Calculation of speech intelligibility considering primary transducers' parameters

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Abstract. The main characteristics of primary transducers are considered. The experiment is carried out to estimate the level of self-noise in microphones and accelerometers. The measurements are taken in identical conditions for all the primary transducers. The statistics on acoustic and vibroacoustic noises in premises is gathered. Based on the findings, the algorithm to calculate speech intelligibility considering the primary transducers' parameters is developed.

Keywords. Speech intelligibility, information security, self-noise level, microphone, accelerometer, algorithm, primary transducer.

1. Introduction
Determined by Pokrovsky's method [1] and adjusted to information security problems [2], the word intelligibility is considered as a criterion for estimating voice information protection from leakage through vibroacoustic channels. It should be noted that the method was designed to estimate the quality of communication lines, and the features of information security differ significantly from it. That leads to a number of drawbacks [3-9]. The intelligibility calculation is based on the measurements of acoustic and vibration signals. Sound level meters as well as microphones and accelerometers are used as means to measure. Apparently, characteristics of primary transducers can influence significantly on the accuracy of the physical quantity measurement and therefore on the result of the speech intelligibility calculation.

The previous experiments [10] showed that the technical characteristics of primary transducers, especially the self-noise level, influence on the accuracy of the physical quantity measurement.

To provide with satisfying protection of the premises from voice information leakage, it is necessary to ensure that conducted measurements of acoustic and vibration signals are accurate. The parameters of primary transducers must be taken into account for the word intelligibility calculation, if protection facilities do not guarantee the high accuracy of measuring.

The experiment has been carried out to estimate the self-noise level in primary transducers in order to evolve a method for calculating speech intelligibility considering the parameters of the primary transducers being used. The actual statistics on the level of acoustic and vibration noise in premises has been gathered, the obtained results have been analyzed, and the conclusion is made.

2. The self-noise level in primary transducers
Various parameters of primary transducers influence on the measuring results one way or another. The results of the conducted experiment described in [10] have showed that the self-noise level and sensitivity of microphones and accelerometers have a great impact on the results of speech intelligibility. It may range from 0.19 (the subject of the conversation in premises is concealed) up to

0.88 (the information is not secured due to significant excess of value 0.4, when the conversation content is concealed).

Sensitivity (transfer factor) is an important technical characteristics of primary transducers. It stands for the ratio of output voltage in primary transducers to sound pressure or vibratory acceleration affecting it. This parameter has a great impact on measuring results.

One of the main technical characteristics of primary transducers is the self-noise level. This parameter shows the minimal level of a signal may be perceived by a primary transducer.

The self-noise level is especially important if the measurements are taken at test points where the satisfied security level is achieved without employing active protection means (noise generators), i.e. the measured signal level is close to ambient noise, and the self-noise level of primary transducers may be greater than the level of ambient noise.

Unfortunately, manufacturers of primary transducers provide with an integral value of this parameter within the whole frequency range (dBA). However, to develop an algorithm considering the parameter for speech intelligibility estimation, it is necessary to know the value of the self-noise level in each of the seven octave bands with the center frequencies of 125, 250, 500, 1000, 2000, 4000, and 8000 Hz.

3. The experimental design

The experiment has been carried out for 3 different accelerometers: SVANTEK SV 80 (class I accuracy), ZETLAB AP 2099-100 (class I accuracy), and ZETLAB AP 2037 (class III accuracy). Following microphones are used in the experiment: GRAS 40AE (class I accuracy) and ZETLAB BC 501 (class III accuracy).

The measurements of acoustic and vibroacoustic signals has been conducted in identical conditions for all the primary transducers (figure 1). Each of the primary transducers has been placed in a sound and vibration insulated box to eliminate the influence of ambient noise on primary transducers. Acoustic and vibroacoustic signals have been measured by the SVAN 959 noise and vibration analyzer.
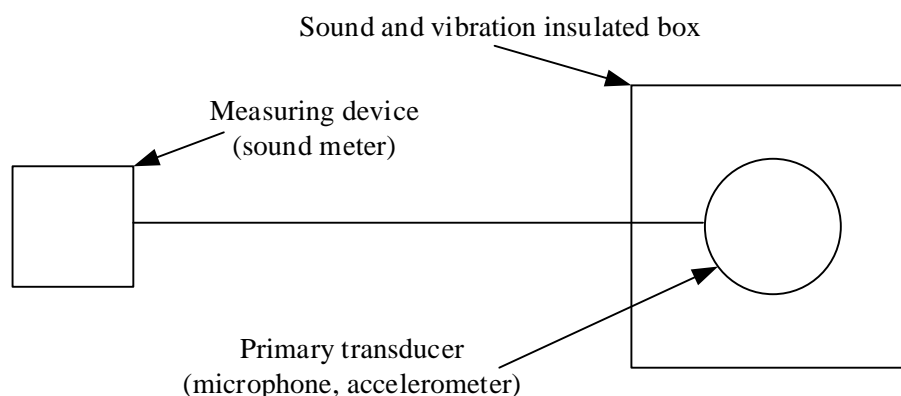

Figure 1. A diagram of the experiment.

4. The results of the experiment

Obtained during the experiment, the self-noise levels of the primary transducers are presented in figure 2 and figure 3.
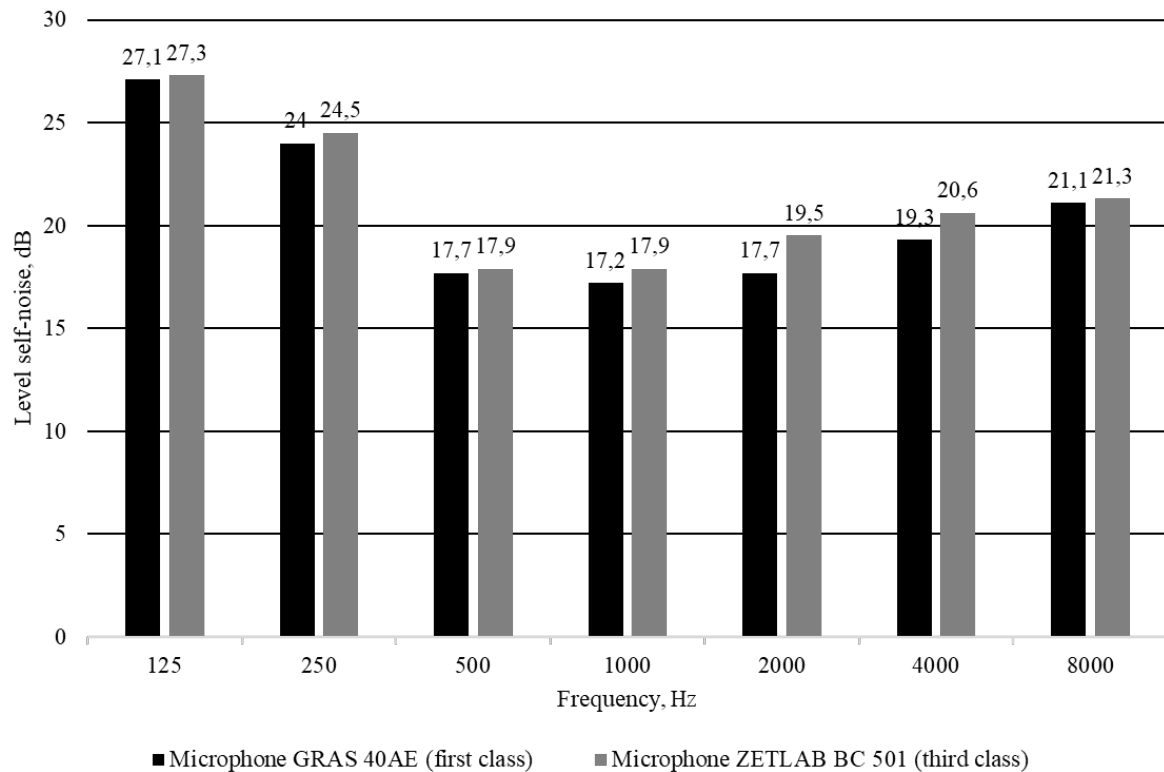
Figure 2. The self-noise level of the microphones.

There has been observed no significant difference in the measured self-noise level of the GRAS 40AE and ZETLAB BC 501 microphones, since the sensitivity level of these microphones is the same. However, GRAS 40AE has been measured to have the smaller self-noise level.

The self-noise level of the primary transducers is close, although the GRAS 40AE microphone has a higher class of accuracy than the ZETLAB BC 501 microphone. This indicates that during the experiments the microphones has not been insulated from ambient noise properly. The result shows that the self-noise level (16 dBA) stated in a product passport has not been obtained for the class I accuracy microphone even with ambient noise reduced in premises and with the microphone placed in a sound insulated box. It may be concluded that applying a microphone with characteristics similar to ZETLAB BC 501 is enough for measurements under real conditions.
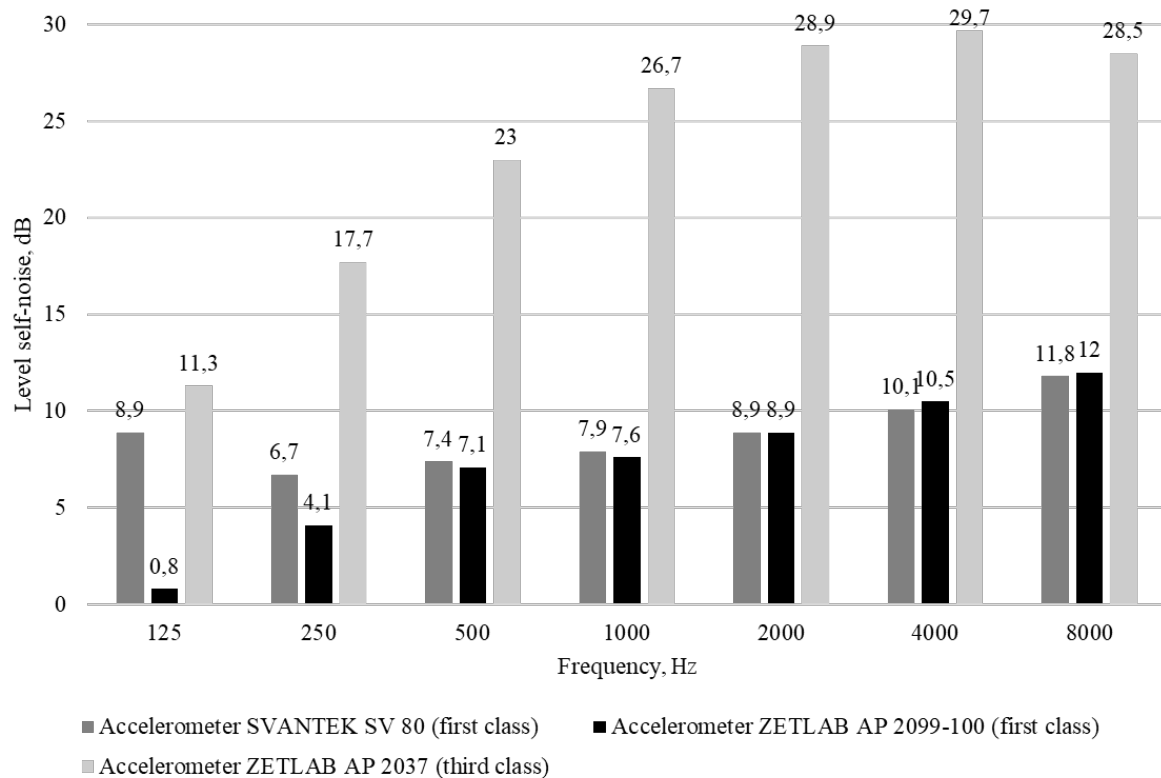
Figure 3. The self-noise level of the accelerometers.

There has been observed no significant difference in the measured self-noise level of the SVANTEK SV 80 and ZETLAB AP 2099-100 accelerometers, since transfer factor is the same for the accelerometers. However, the ZETLAB AP 2099-100 accelerometer has been measured to have the smaller self-noise level. The ZETLAB AP 2037 accelerometer has been noticed to have the significantly greater self-noise level than the SVANTEK SV 80 and ZETLAB AP 2099-100 accelerometers. It is confirmed by the fact that the ZETLAB AP 2037 accelerometer has 10 times smaller transfer factor than the SVANTEK SV 80 and ZETLAB AP 2099-100 accelerometers. It may be concluded that considering of the self-noise level is more important for estimating information leakage through the vibration channel than through the acoustic channel.

5. Measurements of ambient acoustic and vibration noise in premises
The GRAS 40AE microphone has been used to gather statistics on acoustic noise in premises. To gather statistics on vibration noise, the ZETLAB AP 2099-100 accelerometer has been employed, since both of them have the lowest self-noise level of all the studied primary transducers. The SVAN 959 noise and vibration analyzer is used as a measuring device.

The statistics considers data for 10 different premises located in different buildings. All the windows and doors in the rooms were closed tightly during the measurements. The measurements are taken in as complete silence as possible.

The room center has been chosen as a test point to measure acoustic ambient noise, and the measurements of vibroacoustic ambient noise has been carried out at two points: on a window glass and on the wall. The microphone has been placed on a tripod at the height of 1.5 meter above the floor. The accelerometer has been placed on a contact pad stuck to a special beeswax adhesive [11]. The averaged values of the measured results are provided in table 1.

Table 1. The averaged values of acoustic and vibroacoustic ambient noise in premises.

Octave band central frequency F (Hz)	Acoustic leakage channel (dB)	Vibration leakage channel (wall) (dB)	Vibration leakage channel (window) (dB)
125	30.7	8.2	16.4
250	29.4	7.2	10.9
500	25.9	7.7	10.1
1000	21.9	8.6	8.9
2000	20.9	10.2	9.3
4000	20.4	10.2	10.6
8000	21.7	11.9	11.8

6. The algorithm of the calculation method

The algorithm to calculate speech intelligibility considering the parameters of used primary transducers involves the estimation of measured noise levels.

The measured noise level is compared with the self-noise level of primary transducers. If the measured value of the noise level is greater than the self-noise level of a primary transducer, then the calculation is based on the measured noise level. If the measured value of the noise level is smaller than the self-noise of a primary transducer, then the calculation is based on the statistical data on the noise level in a room instead of the measured noise level.

A flowchart of the algorithm for calculating speech intelligibility considering the parameters of primary transducers being used is shown in figure 4.

The flowchart uses the following notations:

- s_izm[i] – an array with the measured noise levels;
- s_sob[i] – an array with the self-noise level of a primary transducer;
- s_stat[i] – an array with the values of statistical data on the noise level in a room;
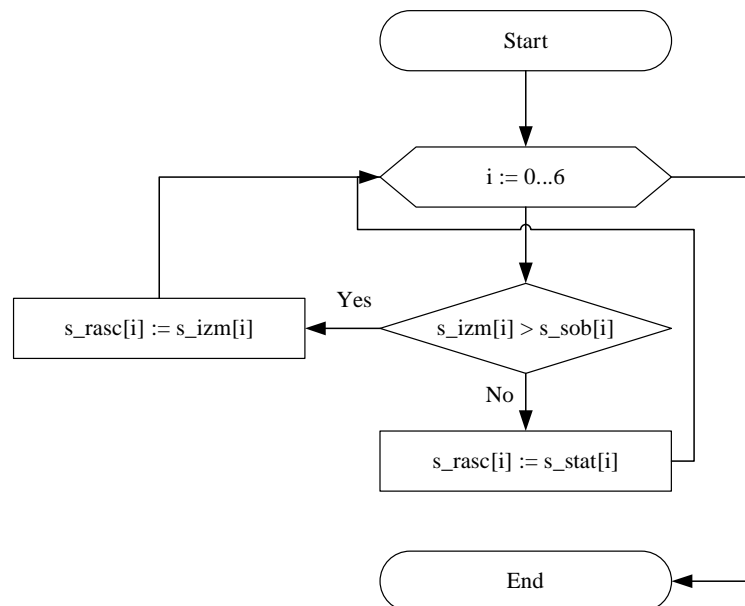- s_rasc[i] – an array with the values of the noise level used for the further calculation.

Figure 4. The flowchart of the algorithm to calculate word speech intelligibility considering the parameters of primary transducers.
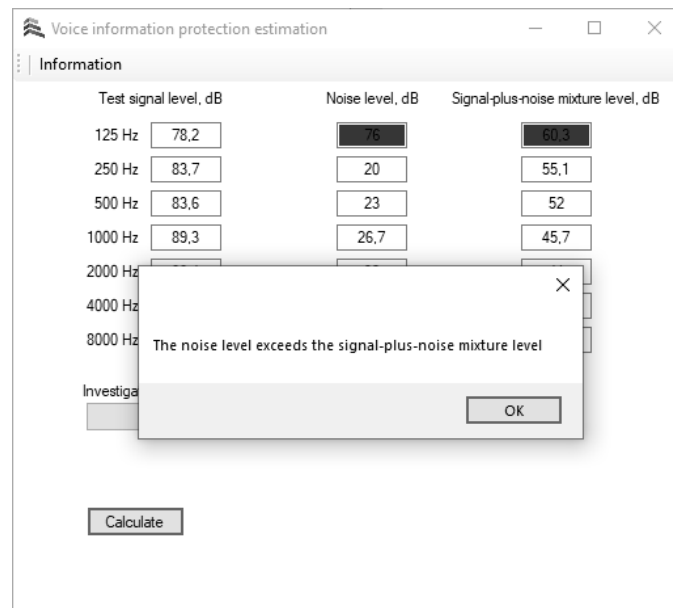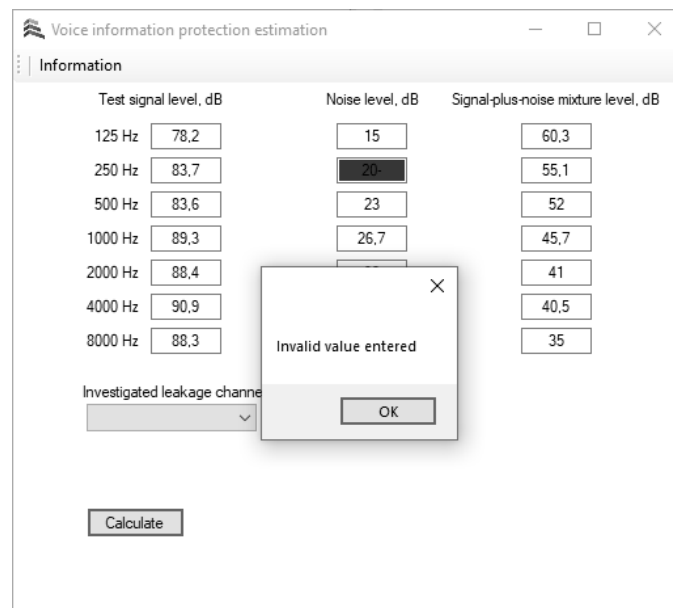
7. The description of a software to calculate speech intelligibility considering the parameters of primary transducers being used

The software code to calculate speech intelligibility considering the parameters of primary transducers being used is written in the object-oriented programming language C#. The software consists of a main program window (figure 5) where a user enters the measured values of the test signal level, the noise level, and the signal-plus-noise mixture.

Figure 5. The main program window of the developed software.

To prevent from invalid information being entered, the values are checked:

- All the fields are checked to be filled in (figure 6);
- The software allows entering numbers, a minus sign, and a decimal separator;
- The noise level is checked to be not greater than the level of a signal-plus-noise mixture (figure 7);
- The values of measurements entered by a user are checked to be valid (figure 8).

Figure 6. The "empty field" error.

Figure 7. The "excessed noise level in a signal-plus-noise mixture" error.

Figure 8. The "invalid value" error.

If the entered values are invalid, the fields with the error are highlighted.

In the main program window a user selects a channel used to measure. Based on the channel, a user should select a primary transducer used to measure. If the vibroacoustic channel was selected, a user should select the surface used for measuring (figure 9).

Figure 9. Selection of a primary transducer.

If the full information was entered, a user click the button "Calculate". After that, according to the algorithm described in section 6, the software analyzes the entered noise level and the self-noise level of the selected primary transducer.

After calculations, a value of speech intelligibility is provided and described according to the normalised values (figure 10). In addition, a bar chart is drawn based on the calculated values. The bar chart shows the noise level, the test signal level, the signal-plus-noise mixture level, the self-noise level of the primary transducer.
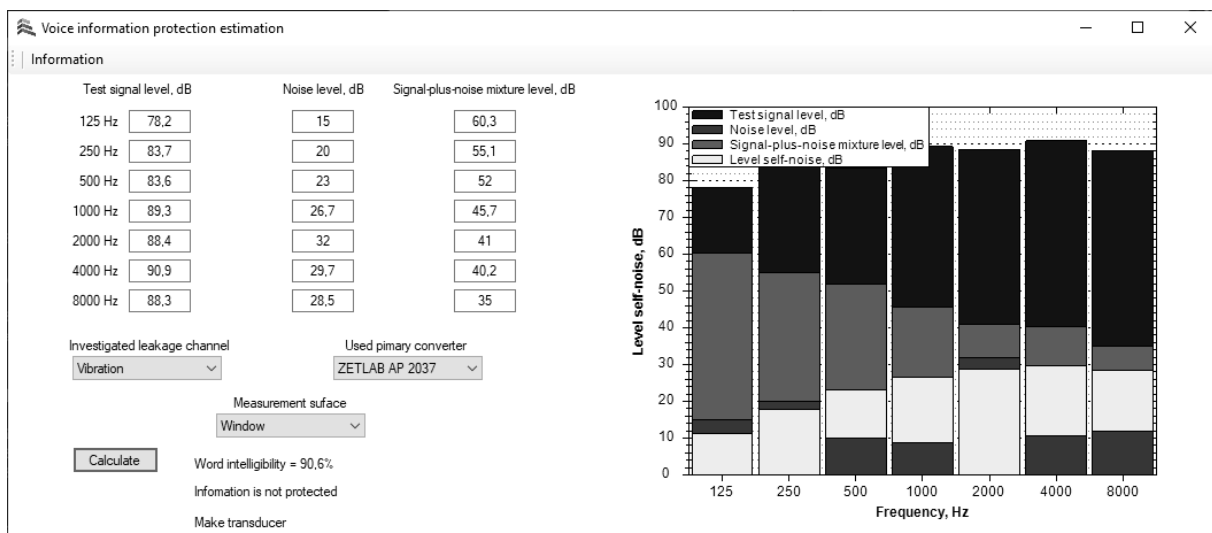

Figure 10. The result provided by the software.

8. Discussion of results

The developed algorithm for calculation of speech intelligibility considering the parameters of the primary transducers adjusts the values of word speech intelligibility for the primary transducers with the high self-noise level. In the particular case, the adjusting ranges from 37% speech intelligibility (the conversation content is concealed) up to 85% speech intelligibility (the conversation is not secured).

Based on the suggested algorithm, the software is developed to calculate speech intelligibility considering the parameters of the primary transducers being used.

9. Conclusion

The conducted research has allowed us to determine the self-noise level of the primary transducers in the octave bands and to gather statistics on the acoustic and vibroacoustic ambient noise level in premises.

The self-noise level of two microphones and three accelerometers has been measured during the experiments.

Applying the best primary transducers, the statistics on acoustic and vibroacoustic ambient noise in premises is gathered.

Based on the obtained data, the software is developed. The software allows adjusting the values of word speech intelligibility considering the parameters of the primary transducers being used.

If it is not possible to use better-quality primary transducers for estimating the level of voice information protection, the developed software is capable to reduce the influence of primary transducers' parameters.

The results of the conducted experiments should be taken into account during tests of protected premises for attestation needs. In addition, updating and improving the measuring devises used to control voice information security must be considered.

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