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ACOUSTICAL LETTER

Study of harmonic distortion on impulse response measurement with logarithmic time stretched pulse

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1. Introduction

The measurement of acoustic impulse response with a low signal output level causes measurement error due to a low signal-to-noise ratio. When the signal output level is increased excessively, however, the measurement error also increases because of the nonlinear behavior of the measurement system. Thus, both types of error limit the measurement error as illustrated in Fig. 1 [1]. This limitation can be overcome using a logarithmic time stretched pulse (Log-TSP [2,3]), which reduces the influence of the nonlinear behavior. In this paper, we study experimentally measurement error reduction by the elimination of harmonic distortion using Log-TSP.

2. Log-TSP signal

One of the traditional signals for measuring impulse response is TSP (time stretched pulse [4]), which is also called 'swept-sine'. Its frequency is swept linearly as time increases. On the contrary, the frequency of Log-TSP is swept logarithmically (Log-frequency is proportional to time). Figures 2(a) and 2(b) show the spectrograms of TSP and Log-TSP, respectively. Equation (1) indicates the definition of Log-TSP in the DFT domain.

$$H(k) = \begin{cases} 1 & (k = 0), \\ \dfrac{\exp(-jak\log k)}{\sqrt{k}} & (k = 1, 2, \cdots N/2), \\ H^*(N-k) & (k = N/2+1, \cdots N-1), \end{cases} \tag{1}$$

$a = 2m\pi/\{(N/2)\log(N/2)\}$ (m: integer),

k represents discrete frequency, and N is DFT length.

3. Occurrence and affection of harmonic distortion

The main nonlinear behavior is the harmonic distortion of a loudspeaker. Figures 3 and 4 show the impulse responses measured by TSP and Log-TSP signals of excessive output level. A problem regarding TSP, shown in Fig. 3, is the overlap of the harmonic distortion (or nonlinear error caused by harmonic distortion) with principal impulse response. On the other hand, as shown in Fig. 4, using Log-TSP creates a clear distinction between harmonic distortion and principal response, which makes it possible to eliminate the harmonic distortion by ignoring the part before the principal response.

4. Evaluation of impulse responses

It is necessary to compare the measurement result with 'true' impulse response for evaluating the measurement error. However, it is difficult to actually acquire 'true' impulse response. Thus in our experiments, a quantity E defined by Eq. (2) has been considered for estimating the measurement error. E is derived by subtracting the result h_{up} acquired by an Up-Log-TSP signal whose frequency is sweeping low-high, from the result h_{down} acquired by a Down-Log-TSP signal whose frequency is sweeping high-low.

$$E = \frac{\overline{(h_{down} - h_{up})^2}}{\overline{h_{down}{}^2}}, \tag{2}$$

where the over-bar denotes time average.

Suppose the main factor of nonlinear errors d_1 and d_2 contained in h_{down} and h_{up} respectively, is hármonic distortion. As shown in Fig. 5, harmonic distortions in h_{down} and h_{up} appear differently and are uncorrelated to each other. Suppose the mutually uncorrelated errors n_1 and n_2 caused by noise are also contained in h_{down} and h_{up}. Then h_{down} and h_{up} can be represented by

$$h_{down} = h_0 + d_1 + n_1, \tag{3}$$

$$h_{up} = h_0 + d_2 + n_2, \tag{4}$$

where h_0 represents 'true' impulse response.

The squared time average of the difference between h_{down} and h_{up} gives the estimate of the sum of nonlinearity-oriented and noise-oriented errors.

$$\begin{aligned} \overline{(h_{down} - h_{up})^2} &= \overline{(d_1 + n_1 - d_2 - n_2)^2} \\ &= \overline{d_1{}^2} + \overline{d_2{}^2} + \overline{n_1{}^2} + \overline{n_2{}^2}. \end{aligned} \tag{5}$$

5. Experiment of harmonic distortion reduction

The impulse responses of a loudspeaker (BOSE:101MM) was measured with varying signal level in an anechoic room. The solid line (A) in Fig. 6 shows the measurement error E of measured impulse responses as a function of signal output level (sound pressure level at a distance of 1 m from a loudspeaker).

Next, the principal responses within ±75 ms from the maximum values of h_{down} and h_{up} are cut out. Harmonic distortion in the measured impulse responses is eliminated by this operation. Then the error power E is calculated for

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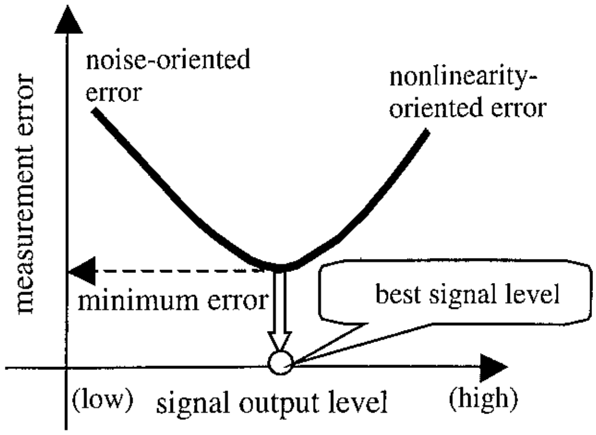

Fig. 1 Relationship between signal level and measurement error.

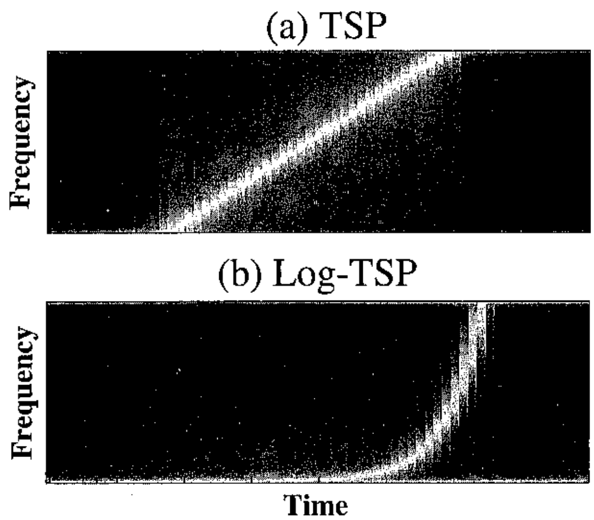

Fig. 2 Spectrogram of (a) TSP and (b) Log-TSP.

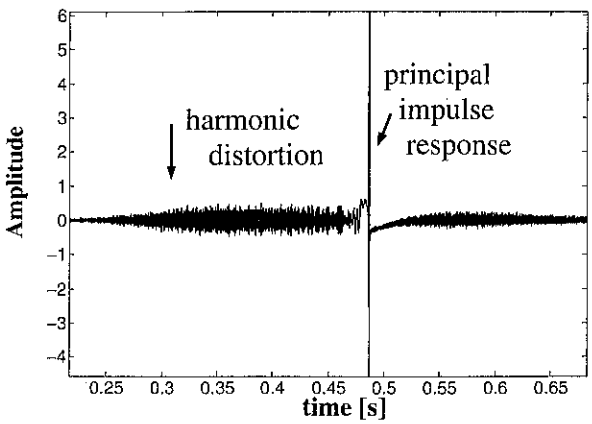

Fig. 3 Nonlinear error with TSP.

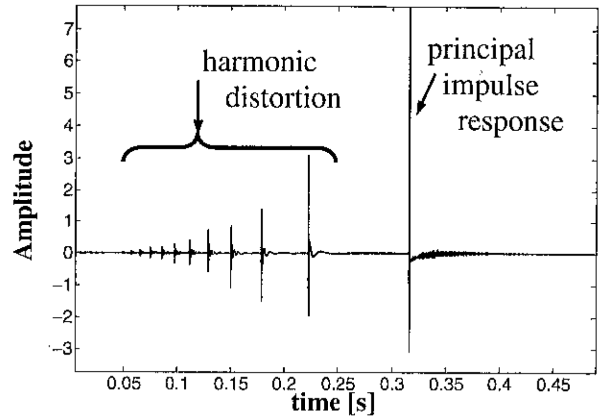

Fig. 4 Nonlinear error with Log-TSP.

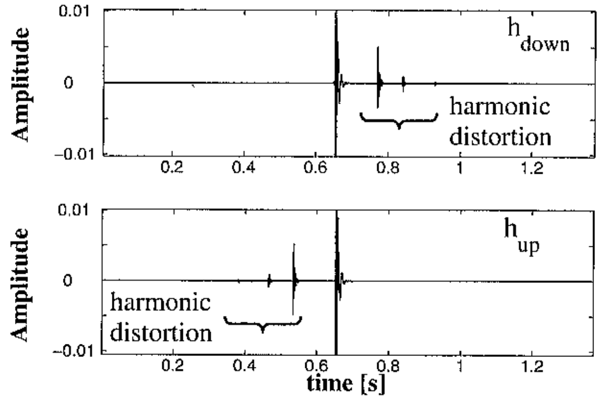

Fig. 5 Harmonic distortions of h_{down} and h_{up}.

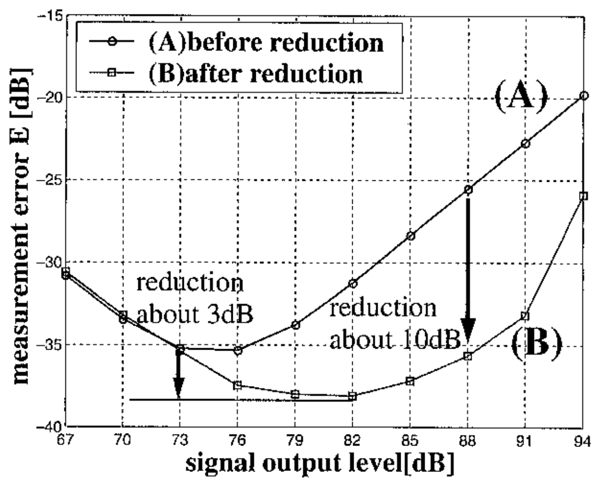

Fig. 6 Measurement errors before and after nonlinear error reduction.

enhanced impulse responses and shown as the dotted line (B) in Fig. 6.

The effect of eliminating harmonic distortion can be seen in Fig. 6. Although the error reduction effect was approximately 10 dB for the same output level, the reduction of the minimum of the error curve line was limited to approximately 3 dB. The limitation is considered to be caused by the following.

1) The nonlinear distortion also may affect the principal impulse response in addition to harmonics.

2) Other errors apart from nonlinear error may occur.

6. Conclusions

It is experimentally confirmed that the measurement error of impulse response caused by harmonic distortion can be reduced by approximately 10 dB with Log-TSP. However, the reduction of the minimum of the error curve line was limited to approximately 3 dB.

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