SOUND INTENSITY Revision C

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Introduction

Sound intensity is the acoustic power per unit area in the direction of propagation. More precisely, the sound intensity is the average rate of energy flow through a unit area normal to the direction of propagation.

The fundamental units of sound intensity are watts per square meter (W/m ^{2}).

Freely Traveling Progressive Wave

The intensity magnitude I is equal to the time-average dot product of the sound pressure p and the particle velocity u.

$$|\,I\,| = \overline{p(t) \cdot u(t)} \tag{1}$$

Free-Field Sound Power and Intensity

A free field is a volume in which there are no reflections. Free-field propagation is characterized by a 6 dB drop in the sound pressure level and in the intensity level for each doubling of distance. This is essentially the "inverse-square law."

Consider a point source, or monopole, which radiates sound in spherical manner in a free field. The intensity magnitude I is related to the sound power W by

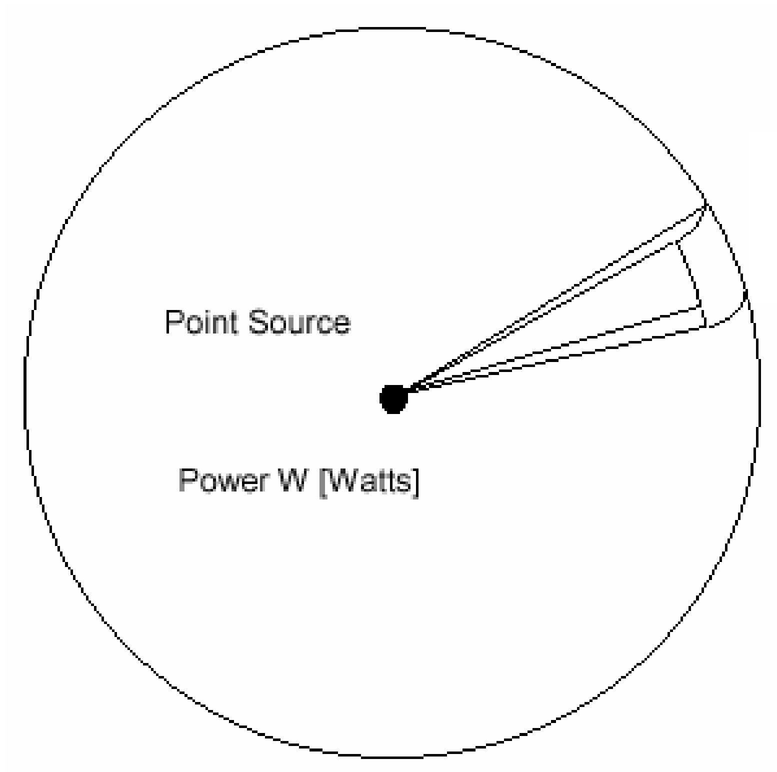
$$|\,I\,| = \frac{W}{4\pi r^2} \tag{2}$$

where r is the radius.

The magnitude symbol on the left side of equation (2) is necessary because intensity is actually a vector.

Note that the denominator in equation (2) is the surface area of a sphere.

The sound intensity in a free field is depicted in Figure 1.



$$|I| = \frac{W}{4\pi r^2}$$

Figure 1. Sound Intensity from a Point Source in a Free Field

Free-Field Pressure and Intensity

The sound intensity is related to the root-mean-square pressure P_{rms} by

$$|I| = \frac{(P_{rms})^2}{\rho c} \tag{3}$$

where

- ρ is the mass density of medium
- c is the speed of sound in the medium

Random Incident Field Pressure and Intensity

An example of a random incident field is a large reverberant room with a diffuse sound field. The intensity in this field is

$$|\, I \,| = \frac{(P_{rms})^2}{4\rho c} \tag{4}$$

Acoustic Impedance

The acoustic or characteristic impedance Z for plane waves is given by

$$Z = \rho c \tag{5}$$

The acoustic impedance value for air and water are given in Table 1.

Table 1. Acoustic Impedance

Medium	Temperature	Speed of Sound (m/sec)	Acoustic Impedance (Pa • sec/m)
Dry Air	0 °C	331.6	428
Dry Air	20 °C	343	415
Distilled Water	20 °C	1481	1.48 (10^6)
Sea Water	13 °C	1500	1.54 (10^6)

Note that the dry air in Table 1 is at a pressure of 1 atmosphere.

Also, the unit of acoustic impedance is often given as rayl, where 1 rayl = Pa · sec/m. This unit is in honor of John William Strutt, Baron Rayleigh.

Decibel Levels

The sound intensity level (SIL) is measured in terms of decibels as

$$\mathrm{SIL} = 10 \log \left[\frac{I}{I_{ref}} \right] \tag{6}$$

where

$$I_{ref} = \begin{cases} 1\,(10^{-12})\ \dfrac{W}{m^2} & \text{for air} \\ 6.7\,(10^{-19})\ \dfrac{W}{m^2} & \text{for water} \end{cases}$$

The sound pressure level in terms of decibels is

$$\mathrm{SPL} = 20 \log \left[\frac{P_{rms}}{P_{ref}} \right] \tag{7}$$

where

$$P_{ref} = \begin{cases} 20\ \mu\mathrm{Pa\ rms} & \text{for air} \\ 1\ \mu\mathrm{Pa\ rms} & \text{for water} \end{cases}$$

Example

Consider the following example from Reference 1.

A lawnmower radiates 0.01 Watts of acoustic power. What are the approximate sound pressure and intensity levels 1.5 m away? This example is not a free-field. Nevertheless, assume that the radiation is free-field in the open air. Also, assume that the ground is perfectly reflective. The power is thus radiated through a hemisphere. The intensity equation for a hemisphere is

$$|\,I\,| = \frac{W}{2\,\pi\,r^2} \tag{8}$$

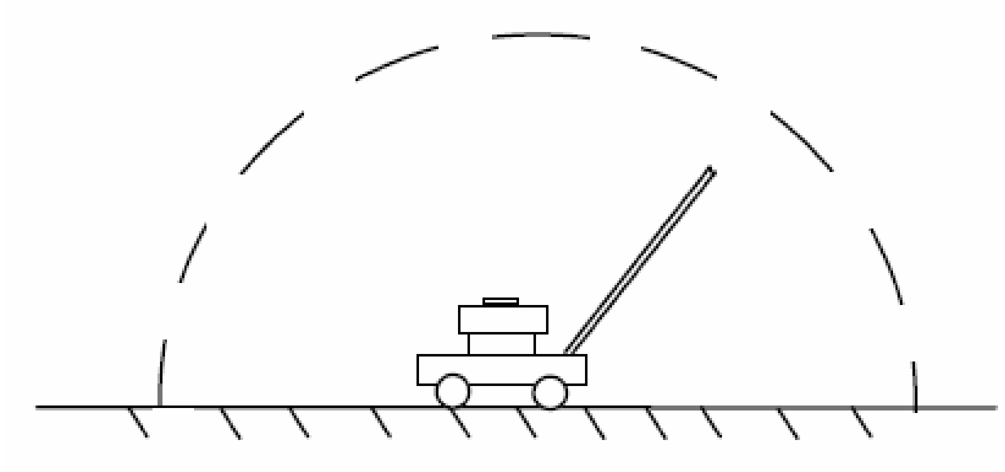


Figure 2. Lawnmower Example

The intensity magnitude at 1.5 meters is

$$|I| = \frac{0.01\ \mathrm{W}}{2\pi(1.5\ \mathrm{m})^2} \tag{9}$$

$$|I| = 0.000707\ \frac{\mathrm{W}}{\mathrm{m}^2} \tag{10}$$

$$\mathrm{SIL} = 10\log\left[\frac{0.000707\ \frac{\mathrm{W}}{\mathrm{m}^2}}{(10^{-12})\ \frac{\mathrm{W}}{\mathrm{m}^2}}\right] \tag{11}$$

The sound intensity level in the air at 1.5 meters is

$$\mathrm{SIL} = 88.5\ \mathrm{dB} \tag{12}$$

The pressure can be found from equation (3). First, solve for pressure

$$P_{rms} = \sqrt{I\rho c} \tag{13}$$

The pressure at 1.5 meters is thus

$$P_{rms} = \sqrt{\left(0.000707 \ \frac{W}{m^2}\right)\left(415 \frac{Pa\, sec}{m}\right)} \tag{14}$$

$$P_{rms} = 0.542 \text{ Pa} \tag{15}$$

The sound pressure level in the air is

$$SPL = 20 \log \left[\frac{0.542 \text{ Pa}}{20 \ (10^{-6}) \text{ Pa}} \right] \tag{16}$$

$$SPL = 88.7 \text{ dB} \tag{17}$$

Note that the sound intensity level and the sound pressure level have approximately the same numerical value.

References

1. Anonymous, Sound Intensity, Bruel & Kjaer, Denmark, 1986.
2. C. Harris, Handbook of Noise Control, McGraw-Hill, New York, 1957.

APPENDIX A

Table A-1. Typical Power Source Outputs	
Source	Acoustic Power
Large Rocket Engine	1 to 10 megawatts
Jet Airplane	10 kilowatts
Pneumatic Chipping Hammer	1 watt
Automobile at 45 mph	0.1 watt
Piano	20 milliwatts
Conversational Speech	20 microwatts
Small Electric Clock	0.02 microwatt
Soft Whisper	0.001 microwatt