Development of the Hearing Aid Measurement System

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***Abstract*—The characteristics of hearing aids should be determined and regulated to ensure patient safety and to optimize the performance of the hearing aids. The objectives of this work were to design and develop a hearing aid measurement system to obtain the performance characteristics of the hearing aids. The implementation of this work is based on the method recommended in the International Electrotechnical Commission (IEC 60118-7). To verify the performance of the developed hearing aid measurement system, the hearing aid characteristics measured from our developed measurement system (such as Maximum OSPL90, Frequency of Maximum OSPL90, HFA-OSPL90, Maximum Full-on Gain, Frequency of FOG Maximum, HFA-FOG, Lowest Frequency, Highest Frequency, RTG @ RTS/60 dB, THD 500 Hz, THD 800 Hz and THD 1600 Hz) were compared with those measured from the commercial hearing aid analyzer and those provided from the hearing aid manufacturer's specifications. The results show that the hearing aid characteristics measured from our developed measurement system were in good agreement with those measured from the commercial hearing aid analyzer and those provided by the hearing aid manufacturer's specifications.**

***Keywords*—Hearing aid, Hearing aid meassurement, IEC 60118-7.**

I. Introduction

Hearing impairment is one of the primary disabilities in Thailand. A hearing aid is an electronic device that can improve an ability of listening for hearing loss people instead of treating with surgery and drug, which are cumbersome, costly and restriction in each patient. Most of the hearing aids today are digitally programmable with computer, allowing the clinician to perform extensive adjustments to the hearing aid and display the predicted results of these adjustments on the computer screen. Hearing aids will amplify sounds in the environment to compensate for the malfunctioning anatomy in the ear itself. There are several types of hearing aids on the market, such as body worn hearing aids, behind-the-ear (BTE) hearing aids, in-the-ear (ITE) hearing aids, in-the-canal (ITC) hearing aids and completely-in-the-canal (CIC) hearing aids. The hearing aid usually placed in or behind the ear [1].

The purposes of the hearing aid's electroacoustic performance measurement are to verify the manufacturer's specifications, to pre-fit a hearing aid before the patient arrives at the clinic, and to establish a baseline that can be used later if the hearing aid comes back into the clinic for repair. In addition, when the hearing aid has been used for a long period of time, the changes of the performance characteristics may occur. Therefore, the characteristic measurement of the hearing aids is essential to minimize harm to the patient and to ascertain whether the hearing aid performs satisfactorily.

The performance of hearing aids is most conveniently measured when the hearing aid is connected to a coupler or an ear simulator. The availability of standard couplers and ear simulator allows measurements to be made in different places at different time but under the same condition [2-3]. A coupler is a small cavity that connects the hearing aid sound outlet to a measurement microphone. The standard coupler used for hearing aids has a volume of 2 cubic centimeters. This volume was chosen because it was an approximation of the volume of the adult ear canal past the earmould when a hearing aid is worn [4]. The ear simulator is performed by simulating the impedance of an ear [5]. The hearing aid can be measured in either a test box or on an acoustic manikin. A test box is a room that has total, or nearly total, absorption on all surfaces. This means that any sound that hits a wall is completely absorbed and none is reflected [6-9]. An acoustic manikin comprises a head and torso, with an ear simulator incorporated inside each ear [10]. In this work, the coupler was used because the measurement technique here is based on the International Electrotechnical Commission (IEC 60118-7) [11].

In view of the above, it is clear that there is a well defined need for the hearing aid measurement system to obtain the performance characteristics of the hearing aid. Consequently, this paper describes a design and development of the hearing aid measurement system based on the method recommended in the International Electrotechnical Commission (IEC 60118-7).

II. Methods

The implementation of the developed hearing aid measurement system is based on the technique recommended in the International Electrotechnical Commission (IEC 60118-7). A schematic diagram and a photograph of this developed

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system are presented in Fig. 1 and Fig. 2, respectively. The system consists of the following parts:

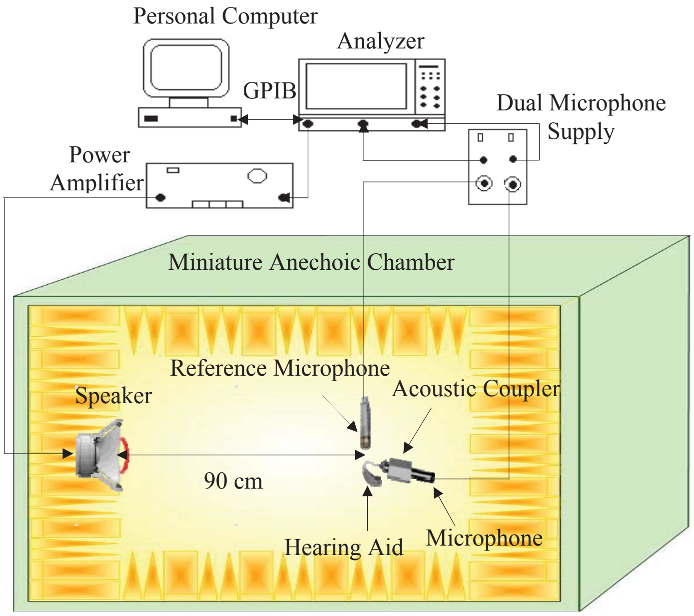

Figure 1. Schematic diagram of the developed hearing aid measurement system.

(1) Personal computer with a custom made software program: A custom made LabVIEW program was used in this research for controlling the output signals of the spectrum analyzer, and obtaining and processing the data from the spectrum analyzer. The personal computer was connected to the spectrum analyzer via the General Purpose Interface Bus (GPIB).

(2) Spectrum analyzer: Spectrum analyzer, model CF-5220 from ONO SOKKI, was used to generate test signals to the power amplifier and receive signals from the dual microphone supply. The spectrum analyzer is 2-channel Fast Fourier Transform (FFT) analyzer mainly for analyzing sound and vibration. The frequency range of this analyzer is between 1 Hz and 100 kHz. This spectrum analyzer can be adjusted to six different output signal modes; sine wave, swept sine wave, pseudo random signal, random signal, periodic random signal and impulse signal. However, only sine wave mode was used in this work. The amplitude of the output signals can be set from 0.001 V to 10 V with a resolution of 1 mV. The operational mode of the analyzer was selected to be sound analysis mode for analyzing signals received from the dual microphone supply.

(3) Power amplifier: Power amplifier, type 2712 from Bruel & Kjaer, Denmark, was employed to amplify the output signals from the spectrum analyzer before sending the signals to the speaker.

(4) Miniature anechoic chamber: A custom-made miniature anechoic chamber was designed and built to absorb the reflections of acoustic waves as well as insulate from external noise and annoyance. The developed miniature anechoic chamber is based on the international standard ISO 3745:2003(E) Annex A [6]. The dimensions of the developed miniature anechoic chamber are 160 cm height, 200 cm width, and 140 cm depth. The chamber's structure was made of aluminum composite. The absorbent material was installed inside the chamber; four walls, ceiling, and floor. The absorbent material was composed of three layers. The first layer was polyurethane foam. The second layer was bagasse paper. The last layer was acoustic wedges made of polyurethane. The height of the acoustic wedges was 30 cm to increase the efficiency of sound wave absorption. After the absorbent materials were installed, the designed miniature anechoic chamber had the following inside dimensions: 92 cm height, 132 cm width, and 72 cm depth [12, 13]. The free-field region of the miniature anechoic chamber was found to be higher than 85 cm from the speaker. In this research, the distance from the center of the speaker to the test point was set to be 90 cm.

(5) Speaker: Speaker, model BM-10CXA coaxial transducer from Paudio, Thailand, was used in this work. Its diameter, impedance, power capacity, sensitivity at 1W/1M and frequency range are 254 mm, 4~8 ohm, 150~300 watts, 98 dB and 20 Hz~40 kHz, respectively. The speaker was mounted near the center of one wall of the chamber as shown in Fig. 1. The sound signals from the speaker were transmitted to the hearing aid to be tested.

(6) Reference microphone: Reference microphone, type 4134 from Bruel & Kjaer, Denmark, was used together with preamplifier type 2669, from Bruel & Kjaer, Denmark. The diameter of the reference microphone is ½ inch. The reference microphone was placed in the miniature anechoic chamber at the test point next to the hearing aid microphone to measure the reference sound for controlling the sound level from the speaker.

(7) Hearing aid: The digital hearing aid, Motion 301P behind the ear model, was used in this work. This hearing aid consists of 8 channel digital signal processing and programming. The sound signals from the speaker were transmitted to the hearing aid and the received sound signals were converted into electrical signals to process and changed back into acoustic signals with a sound transducer of hearing aid. The output sound signals from hearing aid were passed on to the acoustic coupler via the tubing 25 mm length.

(8) Acoustic coupler: Acoustic coupler, model DB 0138 from Bruel & Kjaer, Denmark, consists of a housing, ear mould substitute and airtight screw seal. The response of the acoustic coupler is similar to the acoustic environment of the ear. This coupler has an enclosed air volume of approximately 2 cm^3. The acoustic coupler is used to simulate an average hearing response.

(9) Microphone: Condenser microphone, type 4144 from Bruel & Kjaer, Denmark, was used together with preamplifier type 2669, from Bruel & Kjaer, Denmark. The diameter of condenser microphone is 1 inch. Condenser microphone is inside acoustic coupler, which is used for receiving output sound signals from the acoustic coupler.

(10) Dual microphone supply: Dual microphone supply, type 5935 from Bruel & Kjaer, Denmark, was connected directly to the reference microphone and the condenser microphone with 2 main purposes. Firstly, the unit supplies the necessary power to attached microphone/preamplifier assemblies. Secondly, it has an active circuitry to amplify the output of microphone and sent output signals to the analyzer.

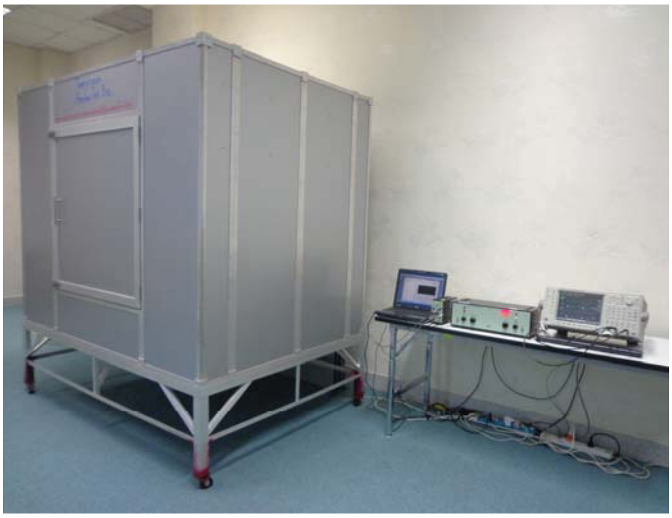

Figure 2. Photograph of the developed hearing aid measurement system.

To verify the performance of the developed hearing aid measurement system following the recommendations specified in the International Electrotechnical Commission (IEC 60118-7), the performance characteristics of hearing aids such as output sound pressure level frequency response curve for an input sound pressure level of 90 dB (OSPL90 frequency response curve), full-on acoustic gain response curve, basic frequency response curve at reference test gain setting and total harmonic distortion must be determined.

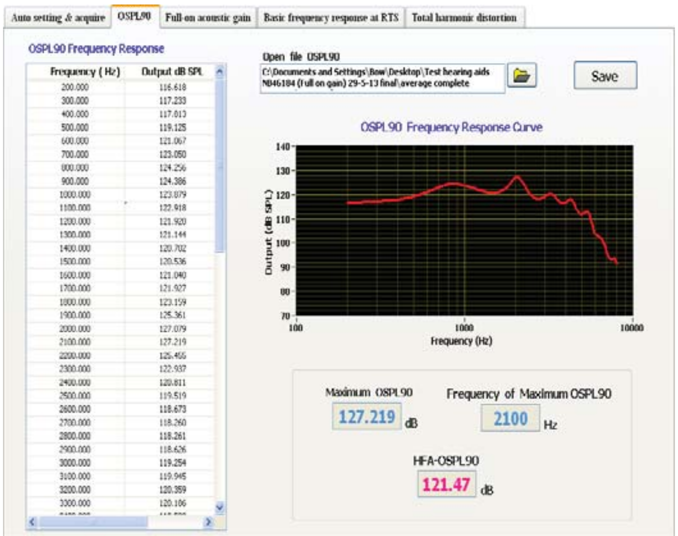

Figure 3. Custom-made LabVIEW program used to determine the maximum OSPL90, the frequency of the maximum OSPL90 and the HFA-OSPL90.

In order to determine the output sound pressure level frequency response curve for an input sound pressure level of 90 dB (OSPL90 frequency response curve), the following procedures must be carried out: set the gain control of the hearing aid to full-on position, set the input sound pressure level to the hearing aid at the level of 90 dB, vary the frequency of the sound source over the frequency range from 200 Hz to 8000 Hz with the frequency interval of 100 Hz, measure the sound pressure level in the acoustic coupler versus frequency and record the OSPL90 frequency response curve, display the maximum OSPL90, the frequency of the maximum OSPL90 and the HFA-OSPL90 (The definition of HFA is an average sound pressure level in decibels at the frequencies of 1000 Hz, 1600 Hz and 2500 Hz). A custom-made LabVIEW program presented in Fig. 3 was employed to determine the maximum OSPL90, the frequency of the maximum OSPL90 and the HFA-OSPL90.

The test procedure of full-on acoustic gain response curve can be explained as follows: set the gain control of the hearing aid to full-on position, set the input sound pressure level to the hearing aid at the level of 50 dB, vary the frequency of the sound source over the frequency range from 200 Hz to 8000 Hz with the frequency interval of 100 Hz, measure the sound pressure level in the acoustic coupler versus frequency and record the full-on gain frequency response curve, subtract 50 dB from full-on gain frequency response. The maximum full-on gain, the frequency of the full on gain (FOG) maximum and the HFA-FOG were obtained by a custom-made LabVIEW program as shown in Fig. 4.

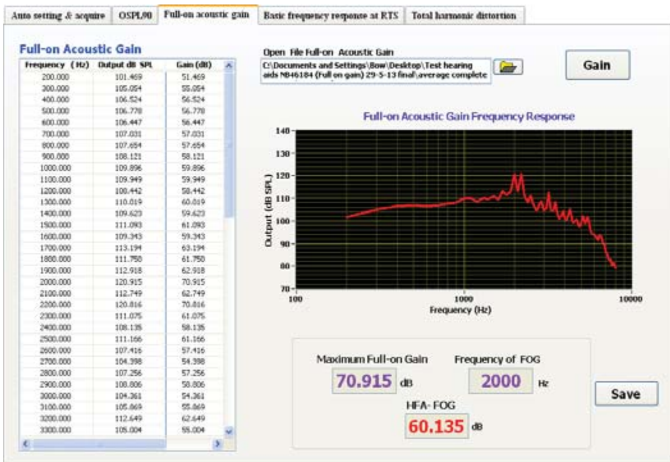

Figure 4. Custom-made LabVIEW program used to obtain the maximum full-on gain, the frequency of the full on gain (FOG) maximum and the HFA-FOG.

To determine the basic frequency response curve at reference test gain setting (RTS), the following procedures have to be performed: set an input sound pressure level to the hearing aid at the level of 60 dB, set the reference test gain (RTG) control of the hearing aid to the reference test setting by adjusting the hearing aid gain control required to produce an HFA–gain as the HFA-OSPL90 minus 77 dB, vary the frequency of the sound source over the frequency range from 70 Hz to 8000 Hz (with the frequency step of 10 Hz at the frequency range from 70 Hz to 100 Hz and with the frequency interval of 100 Hz at the frequency range from 100

Hz to 8000 Hz), measure the sound pressure level in the acoustic coupler versus frequency and record the basic frequency response curve. A custom-made LabVIEW program presented in Fig. 5 was used to determine the bandwidth of the hearing aid in both the lowest and highest frequencies at which the frequency response curve has the value of HFA output level minus 20 dB.

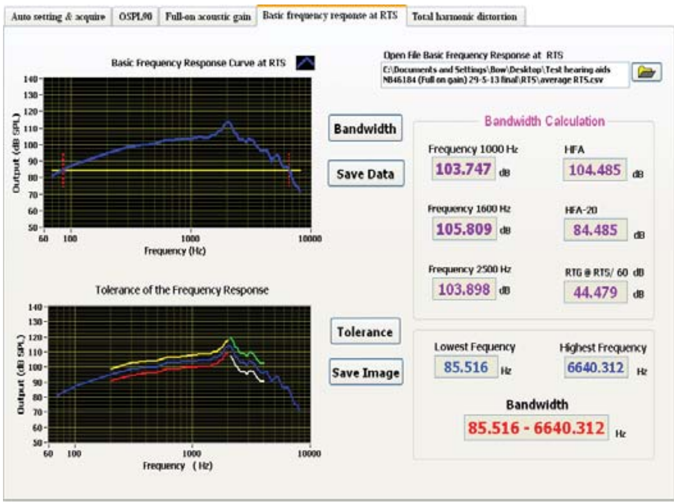

Figure 5. Custom-made LabVIEW program used to determine the bandwidth of the hearing aid.

The test procedure of the total harmonic distortion can be illustrated as follows: set an input sound pressure level to the hearing aid at the level of 60 dB, set the gain control of the hearing aid to the reference test setting (RTS) as mentioned above, measure total harmonic distortion in percent at the 500 Hz for an input sound pressure level to the hearing aid at the level of 70 dB, at the 800 Hz for an input sound pressure level of 70 dB, and at the 1600 Hz for an input sound pressure level of 65 dB. A custom-made LabVIEW program presented in Fig. 6 was used to automatically adjust the input sound pressure level at the desired frequency and obtain the total harmonic distortion data from the spectrum analyzer.

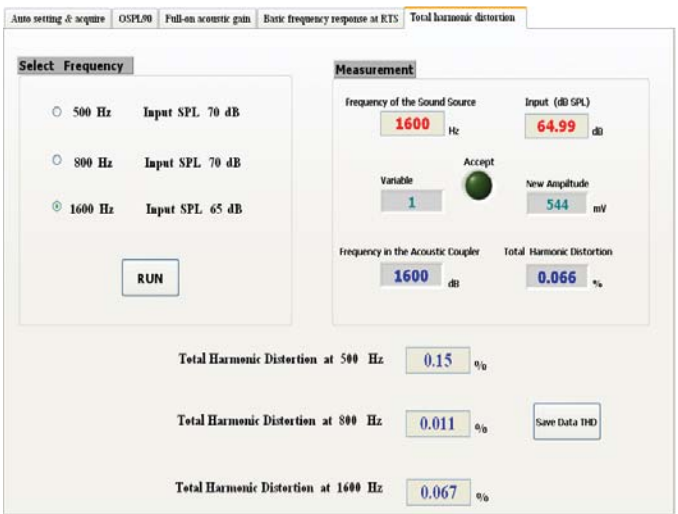

Figure 6. Custom-made LabVIEW program used to find the total harmonic distortion.

III. RESULTS

To verify the performance of the developed hearing aid measurement system, the performance characteristics measured from our developed system (such as Maximum OSPL90, Frequency of Maximum OSPL90, HFA-OSPL90, Maximum Full-on Gain, Frequency of FOG Maximum, HFA-FOG, Lowest Frequency, Highest Frequency, RTG @ RTS / 60 dB, THD 500 Hz, THD 800 Hz and THD 1600 Hz) were compared with the performance characteristics measured from the commercial hearing aid analyzer (model UPL -B7 from Rohde & Schwarz) and the hearing aid manufacturer's specifications as shown on Table I.

TABLE I. COMPARISONS OF THE HEARING AID PERFORMANCE CHARACTERISTICS MEASURED FROM THE DEVELOPED HEARING AID MEASUREMENT SYSTEM, THE COMMERCIAL HEARING AID ANALYZER, AND THE HEARING AID MANUFACTURER'S SPECIFICATIONS

Test Parameters	Developed Hearing Aid Measurement System	Commercial Hearing Aid Analyzer	Manufacturer's Specifications
Maximum OSPL90	127. 22 dB	127. 3 dB	129 dB
Frequency of Max. OSPL90	2,100 Hz	2,200 Hz	-
HFA-OSPL90	121.47 dB	121.7 dB	123 dB
Maximum Full-on Gain	70.92 dB	69.1 dB	70 dB
Frequency of FOG Maximum	2,000 Hz	2,100 Hz	-
HFA-FOG	60.14 dB	60.3 dB	61 dB
Lowest Frequency	85.52 Hz	< 200 Hz	100 Hz
Highest Frequency	6,640.31 Hz	7,100 Hz	6,900 Hz
RTG @ RTS / 60 dB	44.48 dB	44.4 dB	47 dB
THD 500 Hz	0.15 %	0. 3 %	2 %
THD 800 Hz	0.01 %	0. 2 %	1 %
THD 1600 Hz	0.07 %	0. 3 %	1 %

IV. Discussions

To verify the performance of the developed measurement system, the hearing aid performance characteristics measured from the developed measurement system are presented in comparison with those measured from the commercial hearing aid analyzer and those provided from the hearing aid manufacturer's specifications as shown on Table 1. In order to investigate the reproducibility of the measurement system, the measurements were repeated for six times. Therefore, the results presented on Table 1 are the average data of 6 measurements and it is shown that the performance characteristics measured from our developed measurement system yielded results that were in good agreement with those measured from the commercial hearing aid analyzer and those provided by the hearing aid manufacturer's specifications. In addition, our developed measurement system is able to provide more information of the hearing aid's frequency response at all frequency measurement in comparison with the commercial hearing aid analyzer. The developed system can also determine the exact lowest bandwidth frequency of the hearing aid whereas the commercial hearing aid analyzer can only give the approximate lowest bandwidth frequency of the hearing aid.

V. Conclusions

In conclusion, the hearing aid measurement system was successfully developed using the method recommended in the International Electrotechnical Commission (IEC 60118-7). Currently, the developed system is able to determine the performance characteristics of the hearing aid such as output sound pressure level frequency response curve for an input sound pressure level of 90 dB (OSPL90 frequency response curve), full-on acoustic gain response curve, basic frequency response curve at reference test gain setting and total harmonic distortion.

Acknowledgment

This work was supported by grant in aid funded under "Cooperation Project for Production of Science and Technology Development Graduate of Ministry of Science and Technology through National Institute of Metrology (Thailand)" and the Graduate College, King Mongkut's University of Technology North Bangkok.

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