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Comparison of two test methods for determination of broadband sound power levels emitted by products: a reverberation chamber method versus a hemi-anechoic chamber method

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ABSTRACT

The use of sound power levels in specification, labeling, and design of noise-emitting products has a distinct advantage over the use of sound pressure levels in that sound power levels can be considered a property of the device and not of the test environment or distance away from the device. Ideally, end-users of the product should be able to compare sound power levels as a product-selection consideration or develop maximum allowable sound power level specifications for given applications, independent of the test method used to determine sound power levels or particular laboratory performing the testing. With that goal in mind, two commonly used methods for determining sound power levels – a reverberation chamber method and a hemi-anechoic chamber method – are compared, with respect to correlation of determined results as well as practical considerations (test time, measurement instrumentation required, and chamber configuration).

1 INTRODUCTION

1.1 The growing demand for sound power level specifications

As devices containing microprocessors become more ubiquitous in home and office environments, the importance of controlling the noise emissions of these devices becomes more apparent. While measurement of operator sound pressure levels and sound quality analyses are useful, the primary acoustic metric from both the product engineering and product specification standpoint is the sound power emitted by the device. Two laboratory approaches to determination of sound power are discussed and compared here.

1.2 Drawbacks of the use of sound pressure levels in product noise specification

Our primary tool in acoustic measurement – microphones, as well as our ears, respond to sound pressures. In the field of product noise control, the focus is the source of such sound pressures: the product itself. From a measurement standpoint, we would like to quantify noise emissions of products in such a manner that the data we gather is representative of the product under examination, and not other factors. However, two other major factors affect sound pressures emitted by devices that we are able to measure rather directly: the distance away from the sound source that we take measurements from, and the acoustic environment in which the sound source is located. Also, all products (but especially air-cooled equipment with venting limited to specific areas on the chassis, common to the growing class of information-technology equipment) have strong directionality characteristics of the noise emissions; thus, spatial position of the microphone also affects measured sound pressures. Developers of noise-emitting products cannot generally predict or control these other factors in the product's end application, making

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use of sound pressure levels as a single indicator of successful product design dangerous. Furthermore, one can be easily misled when sound pressure levels are offered as a product specification. While test codes specific to types of equipment (dictating microphone positioning and acoustic environment) mitigate these dangers, new product types come to market before test codes can be developed, and sound pressure levels at limited positions still do not tell the whole story. Frustration commonly occurs when a sound pressure level specification lacks details such as distance, position and acoustic environment.

1.3 The advantage of sound power levels in product noise specification

The sound power emitted by a device is commonly considered, and for practical purposes can be considered, a property of the device itself. The use of sound power levels is also advantageous from a product noise control standpoint because these metrics can be applied in estimation of resulting noise levels when the product is used as a component of a larger system or when many products are going to be operating together. For example, when determining whether a building design and associated equipment inventory for a data center (or the far-more acoustically stringent requirements of a call center) are acceptable, knowledge of the sound power levels of the equipment is needed.

1.4 Relating sound pressure to sound power

In a given medium, such as air at standard temperature and pressure, sound power (W) is proportional to the sound energy density (D) moving through an area (A) [1]:

$$W \propto D \times A \tag{1}$$

Sound energy density is proportional mean square sound pressure [2]:

$$D \propto \overline{p^2} \tag{2}$$

The sound power over a surface area is then proportional to the mean square sound pressure and the surface area:

$$W \propto \overline{p^2} \times A \tag{3}$$

Using this relationship, we can measure sound pressures and determine sound power. However, determination of the sound power *emitted by a device* is not as straightforward as a simple sound pressure level measurement. Any approach to determination of sound power emitted by a device requires that measurements be taken at multiple locations in the space around the device, all sound propagation paths are accounted for, and measurements must be sufficiently time-averaged. More importantly, steps must be taken to accurately eliminate or quantify any outside influence on the measured sound pressures used to determine the sound powers. When the device is able to be transported, determination of sound power levels emitted by a device should be conducted in a controlled laboratory environment.

2 LABORATORY APPROACHES TO DETERMINING SOUND POWER

Of three common approaches to determining the sound power emission of a device, two approaches involve laboratory sound pressure level measurements in a known acoustic environment, either an approximation of a diffuse field (a reverberation chamber), or an approximation of a free field (or free field over reflecting plane – an anechoic or hemi-anechoic chamber). (While a third approach, the use of an intensity probe is not discussed further here, it is not as simple as might seem either - the reader can find more information on this approach in reference [3].)

2.1 Sound power determination in an anechoic or hemi-anechoic chamber

2.1.1 Direct method

In an anechoic or hemi-anechoic chamber, sound power can be determined directly by measuring sound pressure levels over a measurement surface of area, given that the measurement surface is in the far field, and has been shown to be free of significant reflected sound energy, and encompasses any significant sound propagation paths. In a free field, the sound power emitted by a device over the measurement surface area is related to measured sound pressures resulting from the device by equation (3). When using standard reference values to measure sound pressure level (L_p) and determine sound power level (L_w) over a measurement surface (S, m^2) in an approximation of a free field or free field over a reflecting plane:

$$L_w = \overline{L_p} + \left[10 \times Log\left(S\right)\right] \tag{4}$$

This assumes that the sound pressure level used to determine sound power level is representative of the average sound pressure level around the device at a given distance. For many classes of products, that can be accomplished using a hemi-spherical measurement surface around the device in a hemi-anechoic chamber. Special considerations must be made that the microphones vary in height from the floor with respect to each other to avoid error in results resulting from phase cancellation between the reflected and direct sound paths to the microphone [4].

2.1.2 Comparison method

Sound power can also be determined by comparison of measured sound pressure level resulting from the device with that resulting from a reference sound source (*RSS*) of “known” sound power (i.e., sound power determined using the method above with increased sampling and stringent chamber requirements) in order to correct for significant unwanted reflections within the chamber. However, when determining sound power in an anechoic or hemi-anechoic chamber, the amount of correction feasible for unwanted reflections is limited, as large correction values indicate an unpredictable sound field (i.e., the sound field is no longer a close enough approximation of a free field to assume free field sound propagation). A small correction in decibels for reflections in the test environment is subtracted from the sound power level determined using the direct measurement method.

2.1.3 Standard test methods

Both approaches have been standardized into test methods: ISO 3745 [5] is applicable when the anechoic or hemi-anechoic chamber is free from significant reflections. ISO 3744 [6] is applicable for use in a hemi-anechoic chamber when small corrections for reflected sound energy are required. These corrections (called K_2 values) are limited to 2 dB.

2.2 Sound power determination in a reverberation chamber

2.2.1 Direct method

In a reverberation chamber with sufficiently small absorption (such that a negligent amount of the direct sound energy emitted by the device is absorbed by the chamber walls), sound power can be determined directly by measuring sound pressure level in the reverberant sound field and determining the effective sound absorption area of the chamber walls and sound absorption due to air. The effective absorption area is determined by first determining the reverberation times of the chamber and applying the Sabine equation [7]. A reverberation chamber with steady-state sound pressures is in energy equilibrium. The sound power being emitted by the device is then the sound power being effectively absorbed by the chamber, which can be determined from an application of equation (3) with the effective sound absorption area as A; however, adjustments must be made to account for a non-uniform distribution of sound energy in the sound field [8], and because the sound pressure levels being measured are those resulting from sound waves that have traveled significant distance as they reflect around the chamber, corrections for atmospheric conditions are required.

Determining the effective sound absorption area poses a number of problems which can affect the test results. First, in order to determine absorption, decay *rates* must be determined, which means that transient sound pressure levels must be measured with sufficient time detail to draw an accurate linear regression on the data – the researcher loses the ability to lower measurement uncertainties in measured sound pressure levels by integrating the signal longer. To account for this, repeated measurements must be gathered into level-time arrays and averaged. Averaging of the data sets must be synchronized with respect to when the sound source used to measure decays was stopped or else the data will be "smeared" and decay rates will appear longer than the actual decay rate, resulting in erroneously high effective absorption areas and determined sound power levels. These and other potentials for error exist that are often overlooked when real-time analyzers with built-in reverberation time functions are used without independent validation of the results given by examination of the actual level-time history for linearity.

2.2.2 Comparison method

Sound power can also be determined by comparison of the reverberant field sound pressure resulting from the device with those resulting from a RSS with known sound power, given that the atmospheric conditions do not change significantly within the course of test and the difference in absorption or room volume due to replacing the device with the RSS is not significant. The equation relating measured sound pressure levels resulting from the device (L_p) to determined power levels (L_w) given the measured sound pressure level from the RSS (L_{pRSS}) and the known sound power level of the RSS (L_{wRSS}) is:

$$L_w = \overline{L_p} + \left(L_{wRSS} - \overline{L_{pRSS}}\right) \tag{5}$$

If the chamber has been shown to be sufficiently diffuse by prior qualification, the conversion factor can be large and the method still applicable.

2.2.3 Standard test method

Both approaches have been standardized into test method ISO 3741 [9], with separate sections for the direct and comparison methods.

3 COMPARISON OF SOUND POWER LEVELS OF REFERENCE SOUND SOURCES DETERMINED USING DIFFERENT TEST METHODS

3.1 Literature review

Sound power emitted by a device is commonly referred to as *the sound power of a device*, without qualification as to the environment it is operating in. The international standard guidelines for use of the standard test methods compared here states that the sound power level determined is "essentially independent of the environment in which the data are obtained" [10].

Review of more scientific literature indicates that the sound power emitted by a device is *not* a property of the device, but is a function of the source and the environment [11, 12, 13, 14]. Reference [11] states "Since an ILG RSS radiates slightly less power below 1000 Hz in a reverberant test room compared to a free field environment, some question arises about which calibration (free field over a reflecting plane or diffuse field) of the RSS is proper…" Some question indeed. In reference [12], the radiation impedance seen by the source is identified as a variable to which the emitted sound power is proportional. If so, the use of RSS calibration levels determined in a similar environment when conducting product testing using a comparison method would not necessarily help: changes in emitted sound power levels of the device as a result of different radiation impedances would not necessarily correspond to changes in emitted sound power levels of the RSS.

The trend common to literature reviewed is that sound power levels determined in a reverberation chamber are lower than those determined in an anechoic or hemi-anechoic chamber, especially at low frequencies: differences of as much as 6 dB in the 50 Hz third-octave band, 3 dB in the 100 Hz band, and converging by 500 Hz to 1000 Hz. One published dataset [12] indicated a difference of almost 4 dB in the 200 Hz third-octave band.

3.2 Data

Acoustic Systems Acoustical Research Facility (*ASARF*) uses reference sound sources for quality assurance and staff proficiency testing, research, and for determination of K_2 values used to provide testing services in accordance with ISO 3744. When comparing sound power levels determined using different test methods, it is imperative that a RSS with very stable emissions be used. The RSS used to compare the test methods here (a model 8612 centrifugal fan manufactured by ILG Industries) meets this requirement[b]. A history of RSS calibrations at an outside laboratory and internal quality assurance testing going back many years shows this.

In order to compare sound power level determination methods fundamentally, use of direct methodology for measurement and determination of sound power levels was used for the data shown here.

Reverberation chamber sound power level determinations were made in a 254 m^3 reverberation chamber with typical averaged early decay reverberation times (T_{15}) shown in Table 1, and rather smooth and linear decay averages from 100 Hz on up. The RSS was placed in 4 independent positions on the floor of the chamber for measurement of the sound pressure levels, and measurements were space- and time- averaged using a rotating microphone boom with a radius 1.52 meters averaged for 64 seconds. The tests in the data set shown were two sets of four tests (each set being repeat tests conducted on or about the same day), one set of tests conducted in 2003 and one set in 2006 as part of laboratory quality assurance and repeatability determination procedures. Data shown here includes the 50 Hz, 63 Hz, and 80 Hz one-third octave bands, in which measurements were made, but the test setup does not meet the requirements of the standard test method in these bands.

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[b] A possible limitation on the applicability of comparison of RSS data to draw conclusions regarding sound power level data correlation of actual products tested using the two different test methods is that reference sound sources have generally have more uniform directional and spectral characteristics.

Table 1: Typical early decay reverberation times for ASARF 254 m^3 reverberation chamber.

Third-Octave Band Center Frequency (Hz)	T_{15} (seconds)
50	1.01
63	1.09
80	1.18
100	1.05
125	1.55
160	2.45
200	3.01
250	3.16
315	3.19
400	3.36
500	3.63
630	3.75
800	3.80
1000	3.72
1250	3.77
1600	3.56
2000	3.38
2500	3.23
3150	3.05
4000	2.69
5000	2.27
6300	1.87
8000	1.46
10000	1.15

Hemi-anechoic chamber sound power level determinations were made using a spiral microphone hemispherical measurement surface with radius of 1.4 meters, microphone positions shown in ISO 3744 Table B.2. While this chamber is generally used for testing in accordance with ISO 3744, no corrections for reflections were applied to the data for presentation here. The tests in the data shown here are one set of 4 tests conducted on or about the same day as part of recent quality assurance testing, and four tests conducted over the last few years. Two of the tests were conducted using a superseded measurement system and microphone mounting hardware (Slight systematic differences in the measurement systems and associated microphone mounting hardware were accounted for in actual product testing by determining K_2 correction values for each system independently). Data below 100 Hz is not available from this test method.

Data shown in Figure 1 below is the differences in sound power levels determined using the two test methods compared to a common reference, the average of 5 reference sound source calibrations in a hemi-anechoic chamber at IBM Hudson Valley Acoustics Laboratory. The variations from the mean are also shown for the calibration data.

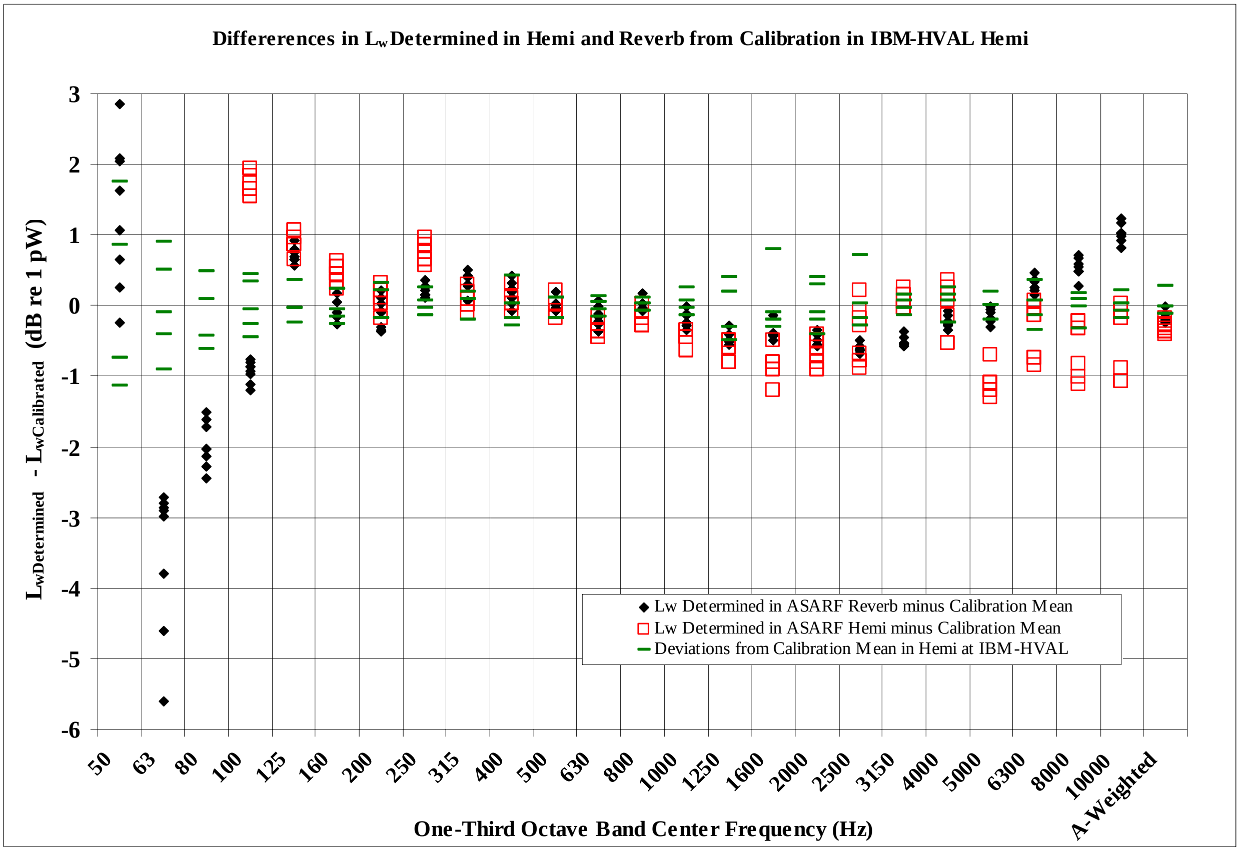

Figure 1: Comparison of sound power level determination methods.

With the quite notable exception of 50 Hz, the trend observed by others is observed here for low frequencies; however data converges by 125 Hz. Albeit with systematic differences, all data is well within the uncertainties listed in the standard test methods.

For the purposes of sound power level specifications, the two test methods yield correlated results such that specification without qualification as to which of the two general test methods to use is acceptable, given that the sound power level emissions of the products are not dominated by low frequency emissions. If selecting between two products based on determined sound power level emissions and the differences in determined emissions are within the systematic bias shown above and in existing literature, it is recommended that only sound power levels determined using the same test method be compared.

4 PRACTICAL CONSIDERATIONS WHEN CHOOSING TEST METHOD FOR SOUND POWER LEVEL DETERMINATIONS

For the product manufacturer wishing to bring broadband sound power level determination in-house, the reverberation chamber method is primarily advantageous from an initial cost standpoint: a reverberation chamber is generally cheaper than a hemi-anechoic chamber, as is the measurement instrumentation (especially when single-channel acquisition is used, although cost of multi-channel systems has dropped significantly in recent years and makes instrumentation less of a factor). For typical measurement setups, the measured sound pressure levels used to determine sound power levels in a reverberation chamber will be higher than in a hemi-anechoic chamber, allowing for slightly elevated background sound pressure levels without affecting the test results for equipment with sound power levels of around 4 A-weighted bels and up.

However, what the product manufacturer saves in cost by constructing a reverberation chamber, they can lose in additional testing capabilities: No directionality data on the product can be gathered in a reverberation chamber, and sound quality work is limited in that the short time-variance of the emissions of the device are lost in a reverberation chamber. While tonal emissions can be measured in a reverberation chamber, additional initial resources are required to "tune" the test setup – finely adjust diffuser, microphone, and source placement in the chamber such that tonal emissions of the product when in the so-determined source positions are sufficiently diffused by the chamber and sampled adequately. This can be a time-consuming process and will involve detailed examination of the sound field in the chamber. The savings in initial cost when deciding to use a reverberation chamber method for in-house product testing is particularly seen for manufacturers of larger machines, especially when the frequency range is interest is extended below 100 Hz, and the size of the product makes selection of a measurement surface in a smaller hemi-anechoic chamber difficult. Manufacturers of HVAC systems, generators, air compressors, or appliances may be well served to use a reverberation chamber approach, especially when directionality is not nearly as much of a concern as overall levels.

For the IT equipment industry, the trend over the last few decades as been to largely abandon the reverberation chamber for use of hemi-anechoic chambers. There is good reason for this. For personal computers, operator position sound pressure levels, while secondary to sound power levels, are an important consideration. Perhaps more importantly are advances in the field of sound quality analysis in recent years. In addition to determination sound power level emissions, the manufacturer can engineer their product with respect to psychoacoustic considerations using high-resolution time waveform data acquired in a hemi-anechoic chamber.

5 CONCLUSIONS

It has been shown with data presented here, as well as previously published data, that the two test methods give comparable determined sound power level emissions, within the frequency ranges commonly tested. However, more research is merited into the low frequency differences. More research is merited into the 50 Hz data not following the observed trend in this data set. Of special interest is the correlation between the determined sound power levels and the noise emissions of devices in actual use environments.

The product manufacturer is well served to focus on sound power level as a metric to assess and control noise emissions. The availability of high-quality acoustic test chambers, measurement instrumentation, and acoustic testing services today allow them to do so.

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7 REFERENCES

[1] Wikipedia contributors, "Sound energy density", *Wikipedia, The Free Encyclopedia*, http://en.wikipedia.org/w/index.php?title=Sound_energy_density&oldid=69577086.
[2] Leo Baranek, Part V in *Acoustics* (Acoustical Society of America, New York, 1996).
[3] *ECMA-160: Determination of Sound Power Levels of Computer and Business Equipment using Sound Intensity Measurements; Scanning Method in Controlled Rooms 2nd edition (December 1992)*" (ECMA International, Geneva, 1992).

[4] Angelo J. Campanella, “Calibration of reference sound sources – a US historical perspective”, *Proceedings of Noise-Con 1996*, pp. 931-936.

[5] *Acoustics - Determination of sound power levels of noise sources using sound pressure - Precision methods for anechoic and hemi-anechoic rooms*, International Standard ISO 3745:2003 (International Organization for Standardization, Geneva, 2003)

[6] *Acoustics - Determination of sound power levels of noise sources using sound pressure - Engineering method in an essentially free field over a reflecting plane*, International Standard ISO 3744:1994 (International Organization for Standardization, Geneva, 1994)

[7] *Acoustics - Measurement of sound absorption in a reverberation room*, International Standard ISO 354:2003 (International Organization for Standardization, Geneva, 2003)

[8] R. V. Waterhouse, “Interference patterns in reverberant sound fields”, *Journal of the Acoustical Society of America*, **27**, 247-258 (1955).

[9] *Acoustics - Determination of sound power levels of noise sources using sound pressure - Precision methods for reverberation rooms*, International Standard ISO 3741:1999 (International Organization for Standardization, Geneva, 1999)

[10] *Acoustics – Determination of sound power levels of noise sources – Guidelines for the use of basic standards and for the preparation of noise test codes*, International Standard ISO 3740:1980 (International Organization for Standardization, Geneva, 1980:E)

[11] American Society of Heating, Refrigerating and Air Conditioning Engineers, “Determining sound power”, Chapter 7 in *1989 Fundamentals Handbook* (ASHRAE, Georgia, 1989).

[12] K. O. Ballagh, “Limitations to the measurement of sound power by the reference sound source method”, *Journal of the Acoustical Society of America*, **72**(5), 1637-1639 (1982).

[13] Paul François, “Characteristics and Calibration of Reference Sound Sources”, *Noise Control Engineering*, Vol. 9-1, July-August 1977, (Institute of Noise Control Engieering, Indiana, 1977).

[14] Per V. Brüel. “The enigma of sound power measurements at low frequencies”, *Brüel and Kjær Technical Review*, No. 3-1978