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Influence of primary elements parameters on result of voice information protection estimation

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Abstract. The purpose of the study is to investigate the main characteristics of measurement microphones. An experiment with use of different parameters microphones was conducted. Influence of the parameters on word intelligibility was estimated. All measurements were made in the same fix point by different microphones. Essential influence of inherent noise level of microphones was discovered by protection estimation in a fix point without active protection means (measurements are made on inherent noise level).

1. Introduction

The criteria of voice information protection from leakage through vibro-acoustic channels is word intelligibility, which can be estimated with the Pokrovsky’s approach [1], adjusted for information security problems [2]. The intelligibility is calculated with results of acoustic and vibrational signals. Sound meters, microphones and acceleration meters are used as measuring means. Obviously, the primary elements characteristics can essentially influence on accuracy of physical quantities measurements and therefore on word intelligibility calculation result. The question is how essential the influence.

Conduct an experiment of word intelligibility estimation in the same fix point with use of microphones with different characteristics to estimate the influence quantity of primary elements. Analyze the derived results and make conclusions.

2. The main microphones characteristics

The main microphones characteristics are the following [3]:

- sound pressure level – ratio of output microphone voltage to sound pressure influencing on it;
- dynamic range – difference between limit sound pressure levels and inherent noise;
- frequency range;
- inherent noise level;
- signal-noise ratio.

All the parameters, one way or another, influence on a measurements result. For example, low sound pressure level of a microphone influence on measurement error (it increases) because the signal on preamplifier is low, and amplification of a low signal leads to error increase. Inherent noise level shows what is the minimal useful signal level can be perceived by preamplifier. Signal-noise ratio is connected with dynamic range and inherent noise level (Sometimes the inherent noise level is not mentioned and signal-noise ratio is mentioned instead).

The inherent noise influence is the most essential in fix points without active protection means.
(noise generators), i.e. the signal is measured on background noise, level of which can be lower than inherent noise level.

3. Experiment

The 3 following microphones were used for the experiment: GRAS 40AE (first accuracy class), ZETLAB BC 501 (third accuracy class) and Behringer ECM8000 used in hardware-software complex for acoustic and vibro-acoustic measurements «Sprout-mini-A».

The main technical characteristics of the compared devices are the same, a big difference is only in inherent noise level. The characteristics are shown in table 1.

| Technical characteristics | GRAS 40AE | ZETLAB BC 501 | Behringer ECM8000 |
|---------------------------|-----------|---------------|-------------------|
| Frequency range, Hz       | 3.15 – 20 000 | 50 – 13 000   | 20 – 20 000       |
| Sound pressure level, mV/Pa | 50        | 50           | 10               |
| Dynamic range, dB         | 19 – 146  | 35 – 140     |                   |
| Inherent noise level, dBA | 19        | 35           |                   |

A fix point (a vestibule with doors), in which word intelligibility (W) with use of Behringer ECM8000 is less than 0.2 (less than 20%). Make the same measurements with use of the other microphones.

4. Experiment results

Word intelligibility calculation was made with use of the approach [2] on 7 octave bands. For word intelligibility estimation the following measurements were made:
- test signal level;
- noise level (background);
- noise+signal mixture (with turned on test signal generator).

The approach [2] consists in next:
- all frequency range of a voice signal separated on 7 octave bands with center frequencies 125, 250, 500, 1000, 2000, 4000, 8000 of Hz respectively;
- for each i-th band the noise level of \( L_{ni} \) and level of a compound of signal + noise by \( L_{(s+n)i} \) is measured;
- levels of signals of \( L_{si} \) for each octave band are calculated;
- feeling levels are calculated;
- on known dependence of \( P(Q) \) coefficients of perception of \( P_i \) for each octave band are calculated;
- the formant intelligibility is calculated;
- on known dependences transfer from formant intelligibility to speech intelligibility.

The derived results of measurements and calculations are show in tables 2–4.

There is no essential difference in measurement of high-level signals (test signal and signal+noise mixture) for different microphones (the difference is less than 2 dB). But for low-level signals (background noise) there is influence of inherent noise level of each microphone. Make calculations of word intelligibility for each microphone (tables 5–7).
Table 2. Levels of test signal in each octave band.

| Average compound octave band frequency F, Hz | Test signal level $L_{\text{testi}}$, $\text{dB}$ |
|--------------------------------------------|---------------------------------|
| 125                                       | 78.2                            |
| 250                                       | 83.7                            |
| 500                                       | 83.6                            |
| 1000                                      | 89.3                            |
| 2000                                      | 88.4                            |
| 4000                                      | 90.9                            |
| 8000                                      | 88.3                            |

Table 3. Noise levels in each octave band.

| Average compound octave band frequency F, Hz | Noise level $L_{\text{ni}}$ (microphone ECM8000), $\text{dB}$ | Noise level $L_{\text{ni}}$ (microphone BC 501), $\text{dB}$ | Noise level $L_{\text{ni}}$ (microphone 40AE), $\text{dB}$ |
|--------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|
| 125                                       | 46.3                                                        | 50.9                                                        | 45.3                                                        |
| 250                                       | 38                                                          | 41.9                                                        | 36.8                                                        |
| 500                                       | 33.3                                                        | 26.5                                                        | 24.9                                                        |
| 1000                                      | 30.2                                                        | 23.1                                                        | 19.1                                                        |
| 2000                                      | 29.2                                                        | 21.8                                                        | 14.9                                                        |
| 4000                                      | 28.3                                                        | 22.0                                                        | 13.6                                                        |
| 8000                                      | 32.9                                                        | 22.1                                                        | 13.5                                                        |

Table 4. Signal+noise levels in each octave band.

| Average compound octave band frequency F, Hz | Test signal level $L_{\text{testi}}$, $\text{dB}$ |
|--------------------------------------------|---------------------------------|
| 125                                       | 60.8                            |
| 250                                       | 55.1                            |
| 500                                       | 52                              |
| 1000                                      | 45.7                            |
| 2000                                      | 41                              |
| 4000                                      | 40.2                            |
| 8000                                      | 35                              |

Table 5. Calculated parameters values with use of ECM8000 microphone.

| Octave band number | Difference between test signal level and average speech level $\Delta L_{\text{ni}}$, $\text{dB}$ | Signal level $L_{\text{si}}$, $\text{dB}$ | Sensation level $Q_{\text{i}}$, $\text{dB}$ | Perception index $p_{\text{i}}$ | Word intelligibility $W$ |
|--------------------|-------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|------------------------|
| 1                  | 25.20                                           | 60.64                           | -35.86                          | 0.0012                           |                        |
| 2                  | 17.70                                           | 55.01                           | -18.69                          | 0.0634                           |                        |
| 3                  | 17.60                                           | 51.94                           | -12.96                          | 0.1462                           |                        |
| 4                  | 28.30                                           | 45.58                           | -21.92                          | 0.0357                           | 0.19                   |
| 5                  | 32.40                                           | 40.70                           | -26.90                          | 0.0127                           |                        |
| 6                  | 37.90                                           | 39.91                           | -31.29                          | 0.0044                           |                        |
| 7                  | 39.30                                           | 30.84                           | -45.36                          | 0.0001                           |                        |
Table 6. Calculated parameters values with use of BC 501 microphone.

| Octave band number | Difference between test signal level and average speech level $\Delta L_n$, dB | Signal level $L_{si}$, dB | Sensation level $Q_i$, dB | Perception index $p_i$ | Word intelligibility $W$ |
|-------------------|-----------------------------------|-----------------|-----------------|-----------------|------------------|
| 1                 | 25.20                             | 60.33           | -40.77          | 0.0003          |
| 2                 | 17.70                             | 54.89           | -22.71          | 0.0307          |
| 3                 | 17.60                             | 51.99           | -11.61          | 0.3092          |
| 4                 | 28.30                             | 45.68           | -14.72          | 0.1156          | 0.50             |
| 5                 | 32.40                             | 40.95           | -19.25          | 0.0577          |
| 6                 | 37.90                             | 40.13           | -23.77          | 0.0203          |
| 7                 | 39.30                             | 34.77           | -30.63          | 0.0052          |

Table 7. Calculated parameters values with use of 40 AE microphone.

| Octave band number | Difference between test signal level and average speech level $\Delta L_n$, dB | Signal level $L_{si}$, dB | Sensation level $Q_i$, dB | Perception index $p_i$ | Word intelligibility $W$ |
|-------------------|-----------------------------------|-----------------|-----------------|-----------------|------------------|
| 1                 | 25.20                             | 60.68           | -34.82          | 0.0017          |
| 2                 | 17.70                             | 55.04           | -17.46          | 0.0772          |
| 3                 | 17.60                             | 51.99           | -4.51           | 0.3570          |
| 4                 | 28.30                             | 45.69           | -10.71          | 0.1919          | 0.79             |
| 5                 | 32.40                             | 40.99           | -12.31          | 0.1586          |
| 6                 | 37.90                             | 40.19           | -16.31          | 0.0921          |
| 7                 | 39.30                             | 34.97           | -21.83          | 0.0364          |

5. Analysis of the results

Results of the experiment showed that inherent noise of microphones influence on word intelligibility essentially. From value 0.19 (hiding of the private conversations fact in accordance with [4]) to 0.79 (information is not protected, value 0.4 – hiding of the private conversations content [4] – essentially exceeded).

6. Conclusion

Influence of the preamplifier characteristics on word intelligibility was investigated. Influence of microphones inherent noise level was experimentally estimated by the example with three different microphones. The derived results show necessity of specifying requirements for preamplifier parameters, especially – inherent noise level. Also, it is possible to specify requirements for background noise on octave bands. If a chosen measuring mean cannot provide signals measurement parameters, especially microphones. The derived results show necessity of specifying requirements for preamplifier characteristics on word intelligibility was investigated. Influence of microphones inherent noise level was experimentally estimated by the example with three different microphones. The derived results show necessity of specifying requirements for preamplifier parameters, especially – inherent noise level. Also, it is possible to specify requirements for background noise on octave bands. If a chosen measuring mean cannot provide signals measurement on this level, consider the measurement result as signal+noise mixture and consider standardized value instead of noise levels (to make so-called «noise calculation»).

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