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Development of sound level meter provided with ultra-low SPL measuring function －Creation and evaluation of super-silent spaces－

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Key Words : Condenser Microphone, Self-noise, Sensitivity, 0-dB Compensation, 0-dB SLM, Dummy Mic

ABSTRACT

As is widely known, SPL measurement using sound level meter (SLM) is limited to higher than 30 dBA, because of the self-noise n(x) of condenser microphone (CM). The authors confirmed n(x) is composed of 3 kinds, each of which is stable enough under the condition –20 ~ +50 deg C to eliminate the influence of n(x) by subtracting its energy from the squared input signal in the integration process, as well as to develop new type of SLM with ultra-low SPL measuring function. This is so-called "0-dB SLM" since it enables to measure SPL down to around 0 dB-SPL. The RMS of n(x) is acquired and stored in ROM in advance, by placing CM in the super-silent space or by using dummy microphone with equivalent capacitance before the actual measurements.

1. Introduction

As we often experience in usual noise or sound insulation measurements, the possible range of SPL observation is somehow limited at higher frequencies, which comes from the fact the lower limit of SLM is only around 30 dBA, level of self-noise n(x) of condenser microphone. The aim of this paper is to verify the possibility to compensate and eliminate the influence of n(x). To realize the compensation in the actual SLM, however, n(x) has to be stable under the condition SLM is used, especially for the temperature.

2. Stability of self-noise n(x)

To verify the stability of n(x), three types of condenser microphones (CM) with their respective preamplifiers were employed, where each CM was replaced by 'dummy microphone' composed of equivalent condenser with capacitance (pF) shown in Table 1 and Fig.1 (c).

Table1 Condenser microphones for the investigation

No	Size and Category (ACO)	Polarization Voltage	Type	Dummy C
①	1/2" ECM	−	Field	20 pF
②	1/1" Condenser	200 V	Pressure	47 pF
③	1/4" Condenser	200 V	Field	6 pF

The results are shown in Fig.2, where each n(x) remains pretty stable at –20~+50℃ and meets each other tightly closer at higher frequencies than 1kH, which determines the lower limit of A-weighted SPL (dBA) measurement.

Based on the stability of n(x) and on the principle the product sum of orthogonal functions converges to zero, the following compensation scheme is proposed:

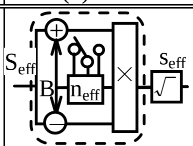
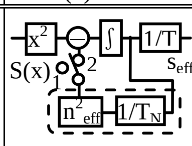
$$S_{eff}^2 - n_{eff}^2 = \frac{1}{T}\int_0^T [S^2(x)]dx - n_{eff}^2$$
$$= \frac{1}{T}\int_0^T [s^2(x) + 2s(x)n(x) + n^2(x) - \overline{n^2}]dx$$
$$\rightarrow \frac{1}{T}\int_0^T s^2(x)dx = s_{eff}^2 \quad (1)$$
$$n_{eff}^2 \equiv \overline{n^2} = \frac{1}{T_N}\int_{-T_N}^0 n^2(x)dx \quad [T_N \approx 10\,\text{sec}] \quad (2)$$

, where S(x)=s(x)+n(x) is the input signal s(x) superimposed by n(x) whose RMS, n_{eff} in Eq.(2), is acquired in advance for each pair of CM and preamplifier before the actual s(x) measurement.

3. Ideas of performing "0-dB compensation"

The execution is done in one of the following three ways to obtain the target, s_{eff}:, compensating n(x) :[1)]

Table2 Execution methods of "0-dB compensation"

	(1)AZC	(2)SNS	(3)TLM
Outline of Algorism			$\delta = 10\log(1-10^{-\Delta/10})$ $x = X - \delta$ $\Delta = \bar{X} - \bar{N}$ $\Delta \rightarrow \delta$
Processing	Multiplication of $S_{eff} \pm B$ ($B = n_{eff}$) result shown with $\sqrt{}$ or 10log	Integration of $S^2(x)$ associated with subtraction of n^2_{eff}	Table look-up to get δ via △
Advantage	Only RMS values are used	Calculation is very simple	All by software

3.1 AZC (Adaptive Zero calibration)

In this approach, calculation is done only for RMS of each parameter as in Table 2 (1), which leads to Eq.(1):

$$X = [S_{eff} - B] \cdot [S_{eff} + B] = S^2_{eff} - n^2_{eff} \rightarrow s^2_{eff} \quad (3)$$

The results are displayed as square root or in dB. This is well-suited for installation to the existing system.

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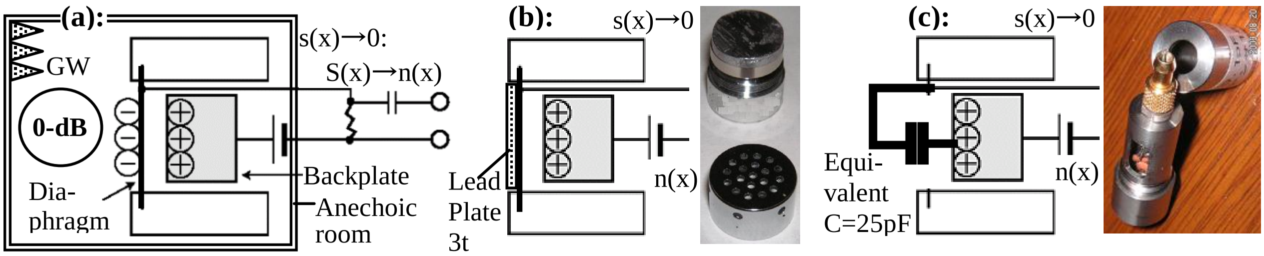

Fig.1 Approaches for acquiring n_{eff} by realizing 0 dB-SPL around the microphone: (a)real CM placed under super-silence, (b)physical model with lead weight onto the diaphragm and (c)electronic model with equivalent capacitance C

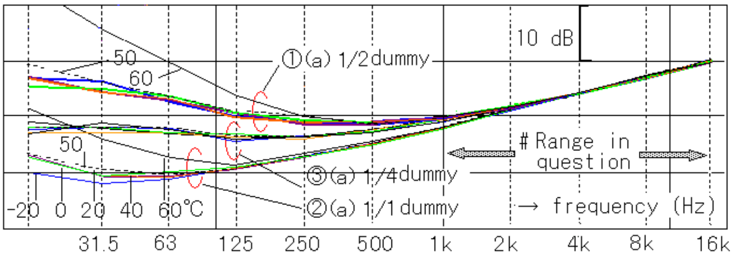

Fig.2 Temperature stability of self-noise n(x) for CM in Table 2

3.2 SNS (Squared Noise Subtraction)

When the squared input $S^2(x)$ is available, direct execution of Eq.(1) is possible. Acquisition of n^2_{eff} is done by selecting switch position '1' with CM under 0 dB-SPL condition (vibration-proof anechoic room, for instance) or by using dummy microphone. For actual measurement position '2' is selected to perform Eq.(1). Similar process takes place in AZC, where X gives n^2_{eff}.

3.3 TLM (Table Look-up Method)

Software scheme of acquiring the correction value δ from level difference △(dB) is also possible by looking up the table for Eq.(5), and done easily in digital SLM:

$$\triangle = X - N = 10\log S^2_{eff} - 10\log n^2_{eff} \quad \text{(dB)} \quad (4)$$

$$\delta \equiv X - x = X - 10\log(10^{X/10} - 10^{N/10})$$

$$= -10\log(1 - 10^{-\triangle/10}) \quad \text{(dB)} \quad (5)$$

$$X - \delta = 10\log(S^2_{eff} - n^2_{eff}) \rightarrow 10\log s^2_{eff} \quad (6)$$

4. Validity examination for 0-dB compensation

To verify the validity of the compensation, three approaches in Fig.1 were carried out using SLM (ACO /6226) for acquiring n^2_{eff}. First, M-sequence signal with increasing level by 1dB step was fed to SLM with n^2_{eff} out of dummy (c) in Fig.1, which is electronic noise termed 1/f and Johnson-Nyquist (P_n=4kRT△f)[2]. Figure 3 clearly shows the validity, where linearity of A-weighted SPL (dBA) is improved by over 20 dB, extended to under 0 dB. The same holds for each 1/1 octave (63-8k Hz).

However, this is not true for real CM because of the physical noise termed "Brownian pressure fluctuation", which arises from random collision of air molecules onto the diaphragm generating another energy at higher frequencies. This is compensated, as in Fig.4 a), only by approach (a) in Fig.1, i.e., by feeding the sine tone to SLM placed in an anechoic chamber whose ambient noise is below –20 dB at each 1/1 octave, not by (b) or (c) using physical or electronic dummy which only gives almost the same result without the compensation as in Fig.4 b) c).

5. Conclusion

Thus "0-dB compensation" for the entire self-noise n(x) including Brownian fluctuation is only possible with n_{eff} obtained under zero pressure condition as in approach (a), employed in newly developed SLM in Fig.5 (ACO/Type 6236/6238). Dummy microphone for the entire n(x) may be a future issue to be further discussed. The most important presupposition that supports the compensation is n(x) stability especially for the temperature and was verified by bringing dry ice and hair-drier in the chamber to observe the change in $n^2(x)$ and the residual error $n^2(x)$-n^2_{eff} which turned out to remain constant around, or less than, 0 dB-SPL implying the lower limit of SPL measurement by new SLM. Thus 0-dB compensation is valid under ordinary measurement condition, -20~50℃.

References:

1) Patent pending for entire "0-dB compensation" technologies
2) BECKING, A. G. and RADEMAKERS, A., "Noise in Condenser Microphones" Acustica 4, 1954 pp.96-98

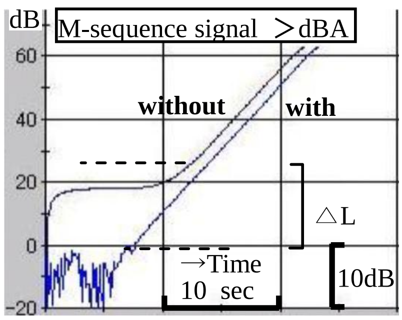

Fig.3 Linearity improvement △L by using (c) in 0-dB compensation

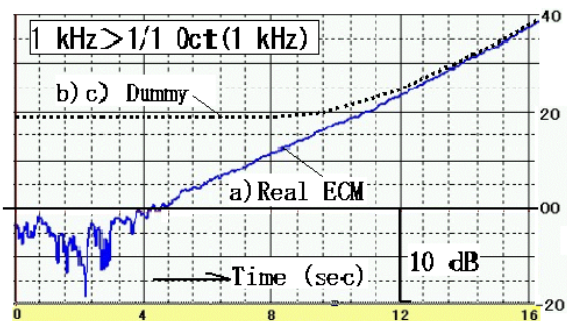

Fig.4 Results of Linearity improvement by 0-dB compensation using n_{eff} obtained in approach (a)

Fig.5 Example of "0-dB SLM" with ultra-low SPL measuring function