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ACOUSTICAL LETTER

Study of acoustical impulse response measurement with small error caused by harmonic distortion

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1. Introduction

Impulse response measurement in acoustic systems, such as room acoustic systems and head-related transfer functions, is an important technology. For such impulse response measurement, the time-stretched pulse (TSP) method is widely used [1]. In this method, however, measurement errors are caused by harmonic distortion when a loudspeaker is driven at high voltage. In contrast, the log-TSP (Pink-TSP) method [2] can eliminate harmonic distortion; however, it has the problem that the signal-to-noise (SN) ratio of high-frequency components decreases [3]. To overcome these problems, we propose a simple method of reducing the effect of harmonic distortion in impulse responses measured by the TSP method.

2. TSP method and harmonic distortion

The TSP signal is a swept sine (SS) signal that has a white spectrum and a lag (or lead) proportional to the frequency f. The SS signal with frequency components that proportionally increase with time is called the up-TSP signal, whereas the SS signal with frequency components that proportionally decrease with time is called the down-TSP signal.

2.1. Effect of harmonic distortion on up-TSP response

Figure 1(a) shows a schematic of the spectrogram of the up-TSP response and its harmonic distortion. The impulse response can be obtained by advancing the time of the frequency components. The higher the frequency range, the larger the advance of the time, i.e., the further to the left the frequency components in the figure are shifted. This is realized by convolving the up-TSP response with the time-reversed up-TSP signal, that is, the down-TSP signal (Fig. 1(b)). As a result of advancing the time of frequency components, harmonic distortion appears to the left of the impulse response, causing nonlinear error.

In the figure, the nonlinear error is seemingly avoided by cutting off the part before the impulse response. However, a low-level impulse response still exists before the maximal impulse response (Fig. 2); therefore, it is difficult to determine the time point at which the response should be cut off.

2.2. Effect of harmonic distortion on down-TSP response

Figure 3(a) shows a schematic of the spectrogram of the down-TSP response and its harmonic distortion. The impulse response can be obtained by advancing the frequency components; in this case, the lower the frequency range, the larger the advance of time (Fig. 3(b)). Contrary to the case of up-TSP response, the harmonic distortion appears to the right of the impulse response.

3. Proposed method for reducing harmonic distortion

The true impulse response is denoted as S, and the nonlinear errors observed in the measurement using up-TSP and down-TSP signals are denoted as D_u and D_d, respectively. Then, the results of impulse response measurement using up-TSP and down-TSP signals are represented by $S + D_u$ and $S + D_d$, respectively. The difference in these measurement results is given by

$$(S + D_u) - (S + D_d) = D_u - D_d \quad (1)$$

D_u and D_d in Eq. (1) exist before and after the time when the maximal impulse response is observed, respectively. Therefore, only D_u can be obtained by extracting the part before the maximal impulse response. If D_u is subtracted from the original impulse response obtained using the up-TSP signal, the effect of the nonlinear error in the impulse response is removed, as expressed by

$$(S + D_u) - D_u = S \quad (2)$$

4. Experimental results

An experiment was carried out in a room with the dimensions of 5.3(W) × 6.0(D) × 2.5(H) m^3 and a reverberation time of 330 ms. Figures 4 and 5 show spectrograms of the impulse response obtained using up-TSP and down-TSP signals, respectively. Figure 6 shows a spectrogram of the difference between the two impulse responses, where only a nonlinear error should exist. In Fig. 6, a measurement error with a shape similar to that of the impulse response remained (the reason for this is unclear). However, we disregarded this error since it has no effect on the extraction of the nonlinear error D_u.

When the nonlinear error D_u in the left part of Fig. 6 was subtracted from the impulse response obtained using the up-TSP signal (Fig. 4), the total nonlinear error was reduced, as shown in Fig. 7.

In this method, it is impossible to remove the nonlinear error D_u that is convolved with the room response and included in the part after the maximal impulse response.

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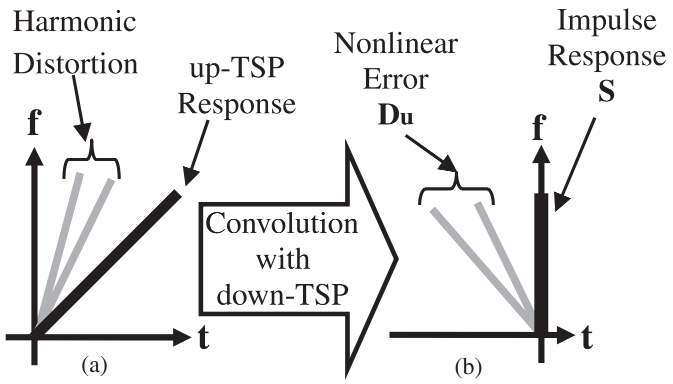

Fig. 1 Effect of harmonic distortion on up-TSP response.

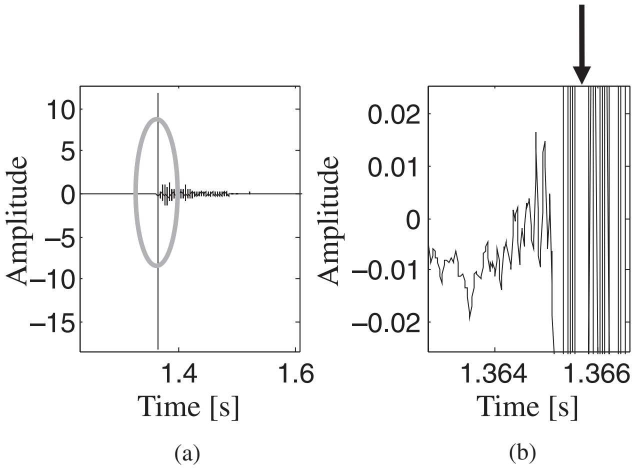

Fig. 2 (a) Impulse response waveform without nonlinear error. (b) Magnified view of circled area in (a). The arrow indicates the time at which the amplitude becomes maximum. Impulse responses also exist to the left of this time.

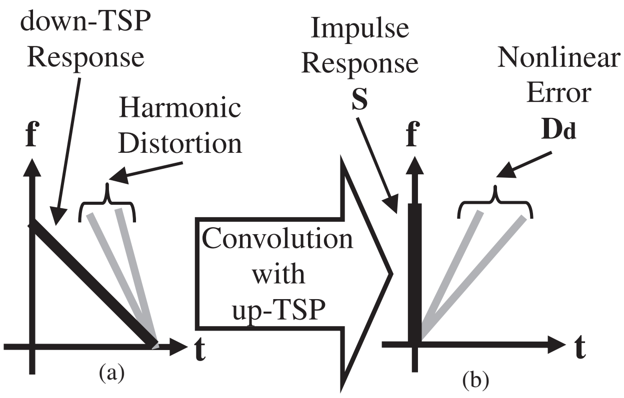

Fig. 3 Effect of harmonic distortion on down-TSP response.

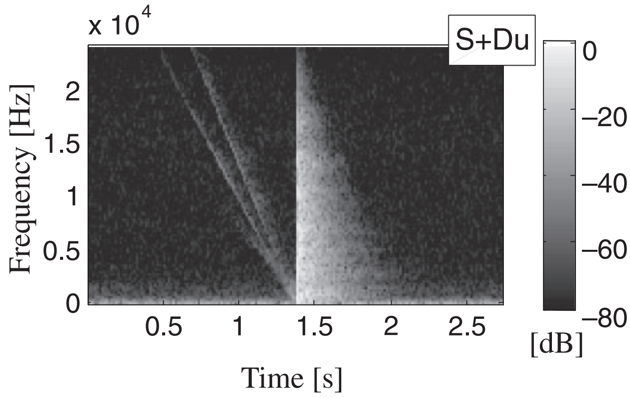

Fig. 4 Spectrogram of impulse response (S+Du) obtained using up-TSP signal.

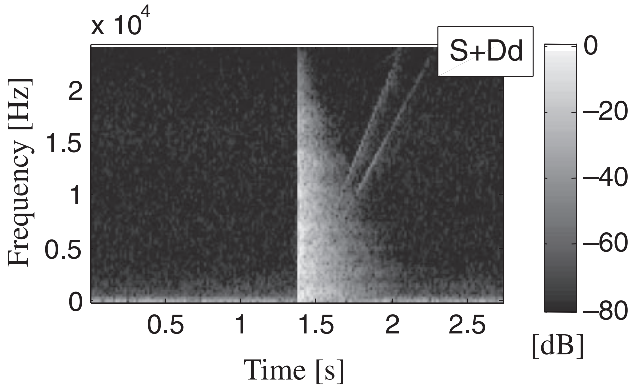

Fig. 5 Spectrogram of impulse response (S+Dd) obtained using down-TSP signal.

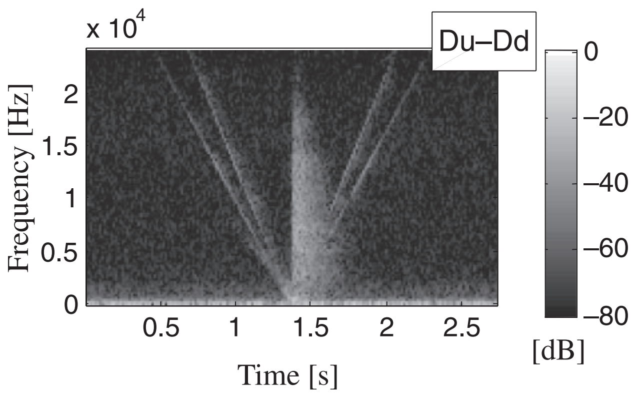

Fig. 6 Spectrogram of nonlinear error (Du-Dd).

However, its effect is considered to be negligible because the ratio of the signal to the nonlinear error is sufficiently large in the region shortly after the maximal impulse response.

5. Conclusions

In this study, we proposed a method of reducing the measurement error caused by harmonic distortion in impulse responses obtained using both up-TSP and down-TSP signals. It was experimentally verified that the measurement error in an impulse response could be reduced by our proposed method in a real environment.

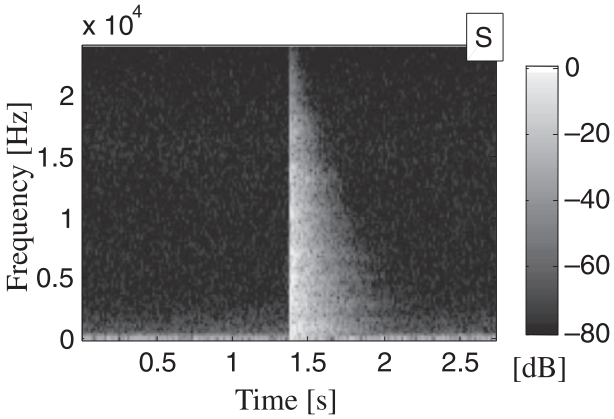

Fig. 7 Spectrogram of impulse response obtained by our proposed method of reducing nonlinear error.

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