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NSMRL's Computer-Controlled Facility for Real-Ear-Attenuation-at-Threshold (REAT) Testing of Hearing Protectors: Re-verification to ANSI standard

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14. ABSTRACT
A psychoacoustic research facility incorporating a reverberant sound field exists in the Naval Submarine Medical Research Laboratory (NSMRL) to perform empirical measurement of noise attenuation capabilities of hearing protection devices (HPDs) intended for defending human hearing against hazardous sound. This facility, its instrumentation, and the test protocol employed are implemented to meet the real-ear-attenuation-at-threshold (REAT) test requirements of ANSI standard S12.6-2008 Method for Measuring the Real-Ear Attenuation of Hearing Protectors, hereafter referred to as S12.6-2008 (American National Standards Institute, 2008). This report provides an overview of the physical facility and the instrumentation used to conduct HPD attenuation testing as indicated by S12.6-2008. Furthermore, the procedures employed and the resulting acoustic verification data obtained for demonstrating that the facility meets the guidelines of S12.6-2008, are presented in detail. The verification data presented in this report indicate the facility is in accordance with S12.6-2008.

15. SUBJECT TERMS
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The reverberant real ear attenuation at threshold (REAT) testing facility and its instrumentation used to evaluate hearing protection devices (HPD) at the Naval Submarine Medical Research Laboratory (NSMRL) was configured and installed at the request of NSMRL's Drs. Lynne Marshall and Jeremy Federman. The original effort by Virginia Polytechnic Institute and State University's Drs. Kichol Lee and John Casali to design, build and calibrate a custom computer-controlled software/hardware integrated system to conduct REAT test was conducted under SAIC contract; hereafter, this system is referred to as the VT HPD Test system. For SAIC, Eric Scansen was Technical Contact and Adam Kranz was Subcontract Representative.

Initial Installation and calibration of the REAT system at NSMRL was performed by Dr. Lee from Virginia Polytechnic Institute and State University, with a follow-up visit for demonstration and testing by Drs. Lee and Casali. During these visits, Dr. Federman provided on-site assistance from NSMRL, and was also directly responsible for the test room facility's room renovation and retrofit.

The new measurement data to requalify the REAT testing facility were acquired with assistance from Mr. Derek Schwaller.

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List of Acronyms

ANSI – American National Standards Institute

B&K – Brüel & Kjær

DSP – Digital Signal Processors

HPD – Hearing Protection Device

MAF – Minimum Audible Field

NI – National Instruments

NRR – Noise Reduction Rating

NSMRL – Naval Submarine Medical Research Laboratory

OB – Octave Band

REAT – Real Ear Attenuation at Threshold

RMS – Root Mean Square

RT60 – Reverberation Time to decay 60 dB

SAIC – Science Application International Corporation

SLM – Sound Level Meter

SPL – Sound Pressure Level

TDT – Tucker-Davis Technologies

VI – Virtual Instrument

Summary

A psychoacoustic research facility incorporating a reverberant sound field exists in the Naval Submarine Medical Research Laboratory (NSMRL) to perform empirical measurement of noise attenuation capabilities of hearing protection devices (HPDs) intended for defending human hearing against hazardous sound. This facility, its instrumentation, and the test protocol employed are implemented to meet the real-ear-attenuation-at-threshold (REAT) test requirements of ANSI standard S12.6-2008 *Method for Measuring the Real-Ear Attenuation of Hearing Protectors*, hereafter referred to as S12.6-2008 (American National Standards Institute, 2008). The REAT test system, named the VT HPD Test System, was developed by the original report's authors (Kichol Lee, Ph.D. and John G. Casali, Ph.D., CPE) at Virginia Polytechnic Institute and State University, and thereafter installed and calibrated at NSMRL. This report provides an overview of the physical facility and the instrumentation used to conduct HPD attenuation testing as indicated by S12.6-2008. Furthermore, the procedures employed and the resulting acoustic verification data obtained for demonstrating that the facility meets the guidelines of S12.6-2008, are presented in detail. The tests described herein were conducted during October through December, 2017 (and subsequent monthly tests were conducted as per the standard). The verification data presented in this report indicate the facility is in accordance with S12.6-2008.

The ANSI 12.6 standard was updated in 2016. However, this report is specific to the 2008 version of the standard since the NSMRL REAT system was designed to the 2008 standard specifications. Nevertheless, the system passes the ANSI 12.6-2016 4.2.1.1 Uniformity terminology change by being within ± 2.5 dB as required (American National Standards Institute, 2016). Moreover, the 2008 version calls for a more stringent measurement schedule that requires a calculation of the median of five tests compared to a single measurement required in the 2016 version. Future testing could be done to verify the changes in 4.3.4 Attenuator Range and System Linearity to determine whether the NSMRL REAT system meets all specifications of the 2016 version. Such testing would require a measurement of 1/3 octave band (OB) test signals instead of pure tones in order to comply with the new standard that requires the room to comply with the 2 dB maximum difference over the total attenuator range and 1 dB difference over an 80 dB range. However, in the case of the sound levels within 20 dB of the noise floor where voltage measurements are to be taken, the use of pure tones, like those found in the current report in Tables 19, 21, 23, 25, 27, 29, 30 and 31, would be acceptable. In addition, the measurement of 1/3 OBs between 80 Hz and 10,000 Hz in 10 dB increments could also be obtained until the ambient noise floor is reached without a difference greater than 2 dB for the same 4.3.4 section of the 2016 standard. If these criteria were to be verified in the future, the NSMRL VT HPD System would be compliant with ANSI 12.6-20

Test Facility and Instrumentation

Test Facility

Testing is conducted in a reverberant sound field established within an irregular polyhedron-shaped testing room, which is located in the Naval Submarine Medical Research Laboratory (NSMRL). The wall and ceiling panels of the test room are covered with hard-surfaced gypsum board. The floor is smooth concrete that is covered with epoxy coating. The entrance door is outfit with double-gaskets with rubber seals and is recessed 15 centimeters (cm) on the hinge side that is closest to the southwest corner and 18 cm closest to the northwest corner. The dimensions of the door are 221 cm tall by 104 cm wide. The door is 8 cm above the floor inside the room and there are 15 cm of clearance above the door before it is no longer recessed. Three silent LED lights provide illumination inside the test space controlled from outside the room. As currently configured, the test room has the dimension shown in Figures 1-6. Since the room is an irregular polyhedron, figures for the dimensions of the walls and floor are included to give an accurate representation of the room.

In addition, there is a ventilation opening in the ceiling of the room to allow for HVAC air flow in and out of the room. The gypsum board prevents the open vent from impacting acoustics as well as the subject underneath the vent. The diameter of this opening is 41 cm with the circle's center measured 147 cm from the south wall at 97 cm from the south east corner. In order to prevent the airflow from interfering with the acoustics of the room, a piece of the hard-surfaced gypsum board mounted to a weed frame is suspended from the ceiling just below the ventilation opening. This piece of gypsum board is a 71 cm wide and long. The northeast corner of the board is 127 cm from the north wall and 89 cm from the east wall. The board is suspended parallel to the ceiling by screw eyes and wire rope and the distance each corner hangs from the ceiling is 18 cm.

There is a window in the room that allows for visualization of the subject during testing. The window is recessed 23 cm within the west wall, with 15 cm of that being gypsum board and the other 8 cm being sheet metal. The width and height of the window is 79 cm and is placed 71 cm from the northwest corner and 132 cm from the floor. Also on the west wall are two pass-through holes. The first is both 10 cm wide and tall and is located 66.0 cm from the northwest corner and 74 cm from the floor. It is covered by a Styrofoam block that is 10 cm and 9 cm tall to allow wires to pass underneath the block. The second pass-through is 13 cm wide and 20 cm tall and is located 18 cm from the northwest wall and 117 cm from the floor. It is covered by sheet metal with four 3 cm inch diameter pass-through holes

Facility Configuration

The test room is configured for HPD testing as shown in Figure 1-6. Three 2-way loudspeakers (KEF R100), none of which are directed at the subject, are used to provide a random incidence sound field around the subject's head. Uniform sound level output from each loudspeaker at the subject's head position is achieved through a computer-controlled loudspeaker equalization, or offset, procedure. Each loudspeaker is supported by a stand, and oriented to one of the three orthogonal planes of the test room. Speaker 1 faces the corner of the west and north walls as seen from the subject chair. Speaker 2 is directed toward the corner of the north and east walls. Speaker 3 is oriented horizontally (parallel to the floor) such that the speaker cones face the ceiling in the corner where the east and south wall meet. The exact positions and orientations of the three speakers can be seen in Figure 2.The speaker orientations in Figure 2 show the exact location of speaker stands, upon which each speaker is placed in the center of its stand's top plate. None of the loudspeakers are oriented such that their firing axes are pointed directly at the subject. During testing, the subject is seated, facing the north wall of the test room so that his/her centered ear position is set to approximately the point shown by an arrow symbol in Figure 2 (geometric center of the horizontal plane, 132 cm above the floor). This position is also the reference point for the microphone placement in all system verification tests and pre-test system calibrations.

All Figure measurements are in centimeters.

Figure 1. Orthographic view of Ceiling of REAT Facility (not to scale).

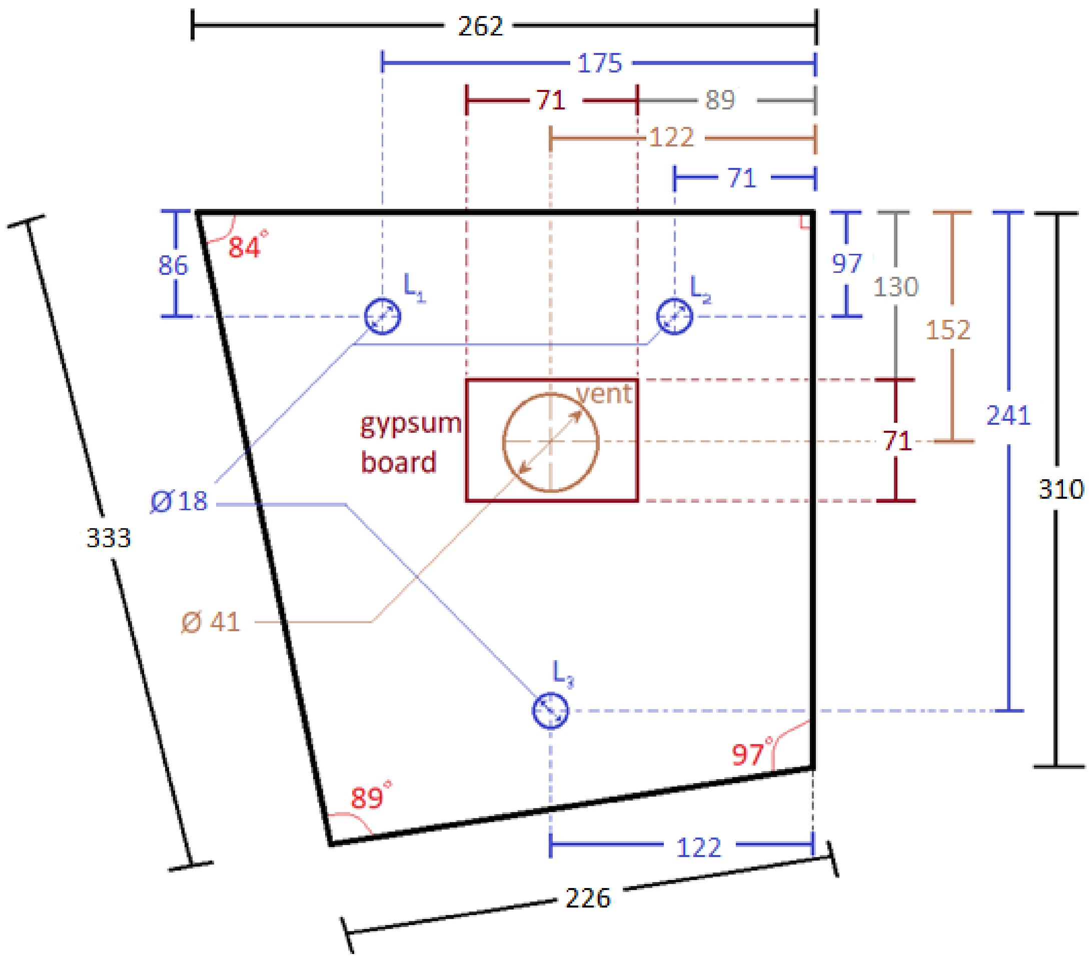
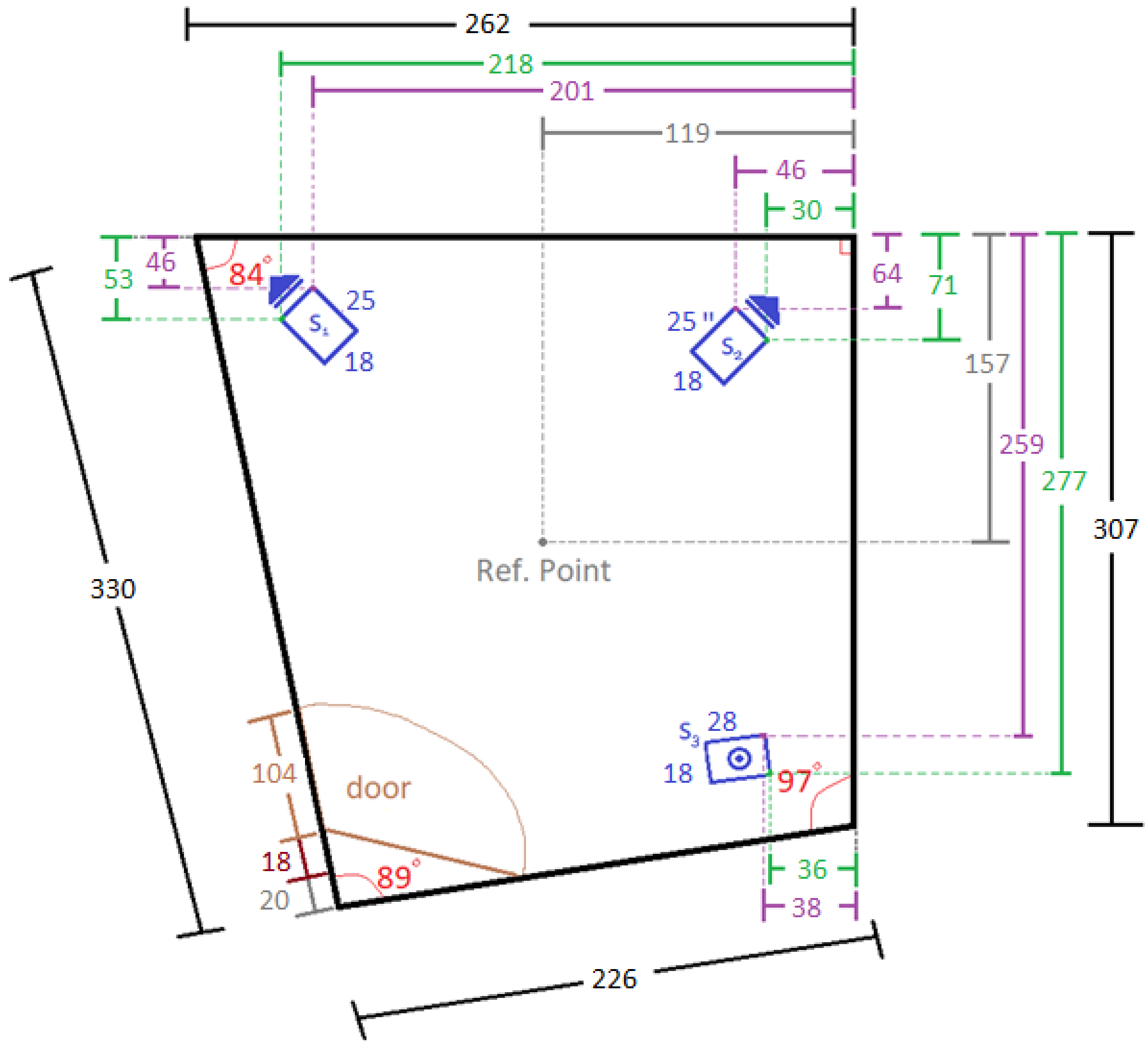
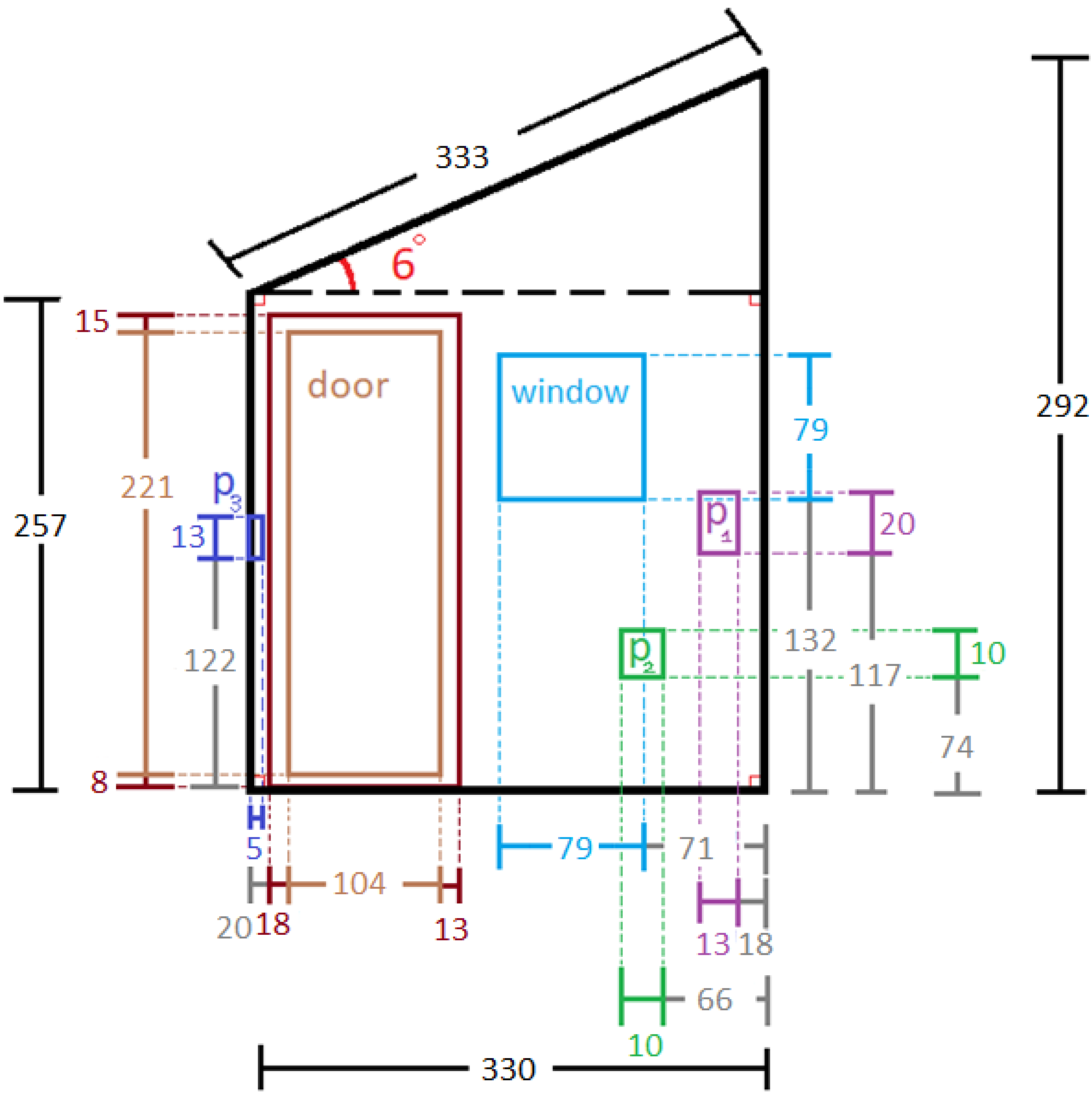


Figure 2. Orthographic view of Floor of REAT Facility (not to scale).



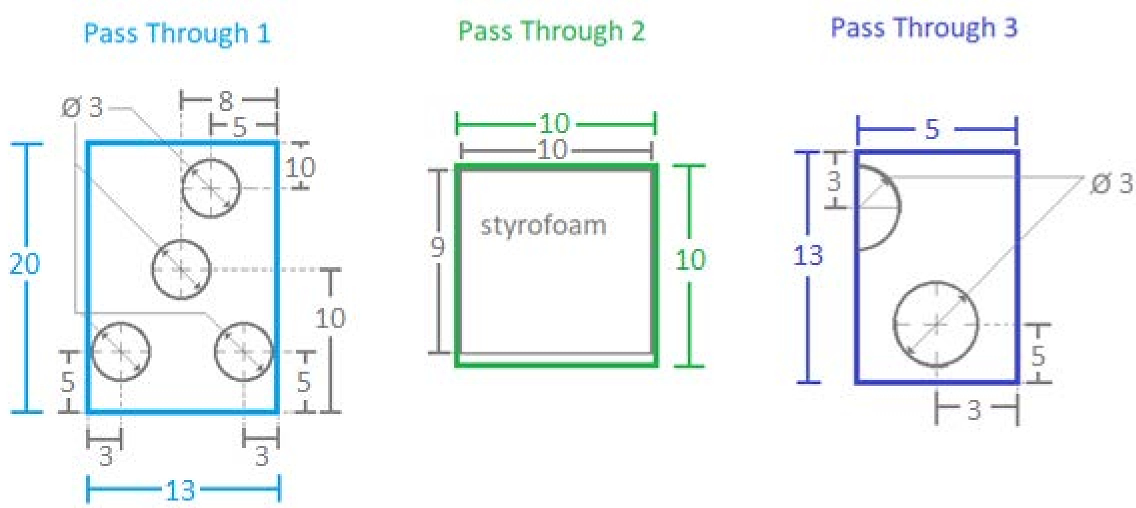
The symbol ⧐ indicates the projection directions of Speakers 1 and 2 while the symbol ⊙ indicates that Speaker 3 is projected upward. Ref. Point is where the reference point is located in this two dimensional plane

Figure 3. Orthographic view of West Wall of REAT Facility (not to scale).



Pass-through holes labeled p1, p2, and p3 are shown in more detail in Figure 4

Figure 4. Orthographic View of Pass-Through Holes From West Wall Perspective (not to scale).



The top hole of Pass-Through 1 contains the wire of a preamplifier extension cable that connects a B&K sound level meter to the microphone used for calibration. All holes are stuffed with sound attenuating foam to prevent the passing of external sound to the test chamber.

Pass-Through 2 has its opening covered by a Styrofoam block with just enough space underneath to allow for nine wires to pass through. Six connect the attenuators to the speakers, one is for the subject response button, and one is for a talkback microphone. The last is a wire in the top right corner that connects to the examiner's talkforward microphone.

Pass-Through 3 is unused in the REAT system configuration. Two of its holes are covered by being outside the room dimensions. All of Pass-Through 3's holes contain sound attenuating foam to prevent passage of sound into the test chamber.

Figure 5. Orthographic view of South Wall of REAT Facility (not to scale).

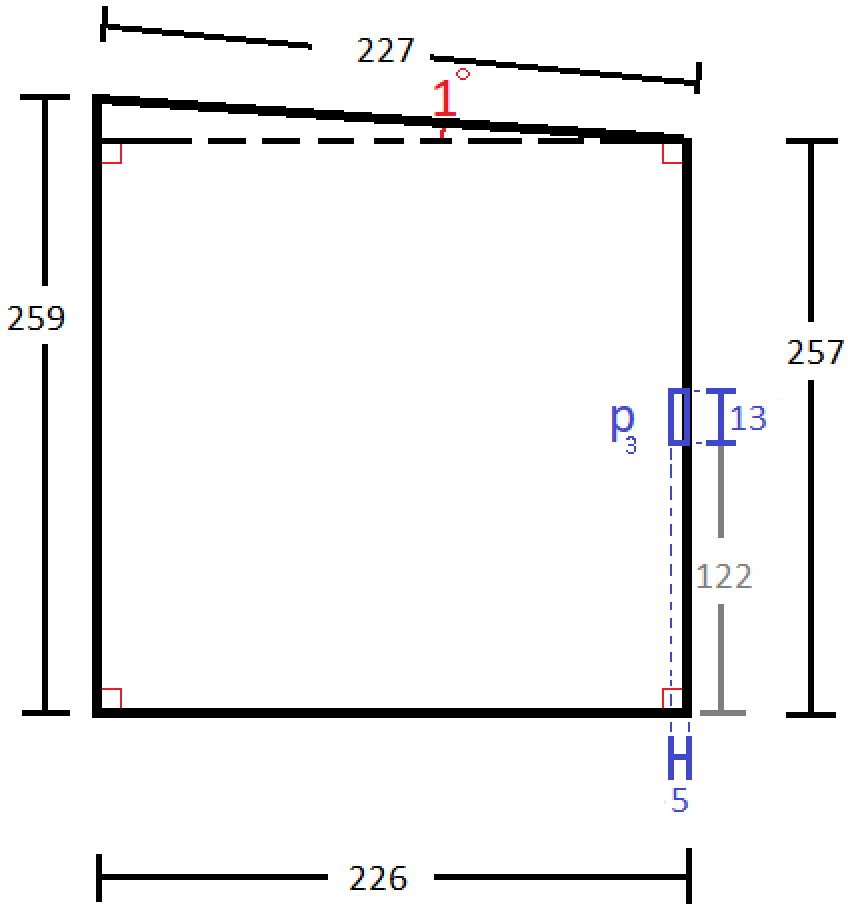
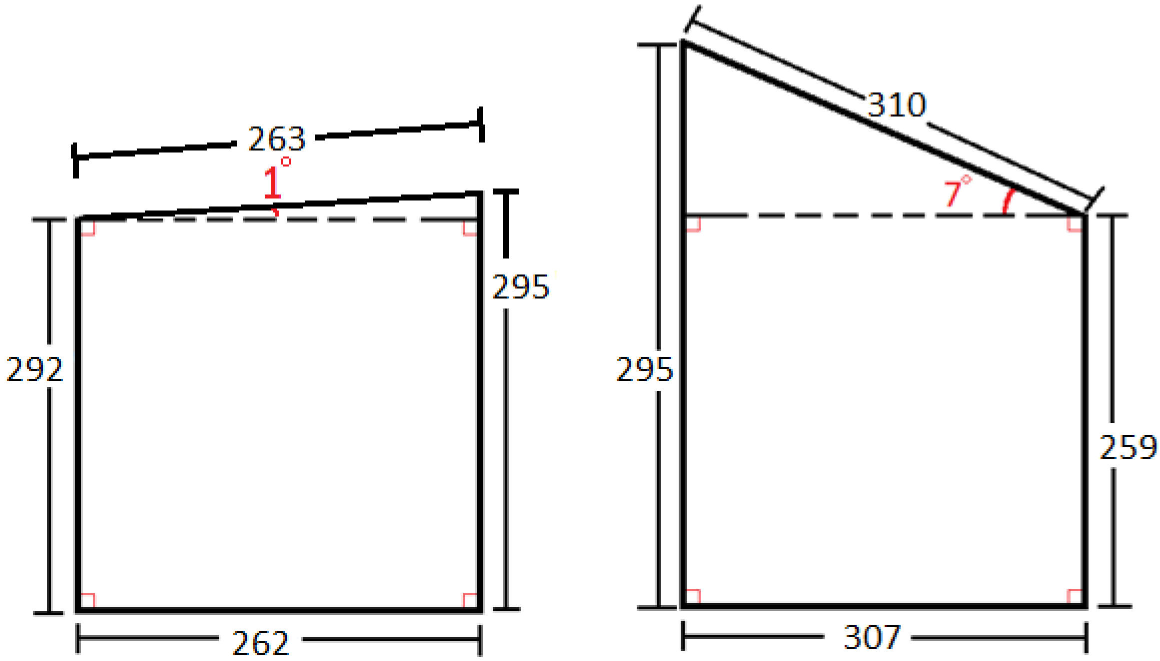


Figure 5 depicts a hole in the gypsum board on the South wall that enables access to the actual pass-through (p3) on the West wall.

Figure 6. Orthographic view of North and East Walls of REAT Facility (not to scale).



North wall (left) and East wall (right) contain no modifications or noteworthy features.

Instrumentation and Operational Techniques

The instrumentation used for the presentation of test signals and recording of subject responses is the "VT HPD Test" integrated test system. The VT HPD Test system consists of a control Personal Computer (ASUS 877 V-PRO) and two 2-channel digital signal processors (DSPs) (RP2.1 Tucker-Davis Technologies [TDT]) with digitally programmable attenuators (TDT PA5x). Via USB connection, the personal computer interfaces with, and controls, the DSPs and attenuators. The computer provides the capabilities necessary for controlling the complex audiometric procedures in real time and possesses sufficient hard disk space for all controller and utility programs. All experimenter controls of the test stimuli and scoring/recording of subject responses are implemented via the computer.

The DSPs generate pulsed (for 250 ms at 2 pulses per second) 1/3 octave band (OB)-filtered noise centered at 125, 250, 500, 1000, 2000, 4000, and 8000 Hz in accordance with S12.6-2008. A separate executable file provides nine signals, those of ANSI 12.6-2008 plus 1/3 OBs centered at 3150 and 6300 Hz, in order to conduct ANSI 3.19-1974 attenuation tests (American National Standards Institute, 1974). All signal generation, attenuation, and presentations are accomplished via three independent channels. Each channel is routed to a 2-way loudspeaker inside the test room. Over each channel, the signal passes through a level attenuator (PA5x, with a range of 0 to -120.0 dB in 0.1 dB steps) into a 100-watt 4-channel power amplifier, which drives each 8-ohm impedance loudspeakers via a separate channel. The signals for each 1/3 OB are equalized via software control such that their relative levels meet the minimum audible field (MAF) contour with corrections for the response of the test room. The MAF contour is modifiable in a software program.

Audiograms for unoccluded and occluded subject thresholds are obtained in accordance with the guidelines in Section 7 of ANSI 12.6-2008. Audiograms are collected automatically (under computer control and scoring), employing the Békésy tracking method with the subject controlling the signal level through a sound level attenuator via a silent, detent-free, push button response switch. The dB-step and time-per-step values are set to a 1 dB step size with a 0.5 second duration per step resulting in an attenuator slope of 2 dB/s. The presentation order of the 1/3 OB test signals is 125 Hz through 8000 Hz consecutively.

An infinite number of excursions of the audiogram trace are available during any trial at each frequency, and a test frequency may be skipped at the discretion of the experimenter and under his/her control, if the trace is unacceptable. Traces are shown on the computer screen as numerical 'step' values as a trial progresses. This allows the experimenter to monitor the screen in order to check for audiogram reliability in real time. The computer program continuously samples the trace to determine if it meets the criteria for an acceptable trial. The standard scoring criteria set are based on Section 7.4 of ANSI 12.6-2008, "Threshold measurement method – Békésy tracking procedure" (ANSI, 2008, p. 10) A trace is considered acceptable if there are at least six reversals (ignoring the first reversal after a change in frequency), in which no peak is lower than any valley, and the range of any excursion (peak to valley difference) is greater than or equal to 3 dB but does not exceed 20 dB. (These criteria were invoked since ANSI S3.19-1974 contained no such guidelines for acceptable automatic audiogram traces and the S12.6-2008 requirements follow consensus for audiometric practices.) At the end of an audiogram, the threshold for a given frequency is calculated and stored by the computer as the exact (to 0.1 dB resolution) midpoint of the trace excursions for that frequency. As each trial is completed, the thresholds and attenuation data are displayed on the computer screen for experimenter confirmation and stored automatically with filenames created with a subject identifier and other demographic data, as well as the test data. When the required number of subjects for the type of HPD being tested have undergone the threshold tests, the attenuation means, ranges, standard deviations, and a Noise Reduction Rating (NRR) are calculated from the scored data using an Excel spreadsheet. The data can also be used to manually calculate an NRR, or any other type of rating, for the HPD, by reprogramming the formulae in Excel.

In addition to the aforementioned instrumentation for the presentation of test signals and conduct of the threshold tests, several peripheral systems exist in the facility. In accordance with section 4.3.6 of the S12.6-2008 standard, NSMRL's VT HPD Test system can be used to generate a pink noise signal to aid the subject in fitting the HPD. This signal is presented through all three loudspeakers at 90 dB SPL default value, but can be adjusted to as soft as 70 dB SPL or as loud as 100 dB SPL.

A two-way intercom system provides for immediate communication between subject and experimenter, and this system incorporates a "hot" microphone in the interior of the chamber so the subject does not have to rely on a push-to-talk switch. In accordance with Section 4.5 of the S12.6-2008 standard, a viewing window is present so that the experimenter can visually monitor the chamber interior. Because the subject is not to re-adjust the HPD after the test commences, the viewing window is useful in helping to ensure subject compliance.

Verification Procedures & Data for ANSI S12.6 (2008) Physical Requirements

This section details the measurement procedures and resultant data used to verify calibration of the physical facility and sound field, as well as the signal generation, control and presentation of subsystems. Referring to section 4, “Physical Requirements”, of ANSI 12-6-2008, each ensuing verification procedure discussed herein is keyed to the HPD test standard by ANSI12.6-2008 subsection and paragraph. For example, “Test site” constitutes to subsection 4.2 and the reverberation time requirements appear as subsection 4.2.2. Also, the specifications given in S12.6-2008 are quoted at the beginning of each subsection herein.

Unless noted otherwise, all measurements for the ANSI 12.6-2008 physical requirements were obtained using a real-time analyzer (Brüel & Kjær Type 2270) provided by NSMRL. This analyzer incorporates digital 1/1 and 1/3 octave bandwidth filters which meet ANSI S1.11-1986 “Specifications for Octave-Band and Fractional-Octave-Band Analog and Digital Filters” for Class O-AA (American National Standards Institute, 1986).

The microphones used were dependent on the particular measurement being obtained. The microphone models pertinent to each measurement are specified and reported below in the relevant section to which they apply. All verification measurements were obtained with the chamber configured exactly as for testing, unless otherwise specified (e.g., 4.2.1.1 Uniformity measurements are to be taken with the subject and subject’s chair absent from the room).

4.1 Test Signals

In accordance with ANSI S12.6 (2008): “Test Signals shall consist of pink or white noise, filtered into one-third octave-bands. Center frequencies shall include at least 125, 250, 500, 1000, 2000, 4000 and 8000 Hz” (ANSI, 2008, p. 4). NSMRL’s VT HPD Test system generates and presents pulsed (for 250 ms at 2 pulses per second) 1/3 octave band-filtered noise centered at 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. An optional executable file adds bands centered at 3150 and 6300 Hz for S3.19 testing as well.

4.2 Test Site

4.2.1 Diffuse sound field requirements

4.2.1.1 Uniformity

In accordance with ANSI S12.6 (2008), which states:

> The sound pressure level measured using an omnidirectional microphone at six positions relative to the reference point, with the subject and the subject’s chair absent, ±15 cm in front-back, up-down, and left-right axes shall remain within a range of 5 dB for each test signal. The difference between the left-right positions shall not exceed 3 dB. The orientation of the microphone shall be kept the same at each position. (ANSI, 2008, p. 4)

Uniformity measurements were made using a sound level meter (Brüel & Kjær Type 2270) and a 1-inch microphone (Brüel & Kjær Type 4145). 30-second L_{eq} measurements were obtained at each of the six test positions for each of the seven test bands. The room was configured exactly as for testing, but without the subject or chair present. The 1/3 OB measurements were obtained using a steady-state pink noise test signal generated by the VT HPD system presented at 70 dBA. (See Tables 2 and 3.)

As shown in Table 2, the fourth column (Δ, R-L) presents the difference in SPL between the right and left microphone positions for each of the 1/3 OBs. The right-left differences of all test bands are below the 3 dB maximum allowed in S12.6-2008. The eighth column (Δ, SIX) in Table 3 shows SPL variations for each test band across all six measurements. All variations are below the 5 dB maximum specified in the standard. Therefore, results show the NSMRL REAT test room meets all uniformity criteria.

Table 1. Test Signal Variation at Right/Left Positions about Head Center.

1/3 OB Center (Hz)	Right (dB SPL)	Left (dB SPL)	Δ* R-L (dB)	Δ** Allowed (dB)
125	49.74	50.57	0.83	3.0
250	48.82	48.79	0.03	3.0
500	56.22	54.32	1.9	3.0
1000	58.43	57.84	0.59	3.0
2000	58.55	58.78	0.23	3.0
4000	59.66	58.94	0.72	3.0
8000	57.53	57.72	0.19	3.0

*Absolute value dB difference between right and left microphone positions.

**Allowed variation per standard

Table 2. Test Signal Variation at Six Positions about Head Center.

1/3 OB Center (Hz)	Left (dB SPL)	Right (dB SPL)	Front (dB SPL)	Back (dB SPL)	Up (dB SPL)	Down (dB SPL)	Δ* Six (dB)	Δ ** Allowed (dB)
125	50.57	49.74	50.55	49.85	49.95	49.59	0.98	5.0
250	48.79	48.82	49.59	47.84	49.36	49.02	1.75	5.0
500	54.32	56.22	55.08	55.20	55.13	55.56	1.90	5.0
1000	57.84	58.43	58.13	57.54	58.26	58.07	0.89	5.0
2000	58.78	58.55	57.89	58.21	59.08	58.62	1.19	5.0
4000	58.94	59.66	59.07	59.43	59.20	59.26	0.72	5.0
8000	57.72	57.53	57.25	57.53	57.41	57.09	0.63	5.0

* Absolute value dB difference between right or left, back and front or up and down microphone positions

**Allowed variation per standard

4.2.1.2 Directionality

In accordance with ANSI S12.6 (2008):

The directionality of the sound field shall be evaluated at the reference point for test bands with center frequencies greater than or equal to 500 Hz, with subject and the subject's chair absent. The measurements shall be conducted with a directional microphone that exhibits in its free-field polar response at the one-third octave test

> bands, at least 10 dB front-to-side rejection for a cosine microphone, or at least 10 dB front-to-back rejection for a cardioid microphone.
>
> The Sound field shall be considered to approximate a random incidence field if, when the microphone is rotated at the reference point through 360 degrees in each of the three perpendicular planes defined by the front-back, up-down, and left-right axes coincident with the reference point, the observed sound pressure level in each test band remains within the variation allowed in Table 1 when the measurements are evaluated separately for each plane. The sound pressure levels may also be obtained by measuring at fixed 15 degree increments as the microphone is rotated 360 degrees in each plane. (ANSI, 2008, p. 4)

Before making directionality measurements, the microphone for such testing (Azden SGM-1X) was evaluated to confirm its specifications to fulfill the 10 dB front-to-back rejection requirement for cardioid microphones. The microphone was placed in NSMRL's anechoic chamber 305 cm from a loudspeaker both at the same height of 109 cm. The loudspeaker presented a pure tone using a waveform generator (Tucker-Davis Technologies) set at 2.00 volts at the test frequencies (125, 250, 500, 1000, 2000, 4000 and 8000 Hz). The setting of 2.00 volts was chosen in order to get a stable sine wave to measure on an oscilloscope (Tektronix TDS 224). The microphone was placed at 0° eccentricity directly facing the loudspeaker (Tannoy Reveal 601p) and a measurement was obtained. Next, the microphone was rotated 180 degrees and a second measurement was obtained. The voltage measurements at the same presentation levels were recorded on the oscilloscope and the measured difference in dB was calculated by converting the differences in voltages to decibels. The post-calculation values were then reported as the free field rejection (See Table 3). The allowable sound field variations were determined by interpolating the values from Table 1 in the ANSI 12.6-2008 standard. The allowable sound field variations are the maximum allowable variations for the sound directionality measurements. Results showed that the microphone exceeded the 10 dB rejection requirement qualifying it for directionality measurements.

Table 3. Azden SGM-1X Microphone's measured front-to-back rejection and resultant allowable sound field variation.

1/3 OB Center (Hz)	Measured Microphone Free-Field Rejection (dB SPL*)	Minimum Front-to-Back Rejection for Cardioid Microphone (dB)	Allowable Sound Field Variation (dB**)
125	16.60	10.00	4.320
250	15.94	10.00	4.188
500	11.87	10.00	3.374
1000	16.96	10.00	4.392
2000	10.41	10.00	3.082
4000	10.12	10.00	3.024
8000	10.32	10.00	3.064

*Obtained through acoustic measurements in NSMRL anechoic chamber

**From Table 1, ANSI 12.6-2008. (Values interpolated, per standard, as necessary)

In order to perform data collection for the directionality test, the microphone (Azden SGM-1X) was mounted in a switch-controlled, single-plane rotatable device. For each measurement, the microphone was rotated around the x, y, and z axes in 15-degree increments. Specifically, while the REAT system generated a pink noise test signal at 79 dB SPL, 1/3 octave band measurements were obtained (125 to 8000 Hz) at discrete 15-degree increments about each of the three principal axes. The y-axis is in the horizontal plane with the axis of the microphone oriented front-to-back with respect to the subject, the z-axis is also in the horizontal plane with the axis of the microphone oriented left-to-right with respect to the subject and perpendicular to the y-axis, and the x-axis is in the vertical plane perpendicular to both the y- and the z-axes. Through 360 degrees of rotation, a total of 24 measurements were recorded for each axis of rotation. At each of the 24 positions, one measurement that included all seven 1/3 octave band frequencies was taken. The actual SPL measurements for each 1/3 octave test band at each microphone position were processed by the SLM and are shown in Tables 5-7 for the x, y, and z axes respectively. For each table, the last three rows show the *mean* SPL for each of the seven test bands for that axis, the overall *variation* between measurements over 360 degrees, and the *allowable variation* per the S12.6-2008 standard. While all frequencies were tested and measured for directionality, S12.6-2008 only requires those at or above 500 Hz to pass. All test bands at or above 500 Hz met the S12.6-2008 standard requirements in all three axes.

Table 4. Sound field directionality data for microphone rotation about the X-Axis (in dB SPL) with measured sound level at position 0 (degrees) and deviations (dB) for all other positions.

Mic Position (deg.)	125 Hz (dB)	250 Hz (dB)	500 Hz (dB)	1000 Hz (dB)	2000 Hz (dB)	4000 Hz (dB)	8000 Hz (dB)
0	40.1	40.9	48.3	47.3	47.4	47.5	40.6
15	0	0.4	0	-0.1	-0.2	0.2	0.1
30	0.3	0.4	-0.1	-0.1	-0.7	0.1	0.3
45	0.1	0.8	-0.1	0.1	-1	-0.2	0.2
60	0.3	0.3	0	0	-1.3	-0.2	0.2
75	0.3	0.4	0	-0.1	-1.6	-0.3	0.1
90	0.3	0.6	0.1	-0.2	-1.7	-0.4	-0.7
105	0.3	0.9	0.2	-0.5	-1.8	-0.3	-1.5
120	-0.1	1.1	0.3	-0.9	-1.8	-0.2	-1.4
135	0.2	1	0.6	-1.2	-1.8	-0.8	-1.2
150	0.3	1	0.3	-1.3	-1.6	-1	-1.8
165	0.3	1.3	0.2	-1.5	-1.6	-0.8	-2.4
180	0.3	1.1	0.1	-1.5	-1.6	-0.5	-2
195	-0.1	1.1	0	-1.4	-1.5	-0.1	-0.9
210	0.1	1.1	-0.3	-1.3	-1.3	0.3	-0.2
225	0.2	0.9	-0.6	-0.9	-1	0.7	-0.3
240	0.2	0.5	-0.6	-0.7	-0.8	0.8	-0.1
255	-0.3	0.3	-0.6	-0.5	-0.7	0.7	-0.1
270	-0.4	0.1	-0.5	-0.4	-0.6	0.3	-0.5
285	-0.5	-0.2	-0.4	-0.3	-0.4	0.2	-1.1
300	-0.4	-0.5	-0.1	-0.3	-0.4	-0.1	-0.9
315	-0.5	-0.4	-0.1	-0.2	-0.3	-0.4	-0.4
330	-0.2	-0.1	-0.1	-0.1	-0.1	-0.3	-0.2
345	-0.2	-0.3	0.2	0	0.1	-0.2	-0.4
Mean	0	0.5	-0.1	-0.6	-1	-0.1	-0.6
Variation	*0.8*	*1.8*	*1.2*	*1.6*	*1.9*	*1.8*	*2.7*
Allowed	*4.32*	*4.188*	*3.374*	*4.392*	*3.082*	*3.024*	*3.064*

Table 5. Sound field directionality data for microphone rotation about the Y-Axis (dB SPL) with measured sound level at position 0 (degrees) and deviations (dB) for all other positions.

Mic Position (deg.)	125 Hz (dB)	250 Hz (dB)	500 Hz (dB)	1000 Hz (dB)	2000 Hz (dB)	4000 Hz (dB)	8000 Hz (dB)
0	39.9	40.5	48.6	47.7	47.9	47.3	40.7
15	0.1	-0.2	0.4	-0.1	0.2	-0.1	-0.2
30	0.2	-0.3	0.3	0	0.1	-0.4	-0.4
45	0.2	-0.3	0.3	0.2	0	-0.6	-0.4
60	0.7	-0.5	0.6	0.2	-0.3	-0.4	0
75	0.5	-0.2	0.5	0.1	-0.4	0	-0.5
90	0.3	-0.3	0.3	0.3	-0.4	-0.2	-0.8
105	0.2	0	0.1	0.1	-0.4	-0.3	-0.8
120	0.3	0	0	0.1	-0.5	-0.5	-0.3
135	-0.1	-0.2	-0.1	0.4	-0.7	-0.4	0
150	-0.4	-0.6	-0.4	0.3	-0.8	-0.3	-0.6
165	-0.5	-0.8	-0.5	0.4	-1	0.1	-0.8
180	-0.4	-1	-0.6	0.2	-0.9	0	-0.7
195	-0.7	-1.2	-0.7	0.3	-0.7	-0.1	-0.1
210	-0.5	-1.8	-0.8	0.1	-0.6	0	-0.1
225	-0.2	-1.6	-0.7	-0.1	-0.5	0.1	-0.1
240	-0.5	-1.6	-0.5	-0.2	-0.5	-0.1	0
255	-0.4	-1.4	-0.4	-0.5	-0.6	-0.5	-0.1
270	-0.3	-1	-0.2	-0.6	-0.6	-0.5	-0.2
285	-0.2	-0.9	0	-0.8	-0.7	-0.7	-0.2
300	-0.4	-0.5	-0.3	-0.7	-0.8	-0.8	-0.5
315	-0.2	-0.2	-0.1	-0.6	-0.7	-0.5	-0.5
330	0	-0.1	-0.2	-0.4	-0.5	-0.3	-0.8
345	0.3	-0.1	0	-0.3	-0.2	0	-0.4
Mean	-0.1	-0.6	-0.1	-0.1	-0.5	-0.3	-0.4
Variation	*1.4*	*1.8*	*1.4*	*1.2*	*1.2*	*0.9*	*0.8*
Allowed	*4.32*	*4.188*	*3.374*	*4.392*	*3.082*	*3.024*	*3.064*

Table 6. Sound field directionality data for microphone rotation about the Z-Axis (dB SPL) with measured sound level at position 0 (degrees) and deviations (dB) for all other positions.

Mic Position (deg.)	125 Hz (dB)	250 Hz (dB)	500 Hz (dB)	1000 Hz (dB)	2000 Hz (dB)	4000 Hz (dB)	8000 Hz (dB)
0	38.4	39.9	47.3	46.3	46.8	46.5	39.6
15	-1	-1.1	-1	-0.9	-0.8	-1.1	-0.8
30	-1.2	-1.1	-1.3	-1.1	-0.8	-1.4	-1.4
45	-1.2	-1.2	-1.5	-1.3	-0.7	-1.3	-1.6
60	-1	-1.1	-1.6	-1.1	-0.7	-1.3	-1.5
75	-1.1	-1.1	-1.9	-1.2	-0.5	-1.3	-1.3
90	-1.4	-0.7	-2.1	-1.5	-0.5	-1.1	-1
105	-1	-0.5	-2.1	-1.6	-0.7	-1	-0.8
120	-1.2	-0.4	-2.1	-1.9	-1.1	-1.5	-0.8
135	-1.3	-0.3	-2	-2.1	-1.3	-1.8	-1.9
150	-1.4	-0.6	-2.1	-2.4	-1.6	-1.9	-2.2
165	-1.6	-0.6	-2.1	-2.7	-1.9	-1.8	-2
180	-1.9	-1.2	-2.2	-2.9	-2.1	-1.7	-1.5
195	-1.6	-1.4	-2	-2.6	-2	-1.3	-1.4
210	-1.9	-2.2	-2	-2.5	-1.8	-1.4	-1.1
225	-1.8	-2.2	-2	-2.2	-1.6	-1.2	-1.2
240	-2.1	-2.2	-1.9	-1.9	-1.3	-1.1	-1.4
255	-2.1	-2.2	-1.7	-1.6	-1.1	-1	-1
270	-2.4	-2.2	-1.4	-1.5	-1	-1.1	-0.8
285	-1.9	-1.9	-1.5	-1.3	-0.9	-1.2	-0.8
300	-1.9	-1.1	-1.1	-1	-1	-1	-1.1
315	-1.8	-1	-1.2	-0.6	-0.9	-0.7	-1
330	-1.6	-0.8	-1	-0.6	-0.9	-1	-0.8
345	-1.6	-0.7	-1	-0.4	-0.7	-0.7	-0.9
Mean	-1.5	-1.2	-1.6	-1.5	-1.1	-1.2	-1.2
Variation	*2.4*	*2.2*	*2.2*	*2.9*	*2.1*	*1.9*	*2.2*
Allowed	*4.32*	*4.188*	*3.374*	*4.392*	*3.082*	*3.024*	*3.064*

4.2.2 Reverberation Time

In accordance with ANSI S12.6-2008: "The reverberation time at the reference point, with the subject and the subject's chair absent, shall not exceed 1.6 s for each test signal" (ANSI, 2008, p. 4)

Reverberation Time (RT60) was measured at the subject's head center position five times. 1/3 octave band values from 125 to 8000 Hz were obtained simultaneously and separated post signal acquisition. Measurements were obtained using a sound level meter (Brüel & Kjær Type 2270) and a 1-inch microphone (Brüel & Kjær Type 4145). The measurements were obtained using an impulse noise created by the clapping of two pieces of wood together. Two 7.5-inch long two-by-four pieces of pine wood that were each taped to a 7.5-inch long .75"-by-2.375" piece of wood were used to create the impulse. While holding the smaller pieces of wood and clapping the two-by-fours together, an impulse noise was created with minimal dampening. A reverberation test module contained in the sound level meter calculated and output the reverberation time data (i.e., RT60). RT60 data in seconds for each of the five measurements, as well as the mean of those measurements, obtained using the described method are presented in Table 7. The reverberation times in the NSMRL REAT test room were demonstrated to be in accordance with section 4.2.2 of S12.6-2008 (2008).

Table 7. Test Room Reverberation Times (RT60).

1/3 OB Center (Hz)	Trial 1 (sec)	Trial 2 (sec)	Trial 3 (sec)	Trial 4 (sec)	Trial 5 (sec)	Mean (sec)	Max Allowed* (sec)
125	0.43	0.34	0.35	0.44	0.40	0.39	1.6
250	0.58	0.48	0.54	0.40	0.55	0.51	1.6
500	0.65	0.68	0.68	0.60	0.63	0.65	1.6
1000	0.73	0.69	0.74	0.72	0.71	0.72	1.6
2000	0.68	0.67	0.68	0.78	0.65	0.69	1.6
4000	0.67	0.68	0.7	0.72	0.67	0.69	1.6
8000	0.49	0.49	0.49	0.49	0.49	0.49	1.6

*Maximum RT60 allowed per S12.6-2008.

4.2.3 Ambient Noise

In accordance with ANSI S12.6-2008:

> The ambient noise at the reference point, with the subject absent, and with all signal presentation equipment on and adjusted to a gain of 20 dB above the levels necessary to elicit the average open threshold of hearing for the group of test subjects at all test frequencies, but with no test signal present, shall not exceed the octave-band levels in Table 2. Ambient noise levels shall be measured at least monthly, or more often if the laboratory conditions warrant. All ventilation and lighting shall be set as would be normal during threshold testing. The noise floor in each frequency band shall be calculated from the median of five measurements made at least 15 minutes apart on the same day or on different days within the past year.
>
> If any extraneous noise becomes audible in the test room during the test, the listener shall signal the experimenter to stop the test. Once the noise has stopped, the test shall

resume for a test frequency prior to which the disruption was first noted. (ANSI, 2008, p. 5)

Ambient Noise measurements were made using a sound level meter (Bruel & Kjaer Type 2270) and 1-inch microphone (Bruel & Kjaer 4145) connected via extension cable (Bruel & Kjaer ZC 0032). Octave band ambient noise measurements were obtained with no subject in the test room and the VT HPD test system powered on with no signal being output. Measured ambient noise levels were found to be in accordance with ANSI S12.6-2008 requirements (See Table 8). All subsequent ambient noise measurements during the test period were recorded to comply with ANSI S12.6-2008 (See Appendix B).

Table 8. Ambient Noise Levels in the Test Facility.

OB Center (Hz)	Permissible Ambient OB SPL (dB)*	Median Ambient OB SPL (dB)	Trial 1 (dB SPL)	Trial 2 (dB SPL)	Trial 3 (dB SPL)	Trial 4 (dB SPL)	Trial 5 (dB SPL)
31.5	57.0	28.89	28.06	28.83	28.89	29.25	29.14
63	43.0	16.73	17.33	16.69	16.57	16.73	19.30
125	29.0	12.08	18.67	13.64	11.53	11.55	12.08
250	21.0	6.85	8.99	16.27	6.40	6.51	6.85
500	16.0	13.10	13.23	13.34	13.01	13.10	12.72
1000	13.0	8.35	8.96	8.35	8.15	8.21	8.61
2000	14.0	7.57	7.59	7.57	7.45	7.44	7.62
4000	11.0	8.59	8.68	8.59	8.58	8.57	8.61
8000	14.0	10.08	10.10	10.07	10.08	10.08	10.10
*Time	Recorded		9:41am	9:57am	10:13am	10:29am	10:45am

*Data was collected on 23 October 2017

4.3 Test Apparatus

In accordance with ANSI S12.6 (2008): "The test apparatus shall include a noise generator, one-third octave-band filter set, control circuits (on-off switch and calibrated attenuators), power amplifier(s), loudspeaker(s), and a head-positioning device. Computer noise generation, filtering and control is also acceptable" (ANSI, 2008, p. 6)

NSMRL's VT HPD Test system consists of three independent channels equipped with several fundamental components. A Personal Computer (ASUS 877 V-PRO) controls a real time digital signal processor (Tucker Davis Technologies RP2.1) that generates and filters pink noise to produce the 1/3 OB test noise bands used in the REAT testing procedure. The PC also controls programmable digital signal attenuators (TDT PA5x). Test signals are independently amplified by three of the four available channels of a 100-watt power amplifier (Applied Research and Technology SLA4 Studio Linear Amplifier). The signals are output to the LF inputs of three loudspeakers (KEF R100) housed in the REAT test chamber (See Figure 2). The subject holds a silent, detent-free pushbutton switch to indicate the audibility of the signal at auditory threshold using the requisite Békésy procedure. Specifically, a stimulus is presented to a subject that is automatically varied at a fixed rate (i.e., increases in attenuation occur when a button is being depressed and decreases in attenuation occur when the button is released) and threshold is determined by the mean of the midpoints of a number of trials (Békésy & Wever, 1960). In addition, the subject's head is maintained at a fixed position in the center of the chamber with assistance from an orienting device suspended from the ceiling. Note: A second orienting device is used to mark the reference point for the center of the head during daily system calibration. The test apparatus portion of NSMRL's VT HPD Test system meets requirements as outlined in paragraph 4.3 of ANSI S12.6-2008.

4.3.1 Test Signal (1/3 Octave Band of Noise)

In accordance with ANSI S12.6-2008:

> The test signals, as measured electrically at the speaker terminals, shall consist of one-third octave bands of pink or white noise, with a spectrum shape equivalent to that which would be created by a filter meeting the requirements of ANSI S1.11 (American National Standards Institute, 2004), Class 0. The mode of operation in changing from one band to another shall be a discrete step function; a gradual continuously adjustable mode of change is not acceptable. (ANSI, 2008, p. 6)

The digital signal processor (Tucker Davis Technologies, RP2.1) component of NSMRL's VT HPD Test system is programmed to generate 1/3 OB noise by first generating a pink noise and then passing it twice through a 5^{th} order Butterworth filter to produce each 1/3 OB test signal. The test system generates each 1/3 OB test noise band separately.

4.3.2 Dynamic Range

In accordance with ANSI S12.6-2008:

> The test apparatus shall be able to generate test signal sound pressure levels at the reference point, for any test band, that vary from at least 10 dB above the subject's occluded threshold of hearing to 10 dB below the subject's open threshold of hearing. For most hearing protectors this is equivalent to a level of 60 dB above to 10 dB below the open threshold of hearing.
>
> NOTE: The level of 10 dB below the threshold of hearing may be calculated on the basis of electrical calibration. (ANSI, 2008, p. 6)

For each of the 1/3 OB test signals, a 30 s L_{eq} measurement of the maximum signal level output from the loudspeakers was measured at a reference point representing the center of a subject's head using a calibrated sound level meter (Brüel & Kjær Type 2270) and 1-inch microphone (Brüel & Kjær Type 4145). A constant (i.e., non-pulsed) signal was used for all measurements.

The maximum output levels for each 1/3 OB are presented in the third column of Table **9**. During an actual REAT procedure, these output levels would be well above the required maximum levels outlined in ANSI S12.6-2008, even for a double passive HPD configuration. Table 9 also presents the minimum audible field values for comparison of the maximum signal output to the open ear threshold of audibility.

For all test bands, NSMRL's VT HPD Test system maximum occluded test signal output level was at least 60.0 dB above the open threshold of audibility, thus meeting the 60 dB requirement in ANSI

S12.6-2008. With a level attenuator range of 120 dB, the 1/3 OB test signal level can be decreased to below the open threshold of audibility in each of the seven test bands.

Table 9. Maximum Loudspeaker Output Levels for Each 1/3 OB Test Signal.

1/3 OB Center (Hz)	Minimum Audible Field (MAF) (dB SPL)	Maximum Loudspeaker Output Level (dB SPL)
125	10.8	88.36
250	-1.16	86.59
500	7.8	93.55
1000	3.4	95.38
2000	2.6	96.41
4000	3.9	97.34
8000	5.3	96.58

4.3.3 Distortion

In accordance with ANSI S12.6 (2008):

> When the test apparatus generates 1/3 octave-band test signals at the reference point, at sound pressure levels which comply with Clause 4.3.2, the sound pressure levels shall be at least 6 dB down from the maximum level in adjacent 1/3 octave bands, at least 30 dB down in 1/3 octave bands one octave or more removed from the center frequency, and at least 40 dB down in 1/3 octave bands two octaves or more removed from the center frequency. During the test, the sound shall be reproduced without audible buzzing, crackle, or rattle. (ANSI, 2008, p. 6)

For the distortion measurements, 1/3 OB test signals were produced at maximum amplifier gain in the test room, and the sound level meter (Brüel & Kjær Type 2270) with a 1-inch microphone (Brüel & Kjær Type 4145) was configured to measure in 1/3 OBs. 30 second L_{eq} measurements were made for each of the seven test bands. SPL measurements were obtained in each of the 1/3 OBs corresponding to each of the two adjacent 1/3 OBs to either side of the 1/3 octave test band being analyzed. The actual transmission loss was calculated by subtracting the SPL for each of the adjacent 1/3 OBs from the SPL for the 1/3 octave test band. These measurements were then compared to the minimum acceptable transmission loss. If the obtained transmission loss in each of the 1/3 OBs was greater than or equal to the specified level, the system was considered to have met the requirements.

The results of the measurements and calculations described for distortion are shown in Tables 10-16. In these tables, the actual (measured) transmission loss for each 1/3 OB test signal (shown in the third column) is compared to the minimum required per S12.6-2008 (shown in the fourth column). In all cases, the measured transmission loss exceeded what is required by the standard.

Table 10. Distortion. Measured vs. Required Transmission Loss for 1/3 OB Centered at 125 Hz.

1/3 OB C.F. (Hz)	Measured (dB SPL)	Transmission Loss Measured (dB)	Transmission Loss Required (dB)
31.5	22.84	65.52	40
40	24.27	64.09	30
50	30	58.36	30
63	39.71	48.65	30
80	52.92	35.44	6
100	77.71	10.65	6
125	*88.36*		
160	77.67	10.69	6
200	55.02	33.34	6
250	47.33	41.03	30
315	40.35	48.01	30
400	44.99	43.37	30
500	29.96	58.4	40
630	30.67	57.69	40

Table 11. Measured vs. Required Transmission Loss for 1/3 OB Centered at 250 Hz.

1/3 OB C.F. (Hz)	Measured (dB SPL)	Transmission Loss Measured (dB)	Transmission Loss Required
50	16.13	70.46	40
63	14.49	72.1	40
80	16.89	69.7	30
100	35.18	51.41	30
125	44.99	41.6	30
160	54.57	32.02	6
200	77.13	9.46	6
250	*86.59*		
315	76.7	9.89	6
400	53.37	33.22	6
500	44.43	42.16	30
630	34.15	52.44	30
800	38.84	47.75	30
1000	29.93	56.66	40

Table 12. Measured vs. Required Transmission Loss for 1/3 OB Centered at 500 Hz.

1/3 OB C.F. (Hz)	Measured (dB SPL)	Transmission Loss Measured (dB)	Transmission Loss Required
100	19.49	74.06	40
125	26.15	67.4	40
160	27.18	66.37	30
200	35.43	58.12	30
250	44.53	49.02	30
315	58.42	35.13	6
400	82.77	10.78	6
500	*93.55*		
630	82.53	11.02	6
800	58.49	35.06	6
1000	46.59	46.96	30
1250	37.93	55.62	30
1600	43.57	49.98	30
2000	35.57	57.98	40

Table 13. Measured vs. Required Transmission Loss for 1/3 OB Centered at 1000 Hz.

1/3 OB C.F. (Hz)	Measured (dB SPL)	Transmission Loss Measured (dB)	Transmission Loss Required
200	17.33	78.05	40
250	17.16	78.22	40
315	20.75	74.63	30
400	37.18	58.2	30
500	46.9	48.48	30
630	61.34	34.04	6
800	85.83	9.55	6
1000	*95.38*		
1250	84.67	10.71	6
1600	60.18	35.2	6
2000	49.11	46.27	30
2500	38.73	56.65	30
3150	38.56	56.82	30
4000	26.25	69.13	40

Table 14. Measured vs. Required Transmission Loss for 1/3 OB Centered at 2000 Hz.

1/3 OB C.F. (Hz)	Measured (dB SPL)	Transmission Loss Measured (dB)	Transmission Loss Required
400	17.89	78.52	40
500	18.11	78.3	40
630	20.07	76.34	30
800	37.95	58.46	30
1000	47.58	48.83	30
1250	61.51	34.9	6
1600	86.14	10.27	6
2000	*96.41*		
2500	85.43	10.98	6
3150	61.09	35.32	6
4000	53.38	43.03	30
5000	40.72	55.69	30
6300	41.2	55.21	30
8000	27.31	69.1	40

Table 15. Measured vs. Required Transmission Loss for 1/3 OB Centered at 4000 Hz.

1/3 OB C.F. (Hz)	Measured (dB SPL)	Transmission Loss Measured (dB)	Transmission Loss Required
800	22.66	74.68	40
1000	20.88	76.46	40
1250	19.62	77.72	30
1600	38.27	59.07	30
2000	47.91	49.43	30
2500	61.6	35.74	6
3150	86.26	11.08	6
4000	*97.34*		
5000	86.35	10.99	6
6300	61.58	35.76	6
8000	51.38	45.96	30
10000	40.14	57.2	30
12500	35.18	62.16	30
16000	27.56	69.78	40

Table 16. Measured vs. Required Transmission Loss for 1/3 OB Centered at 8000 Hz.

1/3 OB C.F. (Hz)	Measured (dB SPL)	Transmission Loss Measured (dB)	Transmission Loss Required
1600	34.15	62.43	40
2000	34.78	61.8	40
2500	36.35	60.23	30
3150	40.41	56.17	30
4000	47.76	48.82	30
5000	59.88	36.7	6
6300	83.12	13.46	6
8000	*96.58*		
10000	81.54	15.04	6
12500	58.84	37.74	6
16000	51.43	45.15	30
20000	40.2	56.38	30

No buzzing, crackling or rattling occurred during the testing.

4.3.4 Control Circuits

In accordance with ANSI S12.6-2008:

> Attenuators shall have a range of at least 90 dB for each test signal with step size of ≤ 2.5 dB. The difference in output between any two attenuator settings, measured with a pure-tone test signal, shall not differ from the indicated difference by more than 3/10 of the indicated increment or by 1 dB, whichever is smaller. Corrections for departure from linearity shall be applied to the data when this requirement is not met. Where possible this test shall be performed acoustically. When the ratio of the acoustically measured sound pressure level to the ambient background noise is less than 20 dB, the linearity of the signal voltage shall be measured at the terminals of the loudspeaker(s). (ANSI, 2008, p. 6)

The three digitally programmable attenuators (TDT PA5x) deployed in the VT HPD system provide a range of 0 dB to -120 dB in 0.1 increments. As an empirical check for linearity of the attenuators, pure tones were produced using the VT HPD Test system and measured by a sound level meter in 10 dB increments. The REAT system software was used to determine the starting point by using the absolute threshold of hearing determined by the software (step level 0) that would change by frequency and moving in 10 dB increments (where each 1 dB increment is a 1 step level change) from that point both up and then down to acquire the full range needed. At each frequency, linearity was verified using a sound level meter (Bruel & Kjaer Type 2270) with a 1-inch microphone (Bruel & Kjaer Type 4145). For a minimum range of 90 dB (using both sound level meter and voltages), measurements were recorded to verify the linearity of the attenuators. The sound level meter was used to measure the sound pressure level for measurements from max output, limited by the range of the attenuators set at 0 dB attenuation down to 20 dB above the ambient noise level (See Table 8). Tables 17-22 present sound pressure levels by frequency. Differences in sound level meter measurements were calculated by subtracting the higher step level minus the next lower step level.

Table 17. Sound Level Measured Linearity at 125 Hz.

Step Level	Measured (dB SPL)	Attenuator 1 level	Attenuator 2 level	Attenuator 3 level	Difference With Previous Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	30.46	70.3	75.2	70.3				
10	40.39	60.3	65.2	60.3	9.93	10.00	0.07	1.00
20	50.48	50.3	55.2	50.3	10.09	10.00	0.09	1.00
30	60.45	40.3	45.2	40.3	9.97	10.00	0.03	1.00
40	70.45	30.3	35.2	30.3	10.00	10.00	0.00	1.00
50	80.44	20.3	25.2	20.3	9.99	10.00	0.01	1.00
60	90.28	10.3	15.2	10.3	9.84	10.00	0.16	1.00
70	99.99	0.3	5.2	0.3	9.71	10.00	0.29	1.00

Table 18. Sound Level Measured Linearity at 250 Hz.

Step Level	Measured (dB SPL)	Attenuator 1 level	Attenuator 2 level	Attenuator 3 level	Difference With Previous Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
10	23.29	72.4	77.3	72.4				
20	33.27	62.4	67.3	62.4	9.98	10.00	0.02	1.00
30	43.36	52.4	57.3	52.4	10.09	10.00	0.09	1.00
40	53.37	42.4	47.3	42.4	10.01	10.00	0.01	1.00
50	63.31	32.4	37.3	32.4	9.94	10.00	0.06	1.00
60	73.25	22.4	27.3	22.4	9.94	10.00	0.06	1.00
70	83.08	12.4	17.3	12.4	9.83	10.00	0.17	1.00
80	92.79	2.4	7.3	2.4	9.71	10.00	0.29	1.00

Table 19. Sound Level Measured Linearity at 500 Hz.

Step Level	Measured (dB SPL)	Attenuator 1 level	Attenuator 2 level	Attenuator 3 level	Difference With Previous Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
20	34.15	71.8	76.7	71.8				
30	44.15	61.8	66.7	61.8	10.00	10.00	0.00	1.00
40	54.25	51.8	56.7	51.8	10.10	10.00	0.10	1.00
50	64.23	41.8	46.7	41.8	9.98	10.00	0.02	1.00
60	74.20	31.8	36.7	31.8	9.97	10.00	0.03	1.00
70	84.11	21.8	26.7	21.8	9.91	10.00	0.09	1.00
80	93.98	11.8	16.7	11.8	9.87	10.00	0.13	1.00
90	103.72	1.8	6.7	1.8	9.74	10.00	0.26	1.00

Table 20. Sound Level Measured Linearity at 1000 Hz.

Step Level	Measured (dB SPL)	Attenuator 1 level	Attenuator 2 level	Attenuator 3 level	Difference With Previous Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
30	27.71	67.7	72.6	67.7				
40	37.81	57.7	62.6	57.7	10.10	10.00	0.10	1.00
50	47.77	47.7	52.6	47.7	9.96	10.00	0.04	1.00
60	57.79	37.7	42.6	37.7	10.02	10.00	0.02	1.00
70	67.73	27.7	32.6	27.7	9.94	10.00	0.06	1.00
80	77.60	17.7	22.6	17.7	9.87	10.00	0.13	1.00
90	87.36	7.7	12.6	7.7	9.76	10.00	0.24	1.00

Table 21. Sound Level Measured Linearity at 2000 Hz.

Step Level	Measured (dB SPL)	Attenuator 1 level	Attenuator 2 level	Attenuator 3 level	Difference With Previous Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
30	29.19	65.2	70.1	65.2				
40	39.21	55.2	60.1	55.2	10.02	10.00	0.02	1.00
50	49.31	45.2	50.1	45.2	10.10	10.00	0.10	1.00
60	59.31	35.2	40.1	35.2	10.00	10.00	0.00	1.00
70	69.26	25.2	30.1	25.2	9.95	10.00	0.05	1.00
80	79.22	15.2	20.1	15.2	9.96	10.00	0.04	1.00
90	89.12	5.2	10.1	5.2	9.90	10.00	0.10	1.00

Table 22. Sound Level Measured Linearity at 4000 Hz.

Step Level	Measured (dB SPL)	Attenuator 1 level	Attenuator 2 level	Attenuator 3 level	Difference With Previous Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
40	26.65	65.1	70	65.1				
50	36.61	55.1	60	55.1	9.96	10.00	0.04	1.00
60	46.62	45.1	50	45.1	10.01	10.00	0.01	1.00
70	56.68	35.1	40	35.1	10.06	10.00	0.06	1.00
80	66.70	25.1	30	25.1	10.02	10.00	0.02	1.00
90	76.65	15.1	20	15.1	9.95	10.00	0.05	1.00
100	86.64	5.1	10	5.1	9.99	10.00	0.01	1.00

When the sound pressure levels dropped below 20 dB above the ambient noise level, measurements were made with an oscilloscope (National Instruments PXI-5922) using a custom filter (LabVIEW VI, See Appendix A). The oscilloscope was used to measure voltage produced by the attenuators in order to avoid any influence of the ambient noise on the measurements. RMS voltage measurements were obtained using a 10th order 1/3 OB Butterworth bandpass filter. The initial dampening caused by the filter was removed to reveal the true filtered waveform. At 500 Hz and the three highest attenuation levels for the 8000 Hz measurements, smaller bandwidths were used to minimize noise. For Tables 23-30, the tables are showing RMS voltage calculations for all three attenuators individually that are used in the system. The calculation to determine RMS voltage difference is

$$\Delta V_{RMS} = 20 * log_{10}(\frac{V_{RMS,1}}{V_{RMS,2}}) \quad \text{Eq. 1}$$

where RMS voltage 1 is the higher step level and RMS voltage 2 is the lower step level. In order to prove both methods provided similar results, there was a single level of overlap for the ranges of the acoustic and the voltage measurements.

Table 23. RMS Voltage Measured Linearity for Speakers 1, 2, and 3 at 125 Hz.

Step Level	RMS Voltage 1 (V)	Attenuator 1 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
-20	0.00017	89.9	9.54	10.00	0.46	1.00
-10	0.00051	79.9	10.04	10.00	0.04	1.00
0	0.00162	69.9	10.10	10.00	0.10	1.00
10	0.00518	59.9				
Step Level	RMS Voltage 2 (V)	Attenuator 2 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
-20	0.00015	94.9	9.15	10.00	0.85	1.00
-10	0.00043	84.9	9.87	10.00	0.13	1.00
0	0.00134	74.9	9.96	10.00	0.04	1.00
10	0.00422	64.9				
Step Level	RMS Voltage 3 (V)	Attenuator 3 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
-20	0.00013	90.8	9.54	10.00	0.46	1.00
-10	0.00039	80.8	9.91	10.00	0.09	1.00
0	0.00123	70.8	10.00	10.00	0.00	1.00
10	0.00389	60.8				

Table 24. RMS Voltage Measured Linearity for Speakers 1, 2, and 3 at 250 Hz.

Step Level	RMS Voltage 1 (V)	Attenuator 1 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
-10	0.00004	92.0	9.12	10.00	0.88	1.00
0	0.00011	82.0	10.18	10.00	0.18	1.00
10	0.00036	72.0	9.98	10.00	0.02	1.00
20	0.00112	62.0				
Step Level	RMS Voltage 2 (V)	Attenuator 2 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
-10	0.00003	97.0	9.54	10.00	0.46	1.00
0	0.00009	87.0	10.16	10.00	0.16	1.00
10	0.00029	77.0	10.00	10.00	0.00	1.00
20	0.00092	67.0				
Step Level	RMS Voltage 3 (V)	Attenuator 3 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
-10	0.00003	92.9	9.80	10.00	0.20	1.00
0	0.00009	82.9	9.85	10.00	0.15	1.00
10	0.00027	72.9	10.03	10.00	0.03	1.00
20	0.00085	62.9				

Table 25. RMS Voltage Measured Linearity for Speakers 1, 2, and 3 at 500 Hz*.

Step Level	RMS Voltage 1 (V)	Attenuator 1 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00040	91.2	9.90	10.00	0.10	1.00
10	0.00125	81.2	9.97	10.00	0.03	1.00
20	0.00394	71.2	9.96	10.00	0.04	1.00
30	0.01240	61.2				
Step Level	RMS Voltage 2 (V)	Attenuator 2 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00030	96.3	9.90	10.00	0.10	1.00
10	0.00100	86.3	10.10	10.00	0.10	1.00
20	0.00320	76.3	9.90	10.00	0.10	1.00
30	0.01000	66.3				
Step Level	RMS Voltage 3 (V)	Attenuator 3 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00030	92.1	9.92	10.00	0.08	1.00
10	0.00094	82.1	9.93	10.00	0.07	1.00
20	0.00295	72.1	10.04	10.00	0.04	1.00
30	0.00937	62.1				

*Used 1/6 Octave Bands

Table 26. RMS Voltage Measured Linearity for Speakers 1, 2, and 3 at 1000 Hz.

Step Level	RMS Voltage 1 (V)	Attenuator 1 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00014	97.3	9.12	10.00	0.88	1.00
10	0.00040	87.3	9.90	10.00	0.10	1.00
20	0.00125	77.3	10.02	10.00	0.02	1.00
30	0.00396	67.3	10.05	10.00	0.05	1.00
40	0.01260	57.3				
Step Level	RMS Voltage 2 (V)	Attenuator 2 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00010	102.3	10.63	10.00	0.63	1.00
10	0.00034	92.3	9.54	10.00	0.46	1.00
20	0.00102	82.3	10.07	10.00	0.07	1.00
30	0.00325	72.3	9.96	10.00	0.04	1.00
40	0.01023	62.3				
Step Level	RMS Voltage 3 (V)	Attenuator 3 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00010	98.2	9.54	10.00	0.46	1.00
10	0.00030	88.2	10.01	10.00	0.01	1.00
20	0.00095	78.2	9.99	10.00	0.01	1.00
30	0.00300	68.2	10.06	10.00	0.06	1.00
40	0.00955	58.2				

Table 27. RMS Voltage Measured Linearity for Speakers 1, 2, and 3 at 2000 Hz.

Step Level	RMS Voltage 1 (V)	Attenuator 1 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00015	94.8	9.54	10.00	0.46	1.00
10	0.00045	84.8	9.61	10.00	0.39	1.00
20	0.00136	74.8	9.90	10.00	0.10	1.00
30	0.00425	64.8	10.10	10.00	0.10	1.00
40	0.01360	54.8				
Step Level	RMS Voltage 2 (V)	Attenuator 2 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00012	99.8	9.54	10.00	0.46	1.00
10	0.00036	89.8	9.70	10.00	0.30	1.00
20	0.00110	79.8	10.05	10.00	0.05	1.00
30	0.00350	69.8	10.06	10.00	0.06	1.00
40	0.01115	59.8				
Step Level	RMS Voltage 3 (V)	Attenuator 3 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00011	95.7	9.28	10.00	0.72	1.00
10	0.00032	85.7	10.07	10.00	0.07	1.00
20	0.00102	75.7	10.04	10.00	0.04	1.00
30	0.00324	65.7	10.05	10.00	0.05	1.00
40	0.01030	55.7				

Table 28. RMS Voltage Measured Linearity for Speakers 1, 2, and 3 at 4000 Hz.

Step Level	RMS Voltage 1 (V)	Attenuator 1 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
10	0.00038	84.7	10.27	10.00	0.27	1.00
20	0.00124	74.7	9.98	10.00	0.02	1.00
30	0.00391	64.7	10.14	10.00	0.14	1.00
40	0.01256	54.7	9.99	10.00	0.01	1.00
50	0.03967	44.7				
Step Level	RMS Voltage 2 (V)	Attenuator 2 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
10	0.00032	89.7	10.15	10.00	0.15	1.00
20	0.00103	79.7	9.98	10.00	0.02	1.00
30	0.00325	69.7	10.13	10.00	0.13	1.00
40	0.01043	59.7	10.00	10.00	0.00	1.00
50	0.03300	49.7				
Step Level	RMS Voltage 3 (V)	Attenuator 3 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
10	0.00031	85.6	9.82	10.00	0.18	1.00
20	0.00096	75.6	9.95	10.00	0.05	1.00
30	0.00302	65.6	10.07	10.00	0.07	1.00
40	0.00963	55.6	10.00	10.00	0.00	1.00
50	0.03047	45.6				

Table 29. RMS Voltage Measured Linearity for Speakers 1, 2, and 3 at 8000 Hz.

Step Level	RMS Voltage 1 (V)	Attenuator 1 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00028	87.5	9.95	10.00	0.05	1.00
10	0.00088	77.5	10.08	10.00	0.08	1.00
20	0.00281	67.5	10.12	10.00	0.12	1.00
30	0.00901	57.5	10.00	10.00	0.00	1.00
40	0.02850	47.5	10.00	10.00	0.00	1.00
50	0.09016	37.5	10.00	10.00	0.00	1.00
60	0.28517	27.5	10.00	10.00	0.00	1.00
70	0.90185	17.5				
Step Level	RMS Voltage 2 (V)	Attenuator 2 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00024	92.5	9.78	10.00	0.22	1.00
10	0.00074	82.5	10.00	10.00	0.00	1.00
20	0.00234	72.5	10.00	10.00	0.00	1.00
30	0.00740	62.5	10.09	10.00	0.09	1.00
40	0.02364	52.5	10.02	10.00	0.02	1.00
50	0.07491	42.5	9.99	10.00	0.01	1.00
60	0.23650	32.5	10.01	10.00	0.01	1.00
70	0.74872	22.5				
Step Level	RMS Voltage 3 (V)	Attenuator 3 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
0	0.00022	88.4	9.80	10.00	0.20	1.00
10	0.00068	78.4	10.08	10.00	0.08	1.00
20	0.00217	68.4	10.09	10.00	0.09	1.00
30	0.00693	58.4	10.01	10.00	0.01	1.00
40	0.02193	48.4	10.00	10.00	0.00	1.00
50	0.06932	38.4	10.00	10.00	0.00	1.00
60	0.21929	28.4	9.98	10.00	0.02	1.00
70	0.69179	18.4				

Table 30. RMS Voltage Measured Linearity for Speakers 1, 2, and 3 at 8000 Hz continued**.

Step Level	RMS Voltage 1 (V)	Attenuator 1 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
-20	0.00003	107.3	4.12	5.00	0.88	1.00
-15	0.00005	102.3	4.79	5.00	0.21	1.00
-10	0.00009	97.3	9.82	10.00	0.18	1.00
0	0.00029	87.3	9.99	10.00	0.01	1.00
10	0.00090	77.3				
Step Level	RMS Voltage 2 (V)	Attenuator 2 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
-20	0.00003	112.4	4.31	5.00	0.69	1.00
-15	0.00005	107.4	4.36	5.00	0.64	1.00
-10	0.00008	102.4	9.95	10.00	0.05	1.00
0	0.00024	92.4	9.93	10.00	0.07	1.00
10	0.00075	82.4				
Step Level	RMS Voltage 3 (V)	Attenuator 3 level	Difference with Next Step (dB)	Target Difference (dB)	Departure (dB)	Allowed (dB)
-20	0.00003	108.2	4.17	5.00	0.83	1.00
-15	0.00004	103.2	4.56	5.00	0.44	1.00
-10	0.00007	98.2	9.82	10.00	0.18	1.00
0	0.00022	88.2	9.99	10.00	0.01	1.00
10	0.00070	78.2				

**Used 1/12 Octave Bands

All measurements support that the control circuits of the system meet S12.6-2008 control circuits' requirements.

4.3.5 Signal Pulsing

In accordance with ANSI S12.6 (2008):

> Test Signals shall be pulsed between 2 and 2.5 times per second, with a 50% duty cycle, and without audible clicks, pops, or other transients. When exciting the system with pure tones at the test signal center frequencies, the on-phase (the time the signal remains within 1 dB of its maximum level) shall be greater than 150 ms, and the output during the off-phase shall reach at least 20 dB below the maximum levels, as measured electrically at the speaker terminals. (ANSI, 2008, p. 6-7)

The silent, detent-free signal control switch operated by the subject produces no noise audible to the normal hearing ear. The digital signal processor (TDT RP2.1) controlled by computer program produces the test signals of VT HPD Test system. These test signals are programmed with 250 ms of on-phase and 250 ms of off-phase. This results in a 50% duty cycle under digital computer control with test signal pulsing 2 times per second.

4.3.6 Fitting Noise

In accordance with ANSI S12.6-2008:

> The fitting noise shall be a broadband random noise presented at an overall A-weighted sound pressure level of approximately 70 dB (re 20 µPa) at the reference point. A higher level of fitting noise may be used for extremely high attenuation devices or systems. (ANSI, 2008, p. 7)

The VT HPD Test system generates a pink noise since it is a broadband random noise. The pink noise is at a level of approximately 90 dB (re 20 µPa) and the output level is adjustable via computer interface by the experimenter to -20 dB and +10 dB giving a range of 70 to 100 dB (re 20 µPa). These output characteristics exceed those required by S12.6-2008.

4.4 Head-Positioning Device

In accordance with ANSI S12.6 (2008):

> A head-positioning device, such as a plumb bob to the nose or the forehead of the subject, shall be used to maintain the subject's head at the reference point. A headrest or bite bar is not acceptable. The device shall not transmit vibrations to the head that affect the threshold measurements, and shall not measurably affect the uniformity of the sound field of the room as specified in Clause 4.2.1.1. (ANSI, 2008, p. 7)

To fulfill this requirement, a small cylindrical-shaped plumb bob is suspended from the ceiling in the appropriate location. This device provides a comfortable surface for the subject to touch his or her nose against during threshold trials. This style of plumb bob device is comfortable and effective for helping subjects attain and maintain a fixed head position during testing.

4.5 Observing of Subjects during Testing

In accordance with ANSI S12.6 (2008): "The test room shall be equipped with a viewing window or video system to allow clear observation of the subject at all times during the test" (ANSI, 2008, p. 7).

The facility that houses NSMRL's VT HPD Test system includes a viewing window so that the experimenter can visually monitor the test chamber interior. Per S12.6-2008, the subject is not to re-adjust the HPD after the test commences. The test administrator is able to ensure subject compliance using the viewing window. Communication between experimenter and subject is facilitated further by a talk-forward and talk-back microphone and loudspeaker system.

Testing Procedures

Data from the preceding sections indicate that the NSMRL HPD REAT test facility and instrumentation conform to all aspects of the ANSI 12.6-2008 standard. NSMRL research personnel are trained regarding the adoption and routine practice of procedures for conduct of HPD attenuation tests intended to adhere to the S12.6-2008 standard, including: Section 5, Test subjects; Section 7.1, Informing the subjects; Section 7.4, Threshold measurement method – Békésy tracking procedure, including Section 8, Method A: trained-subject fit and Section 9, Method B: inexperienced-subject fit (Method A is most similar to Experimenter-Fit as required by EPA, (1990) for HPD labeling purposes using S3.19); and Section 6.1, Minimum number of samples. To accommodate Section 11, Processing and reporting the data, means and standard deviations are computed using the procedures given in S12.6-2008 on the computer, stored on disk and printed in tabular form.

The loudspeaker equalization and minimum audible field (MAF) settings are intended to be calibrated in the facility at the start of each data collection day. Because test signals are continuously monitored and checked during each test, any departures from normal can be readily identified and corrected, if necessary.

References

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Békésy, G. v., & Wever, E. G. (1960). *Experiments in hearing*. New York: McGraw-Hill.

Lee, K., Casali, J. G. (2013) *A computer-controlled facility for real-ear-attenuation-at-threshold (REAT) testing of hearing protectors: development and verification re ANSI S12.6-2008 as installed and calibrated at Naval Submarine Medical Research Laboratory (NSMRL)*. Audio Systems Laboratory, Virginia Polytechnic Institute and State University.

Appendix A

LabVIEW VI for Voltage Measurement

Figure A7. Block Diagram of Oscilloscope VI used to visualize waveforms and measure RMS voltages.

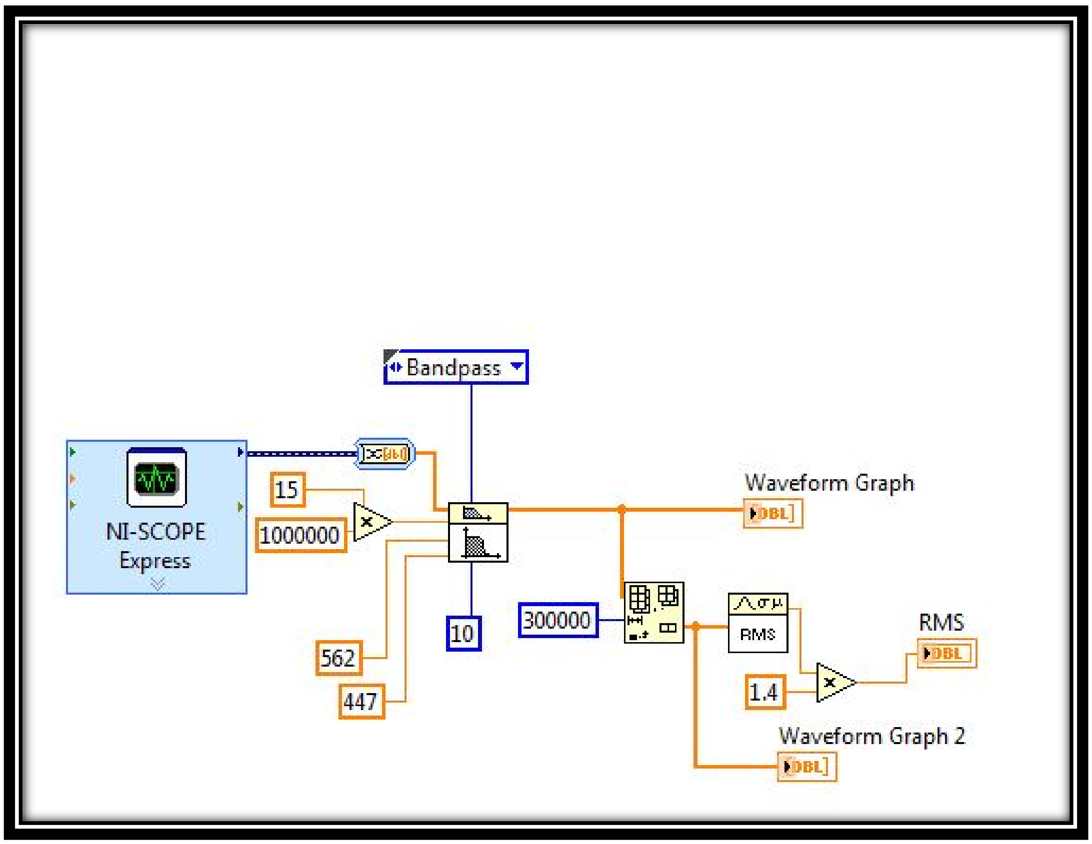
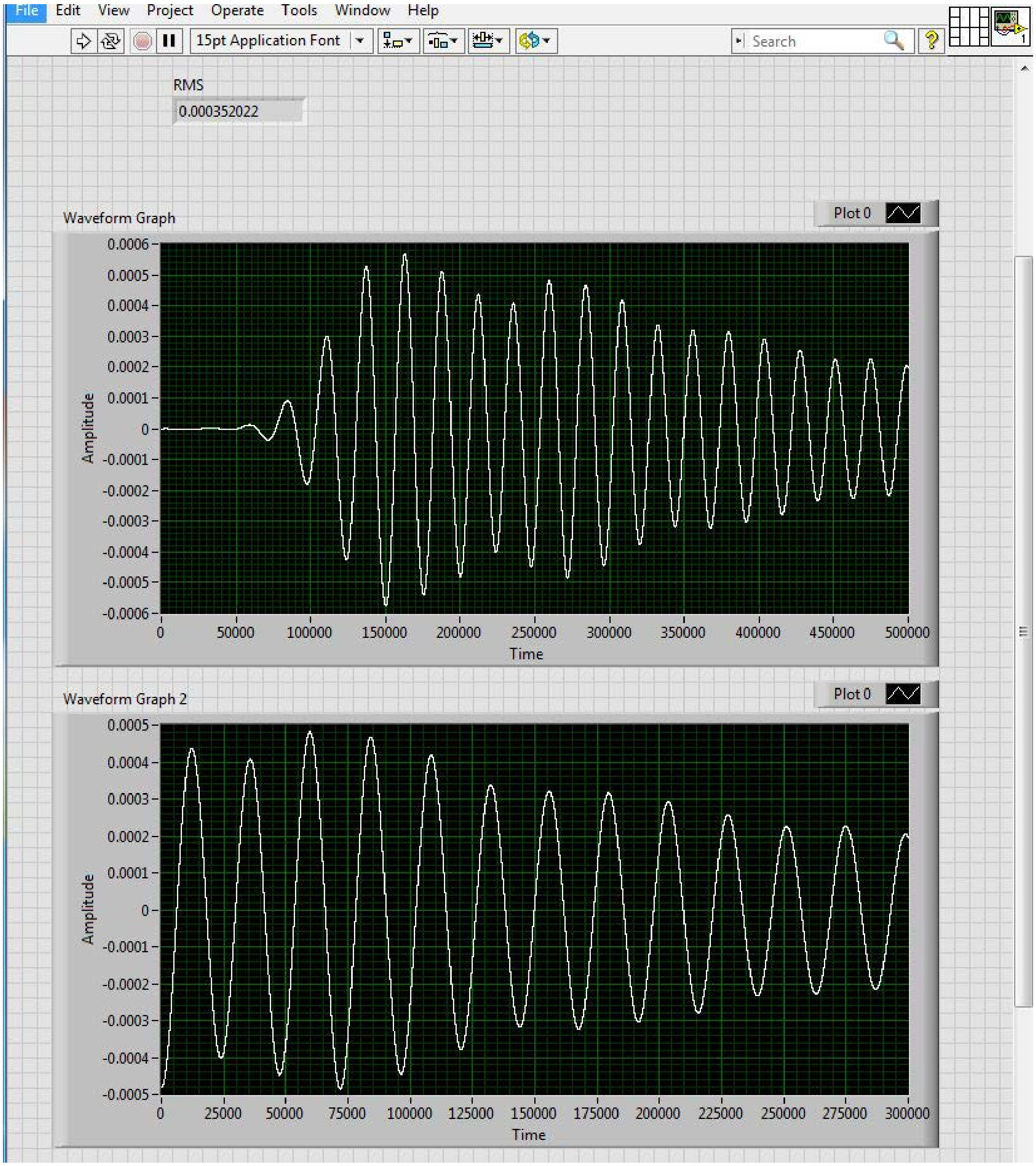


Figure A8. Oscilloscope VI output with RMS section, Waveform Graph section, and Waveform Graph 2 section (which is waveform graph with initial dampening removed).



Appendix B

Monthly Ambient Noise Level Measurements Post-Verification

Monthly Ambient Noise Level Measurements in the Test Facility

Data Collection Date: 11/21/2017

OB Center (Hz)	Permissible Ambient OB SPL (dB)*	Median Ambient OB SPL (dB)	Trial 1 (dB SPL)	Trial 2 (dB SPL)	Trial 3 (dB SPL)	Trial 4 (dB SPL)	Trial 5 (dB SPL)
31.5	57.0	22.92	23.51	22.72	23.32	22.92	22.73
63	43.0	11.53	12.12	10.86	11.30	11.53	13.19
125	29.0	11.11	11.32	11.11	10.86	11.10	12.17
250	21.0	2.49	1.30	2.68	2.49	2.30	5.48
500	16.0	8.33	8.45	8.23	7.99	8.43	8.33
1000	13.0	4.16	4.09	4.35	4.03	4.16	5.04
2000	14.0	3.39	3.45	3.27	3.39	3.23	4.13
4000	11.0	3.92	3.86	3.93	3.79	3.92	4.02
8000	14.0	5.23	5.33	5.23	5.23	5.23	5.29
*Time	Recorded		10:03 am	10:20 am	10:38 am	10:53 am	11:09 am

*As per Table 2, S12.6.

Additional Notes: Minimal buzzing noise from loudspeaker 3

Collected by: Joshua Ginsberg

Signed: [signature]

Date: 11/21/2017

Monthly Ambient Noise Level Measurements in the Test Facility

Data Collection Date: 12/1/2017

OB Center (Hz)	Permissible Ambient OB SPL (dB)*	Median Ambient OB SPL (dB)	Trial 1 (dB SPL)	Trial 2 (dB SPL)	Trial 3 (dB SPL)	Trial 4 (dB SPL)	Trial 5 (dB SPL)
31.5	57.0	23.41	24.36	23.39	23.41	23.49	23.35
63	43.0	12.81	11.57	11.76	12.81	13.13	14.19
125	29.0	11.36	11.95	11.22	11.36	11.35	11.45
250	21.0	0.24	0.41	0.54	0.13	0.24	-0.02
500	16.0	7.92	7.08	7.92	8.23	8.04	7.60
1000	13.0	4.24	3.70	4.38	4.56	4.24	3.87
2000	14.0	2.56	2.31	2.57	2.62	2.56	2.51
4000	11.0	3.77	3.74	3.76	3.83	3.77	3.80
8000	14.0	5.30	5.27	5.30	5.31	5.30	5.33
*Time	Recorded		9:10 AM	9:26 AM	9:42 AM	9:58 AM	10:15 AM

*As per Table 2, S12.6.

Additional Notes: Nothing of note

Data Collected by: Joshua Ginsberg

Signed: [signature]

Date: 12/1/2017

Monthly Ambient Noise Level Measurements in the Test Facility

Data Collection Date: 12/29/2017

OB Center (Hz)	Permissible Ambient OB SPL (dB)*	Median Ambient OB SPL (dB)	Trial 1 (dB SPL)	Trial 2 (dB SPL)	Trial 3 (dB SPL)	Trial 4 (dB SPL)	Trial 5 (dB SPL)
31.5	57.0	26.01	25.87	26.02	26.91	26.01	24.99
63	43.0	2.01	2.27	2.01	1.57	1.68	9.14
125	29.0	3.09	-1.53	3.09	4.26	-2.17	4.86
250	21.0	-2.91	-3.06	-2.91	-1.50	-3.30	1.08
500	16.0	6.23	5.91	6.35	6.48	6.15	6.23
1000	13.0	2.75	2.77	2.64	3.32	2.75	2.72
2000	14.0	2.73	2.88	2.73	2.68	2.78	2.62
4000	11.0	3.75	3.74	3.75	3.75	3.75	3.70
8000	14.0	5.29	5.29	5.29	5.30	5.33	5.24
*Time	Recorded		12:00 PM	12:16 PM	12:32 PM	12:48 PM	1:04 PM

*As per Table 2, S12.6.

Additional Notes: Nothing of note

Data Collected by: Joshua Ginsberg

Signed: ______________________ Date: 12/29/2017

Appendix C

List of Software modules included in the NSMRL VT HPD Test System

Daily_Calibration: This program calibrates each speaker attenuation values so that each speaker produces the same SPL. It generates 'Daily_Calibration.txt' file which will be used by REAT testing programs.

REAT12_6: This program reads in daily calibration results and conducts a REAT test per ANSI S12.6 (2008) standard. (Using seven 1/3 OB test signals.)

REAT3_19: This program reads in daily calibration results and conducts a REAT test per ANSI S3.19-1974 standard. (Using nine 1/3 OB test signals.)

REAT_SINGLE: This program reads in daily calibration results and conducts a REAT test for a single, selected 1/3 OB frequency at a time, selectable from among 125, 250, 500, 1000, 2000, 3150, 4000, 6300 and 8000 Hz.

Fitting_noise: This program will produce approximately 85 dBA pink noise to assist a subject in fitting a hearing protector prior to REAT testing.

TDTStop: Running this program will cause any current program to stop. An experimenter can also use this program to reset TDT equipment after forced stop of REAT testing programs.

Appendix D

User Guidance for Daily Operation

Daily Calibration

1. Calibrate SLM with microphone to be used, using NIST-traceable calibrator.
2. Start “Daily Calibration” by double clicking the icon
3. Measure 1/3 OB 1000 Hz 30 sec L_{eq}
4. Enter the value to terminal screen
5. Repeat 3-4 for speaker 2 and 3
6. Screen will output lowest of the three measured SPL and ask you for current SPL of speaker 1
7. Measure 1/3 OB 1000 Hz 30 sec L_{eq} of speaker 1
8. Press ‘C’ for “correct” if the value is within +- 0.2 dB from the value
9. Press ‘D’ to decrease level if measured SPL is higher than the stated value. Level will decrease by 0.4 dB
10. Press ‘I’ to increase level if measured SPL is lower than the stated value. Level will increase by 0.4 dB
11. Repeat 7-10 until the measured SPL is within +- 0.2 dB of stated value
12. Repeat 6-11 for speaker 2 and 3
13. Close the program by clicking red x box of the terminal window

Note 1: Daily calibration program will generate two text files: ‘Daily_Calibration.txt’ and ‘Daily_Calibration_Log.txt’. ‘Daily_Calibration.txt’ file will contain attenuator values for the three TDT PA5 attenuators in the first line. The values are separated by comma. The second line will contain combined SPL when all three speakers are set to the attenuator values in the first line. The rest of the fields contain the same data as the first and second lines but additional wording is provided for clarity of meaning. Below is a sample content of a ‘Daily_Calibration.txt’ file.

```
30.75,30,34.72 (These are the PA5 attenuator values for getting
identical output from each speaker.)

62.051  (This is the combined output level from the three speakers.)

Speaker 1,2,3 attenuator values:

30.75,30,34.72

Overall SPL value:

62.051
```

‘Daily_Calibration_Log.txt’ file logs daily calibration results. Following each daily calibration, the daily calibration data is appended to the file with current measurement data including a date stamp. If you delete either/both of these files, they will be recreated by the program.

Note 2: Screen output

This is a capture of the screen output from a daily calibration test.

```
Enter SPL of Speaker 1 => 58.03
Enter SPL of Speaker 2 => 57.28
Enter SPL of Speaker 3 => 62.00
SPL of Speaker 1 should be 57.3
Enter C for correct, I for increase, D for decrease...c
SPL of Speaker 2 should be 57.3
Enter C for correct, I for increase, D for decrease...c
SPL of Speaker 3 should be 57.3
Enter C for correct, I for increase, D for decrease...c
```

REAT test procedure

1. Calibrate SLM
2. Run “Daily Calibration” module by double clicking the icon (see above section “Daily calibration” for details).
3. Start REAT test for the applicable ANSI standard (3.19 or 12.6-2008) desired by double clicking the appropriate program icon.
4. Follow on-screen instructions.
5. Test results will be shown on the screen and automatically stored in a file named based on the test information entered by the tester.

Note 1: On-screen output explanation

Below is screen capture of a test run using REAT_Single, which tests only a single frequency.

```
>> REAT_Single

This program will conduct single frequency REAT test.

What is the test name? (any text [TEST])

What is subject number? ([111] or any numeral)

What is subject's age? ([25] or any numeral)

What is subject's sex ([m],f)?

What is the test trial number? ([1],2,3,... )2

What is test condition? (O-occluded, U-unoccluded)

Enter any memo if needed. ([none] or any text)

Which frequency do you want to test?

 ([125], 250, 500, 1000, 2000, 3150, 4000, 6300, 8000)
```

```
Test Title is TEST

Subject number is 111

Subject age is 25

Subject sex is m

Subject test trial number is 2

Test condition is o

Test memo is none

Test frequency is 125

Do you want to change anything? ([N]/Y)

     1


     2


     3
```

Program will ask for the following information.

Test name: This will be the name of a particular test. HPD name can be a choice.

Subject number: This will be the number that you assign to each subject.

Subject’s age: This will be the age of the subject.

Subject’s sex: This will be the sex of the subject. m or f.

Test trial number: S12.6 requires 2 pairs of test per subjects. This will be either 1 or 2.

Memo: This can be used for any kind of note you want to attach to each test. You can enter several words separated by space. Once you hit enter, it will stop.

Hitting enter key without entering any will cause the program to use default values for each field. After entering information into all of the fields, the program will ask you if you need to change any information. Answering ‘Y’ (Yes) will restart the data input while entering N (No) will start the test. Since the test will begin upon entering ‘N’, it is desirable to delay entry of ‘N’ until subjects are ready for testing.

Once the program starts the testing, it will display current SPL output values as they are varied by subject’s control. After testing for each frequency band is completed, the resulting 7 reversals and calculated threshold values will be displayed on the screen. Testing of next frequency band will be started automatically.

After testing of all frequencies is completed, the subject’s data for the test and test result will be displayed on the screen. The same information will be stored in a text file.

Note 2: Text file produced.

A text file will be created to store test results that will be shown on the screen as well. File name will be based on test name, subject number, test condition (‘o’ or ‘u’), and test trial number. They will be connected with ‘_’. ‘Test_subj_111_o_1.txt’ will contain test data of test name ‘Test’, subject number 111, occluded (‘o’) test condition, and trial 1.

REAT Instructions to Subject

Instructions for subject only after audiometric testing and before REAT testing instructions:

"Your listening task will be very similar to the hearing screening you just completed, except the sounds will come from the three loudspeakers in the room and you will hear them with both ears simultaneously. Also, these test sounds are noise-like pulses instead of the tones you just listened to.”

REAT testing instructions:

"You are controlling the level of the noise in the room. The noise will slowly get louder. As soon as you hear the noise, press and hold the button until you no longer hear it. Then, let go of the button. As soon as you hear the noise again, press and hold the button again and then release the button when you can no longer hear it. Continue this until I tell you that you are finished."