- [ ] 2700 Series
- [ ] ATS-2
- [x] APx500 Series

Measuring the Sound Pressure Level of Portable Audio Player Headphones

By Joe Begin

About This Technote

In this Technote, we describe how to measure the sound pressure level developed by portable audio players and their associated headphones, according to British Standard / European Norm 50332[1]. We also show you how to use the APx Portable Audio Player / Headphone Test Utility to facilitate making the necessary measurements with an APx500 analyzer.

Introduction

The BS EN 50332 standard is intended to protect users of portable audio devices from exposure to excessive sound levels, and has been adopted by the 31 European CENELEC (European Committee for Electrotechnical Standardization) member countries. It specifies that portable audio players with headphones (or earphones), whether packaged together or bought separately, shall not deliver a maximum sound pressure level exceeding 100 dBA. It does not apply to acoustically open or acoustically closed headphones that are normally used with mains-operated home stereo receivers, nor does it apply to headphones used for medical purposes, or active noise cancelling headphones.

The standard has two parts:

Part 1: *General method for "one package equipment,"* covers portable audio players and headphones that are packaged together and sold as a unit.

Part 2: *Matching of sets with headphones if either or both are offered separately,* provides standard procedures for measuring:

a) The maximum voltage that can be output by an audio player under standard test conditions, and

b) The sensitivity of a set of headphones or earphones—a measure of what sound pressure level they will produce for a given input voltage, under standard conditions.

Figure 1. APx526 audio analyzer with G.R.A.S. KEMAR manikin type 45BA.

Head and Torso Simulator

A Head and Torso Simulator (HATS) is required for measuring the headphone sound levels. A HATS is a special manikin used for sound quality assessment, engineered to have head and torso dimensions representative of a typical adult. For this Technote, we used a KEMAR Manikin Type 45BA, provided courtesy of G.R.A.S. Sound and Vibration.

Figure 2. Ear simulators and microphones inside the head of the HATS.

The HATS is equipped with a pair of removable pinnae (the outer visible section of the ear), molded from a soft rubber-like compound, and mechanical couplers called Occluded Ear Simulators at the locations of the inner ears, to simulate the mechanical impedance of the ear to incoming sound. Measurement microphones are situated at the location of the eardrum.

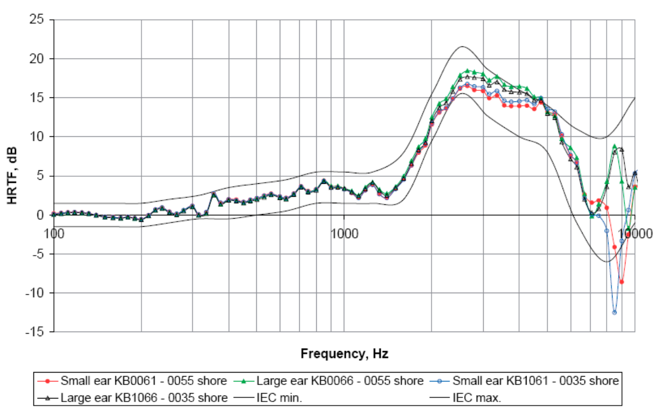

Figure 3. HRTFs for the KEMAR 45BA manikin with different styles of pinnae.

Measuring the sound pressure level at the eardrum is necessary to account for the interaction between the headphones and the ears. However, to correlate sound pressure levels measured at the eardrum with published data from hearing impairment studies and international standards, the raw data must be converted to free field values. This is accomplished using the free field frequency response of the HATS, which represents the difference, as a function of frequency, between the sound pressure level at the ear simulator microphones when the manikin is present and when it is not. The free-field frequency response of the HATS is sometimes referred to as the Head-related Transfer Function (HRTF). Figure 3 shows HRTFs for the KEMAR manikin with different styles of pinnae.

Test Signal

BS EN 50332 requires the use of a special test signal called "program simulation noise," whose spectral content is representative of music and speech. Real music cannot be used for the test signal because music continuously fluctuates in both level and spectral content. Pure tones cannot be used either, because the results would be inaccurate due to the considerable variations in the frequency response of typical headphones.

The program simulation noise can be created by passing pink noise through a special filter network defined in IEC 60268-1[2]. BS EN 50332 adds an additional requirement—that the crest factor of the test signal (the ratio between the instantaneous peak level of the signal and its RMS level) be between 1.80 and 2.2.

We used Matlab to create a digital filter having the same frequency response as the analog filter network described in IEC 60268-1. We then passed pink noise through the filter, adjusted its crest factor using a soft clipping algorithm, and set its level to –10 dBFS.

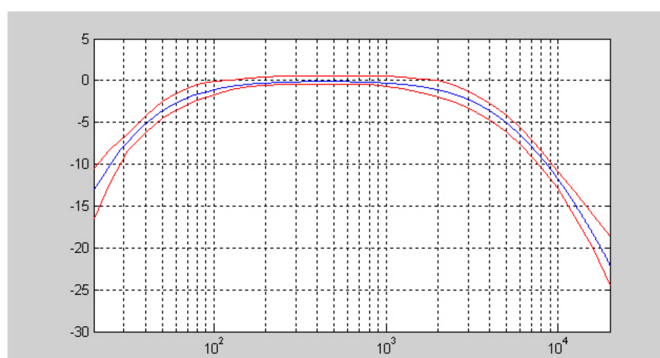

Figure 4. Frequency response in dB of the program simulation noise filter.

BS EN 50332-1

To make the measurements in Part 1, the program simulation noise is played on the portable player, with volume and tone controls set to maximum. The headphones are mounted on the HATS, and the sound pressure level measured by the two ear simulator microphones is averaged and plotted with 1/3 octave resolution. Then the HRTF (Head-Related Transfer Function) of the HATS is subtracted to derive the free-field response. The resulting curve is A-weighted, and then the overall sound pressure level is calculated in dBA. This process is repeated five times, remounting the headphones on the manikin each time to average out any variation in placement.

BS EN 50332-2

Part 2 of BS EN 50332 specifies how to test portable audio players and headphones that are not sold as a package. Unlike packaged sets, the sound pressure level that could be developed in this case cannot be specified in terms of a single metric. Instead, it requires two characteristics—the maximum output voltage (Vm) of the player, and a characteristic called the "Wide Band Characteristic Voltage" for the headphones.

Audio Player Maximum Output Voltage

The audio player maximum output voltage (Vm) defined by the standard is the un-weighted true RMS voltage at the load, measured using an averaging time of 30 seconds or more, using the program simulation noise signal. The player's volume and tone controls are set to maximum, noise reduction (if present) is turned off, and the output is terminated with a resistive load of 32 Ω.

Headphone/Earphone Wide Band Characteristic Voltage

The Wide Band Characteristic Voltage (WBCV) is measured by driving the headphones with an amplifier (output impedance 2 Ω or less) instead of with the portable audio player. WBCV is defined as the un-weighted true RMS voltage measured at the headphones, when the sound pressure level at the HATS is 94 dBA. If the headphones are known to be linear, then the test does not have to be conducted at 94 dBA—instead, the WBCV can be calculated from the measured sound pressure level and RMS voltage using the equation in the standard.

Limits

BS EN 50332-2 specifies limits (see table below) for the player maximum output voltage and the headphone Wide Band Characteristic Voltage. Note that headphones having the minimum allowed WBCV of 75 mV driven by a player putting out the maximum allowed Vm of 150 mV would be expected to develop a sound pressure level a factor of two (or 6 dB) higher than the level of 94 dBA at which WBCV is measured. This corresponds with the 100 dBA limit of Part 1 for a matched set of player and headphones.

Player	Headphones
Vm ≤150 mV	*WBCV ≥ 75 mV*

Table 1. BS EN 50332-2 Limits.

APx Portable Audio Player / Headphone Test Utility

The APx Portable Audio Player/Headphone Test Utility automates and simplifies testing to the BS EN 50332 standard with an APx500 Series audio analyzer. Written in Visual Basic.NET, it uses the APx500 Application Programming Interface (API) to control the APx analyzer and extract the measurement data. It also conducts all the required calculations.

Implementation

To measure the 1/3-octave sound pressure level spectrum, the utility uses the FFT Spectrum result from the APx Signal Analyzer measurement. After retrieving all the FFT bins, a 1/3-octave filter transfer function is applied, and then the total RMS level is calculated (Figure 5). As a result, the FFT spectrum, which typically contains thousands of points, is converted to a 1/3-octave spectrum, with 31 points from 20 Hz to 20 kHz.

Using the Utility

The main window is shown in Figure 5. When started, the utility will open APx500 (if it's not already running) and load a special APx project file named APx_BS_EN50332Test.approjx.

The Measurement Type box lets you select which BS EN 50332 measurement to perform:

Part 1 - Player/Headphone Max SPL measures sound pressure per BS EN 50332-1. This is an open loop test, in which the program simulation noise signal is played from the portable audio player into the headphones mounted on the HATS.

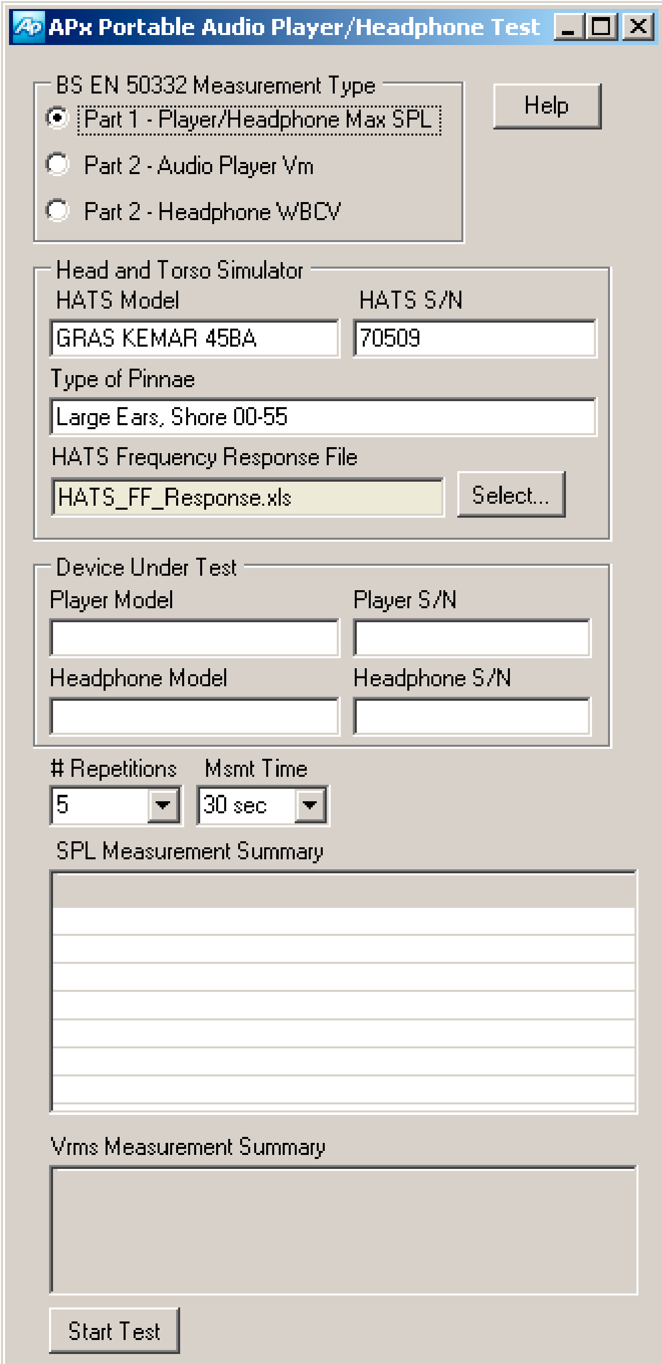

Figure 5. APx utility interface.

Part 2 - Audio Player Vm measures maximum output voltage per BS EN 50332-2. This is also an open loop test, in which the test signal is played from the audio player into 32 Ω resistive loads.

Part 2 - Headphone WBCV measures WBCV per BS EN 50332-2. This is a closed loop test, in which the APx generator feeds an amplifier which drives the headphones.

Identifying the HATS and its Free Field Response

The utility provides fields where you can fill in the model number and serial number of the HATS, as well as the type of pinnae used (this is a requirement of BS EN 50332, because the pinnae can affect the test results).

The free field response of the HATS, in 1/3 octave bands, is contained in an Excel file that you must select. This file uses the same format as the data export from the FFT Spectrum result. Be careful not to change the headings or the worksheet name—otherwise the utility will not recognize the file.

A sample file named HATS_FF_Response.xls is provided. You may edit this file to insert the actual free field response data provided by the manufacturer of the HATS you are using. Note that the utility requires the HATS free field frequency response be specified at all 1/3-octave frequencies from 20 Hz to 20 kHz, and the HATS manufacturer's data may not cover this entire range. For example, the HRTF supplied with the G.R.A.S. Sound and Vibration KEMAR manikin only has data from 100 Hz to 10 kHz. You can simply enter levels of 0 dB below 100 Hz and above 10 kHz, because due to the combination of the program simulation noise filter and the A-weighting filter used in the measurement, the contribution of data outside the 100 Hz to 10 kHz band to the overall results is negligible. If the manufacturer's HRTF data is presented in 1/12-octave bands, it can be converted to 1/3-octaves by taking an average of four 1/12-octave data points at each 1/3-octave frequency.

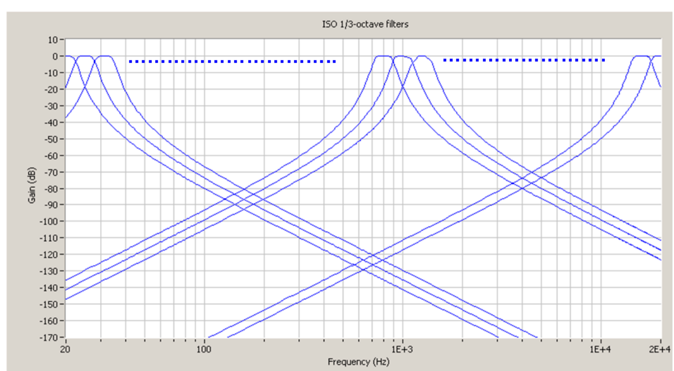

Figure 6. Derivation of the 1/3-octave spectrum from the FFT.

The Program Simulation Noise Signal

The test signal (IEC60268_ProgSignal_48.24_-10dBFS.wav) is already loaded into the APx project file's Signal

Analyzer measurement in the APx to Headphones signal path. The same file in .mp3 format is provided with the utility for use on digital portable audio players.

Figure 7. Calibrating the microphones.

Microphone Field Calibration.

Before using the utility, you must specify the sensitivity of the microphones used in the HATS by setting the APx's dBSPL1 and dBSPL2 references for the left and right side microphones respectively.

To set the level, go to the Reference Levels measurement in APx500 and click Set dBSPL. Next, enter the level of your calibrator in the labeled box (typically 94 dBSPL). Finally, place the calibrator over each microphone and turn it on. When the level has stabilized, click the Set 1 or Set 2 button under dBSPL1 or dBSPL2, as appropriate. Be sure to set the dBSPL references for both the *Player to Headphones* and *APx to Headphones* signal paths.

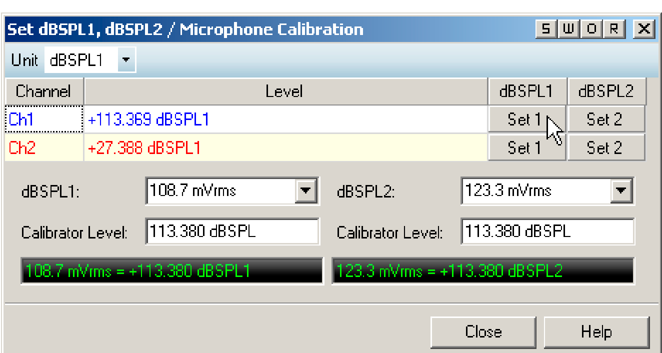

Figure 8. Setting the dBSPL reference levels.

Measuring Player/Headphone Maximum SPL

Once the microphone dBSPL references have been set and the test signal has been loaded onto the portable audio player, you are ready to conduct the Part 1 measurement. Fill in the blanks to specify the model and serial number of the audio player and headphone. The settings for the number of repetitions and the measurement duration default to the values required in BS EN 50332-1 (five repetitions with an averaging time of 30 seconds). The test signal provided is 60 seconds long, to accomodate a variety of durations—it can simply be restarted at the beginning for each itteration.

To begin, click the *Start Test* button and follow the prompts. The utility calculates the number of averages to use in the Signal Analyzer measurement based on the selected input bandwidth, the FFT length, and the specified measurement duration.

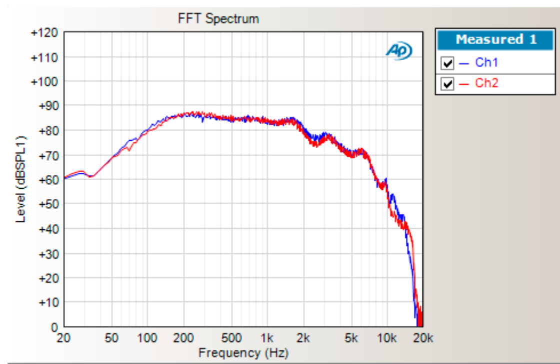

Figure 9. Measured sound level FFT spectra.

During each measurement repetition, the raw FFT sound pressure level spectra are displayed in the APx FFT Spectrum graph (Figure 9). Once the measurement is finished, the utility calculates the 1/3-ocatve spectrum averaged for the left and right channels, subtracts the HATS free field response, and A-weights the result. This curve is then uploaded to the same FFT Spectrum graph in APx (Figure 10), and used to calculate the overall maximum sound pressure level in dBA.

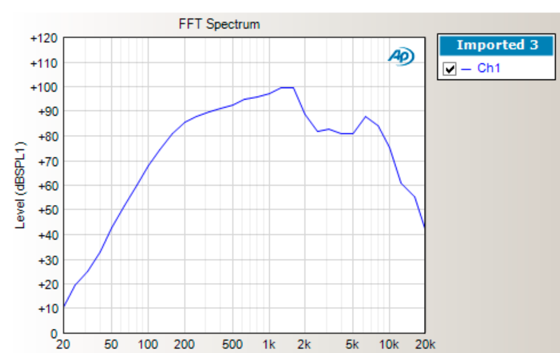

Figure 10. Resulting 1/3-octave sound level spectrum.

After each repetition is completed, you are prompted to reposition the headphones on the HATS (a requirement of BS EN 50332) before the next repetition. When all repetitions are complete, a summary is displayed showing the sound pressure levels in dBA for each repetition in each ear, and the overall average of all the measurements (Figure 11). At this point, the option to export the data to a tab-delimited text file is available.

SPL Measurement Summary

Rep. No.	Ch1(dBA)	Ch2(dBA)	Avg. (dBA)
1	104.5	103.5	104.0
2	106.3	105.0	105.7
3	106.4	105.5	106.0
4	106.7	106.1	106.4
5	102.6	102.7	102.6
Avg.	105.5	104.7	105.1

Figure 11. Maximum SPL measurement.

Measuring Audio Player Maximum Output Voltage

For this test, connect the audio player outputs to 32 ohm resistive loads, and measure the voltage across them using analog inputs 1 and 2 of the APx analyzer. Since headphones and a HATS are not required in this case, the text boxes used to identify these items on the utility's main screen are disabled. Also, since the variability caused by installing the headphones on the ears is not an issue, only one measurement repetition is conducted, and the utility uses a measurement time of 30 seconds (the minimum required in BS EN 50332-2).

To run the measurement, click the Start Test button and follow the prompts. When the measurement is complete, the audio player maximum output voltage is displayed as shown in Figure 12.

Vrms Measurement Summary

	Ch1(Vrms)	Ch2(Vrms)	Avg. (Vrms)
Measured	0.144	0.145	0.145

Figure 12. Player maximum voltage measurement.

Measuring Headphone Wide Band Characteristic Voltage

This is a two-part test, in which the sound pressure level developed by the headphones on a HATS is measured first, followed by a measurement of the input voltage to the headphones. For part one, the APx analog outputs are connected to an amplifier (with an output impedance of 2 ohms or less), which drives the headphones. Be careful not to set the APx generator voltage so high that you destroy the drivers in the headphones. The HATS microphone outputs are connected to analog inputs 1 and 2 on the analyzer.

The signal path named *APx to Headphones* in the project file is used. Ensure that the dBSPL references are set in this signal path as described previously. By default, the analog unbalanced outputs are selected, but you may change to balanced if desired.

The test is intended to be conducted at a sound pressure level close to 94 dBA (it doesn't need to be exactly 94 dBA). Set an initial generator level and run the first part of the test with one repetition and a short measurement time (say five seconds). Repeat as necessary, adjusting the generator level until the resulting sound pressure level is close to 94 dBA. Once set, you can run the test with the five repetitions and the 30 second minimum averaging time required by the standard.

When the sound pressure level measurement is complete, the utility will prompt you to disconnect the HATS microphones and reconfigure the cabling so that APx channels 1 and 2 are connected to measure the input voltage to the headphones. The utility again uses only a single repetition, and a measurement time of 30 seconds.

When completed, the utility displays the measured sound pressure levels, the measured RMS voltages, and the calculated WBCV, as shown in Figure 13. The WBCV is calculated from the measured sound pressure level and RMS voltage using the equation given in section 6.1 of BS EN 50332-2.

SPL Measurement Summary

Rep. No.	Ch1(dBA)	Ch2(dBA)	Avg. (dBA)
1	95.1	94.2	94.7
2	94.7	95.9	95.3
3	94.8	96.0	95.4
4	94.6	96.7	95.7
5	94.4	95.9	95.2
Avg.	94.7	95.8	95.3

Vrms Measurement Summary

	Ch1(Vrms)	Ch2(Vrms)	Avg. (Vrms)
Measured	0.218	0.217	0.217
WBCV	0.201	0.176	0.187

Figure 13. WBCV measurement.

Sample Test Results

We conducted tests on a few portable audio players and headphones, including one matched set. Results are presented in Table 2.

Device Tested	Player/headphone SPL per BS EN 50332-1 (dBA)	Player V_m per BA EN 50332-2 (mV)	Headphone WBCV per BS EN 50332-2 (mV)
Portable audio player #1 with earbud type phones (matched set)	*106.7**	*255**	*72**
Insert-type earphones			*60**
Suprea-aural headphones			*382*
Closed circunaural headphones †			*149*
Open circumaural headphones †			*188*
Portable audio player #2		*145*	
Smart phone		*179**	

Table 2. Test results for various sample devices.

* Value is outside BS EN 50332 limits

† BS EN 50332 does not apply to this type of headphone

References

[1] BS EN 50332: Sound system equipment - Headphones and earphones associated with portable audio equipment – Maximum sound pressure level measurement methodology and limit considerations.

[2] IEC 60268-1 Sound System Equipment Part 1: General

Links

G.R.A.S. Sound and Vibration (KEMAR Manikin Type 45BA): http://www.gras.dk

Related Downloads:

APx Portable Audio Player / Headphone Test Utility: http://ap.com/display/file/495

Technote 107: Measuring the Sound Pressure Level of Portable Audio Player Headphones (this document): http://ap.com/display/file/494

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