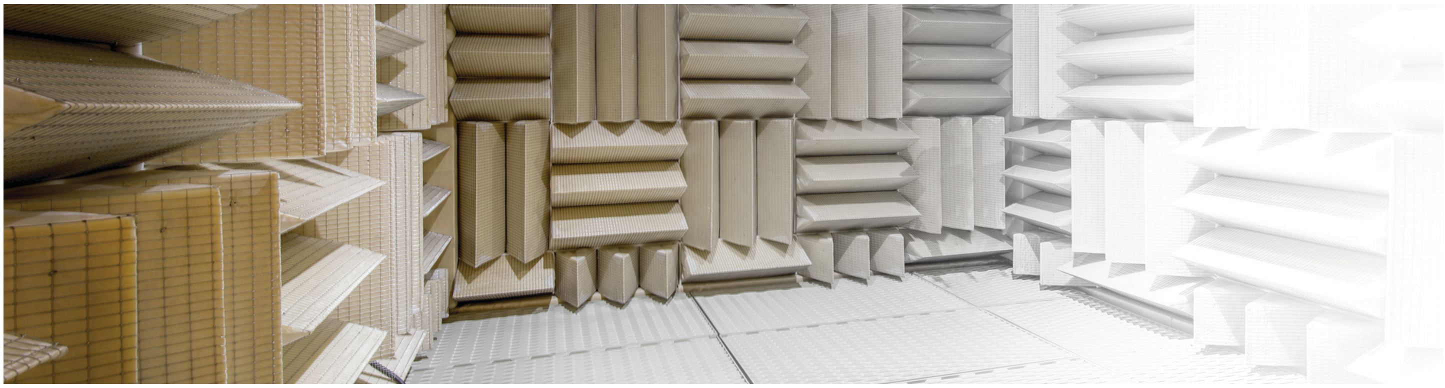

WHITE PAPER | #31

QUANTIFYING ACOUSTIC SOURCES THROUGH SOUND POWER MEASUREMENTS

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Introduction

Consumers of white goods are becoming more aware of product noise radiation. Commercial advertising and more stringent government and industry standards and codes have contributed the increased sensitivity of consumers to product noise. Manufacturers of white goods are increasingly being required to report noise radiation metrics of their products for customer comparison. The most important topics for white goods manufacturers are understanding the correct metrics for reporting noise data and using the proper measurement techniques to obtain this data.

To begin you must understand the basic source-path-receiver paradigm for sound propagation. The problem must start with a device that generates sound waves (source). The source is then connected to a receiver through some propagation media (path) which is commonly air, but could be a structure, another fluid, or a complex combination of these media. Finally the sound wave reaches an object (receiver) where it somehow affects the nature of that object. Usually the receiver is a person, but it could be also be a piece of delicate equipment, an animal, or anything else that can be affected by sound waves. In this paper we will focus on how to characterize the source component of the source-path-receiver paradigm.

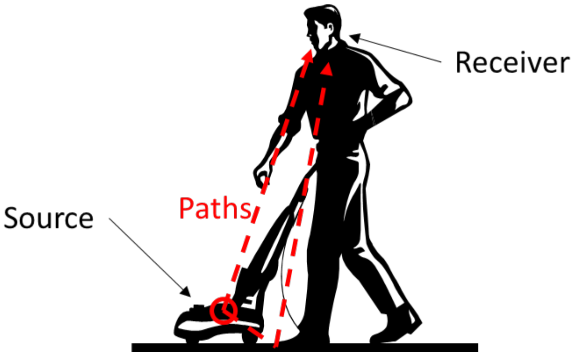


Figure 1. Schematic of a source-path-receiver paradigm for a vacuum cleaner. Notice that there can be multiple paths that the sound can travel to reach the receiver. Here both the direct and reflected paths are depicted.

The most common and well-known type of measurement in acoustics is the measurement of sound pressure level (SPL, or L_P). Although good for measuring sound path and receiver characteristics, SPL alone cannot fully quantify the acoustic characteristics of a source. That is because the SPL generated by a source changes with distance, orientation, ground conditions, atmospheric conditions, and many other factors. A metric is needed that is a measure of the total amount of acoustic energy being emitted from a source. This metric should be independent from the aforementioned path contributions.

Sound power level, often denoted SWL or L_W, is the metric traditionally used for source characterization. Sound power is the total amount of acoustic energy emitted by a source per unit time. This means it is independent of distance from the source. Sound power is measured in standard units of Watts. Sound power level, L_W, is a conversion of the absolute sound power, in Watts, to a decibel level by using the base-10 logarithm and a reference sound power of 1 pW, or 10^{-12} W. Note that a decibel level should always be referenced (i.e. the term “dB re 1 pW” should appear after the sound power level value).

$$L_W = 10\log_{10}\left(\frac{W}{10^{-12}}\right) \text{ dB re 1 pW}$$

There are many ways to measure sound power and several standards exist to guide engineers and technicians in the measurement. This paper will discuss the current standards for measuring the sound power level of a source and demonstrate one particular method using four common household white goods: an air compressor, a cordless vacuum, a blender, and a dehumidifier.

Overview of Sound Power Measurement Techniques

The main differentiator between sound power measurement techniques is the type of environment in which the measurement is made. There are three main types of measurement environments when considering sound power. The first is a free-field. This implies an acoustic field free of reflections. However, there are provisions for consideration of a free-field over one, two, or three, reflecting planes, as long as all of the acoustic energy from the source is reflected out into the remaining free-surface planes, see Figure 1. The second type of measurement environment is reverberant, where the walls of test room reflect the majority of the sound energy back into the room. Typically reverberant rooms are constructed of painted concrete or metal to reflect as much sound from the surfaces as possible. The last type of measurement environment is in-situ. In-situ refers to making a measurement of a sound source in its natural operation environment. This is usually done only with large pieces of industrial equipment where it’s not feasible to move into a free-field (anechoic) or reverberant test chamber.

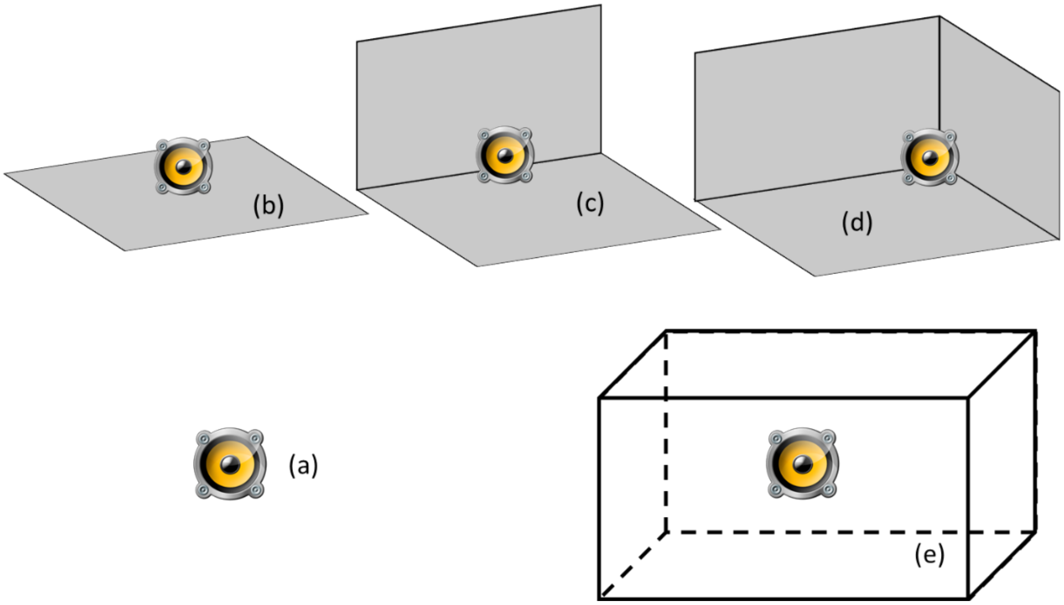


Figure 2. Examples of environments for sound power measurements, (a) free-field, (b) free-field over one reflecting plane, (c) free-field over two reflecting planes, (d) free-field over three reflecting planes, and (e) reverberant field.

Free-Field Methods

In a free-field, sound power can be calculated by measuring the mean-square sound pressure over a surface fully encompassing the source. Free-field microphones, such as PCB 378B02, microphone holders that can be accurately located, and a data acquisition system are required equipment. The standards governing this technique are ANSI-ASA S12.54/ISO 3744, ANSI-ASA S12.55/ISO 3745, and ANSI-ASA S12.56/ISO 3746 for engineering, precision, and survey grade measurements, respectively. The most common measurement surface geometries are hemispherical or 5-sided parallelepiped. These geometries rely on locating a source on a reflecting plane with an acoustic free-field above it. Sound pressure is measured at specified points on the measurement surfaces, defined in the standards, and the surface area of the measurement surface is used to compute the sound power level. Correction factors are available for the background noise levels and environmental factors during the test. The correction factors and acceptability requirements increase in complexity with increased precision of the method. By measuring the surface-averaged SPL, denoted $\overline{L_P}$, L_W is calculated as

$$L_W = \overline{L_P} - K_1 - K_2 + 10\log_{10}\left(\frac{S}{S_0}\right),$$

where *S* is the surface area of the measurement surface, S_0 is the reference surface area of 1 m^2, K_1 is the background noise correction factor, and K_2 is the environmental correction factor.

Reverberant Field Methods

There are two standardized techniques for measuring sound power in a reverberant field. The first is the comparison method, detailed in ANSI-ASA S12.53/ISO 3743 as an engineering grade method. In this technique, a calibrated source of known sound power level, such as the Larson Davis REF500 or REF600, is placed in a reverberant or semi-reverberant environment. The averaged SPL over the entire volume of the room is measured using random incidence microphones, such as the PCB 378B20. The random incidence microphones can be slowly and continuously scanned throughout the volume to obtain the volume average, or placed at several set locations. Next, the unknown source replaces the known source at the same location and the volume averaged SPL is measured again. The sound power level is computed as

$$L_{W_{Unknown}} = L_{W_{Known}} + \overline{L_{P_{Unknown}}} - \overline{L_{P_{Known}}}.$$

The second method for measuring sound power level in a reverberant chamber is a precision method outlined in ANSI-ASA S12.51/ISO 3741. This method requires the tester to rigorously quantify the surface absorption levels in the room in terms of a surface averaged absorption coefficient, $\overline{\alpha}$. This is done by measuring the reverberation time in the room, T_{60}, which is the time it takes for a sound to decay by 60 dB in a given room. Reverberation time is measured using a stationary or impulsive source and random incidence microphones distributed throughout the volume of the room. When the source stops, the room decay times are measured and fitting techniques are used to calculate the T_{60} in different frequency bands. The Norris-Eyring definition of reverberation time is used to compute the surface averaged absorption coefficient. Finally, the unknown source is placed in the room and volume averaged sound pressure levels are measured. Using the averaged sound pressure levels, the surface area of the room (*S*), and the computed surface averaged absorption coefficient, the sound power level can be calculated by

$$L_W = \overline{L_P} - 10\log_{10}\left(\frac{4}{\overline{\alpha}S}\right).$$

In-Situ Methods

The last type of measurement environment is in-situ. These standardized methods are used to measure sound power levels of sources without removing them from their natural environments. There are two main techniques for in-situ measurements, sound pressure (ANSI-ASA S12.57/ISO 3747) and sound intensity (ISO 9614). These standards rely on measuring acoustic quantities close to a source and careful understanding of background noise and interfering noise sources. For brevity, the details of these methods will not be discussed here. However the reader should understand that very robust methods exist for measuring sound power levels of sources in-situ.

Demonstration of the "Free-Field over a Reflecting Plane" Measurement

A demonstration of the ANSI-ASA S12.54/ISO 3744 standard method was conducted using common household items, or white goods. A 1 m radius measurement hemisphere was constructed in the hemi-anechoic chamber at ARL/Penn State. The chamber interior dimensions are 5.5 m by 6.8 m by 9.3 m high. The source was located at the center of the hemisphere and PCB 378B02 free-field microphones were positioned at 20 different measurement locations on the hemisphere surface, as directed in Annex B of the standard. The standard also permits 10 microphone locations, as opposed to the 20 used here, which may be used for non-directional sound sources and is typical throughout the industry. A National Instruments compactDAQ system with NI 9234 dynamic signal acquisition cards was used to collect the sound pressure data from the microphones. Background noise measurements were conducted at each measurement location and used for calculation of the background noise correction factor, K_1. In this measurement facility, the environmental correction factor, K_2, could be ignored. Figure 3 shows photos of the four white goods that were tested for sound power level, and four microphone positions in the hemi-anechoic chamber. Figure 4 shows the measurement grid for locating microphones.

Figure 3. Common household sound sources from left-to-right: 100 psi air compressor, blender/mixer, cordless boom/vacuum, and dehumidifier. The sources are shown in the ARL/Penn State hemi-anechoic chamber with four PCB 378B02 microphones.

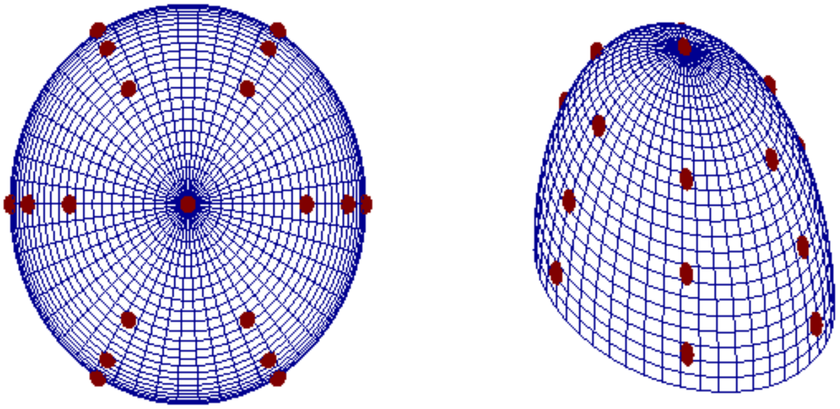


Figure 4. Schematic of the 20 hemispherical microphone locations (red dots) specified in Annex B of ANSI-ASA S12.54/ISO 3744 shown from top view (left) and isometric view (right).

The one-third-octave band individual sound pressure levels, surface averaged sound pressure level, background noise correction, and computed one-third-octave band sound power levels and overall A-weighted sound power level, OAL_W, are reported for each source in Figure 5, Figure 6, Figure 7, and Figure 8. Notice that the background noise correction, K_1, is very small (less than 1 dB) for these measurements because the ARL/Penn State hemi-anechoic chamber is a very quiet environment compared to the levels emitted by these example sound sources. For a lower signal-to-noise ratios, the background noise correction factor will increase. In the following plots, circles represent the sound pressure measured at individual measurement locations, the black line represents the surface averaged sound pressure level using the mean squared pressure over all 20 measurement points, the blue bars represent the one-third-octave band sound power levels, and the red bars represent the OAL_W.

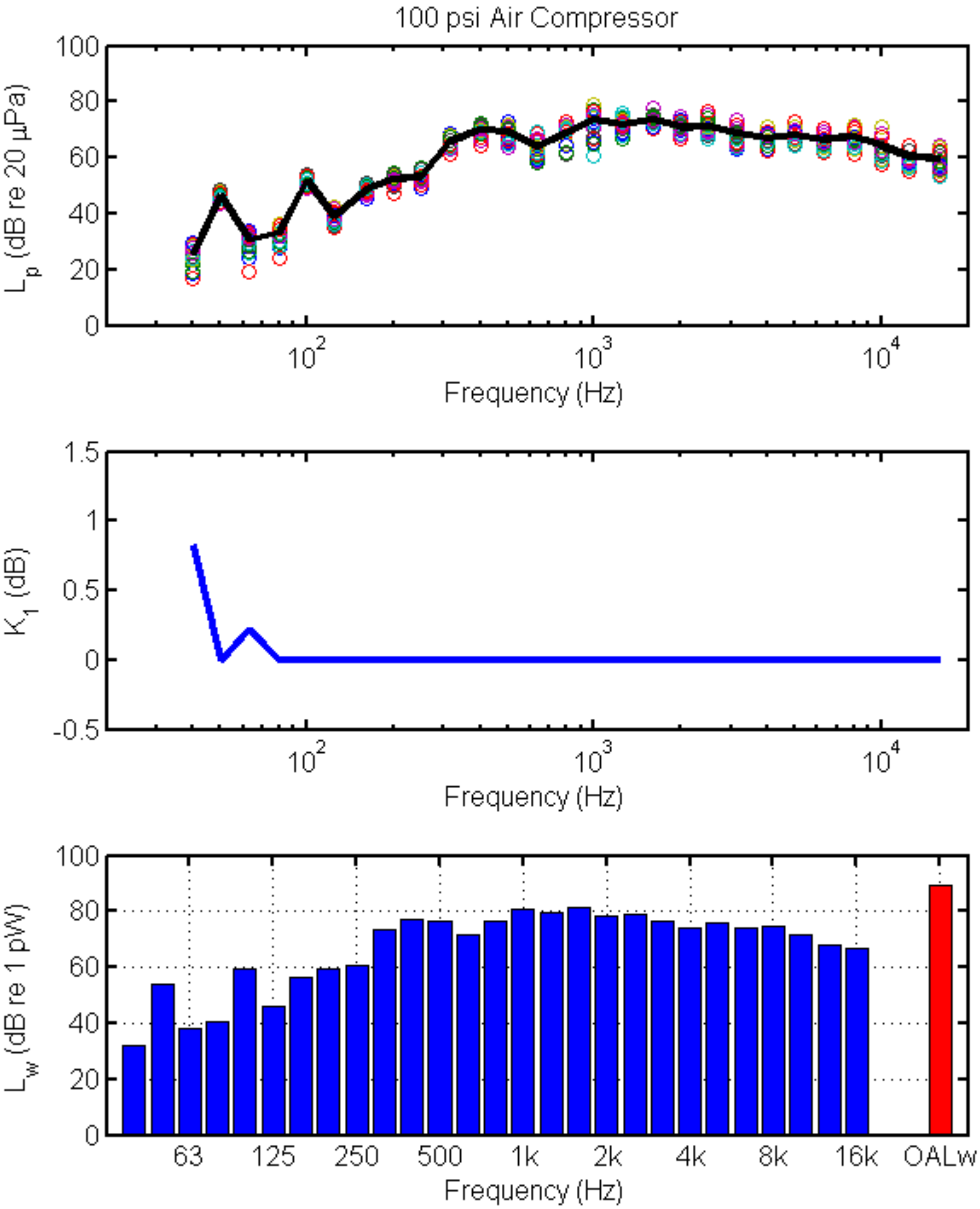


Figure 5. Sound power measurement results of the 100 psi air compressor.

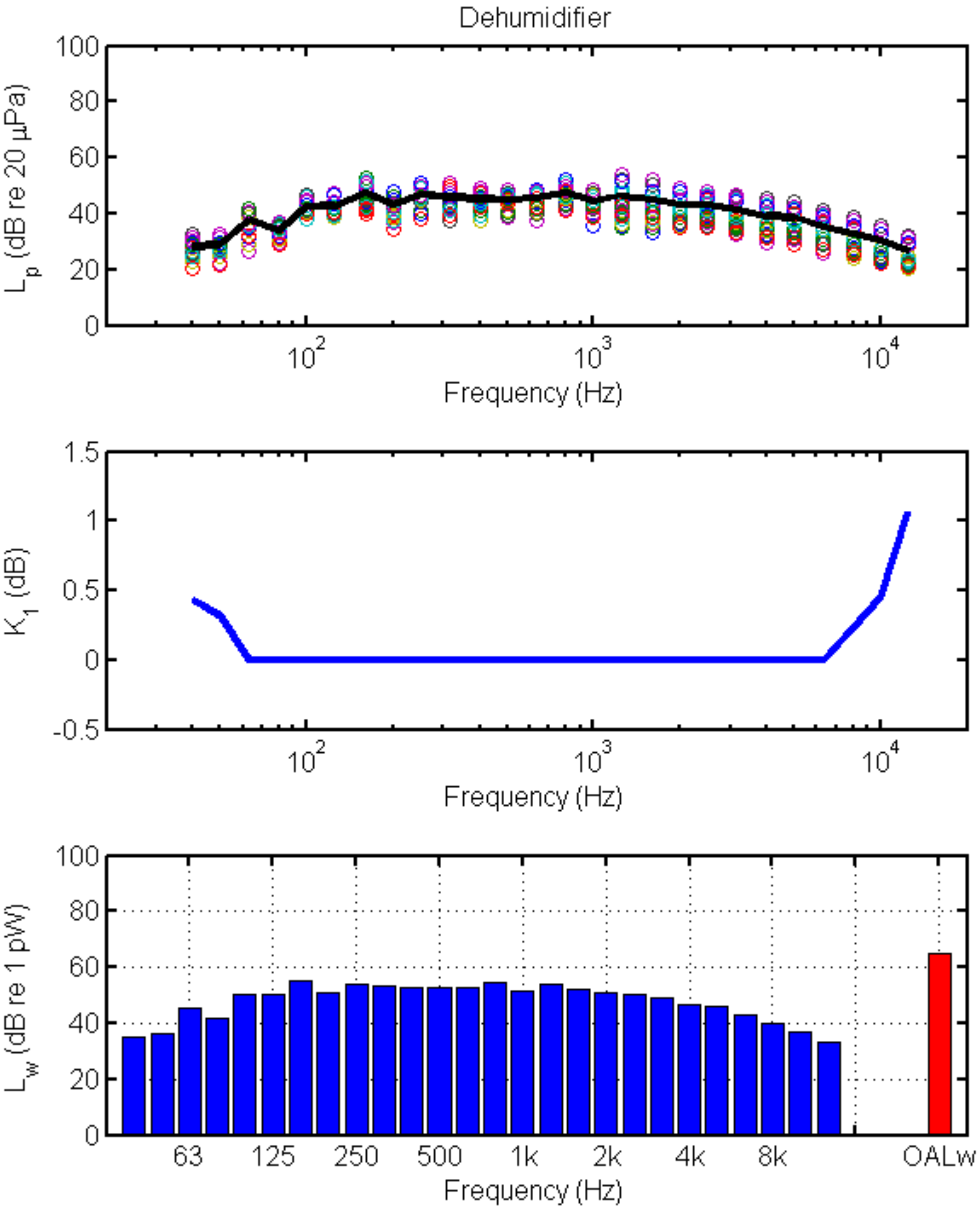


Figure 6. Sound power measurement results of the dehumidifier.

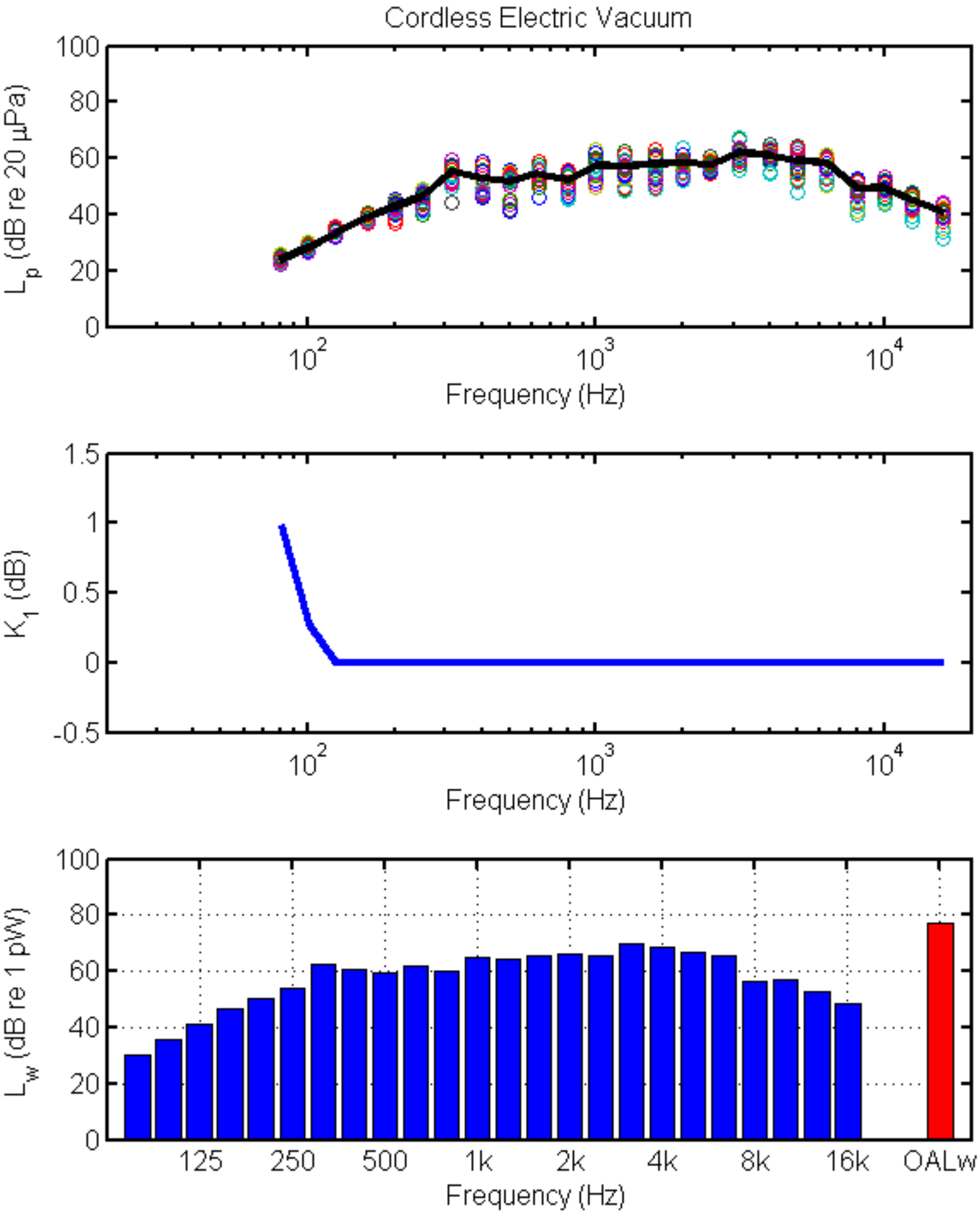


Figure 7. Sound power measurement results of the cordless electric vacuum.

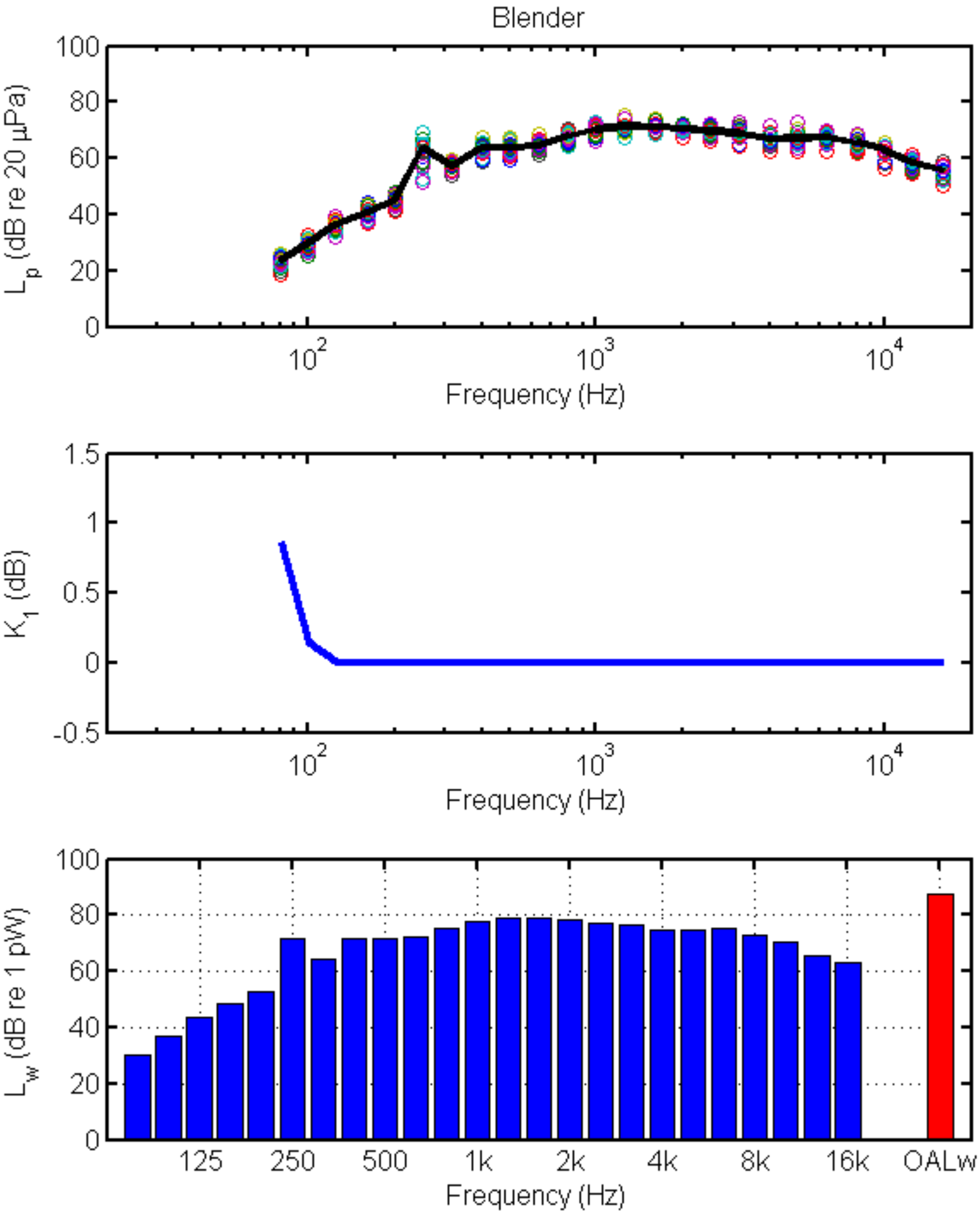


Figure 8. Sound power measurement results of the blender/mixer.

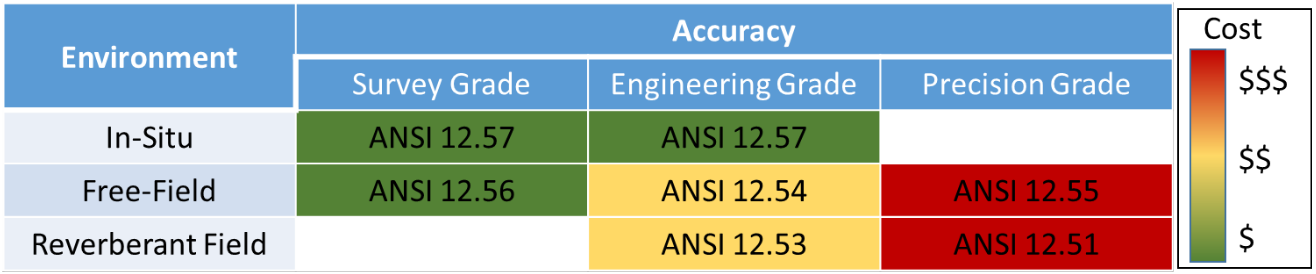
Choosing the right method for your application

There are three main considerations when choosing the right sound power measurement technique for your application: environment, accuracy, and cost. Cost encompasses equipment, facilities, and manpower. All three considerations are related. For example, if you don't have access to a reverberant or anechoic chamber, building these facilities can be quite costly. However, the free-field methods could be used outdoors over a hard surface (concrete or asphalt) to reduce facility costs. The downside of testing outdoors is that the measurement could be subject to weather, unwanted acoustic reflections, and/or extraneous background noise. The in-situ techniques could also be used in this scenario, but precision grade accuracy would not be possible.

All of the techniques rely on multiple microphone measurement locations. If product throughput time is the primary concern, it is possible to set up a microphone grid using one microphone at each location and a data acquisition system with enough channels to record data from all microphones simultaneously (10-20 microphones depending on technique and accuracy). This is typically the best practice for sound power measurements. However, if test equipment cost is the primary driver, a longer test can be performed by using fewer microphones and manually moving them from point-to-point. When moving microphones, you must be careful to ensure the sound source doesn't change characteristics over time, since your measurements are not simultaneous. A good way to do that is to keep one microphone stationary for the entire test and verify afterwards that the SPL measured at that location didn't change over the course of the test. When using the reverberant field measurement techniques, you can also use a rotating boom microphone system to measure the averaged SPL in the room. This will reduce test time and the number of microphones required; however, it requires an expensive rotating boom fixture.

Finally, required accuracy must be considered. With increasing accuracy, comes associated increased cost due to increased hardware requirements and increased testing and reporting time. See each standard for their accuracy bounds and compare them to your requirements to find the right method for you. Table 1 is a summary of the sound power standards sorted by environment, accuracy, and cost.

Table 1. Summary of sound power standards (using sound pressure measurements) arranged by environment, accuracy, and cost.



Environment	Accuracy		
	Survey Grade	Engineering Grade	Precision Grade
In-Situ	ANSI 12.57	ANSI 12.57	
Free-Field	ANSI 12.56	ANSI 12.54	ANSI 12.55
Reverberant Field		ANSI 12.53	ANSI 12.51

Sound Power Measurement Standards

1. ANSI S12.5/ISO 6926, AMERICAN NATIONAL STANDARD - Acoustics - Requirements for the Performance and Calibration of Reference Sound Sources Used for the Determination of Sound Power Levels
2. ANSI S12.50/ISO 3740, Acoustics - Determination of sound power levels of noise sources - Guidelines for the use of basic standards
3. ANSI S12.51/ISO 3741, Acoustics - Determination of sound power levels of noise sources using sound pressure - Precision methods for reverberation rooms
4. ANSI S12.53/ISO 3743, Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for small movable sources in reverberant fields - Part 1: Comparison method for a hard-walled test room
5. ANSI S12.54/ISO 3744, Acoustics – Determination of sound power levels of noise sources using sound pressure – Engineering method in an essentially free field over a reflecting plane
6. ANSI S12.55/ISO 3745, Acoustics — Determination of sound power levels of noise sources using sound pressure — Precision methods for anechoic and hemi-anechoic rooms
7. ANSI S12.56/ISO 3746, Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Survey method using an enveloping measurement surface over a reflecting plane
8. ANSI S12.57/ISO 3747, American National Standard Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering/survey methods for use in situ n a reverberant environment
9. ISO 9614-1, Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 1: Measurement at discrete points
10. ISO 9614-2, Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 2: Measurement by scanning
11. ISO 9614-3, Acoustics -- Determination of sound power levels of noise sources using sound intensity - Part 3: Precision method for measurement by scanning

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