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Impulse response measurement with constant signal-to-noise ratio over a wide frequency range

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1. Introduction

A high signal-to-noise (SN) ratio is desired for the measurement of acoustic impulse response, and thus far, various measurement signals, such as the time-stretched pulse (TSP) signal, have been proposed [1,2]. With this background, Moriya and Kaneda proposed a swept sine signal that can minimize the noise component included in measurement results [3] (hereafter, minimum-noise swept sine signal). However, this signal is insufficient for certain types of applications because the SN ratio differs depending on frequency. In this study, we propose a method of impulse response measurement that maintains a constant SN ratio over the entire frequency band.

2. Principle of impulse response measurement

Figure 1 shows the principle of impulse response measurement in the frequency domain representation (for simplicity, the variable ω is omitted in the figure). A signal with spectrum $S(\omega)$ is input to an unknown system with transfer function $H(\omega)$. Noise $N_0(\omega)$ (including acoustical and electric noise) is added to the system output $H(\omega)S(\omega)$, resulting in the measured signal $H(\omega)S(\omega) + N_0(\omega)$. When this signal is filtered through an inverse filter with the characteristic of $1/S(\omega)$, the estimated value of the transfer function is obtained as $\hat{H}(\omega) = H(\omega) + N_0(\omega)/S(\omega)$. (Impulse response is derived by the inverse Fourier transform of $\hat{H}(\omega)$.)

3. Noise component in measurement result

The noise component included in $\hat{H}(\omega)$, which is expressed as $N_0(\omega)/S(\omega)$, has the same spectrum as that of added noise $N_0(\omega)$ when the measurement signal with a flat spectrum ($S(\omega) = 1$), such as a TSP signal, is used (Fig. 2(a)). When a minimum-noise swept sine signal is used, the peak of the noise component is suppressed, as shown in Fig. 2(b), achieving the minimization of the total noise energy [3]. However, the SN ratio differs depending on frequency, and the frequency response is strongly affected by noise for the frequencies at which the response level of the transfer function is small, as indicated by the dotted circles in Fig. 2(b).

For certain purposes of measurement, the understanding of the frequency response with small response levels becomes important. We propose a method of impulse response measurement that maintains a constant SN ratio over a broad frequency band, although the noise energy integrated over the entire band increases in this method, as shown in Fig. 2(c). The frequency response is clear even in a frequency region with small response, when using our method.

4. Measurement method with constant SN ratio

To keep the SN ratio constant, the spectrum $N_0(\omega)/S(\omega)$ of the noise component included in the measurement result must be proportional to that of transfer function $H(\omega)$. That is,

$$C_N \cdot N_0(\omega)/S(\omega) = H(\omega), \tag{1}$$

where C_N is a constant. Therefore, the spectrum of the measurement signal should be

$$S(\omega) = C_N \cdot N_0(\omega)/H(\omega). \tag{2}$$

(For the method of deriving a swept sine signal with such a spectrum, see ref. 3). However, the transfer function $H(\omega)$ in Eq. (2) is not known in advance. Therefore, in our proposed method, the measurement in which the measured (estimated) value of $H(\omega)$, namely, $\hat{H}(\omega)$, is used recursively is repeated to increase measurement accuracy.

Figure 3 shows a block diagram of our proposed method. Procedures (1)–(7) are explained as follows. (1) Assuming noise to be stationary, the estimated noise spectrum, $\hat{N}_0(\omega)$, is obtained. (2) An appropriate initial characteristic is given to $\hat{H}(\omega)$. (3) Measurement signal S is synthesized. (For example, if $\hat{H}(\omega) = \hat{N}_0(\omega)$, then $S(\omega) = C_N$, and the measurement signal becomes a TSP signal.) Next, measurement is carried out using the synthesized measurement signal. (4) The measured signal is filtered through an inverse filter, and (5) $\hat{H}(\omega)$ is obtained. (6) $\hat{H}(\omega)$ is fed back to the system and the signal is resynthesized, and the measurement is repeated in this manner. (7) When $\hat{H}(\omega)$ with a satisfactory SNR characteristic is obtained, the repetition is stopped and a measurement result is obtained. The judgment criterion of repetition is not yet established, so the repetition is judged by human observation. Usually, the repetition converges after several repetitions.

5. Demonstration by simulation

The validity of our method was verified by simulation. The transfer function of a loudspeaker measured in an anechoic room was used as the transfer function of the unknown system, $H(\omega)$. For additional noise $N_0(\omega)$, Hoth

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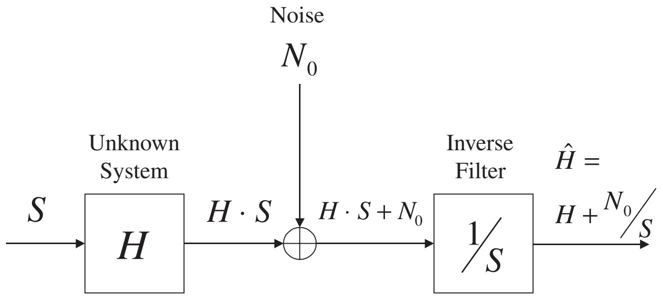

Fig. 1 Principle of impulse response measurement.

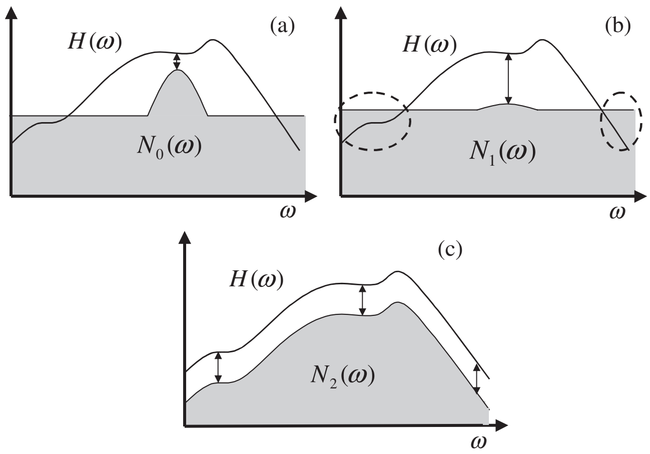

Fig. 2 Models of noise component included in measurement results obtained using (a) TSP signal, (b) minimum-noise swept sine signal, and (c) our signal that results in a constant SN ratio over the entire frequency band.

noise [4] was added so that the SN ratio was 12 dB. Also, the lower limit of frequency was set to approximately 70 Hz to exclude the frequency bands with extremely low SN ratios from the measurement target.

Figure 4 shows the measurement result of the unknown system using a TSP signal, which corresponds to the initial value of $\hat{H}(\omega) = \hat{N}_0(\omega)$ in our method. In the figure, the estimated transfer function of the unknown system ($\hat{H}(\omega)$), the noise component ($\hat{N}_0(\omega)/S(\omega)$) included in the estimated value, and the true transfer function ($H(\omega)$) are represented. In the low-frequency region, the transfer function is strongly affected by noise, resulting in the low estimation accuracy.

Figure 5 shows the measurement result for the signal synthesized using the estimated transfer function $\hat{H}(\omega)$ in Fig. 4 ($S(\omega) = \hat{N}_0(\omega)/\hat{H}(\omega)$). The estimation accuracy of the transfer function in Fig. 5 becomes higher than that in Fig. 4 for the frequencies of 1,000 Hz or lower. By comparing the line of the estimated transfer function and that of the noise component in Figs. 4 and 5, we also confirmed that the SN ratio is kept constant over a wider range in Fig. 5 than the SN ratio in Fig. 4.

However, the SN ratio is still low for 200 Hz or lower. Figure 6 shows the result obtained after repeating the measurement five times. The measurement results were

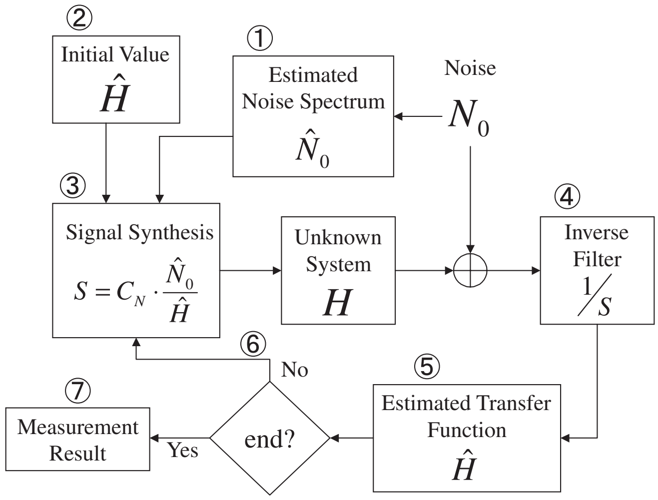

Fig. 3 Block diagram of our measurement method.

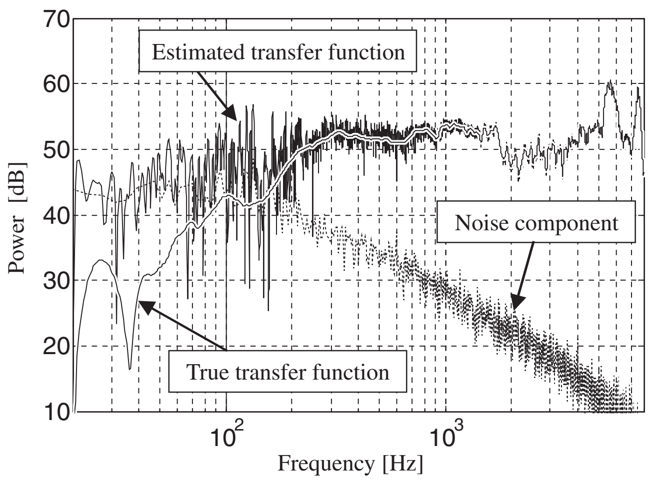

Fig. 4 Measurement result obtained using our method (first round). TSP signal ($S(\omega) = 1$) was used and the noise component included in the result is $N_0(\omega)/S(\omega) = N_0(\omega)$.

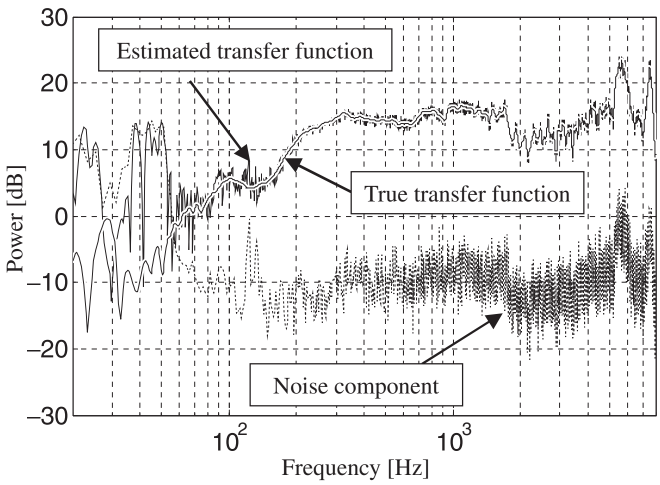

Fig. 5 Measurement result obtained using our method (the second time).

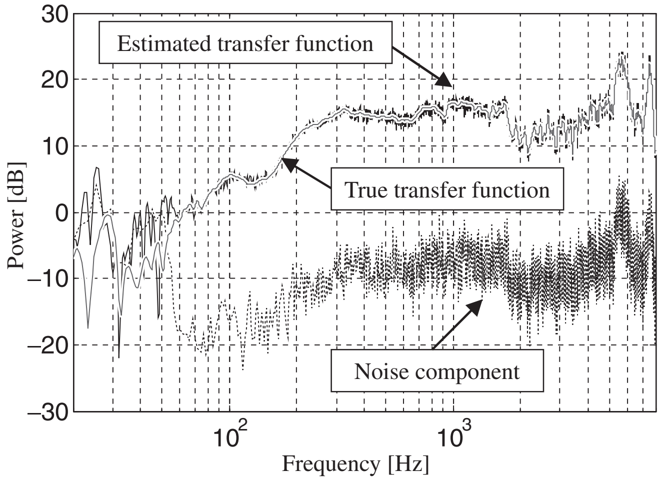

Fig. 6 Result obtained after repeating measurement five times.

almost the same after the fifth repetition under this condition. From the comparison between the line of the estimated transfer function and that of the noise component in Fig. 6, the SN ratio is found to be almost constant for 70 Hz or higher, confirming the validity of our proposed method. Therefore, our method enables the understanding of the outline of transfer characteristics, even for frequency bands with a small response level of the transfer function.

6. Conclusion

In this study, we proposed a method of impulse response measurement that maintains a constant SN ratio over the entire frequency band. This method enables the understanding of the transfer characteristics for frequency bands where the response level of the transfer function is low. The effectiveness of our method was confirmed by simulation.

References

[1] T. Fujimoto, “A study of TSP signal getting higher SN ratio at low frequency bands —Removal of harmonic distortion—,” *Proc. Spring Meet. Acoust. Soc. Jpn.*, pp. 555–556 (2000.3).
[2] M. Morise, T. Irino, H. Banno and H. Kawahara, “Warped-time-stretched pulse: An acoustic test signal robust against ambient noise,” *J. Acoust. Soc. Am.*, **120**, 3223 (2006).
[3] N. Moriya and Y. Kaneda, “Impulse response measurement that maximizes signal-to-noise ratio against ambient noise,” *Acoust. Sci. & Tech.*, **28**, 43–45 (2007).
[4] IEEE Standard 269-2001, p. 82.