is often referred to "$1/f^2$-noise", the high frequencies being much more attenuated than in pink noise. This generated red noise with a slope of -6 dB per octave towards low frequencies is used for the further investigations. The noise level was varied with different levels. Figure 3 illustrates an example of a time and frequency spectra of the generated background noise level.

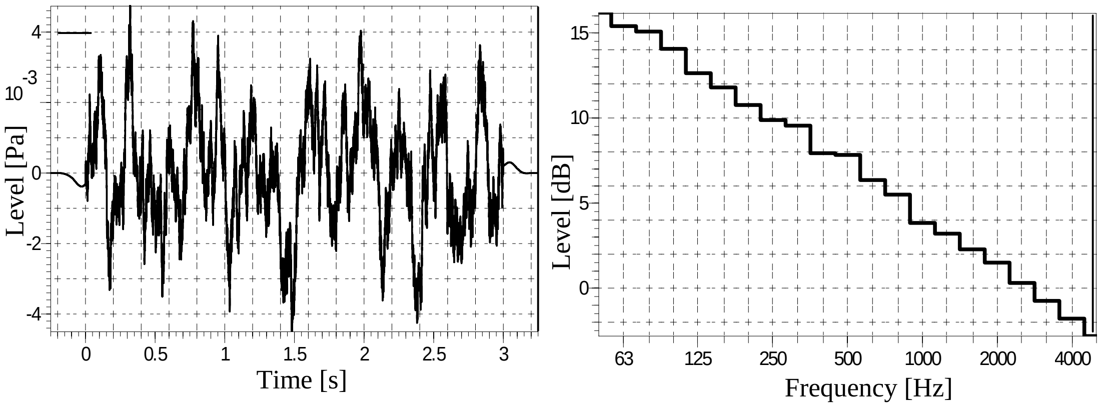

Figure 3 – Red noise as a function of time and as a function of frequency with level of 15 dB

The background noise level for this investigation was varied from 15 dB(A) up to 25 dB(A) (broadband).

LOUDNESS

Loudness is probably the most important and well-known psychoacoustic quantity, describing the human sensation and reaction to sound. Loudness depends not only on sound pressure level, but also on other factors such as temporal and spectral masking, bandwidth, frequency and duration. The sensation of loudness in different frequencies (see [5]) is shown in Figure 4.

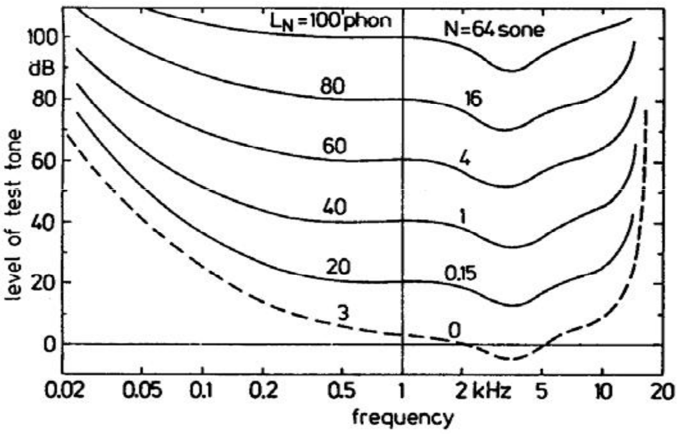

Figure 4 – Equal-loudness contours for pure tones in a free sound field. The parameter is expressed in loudness level, L_N, and loudness, N [5]

A first approach was carried out using a commercial software package in order to produce the signals in time domain, i.e. pink noise as source noise and red noise as the background noise. Then the psychoacoustic parameter loudness from the overall signal in the receiving room (i.e. addition of the signal of the sound level in the receiving room and the signal of the background noise) was calculated. The duration of the generated signals was limited to 3 seconds due to the digital filter characteristic, to ensure a sufficient signal analysis.

AIRBORNE SOUND INSULATION

The problem considered here is the transmission of noise from one dwelling unit to another. For this reason a construction was chosen having an airborne sound insulation of 53 dB, which was calculated using the Standard EN ISO 12354-1. The construction was varied from a heavy weight in on case to a lightweight construction in the other case, all having the same flanking constructions. The spectrum adaptation term (*C*) calculated was found to be for the heavy weight construction $C_{50\text{-}5000} = -3\ dB$ and for the lightweight construction $C_{50\text{-}5000} = -5\ dB$.

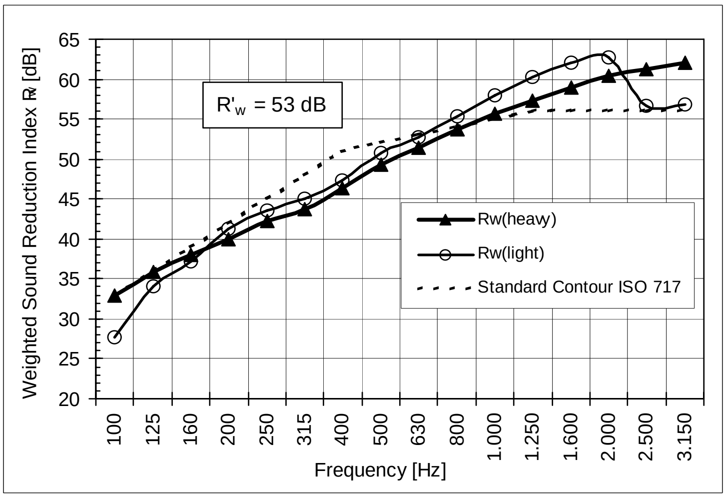

Figure 4 – Weighted Sound Reduction Index (R'_w) as a function of frequency. The bold solid line shows the heavy weight and the thin solid line the lightweight construction. The dashed line indicate the standard contour of ISO 717

The weighted sound reduction index of both constructions was varied from 48 dB up to 68 dB. In order to calculate the level difference from the virtual room, pink noise was used as noise source with a sound pressure level of 70 dB(A). Thus the power varies inversely with frequency - for this reason it is often referred to as "1/f noise", with a slope of -3 dB per octave toward low frequency. By sending the source signal through the designed filter, which is the spectrum of the airborne sound insulation ($R'_w(f)$), the resulting signal of the receiving sound level is obtained. To the resulting filtered signal the background noise is added. All signals are manipulated with respect to their time spectra. The resulting sound level (composed signal) in the receiving room is shown in Figure 5.

The resulting signal in terms of sound pressure level in the receiving room for the two different constructions in question, i.e. heavy and lightweight, is presented in Figure 6 as a function of frequency. The sound level in the receiving room (i.e. the source signal having passed the filter characterised by the sound insulation) was combined with some well defined background noise levels varying form 15 dB up to 25 dB. The resulting signal represents the sum of both, i.e. the signal of the receiving room ("pure") and the signal of the background noise. In fact, the background noise will mask the receiving sound level. The effect of masking, however, is included in calculating the loudness spectra. The loudness was plotted as a function of R'_w in Figure 7. Here it is seen that the loudness decreases considerably with increasing weighted sound reduction indices (R'_w). At a weighted sound reduction index, however, of about 63 dB and above, very small increase in loudness is observed. It is assumed that for very high sound insulation the loudness will not be affected severely. This especially holds if one considers the interference of background noise.

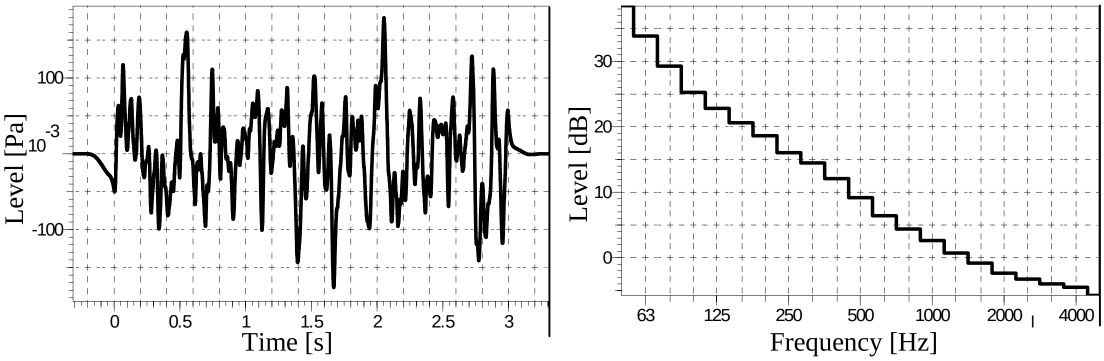

Figure 5 – Composed signal as a function of time and as a function of frequency. Source signal pink noise with 70 dB(A). Airborne sound insulation R'_w = 53 dB. No background noise was introduced to the signal.

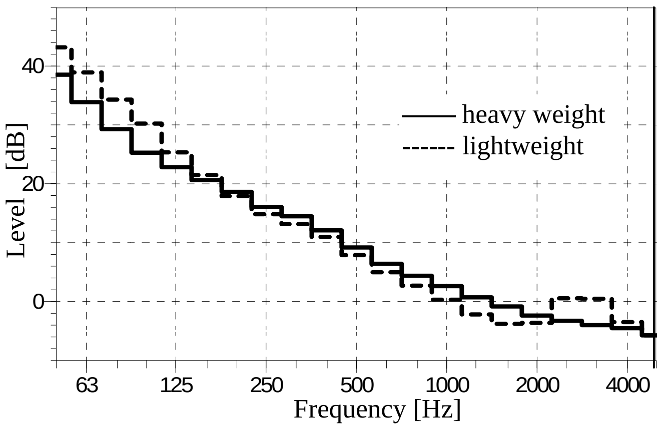

Figure 6 – Sound pressure level in the receiving room as a function of frequency. Source signal pink noise with 70 dB(A). Airborne sound insulation R'_w = 53 dB. No background noise. The solid curve indicates the heavy weight and the dotted curve the lightweight construction.

From Figure 6 it is observed, that with increasing sound insulation, the differences between the two constructions become very small, independently of the type of construction (i.e. in this case the heavy or the lightweight construction). In the case of a constant source signal, the loudness of this resulting signal depends upon weighted sound reduction index and background noise. For low sound insulation, i.e. small R'_w, we identify rather large changes in loudness with varying source strength. Increasing the sound insulation, provided the source signal is held constant, the loudness reduces less until the slope of the loudness curve becomes a horizontal line, which means no changes in loudness for an increase in sound insulation. The shapes of loudness contours indicate for the two investigated cases that loudness grows more rapidly with increased level for low frequencies than for middle frequencies. Since we have used random noise spectra for source signal and for background noise it might indicate that the tonal balance of the sound signal (i.e. speech or music) might be affected by the sound level itself.

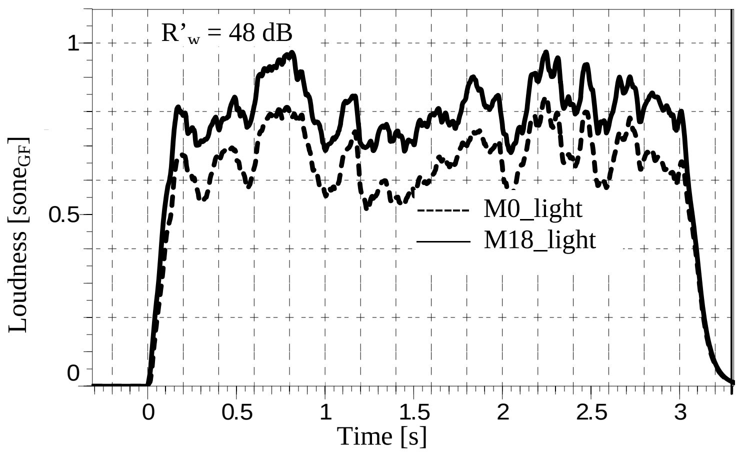

Figure 7 – Loudness as a function of time. Source signal pink noise of 70 dB(A). Lightweight construction of R'$_w$ = 48 dB. The Solid line indicates the filtered signal (receiving sound signal) with interfering background noise signal having level of 18 dB(A). The dashed line indicates no interfering background noise. The calculated loudness of the receiving sound level without background noise is N_{M0} = 0,664 sone and with background noise N_{M18} = 0,809 sone. Yielding a difference in loudness of ΔN = 0,145 sone.

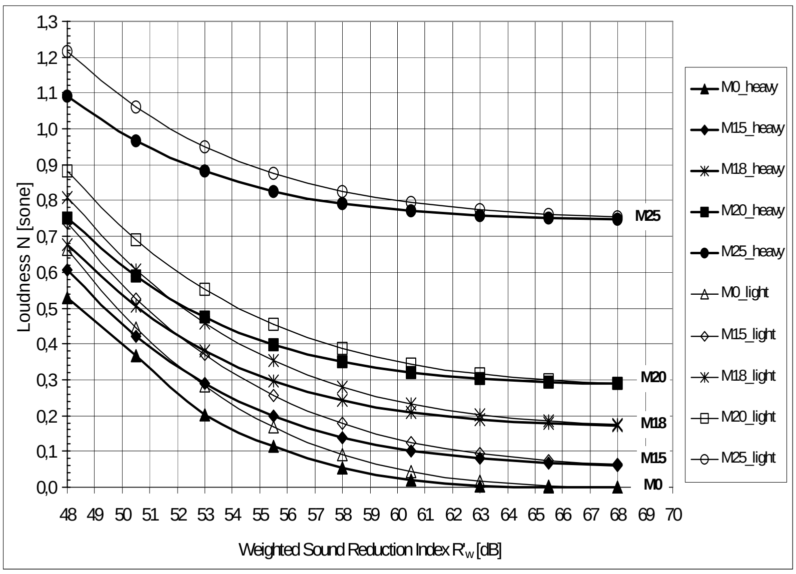

Figure 8 – Loudness plotted as a function of weighted sound reduction index. Investigated are different constructions (lightweight and heavy weight) having different airborne sound insulation from 48 dB up to 68 dB and different background noise level (M: masker).

From Figure 8 it is seen that no significant difference between the two investigated constructions appears. If a substantial distinction of an improved sound insulation is considered, a doubling of Loudness is a first approach. Depending on background noise level a doubling of Loudness leads to a rough necessary increment in R'_w.

For very quiet environments (less than 15 dB(A)) a minimum of the necessary increment of $\Delta R'_w = 3{,}5$ *dB* is needed. Provided the background noise level is 15 dB(A) and higher but less than 20 dB(A), an increment of about $\Delta R'_w = 5$ *dB* is needed. If the background noise level is 20 dB(A) and higher but less than 25 dB(A) than an increment of about $\Delta R'_w = 9{,}5$ *dB* and if the background noise level is of about 25 dB(A) the necessary increment needed should be at least of about $\Delta R'_w = 24{,}5$ *dB*.

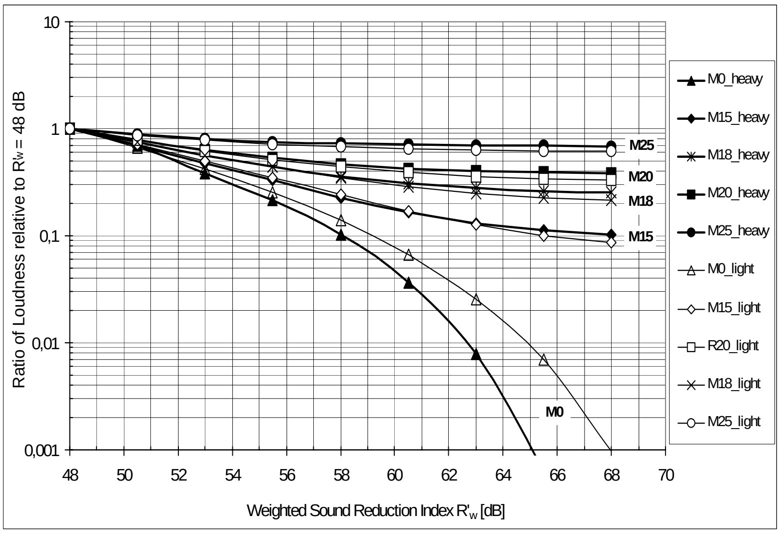

Figure 9 — Ratio of loudness rel. to R'_w=48 dB for different constructions (lightweight and heavy weight) having different airborne sound insulation from 48 dB up to 68 dB and different background noise level (M: masker).

The different results corresponding to varying sound insulation and background noise, can be seen with the ratio of the loudness relative to a sound insulation of 48 dB for heavy and lightweight construction in Figure 8. Main parameter here is the background noise level.

SUMMARY

Concerning Loudness, the airborne sound insulation of a lightweight and a heavy weight construction were studied. In a very first step it was found that an improvement in sound insulation must be at least 3 dB. The results show that in a very quiet environment this $\Delta R'_w$ ought to be considered for a significant increase in acoustic comfort. An increase of background noise leads to a dramatic increase of needed increment in R'_w. An average background noise of about 18 dB (A) was found yielding a needed 5 dB increase of sound insulation. It becomes clearly though that the presented investigation is to be continued in a more detailed way in the future. As a next step it is proposed to focus on the background noise and in more detail the influence of the structural information of the signal transmitted.
The first author is indebted to Professor Jian Kang from the University of Sheffield for his supervision and helpful comments.

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