Acoust. Sci. & Tech. **27**, 2 (2006)

ACOUSTICAL LETTER

A two-channel impulse response measurement system based on a DSP starter kit

Daisuke Yamagishi* and Kenji Ozawa†

Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, 4–3–11 Takeda, Kofu, 400–8511 Japan

(*Received 5 October 2005, Accepted for publication 24 October 2005*)

Keywords: Impulse response, DSP starter kit, Time stretched pulse
PACS number: 43.58.Gn, 43.58.Ta, 43.60.Qv [DOI: 10.1250/ast.27.117]

1. Introduction

A method using a time stretched pulse (TSP) to measure the transfer function of an acoustic system with a high signal-to-noise (SN) ratio has been proposed [1]. A typical application of this method is to measure the head-related transfer function (HRTF), which describes the spectral filtering that occurs between a sound source and the listener's ear, when employing the binaural technique [2]. To use the binaural technique, it is necessary to measure two HRTFs, one for each ear, in various sound fields. Although there are some portable measurement systems on the market, a more easy-to-use and cost-effective system will be of great benefit to many acousticians. High-performance digital signal processors (DSPs) are now readily available. In this article, we describe the construction of a two-channel impulse response measurement system with the TSP technique using a lightweight and inexpensive DSP starter kit (DSK).

2. System overview

2.1. DSP starter kit (DSK)

The constructed measurement system is based on a DSK manufactured by Texas Instruments Incorporated. A DSK is an evaluation board that involves a coder and decoder (CODEC), external memories, an interface to a host personal computer (PC), and a DSP. The DSK used in this study contains a TMS320C6713DSP, which is projected to operate at 255 MHz and delivers up to 1,350 million floating-point operations per second (MFLOPS) [3]. Moreover, the DSK includes 512 K words of Flash and 16 MB SDRAM. The DSK interfaces with a PC using a universal Serial Bus (USB); thus, it is easy to generate a development environment using a notebook PC. Figure 1 shows an overview of the measurement system constructed in this study: a notebook PC is the system host and connects to the DSK via a USB port. A measurement program was coded using the C language in the CCS (Code Composer Studio), an intelligent development environment specific to the DSK [3].

2.2. Specifications

Table 1 shows the specifications of the measurement system. The system is able to generate a TSP of up to 4,096 points. This represents the maximum value of a stable operation, which is restricted by the amount of the SDRAM and by zero-insertion between the intervals of repeated TSP radiations for averaging. Although the default value for the number of repetitions is 64, a user can change the number up to 2^{40}. A user can change some of the conditions shown in Table 1 by editing a header file named Setting.c. The available conditions are the number of points of a TSP, a parameter that determines the length of a TSP, and the number of repetitions. Note that although a longer TSP has larger power and results in a higher SN ratio, it also increases an error caused by linear convolution with its inverse TSP [1]. Since the error tolerance may differ depending on the requirements of the user, the system allows the user to determine this parameter.

2.3. Descriptions

A user of this measurement system can select one of the following three functions with a dipswitch on the DSK.

(1) Measurement of TSP responses on two channels
(2) Measurement of impulse responses on two channels
(3) Calculation of impulse responses from TSP responses that were measured previously

Descriptions of the measurement program are as follows.

2.3.1. Generation and radiation of a TSP, and recording the response

TSPs are generated according to the parameters in the header file. The number of points of a TSP can be set at up to 4,096, as described above; this is achieved by a software design that stores a TSP of the designated length in the external SDRAM on the DSK rather than in the internal memory of the DSP. Next, the TSP is repeatedly radiated and the responses are simultaneously recorded.

2.3.2. Averaging

Because the amount of an external memory on the DSK is limited, it is difficult to average the TSP responses after recording the whole responses to the repeatedly radiated TSPs. Thus, whenever a TSP response of the same number of points as the radiated TSP is recorded, the responses are accumulated. Averaging is accomplished by calculating the quotient of the accumulated responses divided by the number of repeated radiations after recording the whole TSP responses.

2.3.3. Linear convolution with an inverse TSP

An inverse TSP corresponding to the TSP is generated. Next, an impulse response is calculated by linear convolution of the TSP response with the inverse TSP. The impulse response is transferred to the host PC as binary data.

*e-mail: g05mk037@ccn.yamanashi.ac.jp
†e-mail: ozawa@yamanashi.ac.jp

Fig. 1 Overview of the constructed system.

Table 1 Specifications of the constructed system.

Number of channels	2
Sampling frequency	48 kHz (default)
Quantifying bit number	D/A: 15 bit, A/D: 16 bit
Length of a TSP	4,096 (maximum)
Pulse stretch parameter	1,200 (default)
Number of repetitions	64 (default)

3. Evaluation of the measurement system

3.1. Dynamic range

The dynamic range of the system was evaluated using the following procedure: First, a test signal consisting of 0.2-s white noise with a maximum amplitude of 32,767 followed by 0.2-s silence was prepared. The analog input and output terminals of the measurement system were then short-circuited. Next, the test signal was radiated and the response was simultaneously recorded. Finally, 64 signals of 128-point length were obtained from both the responses to the white noise and the silence, and their frequency spectra were averaged separately. Figure 2 shows the results. The dynamic range of the measurement system is approximately 80 dB for frequencies above 1 kHz.

3.2. Comparison with another measurement system

In order to validate the performance of this measurement system, HRTFs were measured and the results were compared with results measured using another system. The comparison system was based on a high-accuracy sound card (Yamaha, DS2416), which has been used in our laboratory. A loudspeaker (Yamaha, NS-3MX) was placed to the right (at a 45° angle) and 1 m in front of a dummy head (Koken, SAMRAI) in a reverberant room. Sixty-four TSPs were radiated from the loudspeaker, and the responses were measured at the entrances of the open ear canals. Figure 3 shows the results for the right and left ears, respectively. As the results show good agreement, we conclude that the new system is reliable.

4. Summary

In this study, we constructed a two-channel impulse response measurement system based on a DSP starter kit. The

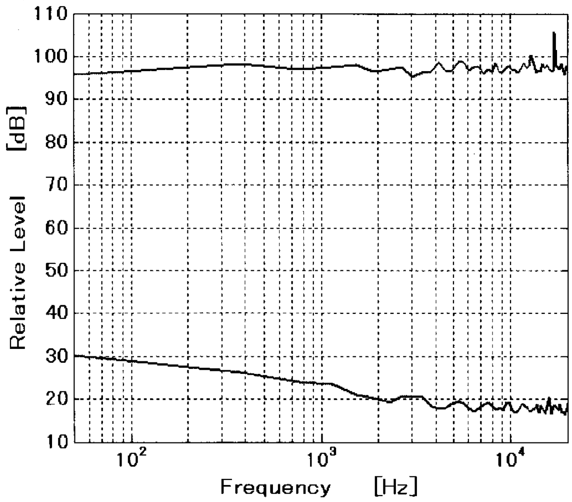
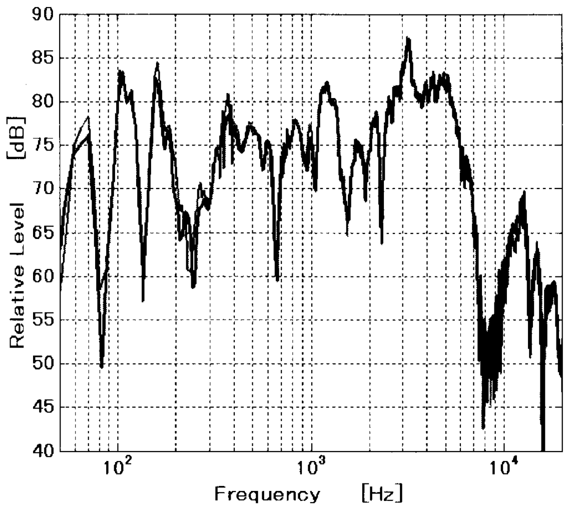
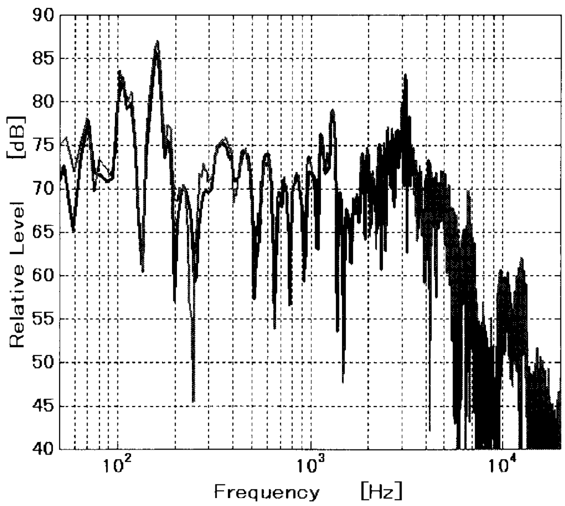


Fig. 2 Dynamic range of the constructed system. Upper line: White noise of the maximum amplitude, Lower line: Intrinsic noise.



(a) R channel



(b) L channel

Fig. 3 Comparison of measured HRTFs. Thin line: Comparison system, Thick line: Constructed system.

program described above is available at the following URL: "http://www.ccn.yamanashi.ac.jp/~ozawa/lab.htm"

Acknowledgements

This study was partially supported by Japan Society for the Promotion of Science (KAKENHI, 17560336), and was carried out under the Cooperative Research Project Program of the Research Institute of Electrical Communication, Tohoku University (No. H15/A08). The authors wish to thank Mr. Masaki Yamamoto of University of Yamanashi for his help in measuring HRTFs, and Prof. Yôiti Suzuki of Tohoku University and Dr. Masanao Ohashi of Ono Sokki Co., Ltd. for their comments during preparation of this manuscript.

References

[1] Y. Suzuki, F. Asano, H.-Y. Kim and T. Sone, "An optimum computer-generated pulse signal suitable for the measurement of very long impulse responses," *J. Acoust. Soc. Am.*, **97**, 1119–1123 (1995).

[2] H. Møller, "Fundamentals of binaural technology," *Appl. Acoust.*, **36**, 171–218 (1992).

[3] Texas Instruments: www.ti.com, <http://focus.ti.com/docs/toolsw/folders/print/tmdsdsk6713.html>, (2005.9.15).