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Effective measurement method for reverberation time using a constant signal-to-noise ratio swept sine signal

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1. Introduction

Reverberation time is a basic characteristic of room acoustics, which is calculated from the impulse response (IR) of the room. In the measurement of reverberation time from the IR, a high signal-to-noise ratio (SNR) is required over a wide frequency band. In a previous paper, the authors proposed the use of a constant signal-to-noise ratio swept sine (CSN-SS) signal that provides a constant SNR of the measured IR over the frequency band of interest [1,2]. In this paper, the authors propose an effective measurement method for reverberation time using the CSN-SS signal.

2. Control of SNR using CSN-SS signal

Figure 1 shows the principle of IR measurement in the frequency domain. $H(k)$ is the transfer function of a target system, which is the Fourier transform of IR, where k is the discrete frequency number, although it is omitted in Fig. 1 for simplicity. $H(k)$ can be measured using a measurement signal $S(k)$, such as a swept sine signal. The noise component expressed as $N(k)/S(k)$ is included in the measurement result, where $N(k)$ is an environmental noise added to the system output.

The SNR of this result is the power ratio of $H(k)$ to $N(k)/S(k)$:

$$SNR(k) = \frac{|H(k)|^2}{P_N(k)/|S(k)|^2}, \quad (1)$$

where $P_N(k)$ is the power spectrum of the noise $N(k)$.

Now, let us define $D_{SN}(k)$ as the desired frequency-dependent SNR. Solving equation (1) for $|S(k)|^2$ gives

$$|S(k)|^2 = D_{SN}(k) \cdot \frac{P_N(k)}{|H(k)|^2}. \quad (2)$$

This means that the desired SNR $D_{SN}(k)$ can be obtained using the measurement signal with the power spectrum of Eq. (2).

However, $|H(k)|$ is unknown in actual measurements; thus, $|S(k)|^2$ is calculated using $|\hat{H}(k)|$, which is an estimated transfer function derived by a preliminary short-time measurement.

3. SNR requirement for reverberation time measurement

According to ISO 3382, the instantaneous peak power level of an IR must be 45 dB above the background noise level in each frequency band (1 or 1/3 octave band) in the measurement of T_{30}. Figure 2 shows the instantaneous power model of the noise component and IRs of different frequency bands when the ISO requirement is satisfied. In the figure, the peak levels of the IRs are normalized to 0 dB.

Since all the decay curves are different, the IR energies (with the size of E_1 or E_2) are different. On the other hand, the noise component energy E_N is constant independently of the band. Therefore, the desired SNR to obtain the constant background noise level (−45 dB under the IR peak) independent of the frequency band is

$$D_{SN}(k) = E_k/E_N \ (k = 1, 2, \cdots). \quad (3)$$

The transfer function $H(k)$ and IR energy E_k of each frequency band can be estimated from a preliminary measurement with relatively high background noise level, e.g., about −20 dB. In the preliminary measurement, a minimum-noise swept sine (MN-SS) signal [3], which minimize the noise component in a measurement result, is used. The background noise level of the preliminary measurement is about 20 dB higher than that of the main measurement. Since the required measurement signal length is inversely proportional to the background noise level, the preliminary measurement can be performed in 1/100 of the time of the main measurement.

4. Evaluation of proposed method by simulation

To evaluate the proposed method, we simulated an IR measurement. In the simulation, an actual room IR and Hoth noise, which has a typical room-noise spectrum, were used. Two conventional IR measurement signals, time-stretched pulse (TSP) [4] and Log-SS [5], and a CSN-SS signal were used for comparison. These signals had the same energy and signal length. The bands of interest were sixteen 1/3 octave bands covering the frequency range of 125–4,000 Hz.

Figure 3 shows the background noise levels of each frequency band obtained using the three measurement signals. The noise level obtained using CSN-SS is almost constant at −45 dB over the bands of interest (between the vertical dashed lines). In contrast, the noise levels obtained using TSP and Log-SS are not constant (high in the low-frequency range and low in the high-frequency range).

The difference between the maximum noise levels obtained using Log-SS and CSN-SS within the bands of

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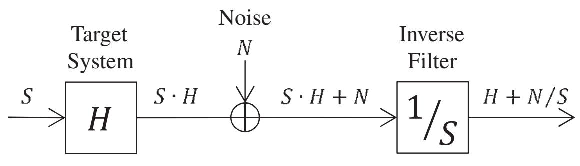

Fig. 1 Principle of IR measurement.

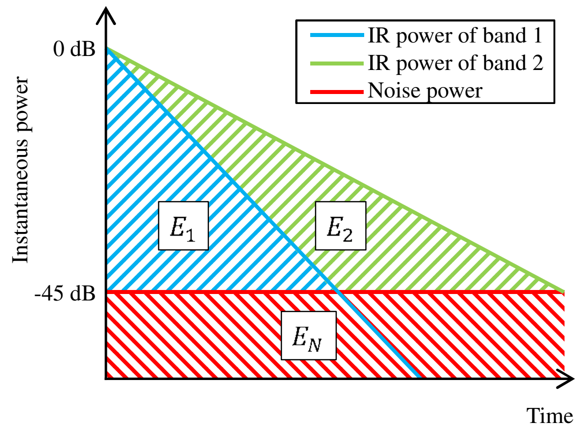

Fig. 2 Instantaneous power model of noise component and IRs.

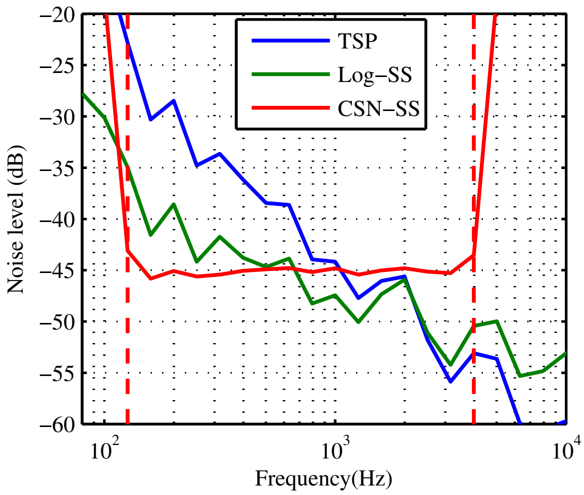

Fig. 3 Obtained background noise levels of each frequency band obtained using three measurement signals.

interest is about 8 dB. This means that the length of Log-SS should be about 6 times larger than that of CSN-SS to reduce the maximum noise level to −45 dB within the bands of interest.

Figure 4 shows the instantaneous power levels of the measured IRs in three bands, 125, 500, and 2,000 Hz, obtained using (a) TSP, (b) Log-SS and (c) CSN-SS. The right-hand sides of the figures show the background noise levels of the three bands. The noise levels obtained using TSP and Log-SS vary considerably with the frequency band, whereas those

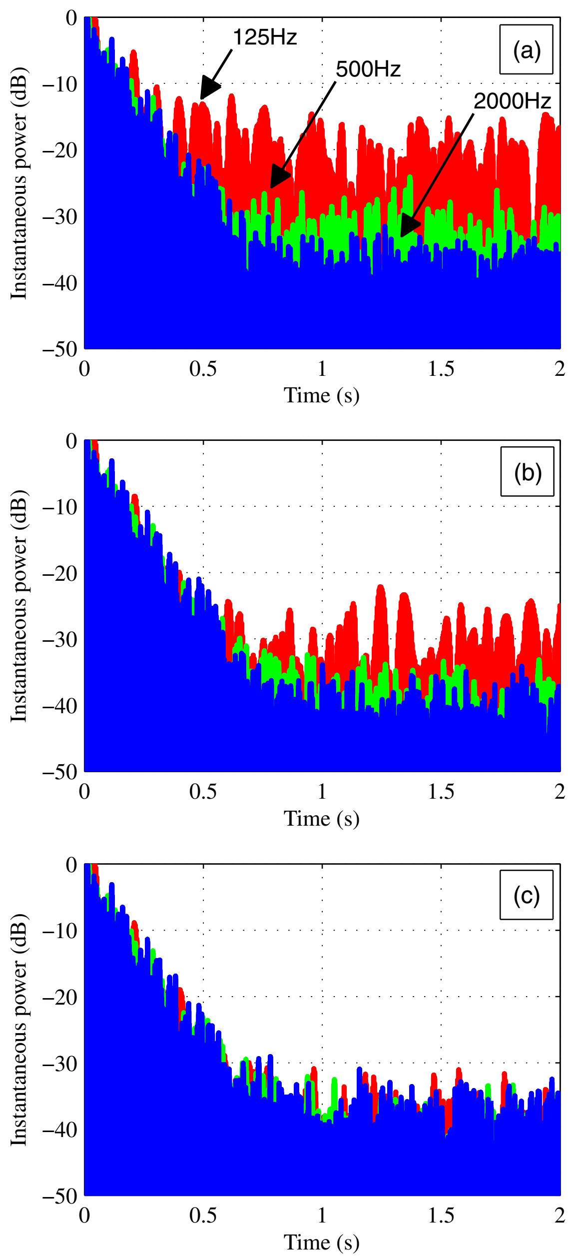

Fig. 4 Background noise levels of three frequency bands obtained using three signals, (a) TSP, (b) Log-SS, and (c) CSN-SS.

obtained using CSN-SS are constant independently of the frequency band.

5. Conclusion

In this paper, we propose a new IR measurement method that enables us to achieve constant background noise levels over the bands of interest. With this method, the signal length necessary to measure reverberation time is reduced to about 1/6 in comparison with Log-SS.

References

[1] H. Ochiai and Y. Kaneda, "Impulse response measurement with constant signal-to-noise ratio over a wide frequency range," *Acoust. Sci. & Tech.*, **32**, 76–78 (2011).

[2] H. Ochiai and Y. Kaneda, "A recursive adaptive method of impulse response measurement with constant SNR over target frequency band," *J. Audio Eng. Soc.*, **61**, 647–655 (2013).
[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] Y. Suzuki, F. Asano, H. Kim and T. Sone, "An optimum computer-generated pulse signal suitable for the measurement of very long impulse response," *J. Acoust. Soc. Am.*, **97**, 1119–1123 (1995).
[5] A. Farina, "Simultaneous measurement of impulse response and distortion with a swept-sine technique," *108th AES Convention*, 5093, (D-4) (2000).