ENVIRONMENTAL NOISE PHYSICAL PRINCIPLES AND PARAMETERS

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APAT

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Summary

1. What is Noise?
2. Sound Waves: the physical properties of noise
3. Sound Waves: the measurement of noise
4. Types of Noise
5. Environmental Noise Propagation

1 – WHAT IS NOISE?

- ***Sound*** is a form of energy
- ***Sound*** can be defined as any pressure variation detected by human ear
- ***Sound*** is made when air molecules vibrate and is transmitted as a longitudinal wave motion, called *sound wave*
- ***Noise*** is unwanted sound
- ***Noise*** can be produced by many sources - man's vocal cord, a running engine, an operating machine tool, and so on
- ***Noise*** can disturb man's work, rest, sleep and communication; it can damage his hearing and evoke other psycological or physiological reactions

- The ***speed of sound*** is variable and mainly depends on the temperature and the properties of the substance through which the wave is traveling (material)
- In air, sound propagates at a speed of approximately 340 m/s
- In liquids and solids, the propagation speed is more high: 1500 m/s in water and 5000 m/s in steel
- In general, the *speed of sound* **c** is given by

$$c = \sqrt{\frac{C}{\rho}}$$

where ***C*** is a coefficient of stiffness
ρ is the density of medium

2 – SOUND WAVES: THE PHYSICAL PROPERTIES OF NOISE

- There are two important characteristics of sound or noise - ***frequency*** and ***loudness***

- When a sound wave travels through air, the atmospheric pressure varies periodically. The number of pressure variations per second is called the ***frequency of sound*** **(f)**, and it's measured in Hertz (Hz) defined as cycles per second

- The *wavelength* (λ), or distance between wave crests, is related to *frequency* and *speed of sound*: $\lambda = c/f$

- For humans, hearing is limited to frequencies between about 20 Hz and 20000 Hz : ***Audible Frequency Range***

- The perceived magnitude of sound is defined as ***loudness***

- The perception of ***loudness*** is related to both the intensity and duration of a sound (*frequency*)

- A *mechanical energy* flow accompanies a sound wave
- **Sound Power (W)** is the rate at which the energy is radiated by a source [energy per unit time: watts]
- **Sound Intensity (I)** describes the rate of energy flow through a unit area [watts per square meter]
- For a spherical sound source, the **Intensity** (**I**) in the radial direction is function of the distance *r* from the center of the source:

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

- A sound source radiates power and this results is a sound pressure
- **Sound Power (Pac)** is the cause - **Sound Pressure (*p*)** is the effect
- **Sound Pressure (*p*)** is the local pressure deviation from the ambient (average, or equilibrium) pressure caused by a a sound wave [pascal (Pa)]

❖ In a free sound field, the **Sound Intensity (I)** is related to the **Sound pressure (p)** by the expression:

$$I = \frac{p^2}{Z}$$

where Z is the characteristic acoustic impedance of the medium

❖ Compared to the static air pressure (10^5 Pa), the audible sound pressure variations are very small ranging from about 20μPa (20×10^{-6} Pa) – *threshold of haering* - to 100 Pa – *threshold of pain* –

❖ As the human ear responds logarithmically rather linearly to sound stimulus, it is more practical to express acoustic parameters as a logarithmic ratio of the measured values to a reference value. This logarithmic ratio is called **Decibel**

$$dB = 10 \log_{10}\left(\frac{A}{A_0}\right)$$

2 – SOUND WAVES:
THE MEASUREMENT OF NOISE

- Any acoustic quantity that is related to sound energy (power, intensity, pressure) may be expressed as a decibel level
- To establish an absolute level, a reference value must be agreed:

$W_o = 10^{-12}$ W;

$I_o = 10^{-12}$ W/m^2;

$p_{ref} = 20$ μPa;

- **Sound power level**

$$L_W = 10\log_{10}\left(\frac{W}{W_0}\right)$$

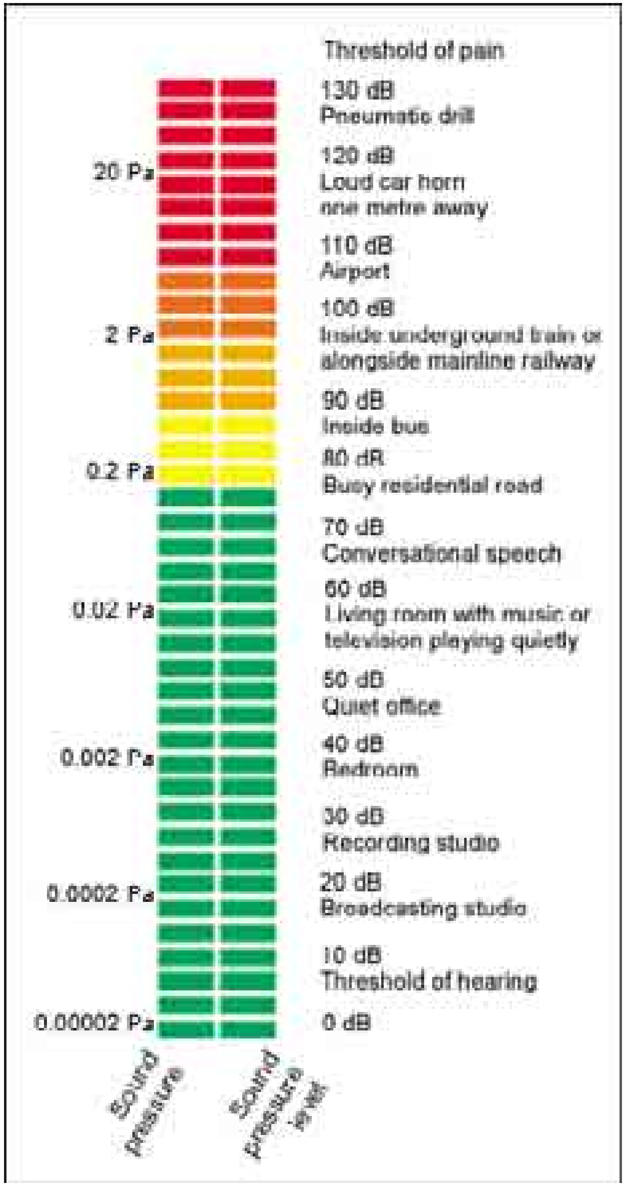
- **Sound Intensity level**

$$L_I = 10\log_{10}\left(\frac{I}{I_0}\right)$$

- **Sound Pressure level**

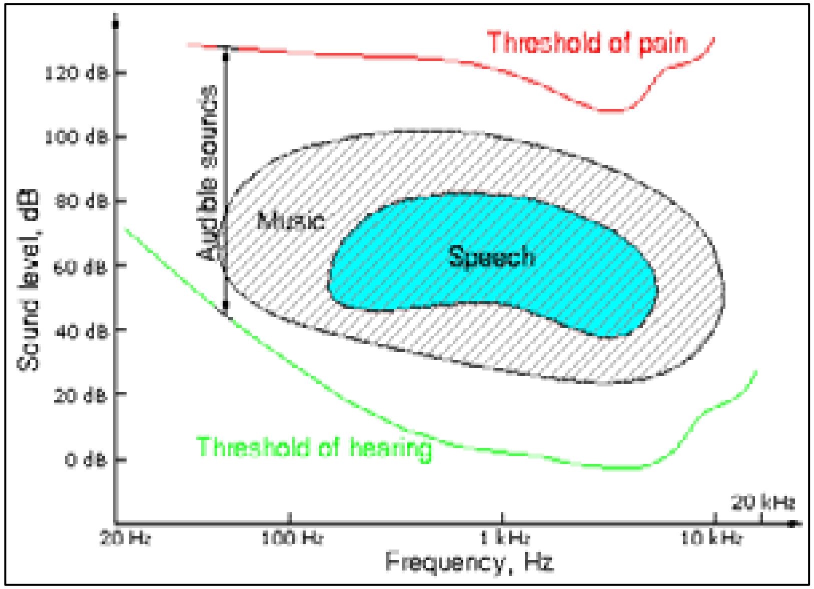
$$L_p = 10\log_{10}\left(\frac{p^2}{p_{ref}^2}\right) = 20\log_{10}\left(\frac{p}{p_{ref}}\right)$$

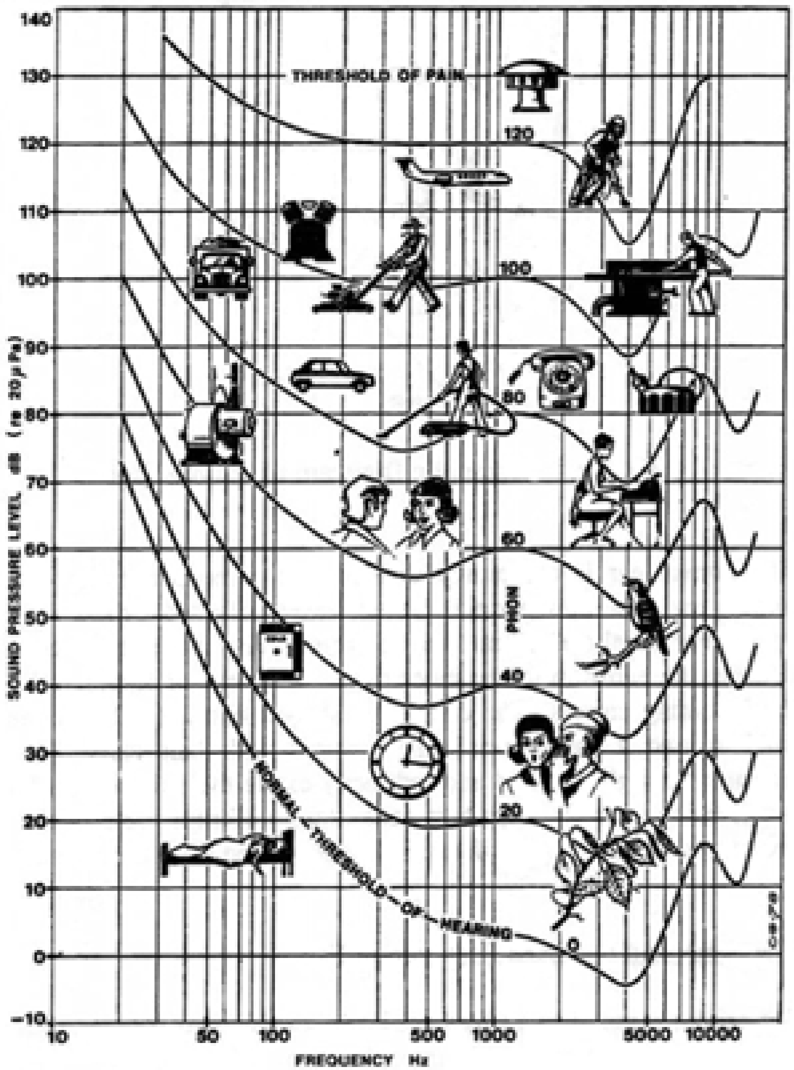
In terms of sound pressure levels, the scheme shows audible sound ranges from the thresholds of haering at 0 dB to the thresholds of pain at 130 dB and over and the related pressure values



Frequency and Loudness Response of Ear

The Audible Frequency Range

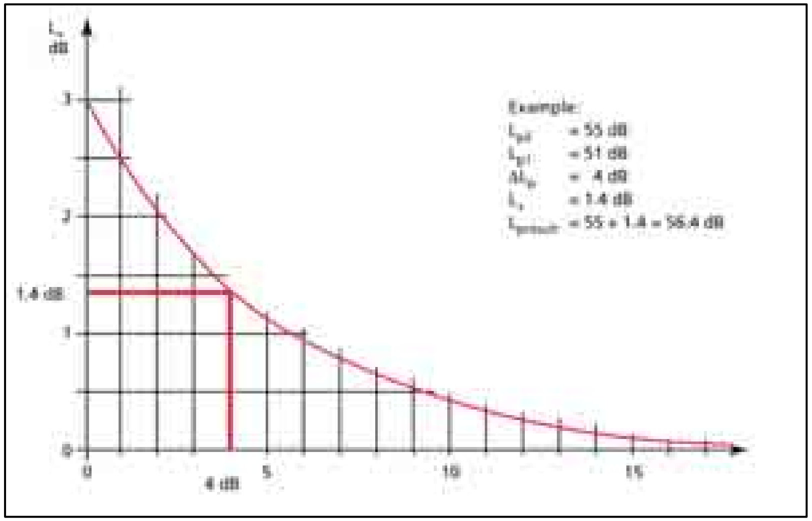




Adding and Subtracting Sound Levels

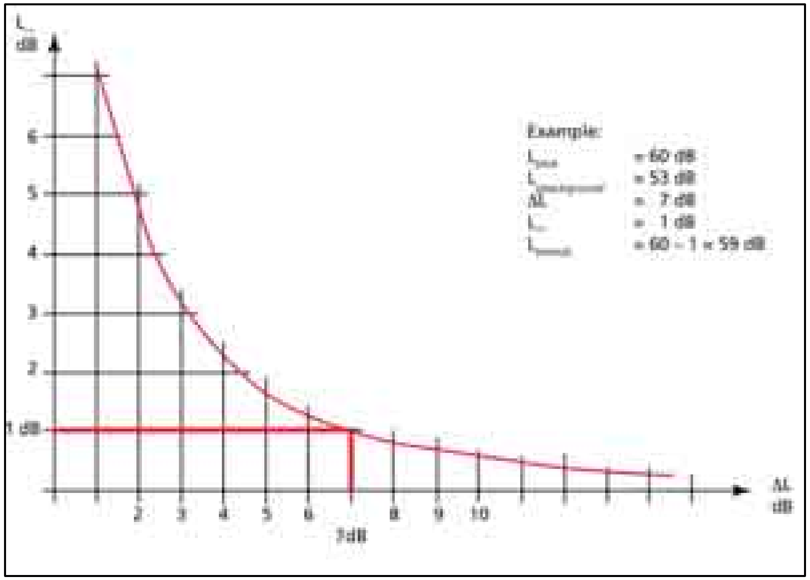
- *Adding Sound Levels*

$$L_{presult} = 10\log_{10}\left(10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + 10^{\frac{L_{p3}}{10}} + \ldots.. + 10^{\frac{L_{pn}}{10}}\right)$$



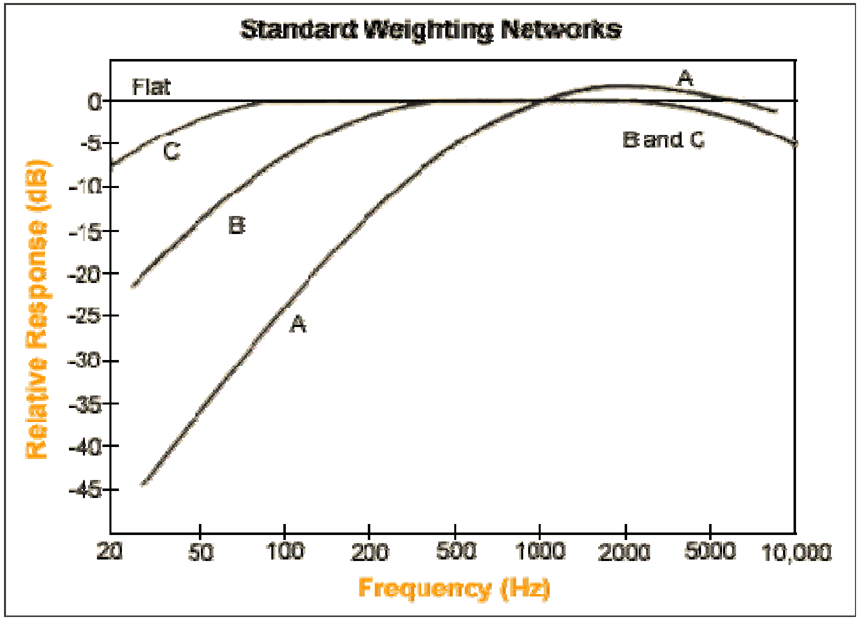
- *Subtracting Sound Levels*

$$L_{presult} = 10\log_{10}\left(10^{\frac{L_{ptot}}{10}} - 10^{\frac{Lpbackground}{10}}\right)$$



Frequency Weighting Curves

- The response of the human ear to sound depends on the frequency of the sound
- On this basis the concept of weighting scales has been defined; weighting filters can be applied measuring sound
- The most common weighting frequency used is “A-weighting”, providing results denoted as dB(A)
- The dB(A) is used as it conforms approximately to the response of the human ear
- The “C-weighting” is also used assessing very loud or very low-frequency sounds



Equivalent continuous sound pressure level

- *Equivalent continuous A-weighted sound pressure level* is widely used around the world as an index for noise
- It is defined as "the A-weighted sound pressure level of a noise fluctuating over a period of time T, expressed as the amount of average energy."
- It is expressed as:

$$L_{Aeq} = 10 \log_{10} \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2}{p_0^2} dt \right]$$

where

L_{Aeq} = equivalent continuous A-weighted sound pressure level [dB]

p_0 = reference pressure level = 20μPa

p= A-weighted pressure [Pa]

t_1 = start time for measurement [s]

t_2 = end time for measurement [s]

Lden and Lnight (Directive 2002/49/EC)

- L_{den}

The L_{den} is the day-evening-night noise indicator for overall annoyance

The L_{den} is the equivalent continuous noise level over a whole 24-hour period, calculated for an annual period, with a 5 dB weighting for evening and a 10 dB weighting for night to reflect the greater noise-sensitivity of people at those times

$$L_{den} = 10 \log_{10} \frac{1}{24} \left(12 * 10^{\frac{L_{day}}{10}} + 4 * 10^{\frac{L_{evening} + 5}{10}} + 8 * 10^{\frac{L_{night} + 10}{10}} \right)$$

- L_{night}

The L_{night} is the equivalent continuous noise level over the night-time period. It does not contain any night-time noise weighting.

The European Environmental Noise Directive requires noise levels to be assessed in terms of Lden and Lnight

4 – TYPES OF NOISE

When measuring noise, we need to know the type of noise so that we choose the parameters to measure, the equipment to use and the duration of measure

- *Countinuous Noise*

This type of noise is produced by machinery that operates without interruption in the same mode, for example blowers, pumps and processing equipment

- *Intermitted Noise*

When machinery operates in cycles, or when single vehicles or airplanes pass by, the noise level increases and decreases rapidly. A single passing vehicle or aircraft is called “an event”

- *Impulsive Noise*

This type of noise is produced by impacts or explosions, having a high peak of short duration or a sequence of such peaks. A sequence of impulses in rapid succession is termed repetitive impulsive noise

When measuring noise the most important parameter is L_{eq} or, better, $\mathbf{L_{Aeq}}$. The $\mathbf{L_{Aeq}}$ is known across the globe as the essential averaged parameter.

The $\mathbf{L_{Aeq}}$ is the level that represents the amount of energy present in the measured, fluctuating sound pressure level.

The $\mathbf{L_{Aeq}}$ is a measure of the averaged energy in a varying sound level.

An **analysis of the statistical distribution** of sound levels is an useful tool when assessing noise. This analysis provides information about the variability of noise level. For example the L_{90} is used as an indicator of background noise level, while L_{10} or L_5 are used to indicate the levels of the specific noise events.

A **spectral analysis** also may be needed to assess annoyance, especially when noise is characterized by distinct tones or low frequency.

5 – ENVIRONMENTAL NOISE PROPAGATION

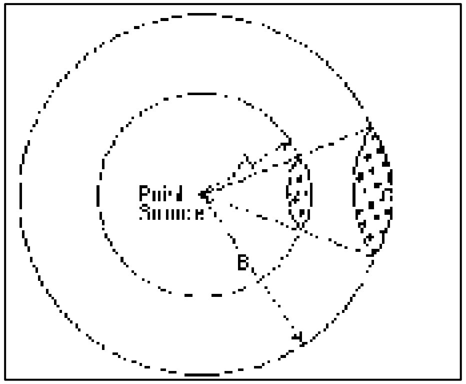
The most important factors affecting noise propagation are:

- *Type of source*
- *Distance from source*
- *Air absorption*
- *Wind*
- *Temperature*
- *Obstacles such as groud and barriers*

Type of Source

❖ *Point Source*

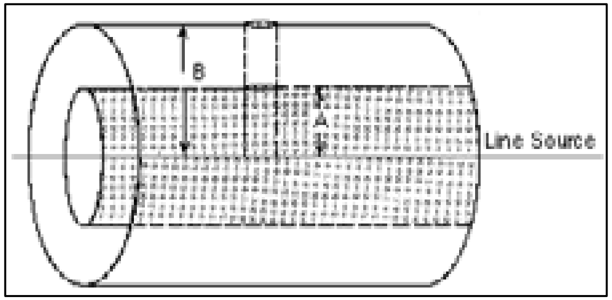
A source may be considered a *Point Source* if its dimensions are small compared with the distance to the receptor, for example, fans and chimney stacks.



The sound energy spreads out spherically

❖ *Linear Source*

A source may be considered a *Linear Source* if it is narrow in one direction and large in the other one. A *Linear Source* can be composed of many point sources operating simultaneously, such a stream of vehicles on a busy road.



The sound energy spreads out chilindrically

Distance from Source

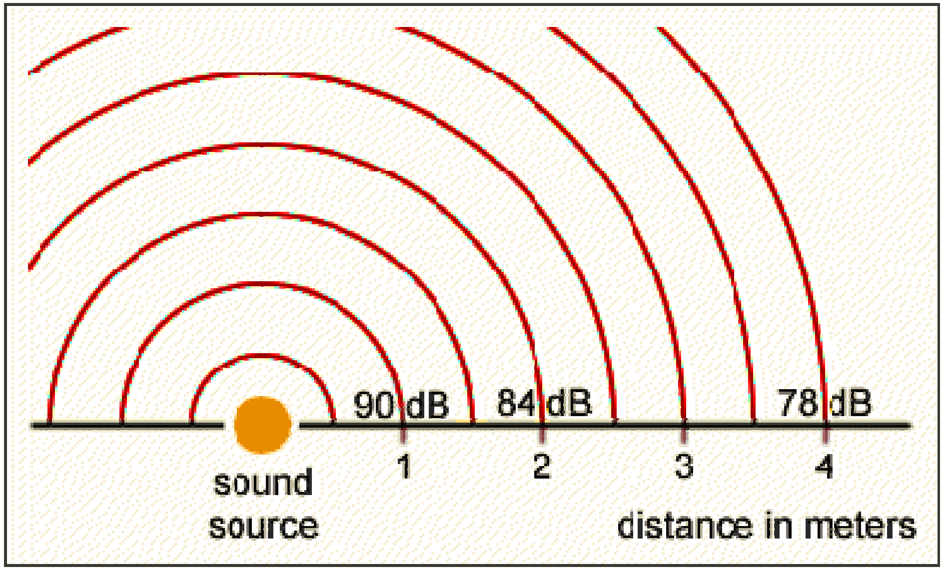
Many noise control problems require a practical knowledge of the relationships between sound field, sound pressure, and sound power

❖ *Free Field*

In a **free field** (no reflections), sound radiates into space from a source uniformly in all directions.

The sound pressure produced by a **point source** is the same in every direction at equal distances from the source.

The sound pressure level decreases 6 dB for each double distance from the **point source.**



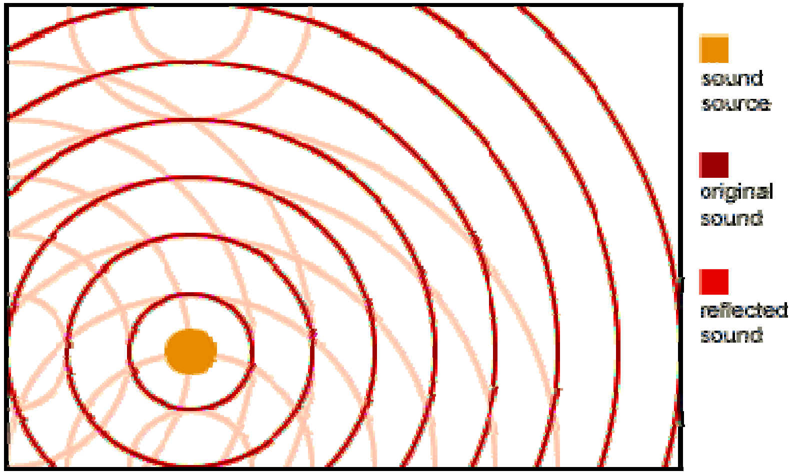
❖ *Reverberant Field*

In many situations, noise problems are complicated by the fact that the noise is confined in a room.

When sound-reflecting objects are introduced into the sound field, the wave picture completely changes because of the reflections .

Far from the source, unless the boundaries are very absorbing, the reflected sound dominates. This region is called “reverberant field”.

If the sound pressure levels in a reverberant field are uniform throughout the room, and the sound waves travel in all directions with equal probability, the sound is said to be diffuse.



Type of Source and Distance from Source
Point Source - Non-Directional Sound in a Free-Field

The simplest relation between sound power level (L_w) and sound pressure level (L_p) is found for a free-field, non-directional sound source, as given by the following equation:

$$L_p = L_w - 20\log_{10} r - k$$

where

L_p = sound pressure level (dB)
L_w = sound power level (dB)
r = distance from the source in meters
k = 11.0 dB for metric units

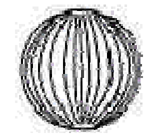
Type of Source and Distance from Source
Point Source - Directional Sound in a Free-Field

If the sound is directional in a free field, the relationship between sound power level and sound pressure level becomes:

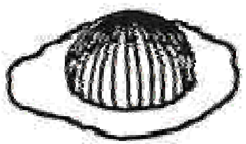
$$L_p = L_w - 20\log_{10} r + 10\log_{10} Q - k$$

Q= directivity factor
k = 11.0 dB for metric units

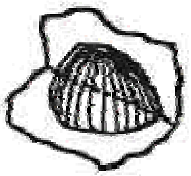
The Directivity Factor (Q) is a dimensionless quantity that is a measure of the degree to which sound emitted by a source is concentrated in a certain direction rather than radiated uniformly in a spherical pattern



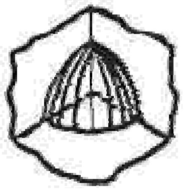
Spherical Radiation
Q = 1



1/2 Spherical Radiation
Q = 2



1/4 Spherical Radiation
Q = 4



1/8 Spherical Radiation
Q = 8

Point Source
Unknown Sound Pressure Level

In most situations, the sound power level (L_w) is unknown.

We can measure the sound pressure level (L_p) at a point in the far field, and relate it to another point further from the source.

For sound radiation from a point source in a free field, the following relationship applies:

$$L_{p1} - L_{p2} = 20\log_{10}\left(\frac{r_2}{r_1}\right)$$

where
L_{p1} = sound pressure level at point 1
L_{p2} = sound pressure level at point 2
r_1= distance from source to point 1
r_2 = distance from source to point 2

In general, the sound pressure level (L_p) at a receptor caused by a noise source with sound power level L_w can be determined by the following equation:

$$L_p = L_w + DI - A_{propagation}$$

where:

DI = Directivity correction in dB if the source does not emit sound equally in all direction ($10 \log_{10} Q$)

$A_{propagation}$ = Propagation Attenuation in dB

$$A_{propagation} = A_{div} + A_{atm} + A_{surf}$$

A_{div} is the attenuation due to the geometrical spreading
For a point source $A_{div} = 20 \log_{10} r$

Atmospheric Attenuation - A_{atm}

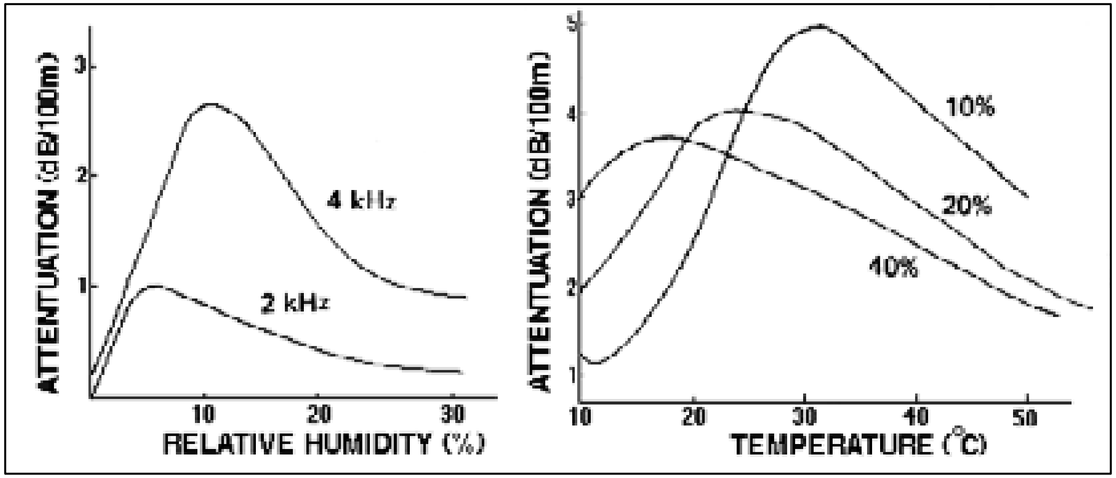
❖ *The Air Absorption*

✓ There are two mechanisms by which acoustic energy is absorbed by the atmosphere: *molecular relaxations* and *viscosity effects*

✓ The most important is molecular relaxation

✓ High frequencies are absorbed more than low

✓ The amount of absorption depends on the temperature and humidity of atmosphere

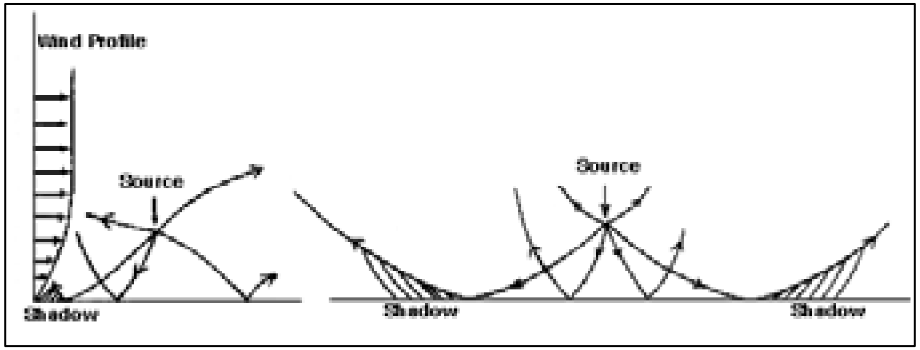


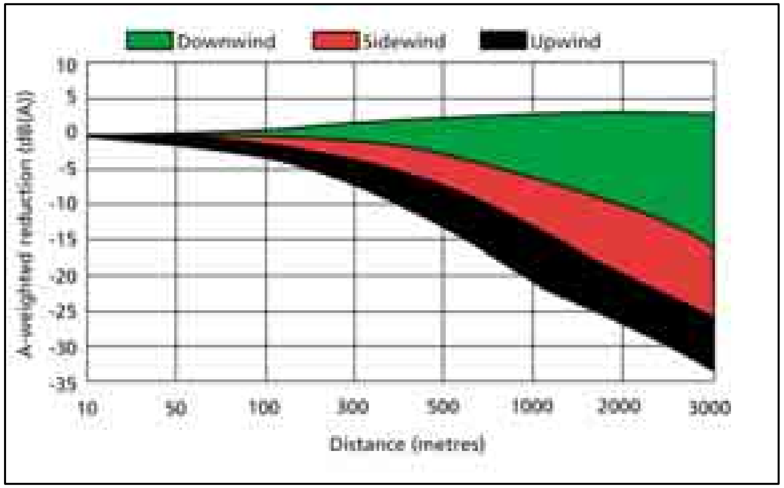
❖ *Wind effect*

✓ When wind is blowing there will always be a wind gradient

✓ Wind speed increases with altitude, which will blend the path of sound to “focus” it on the downwind side and make a “shadow” on the upwind side of the source

✓ For great distance, the wind effect becomes appreciable





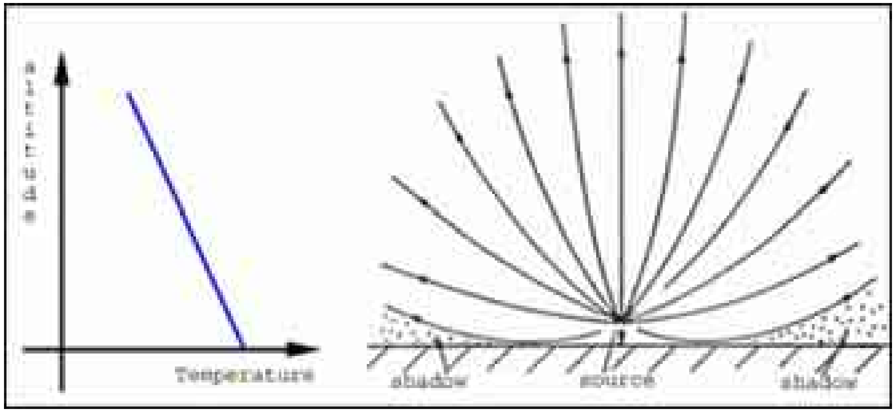
❖ *Temperature effects*

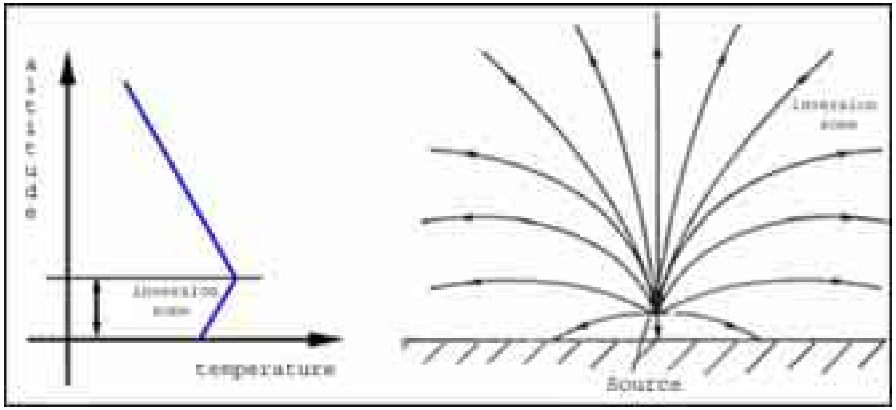
The speed of propagation in a gas depends on the temperature of the gas
Higher temperatures produce higher speed of sound

Since the temperature of the atmosphere is not uniform (*temperature gradient*) there are local variations in the speed of sound.

✓ On a sunny day, temperature decreases with altitude, giving a "shadow" effect for sound

✓ On a clear night, temperature may increase with altitude (*temperature inversion*),"focusing" sound on the ground surface

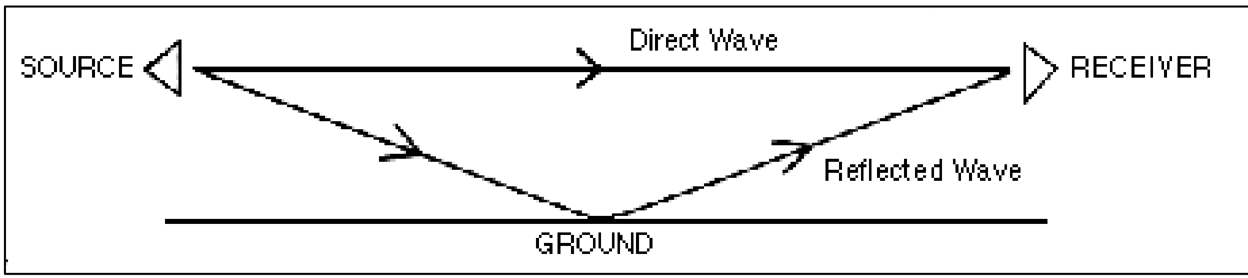




Surface Attenuation - A_{surf}

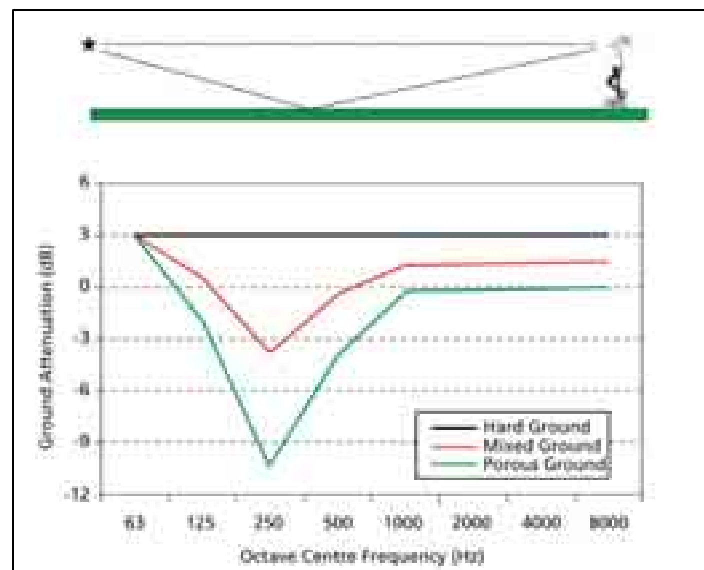
❖ *Ground effect*

Sound reflected by the ground interferes destructively with the directly propagated sound



The effect of the ground is different for acoustically hard (concrete or water), soft (grass, trees or vegetation) and mixed surfaces

This effect is normally noticed over distances of several meters and in frequency range of 200 ÷ 600 Hz



- *Barriers*

The noise reduction caused by a *solid barrier* depends on two factors:

1. The path of the sound wave as it travels over the barrier compared with direct trasmission to the receptor – *a barrier should be at least high enough to obscure the "line of sight" between the noise source and the receptor; a barrier is most effective when placed either very close to the source or to the receptor*
2. The frequency content of noise – *a barrier is most effective for high frequencies since low frequencies are diffracted around the edge of a barrier more easily*