Sound Power Basics
(Part 1)

Chad M. Walber, PhD
Research and Development Engineer

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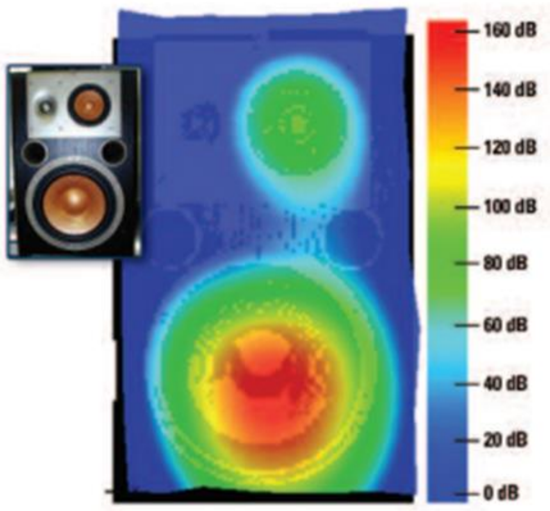
- Over 10 years expertise in dynamic sensing, instrumentation, signal processing, acoustics, and calibration systems
- Sensor Design Engineer and Calibration System Specialist for 3 years at PCB's Technology Center
- Doctor of Philosophy in Mechanical Engineering-Engineering Mechanics, Michigan Technological University
- IEC Electroacoustics TC 29 WG 5 (Microphones) Standards Committee Member
- ASA Standards Committee S1/WG1 (Microphones) Chair
- Technical papers published include:
  - "Desinent Cavitation in Torque Converters"
  - "Measuring and Comparing Frequency Response Functions of Torque Converter Turbines Submerged in Transmission Fluid"
  - "Characterizing Torque Converter Turbine Noise"
  - "Calibrating and Protecting Microphones to Allow Acoustic Measurements in Hazardous Environments"

Outline

- **Acoustics**
  - Definitions
  - Particle Motion vs. Waveform Propagation
  - Sound Fields
  - Octave Band Analysis
- **Sound Power Measurements**
  - Why Measure and Who Measures?
  - Sound Power Equations
  - Standards
  - Methodologies
  - Sound Intensity Measurements
    - Standards

Definitions

Sound - a mechanical wave that is an oscillation of pressure through some medium (solid, liquid, or gas). These oscillations must be within the range of hearing.



Acoustics - interdisciplinary science that deals with the study of all mechanical waves in gases, liquids, and solids including vibration, sound, ultrasound, and infrasound

Noise - any sound or signal that is unwanted by the receiver. Which sounds or signals that are not wanted are, by definition, determined by whoever is listening, measuring, or analyzing them.

Acoustic Metrics

Sound pressure

- Local pressure deviation from the ambient atmospheric pressure, caused by a sound wave. In air, sound pressure can be measured using a microphone, and in water with a hydrophone. The SI unit for sound pressure is the pascal (Pa).

Particle velocity

- Velocity of a particle in a medium as it transmits a wave. In the case of sound, this is a longitudinal wave of pressure.

Sound power

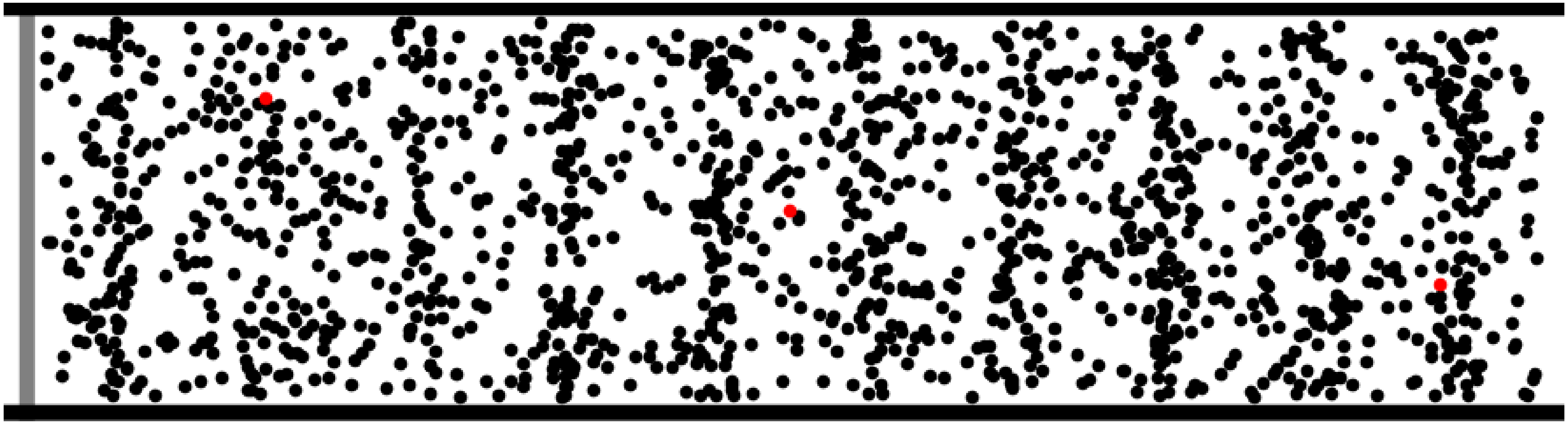
- A measure of sound energy per unit time. It is measured in watts (W) and can be computed as sound intensity times area.

Sound intensity

- The sound power per unit area.

  The usual context is the noise measurement of sound intensity in the air at a listener's location as a sound energy quantity. Sound intensity is not the same physical quantity as sound pressure. Hearing is directly sensitive to sound pressure which is related to sound intensity

Acoustic Particle Motion vs. Wavefront Propagation



The speed of sound is the distance travelled during a unit of time by a sound wave propagating through an elastic medium.

In dry air at 20° C (68° F):

343.2 m/sec	1,236 km/hr	kilometer in 3 sec.
1126 ft/sec	768 mi/hr	1 mile in 5 sec.

Acoustic Field Type Shape According to a Microphone

Free Field

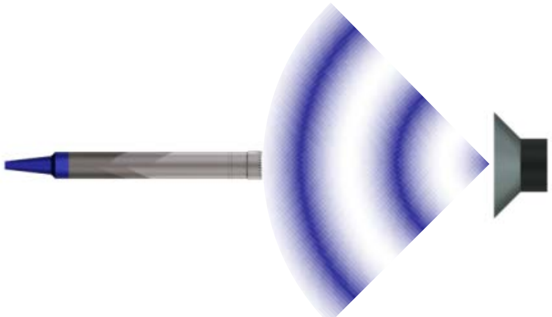
- No reflections
- Primary direction of the sound source and the axis of the microphone are collinear

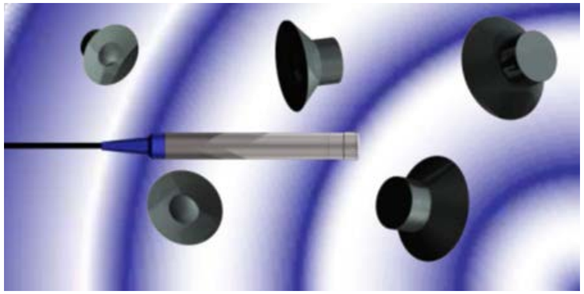
Diffuse/Random Incident Field

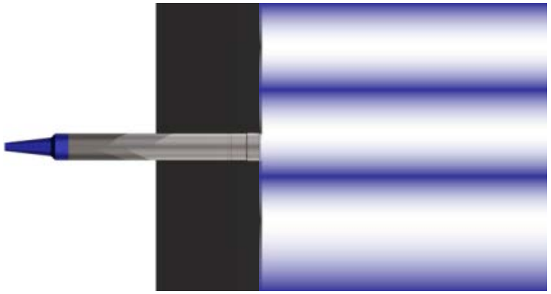
- Reflections
- Multiple sources are transmitting in multiple locations

Pressure

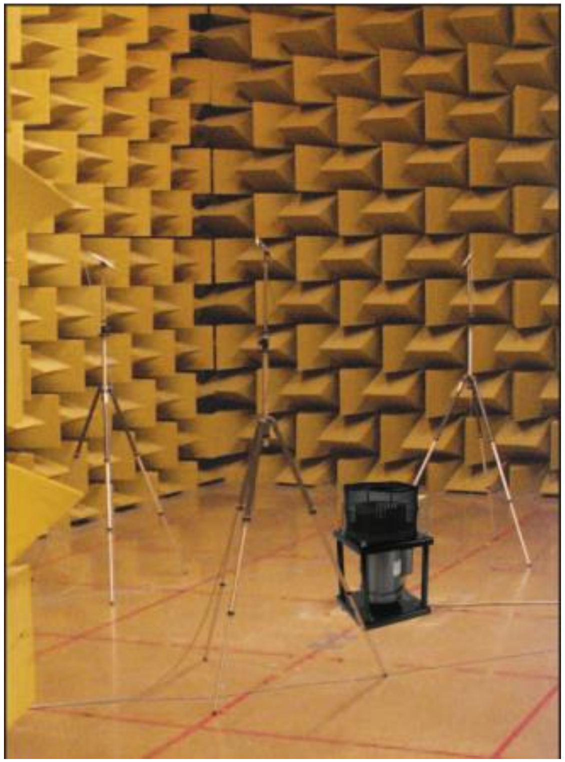
- Flush mounted inside a duct or acoustic coupler
- Similar to pressure transducer







Acoustic Field Type
Shape According to Source



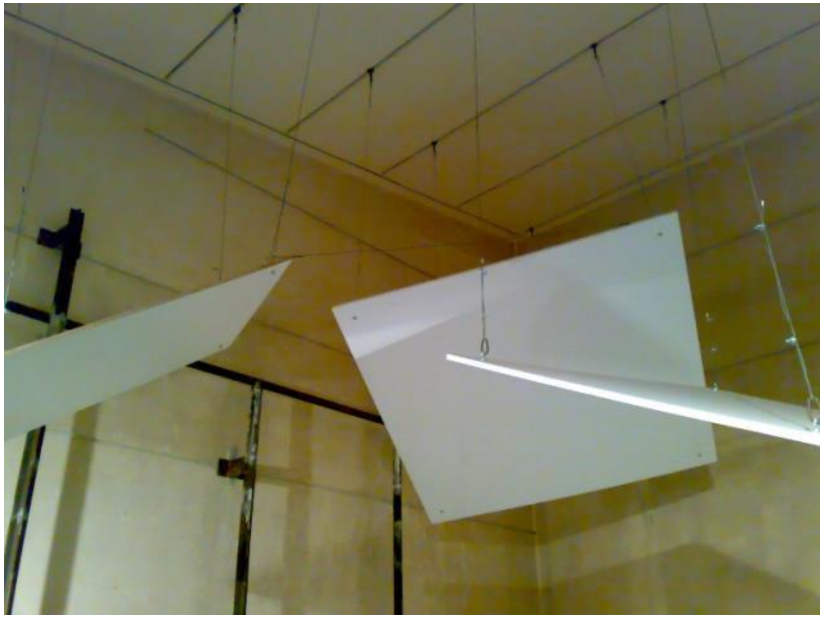
Free Field/

Anechoic Room:

- No reflections
- Only one sound source exists

8

Acoustic Field Type
Shape According to Source



Diffuse Field/
Reverberant room

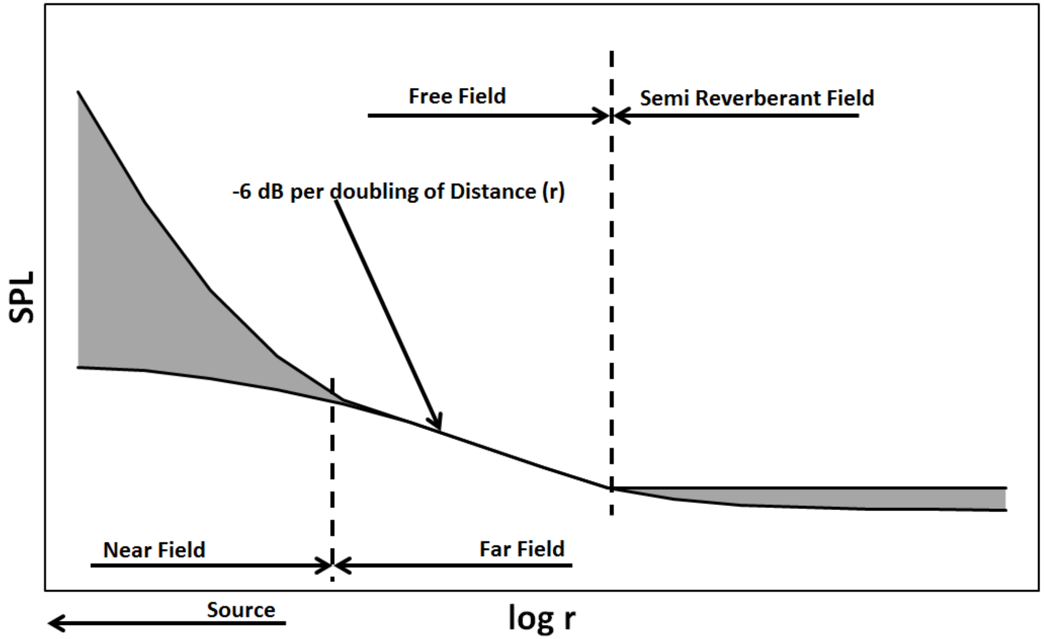
- Reflections
- Multiple sources are transmitting in multiple locations

Acoustic Field Type Shape According to Source

In Situ

- Actual environment where source under test exists
- Can have a sound field that is both free and diffuse

Acoustic Field Type
Location with Respect to Source



Near Field

- Source is within a wavelength of interest of microphone
- Reflections and vibrations from different surfaces of source appear as individual sources

Far Field

- Source is a wavelength of interest or more away from microphone
- Source appears as if it were an acoustic point source

Octave Band Analysis

1/1 (Whole) Octave Bands			1/3 Octave Bands		
Low	Center	High	Low	Center	High
89.1	126	178	112	126	141
			141	158	178
			178	200	224
178	251	355	224	251	282
			282	316	355
			355	398	447
355	501	708	447	501	563
			562	631	708
			708	794	892
708	1000	1413	891	1000	1122
			1122	1259	1413
			1412	1585	1779
1412	1995	2819	1778	1995	2240
			2238	2512	2819
			2817	3162	3550
2817	3981	5626	3547	3981	4469
			4465	5012	5626
			5621	6310	7082
5621	7943	11225	7077	7943	8916
			8909	10000	11225
			11216	12589	14131
11216	15849	22396	14120	15849	17790
			17776	19953	22396
			22378	25119	28195

- **Octave Band Filters** are a series of filters applied to analyze acoustic data.
- The whole acoustic frequency spectrum is divided into set frequency ranges called bands.
- Each band is an octave higher than the one below it, an **Octave** being a doubling of frequency.
- Common Octave divisions are 1/1 (Whole), 1/3, 1/6, and 1/12. The smaller the fraction, the more discrete frequency resolution can be determined.

Sound Power Measurements

Why measure Sound Power?

- Product Optimization
  - Household appliances and motor vehicles
- Legal/Occupational Health
  - Industrial machinery, electrical machinery, and motor vehicles
- Government Directives
  - All products mentioned above

Who Measures Sound Power ?

- Laboratories
- Consultants
- Manufacturers
  - Office Equipment
  - Computers
  - Automobiles and Components
  - Yard Equipment
  - Appliances
  - HVAC
  - Power Tools

PCB PIEZOTRONICS INC.

Sound Power Equations

$$L_w = \bar{L}_p + 10\log(\frac{S}{S_0}) + 10\log(\frac{p_0^2 S_0}{\rho c W_0})$$

With Sound Pressure

If the source is being measured in a free field, anechoic, or hemi-anechoic room

$$L_w = \bar{L}_p + 10\log\left(\frac{A}{A_0}\right) - 6 + C.$$

If the source is in a diffuse field

$$L_w = 10\log\left(\sum_{i=1}^{N}\frac{W_i}{W_0}\right) \quad W_i = I_n S_i$$

With Sound Intensity

ISO Sound Power Standards by Measuring Sound Pressure

Standard	
ISO 3740	Guidelines for use of basic standards and for the preparations of noise test codes (ANSI S12.30)
ISO 3741	Precision method for broad band sources in reverberation rooms (ANSI S12.31)
ISO 3742	Precision method for discrete frequency and narrow band sources in reverberation rooms (ANSI S12.32)
ISO 3743	Engineering methods for special reverberation test rooms (ANSI S12.33)
ISO 3744	Engineering method for free-field conditions over a reflecting plane (ANSI S12.34)
ISO 3745	Precision method for anechoic an semi-anechoic rooms (ANSI S12.35)
ISO 3746	Survey method (ANSI S12.36)
ISO 3747	Survey method using a reference sound source

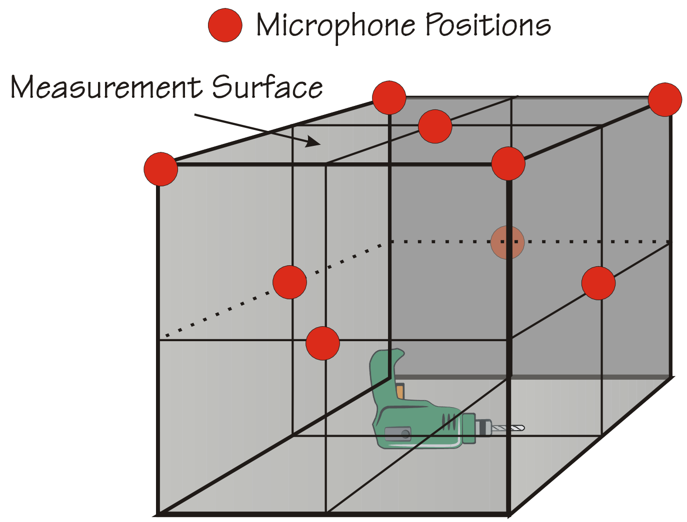
ISO Sound Power Standards

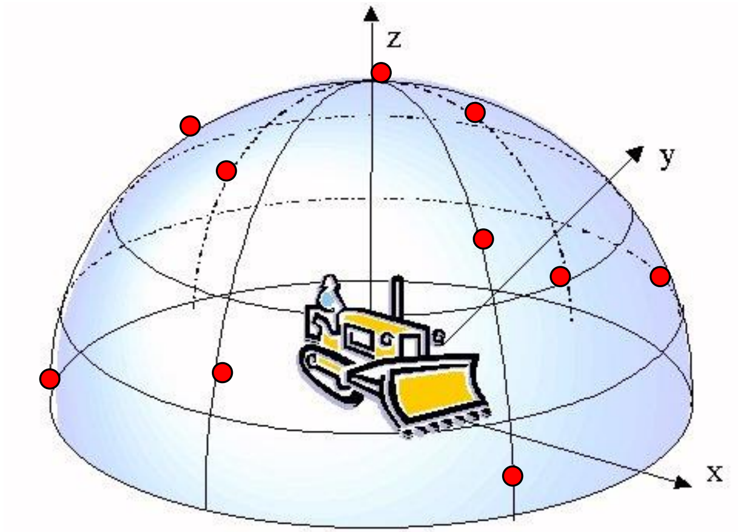
ISO Standard	Classification	Test Environment	Noise Characteristic	Obtainable Sound Power Information
3741	Precision	Reverberation Room	Steady/ Broadband	1/1 or 1/3 Octave Bands, A Weighted
3742			Steady discrete frequency/ Narrow band	
3742	Engineering		Steady, broadband, narrow band, or discrete frequency	Octave Bands, A Weighted
3744		Outdoors or Large Room	Any	1/1 or 1/3 Octave Bands, A Weighted
3745	Precision	Anechoic or Semi-Anechoic		
3746	Survey	None		A Weighted
3747			Steady, broadband, narrow band, or discrete frequency	

Direct Method of Sound Power Measurements

Spatially average sound pressure measurements of source under test

- Parallelepiped or "Shoebox" microphone arrangement in reverberant rooms
- Spherical microphone arrangement in Anechoic or Hemi-Anechoic rooms

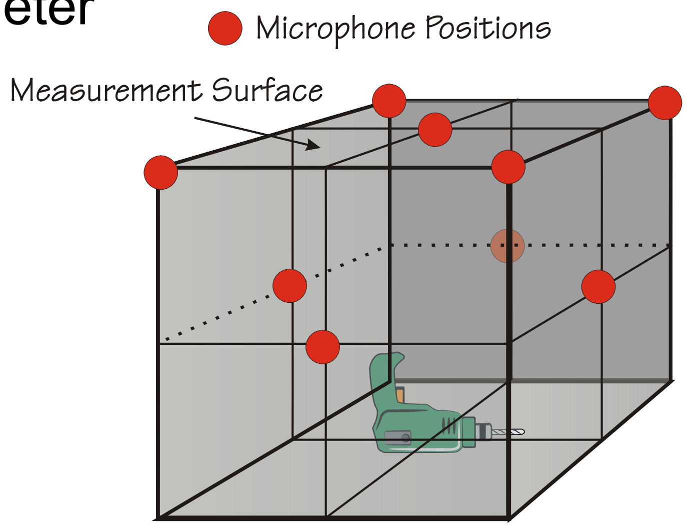


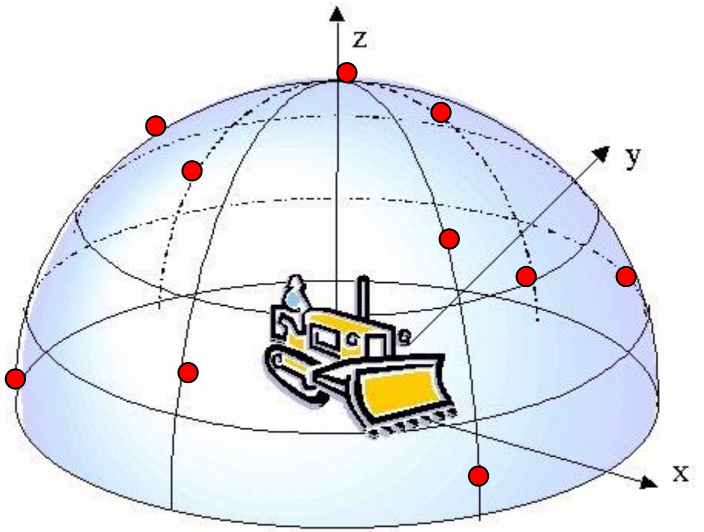


Microphone Locations

The dimensions of the test hemisphere/shoebox should be equal to or larger than all of:

- Twice the largest source dimension **or** three times the distance of the acoustic center of the source from the reflecting plane. Use whichever is larger (for a semi-anechoic room).
- The wavelength of the lowest frequency of interest
- 1 meter





Direct Method of Sound Power Measurements

Measured by:

- Spatially average sound pressure measurements of source under test
  - Parallelepiped or “Shoebox” microphone arrangement in reverberant rooms
  - Spherical microphone arrangement in Anechoic or Hemi-Anechoic Rooms
- Background Noise
  - Must be at least 10 dB less than source under test
    - A correction factor will be required (K1)
    - K1 is negligible for sources 20 dB greater than background.
- Room Correction (K2)

Direct Method of Sound Power Measurements

- Room Corrections (K2) Calculation
  - Volume
  - Surface Area
  - Environmental Conditions
    - Temperature
    - Humidity
    - Ambient Pressure

Comparison Method of Sound Power Measurements

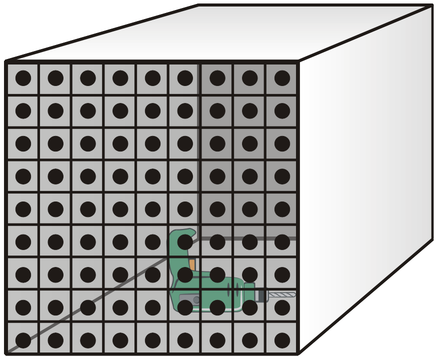
Measured by:

- Spatially average sound pressure measurements of source under test
  - **Parallelepiped or "Shoebox" microphone arrangement in reverberant rooms**
  - **Comparison Sound Power <u>cannot</u> be performed in an anechoic room**
- Background Noise
  - Must be at least 10 dB less than source under test
    - A correction factor will be required (K1)
    - K1 is negligible for sources 20 dB greater than background.
- **Room Corrections**
  - **Determined by measuring a well-known reference source**
  - **Typically due to poor measurements of K2 with test source**

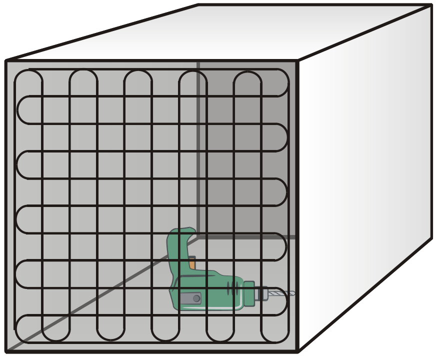
ISO Sound Power Standards by Measuring Sound Intensity

The ISO 9614 Series describes the requirements for measuring Sound Power with the use of an Intensity Probe.

- Environment is not relevant due to nature of measurement
- Background noise should be consistent
  - Any sudden sounds can cause measurement error
- Parallelepiped arrangement for intensity measurements
  - Point by point measurements are taken over a predetermined grid
  - Scanning measurements are taken by uniformly waving the probe normal to each surface



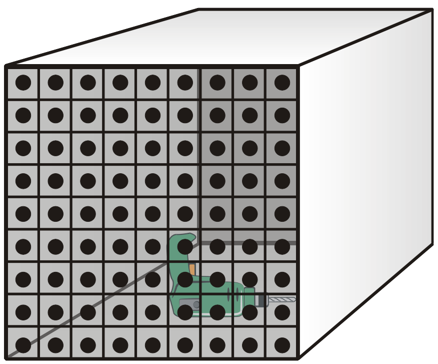
$$L_w = \sum_{i=1}^{N} L_{Ii} \, x \, A_i$$



$$L_w = \int dL_I \, x \, A$$

ISO Sound Power Standards by Measuring Sound Intensity

- Methods for assuring uniform measurements
  - Gantry systems
  - Local positioning systems



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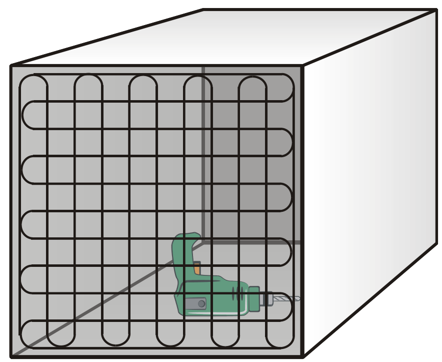

$$L_w = \int dL_I \, x \, A$$

ISO Sound Power Standards

Standard	Measurement	Source
ISO 7779:2010	Acoustics: Measurement airborne noise	Information technology and telecommunications equipment.
ISO 9295:1988	Acoustics: Measurement of high-frequency noise	Computer and business equipment
ISO 7235:2003	Acoustics: Laboratory measurement procedures	Ducted silencers and air-terminal units; Insertion loss, flow noise and total pressure loss
ISO 9645:1990	Acoustics: Measurement of noise (Engineering method)	Two-wheeled mopeds in motion
ISO 11094:1991	Acoustics: Test code for the measurement of airborne noise	Power lawn mowers, lawn tractors, lawn and garden tractors, professional mowers, and lawn and garden tractors with mowing attachments.

ISO Sound Power Standards Governed by Other Committees

Standard	Committee	ISO Standard
TC 23/SC 2	Tractors and Machinery for Agriculture and Forestry, Common Tests	ISO 7216:1992 – Acoustics: Agricultural and forestry wheeled tractors and self-propelled machines; Measurement of noise emitted when in motion
TC 39/SC 6	Machine Tools, Noise of Machine Tools	ISO 230-5:2000 – Test code for machine tools; Part 5: Determination of the noise emission. ISO 7960:1995 – Airborne noise emitted by machine tools; Operating conditions for woodworking machines
TC 42	Photography	ISO 10996:1999 – Photography, still-picture projectors; Determination of noise emissions
TC 60	Gears	ISO 8579-1:2000 – Acceptance code for gear units; Part 1: Test code for airborne sound
TC 70	Internal Combustion Engines	ISO 6798:1995 – Reciprocating internal combustion engines; Measurement of emitted airborne noise; Engineering method and survey method

Thank You!

Questions or Comments?