# Basic Guide to Architectural Acoustics

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Over the years acoustics has gained a reputation as a black art with only a select few understanding its finer detail. The purpose of this guide is to simply explain the basic principles of acoustics and how these affect the average person.

## The Basics

### What is sound?

Sound in air is the fluctuation of pressure above and below atmospheric pressure. This pressure fluctuation travels through the air as a wave, similar to the way a disturbance travels along a slinky.

Sound is produced due to the disturbance of air, generally from a vibrating object. A speaker cone is a good illustration. It may be possible to see the movement of a speaker cone, providing it is producing very low frequency sound. As the cone moves forward the air immediately in front is compressed causing a slight increase in air pressure, it then moves back past its rest position and causes a reduction in the air pressure (rarefaction). The process continues so that a wave of alternating high and low pressure is radiated away from the speaker cone at the speed of sound.

### Frequency

The number of waves every second is described as the frequency of the sound and is measured in Hertz (Hz). The beep that your computer generates is probably somewhere around 3000 Hz (cycles per second) whereas a transformer will hum at a much lower frequency, say 100Hz. The frequency of a signal corresponds to its subjective pitch. Roughly speaking the ear works over the frequency range 20Hz to 20 kHz, though this range begins to shorten over age and for most practical applications the range is 31Hz to 16 kHz.

This leads us onto the most commonly used acoustic parameter, dB(A). Over the range of the human hearing, the ear has a 'frequency response' and is more sensitive at some frequencies than others. 'A-Weighting' is a frequency filter used to present a noise-level in such a way as to represent the human ear's sensitivity to noise.

For most everyday uses sound levels are often measured as A-Weighted overall values summed over the frequency range, however when dealing with more complicated analysis such as noise control design this is often not accurate and frequency information of the signal would also be required. The noise signal is generally divided up into a number of discrete intervals. The most common is octave band analysis, or if finer detail is required third-octave band. Most musicians will be familiar with the concept of an octave, in acoustic terms an octave relates to a doubling of frequency.

### The Decibel

The decibel is probably the one parameter that is most associated with noise, hearing and acoustics. It is used to describe sound pressures and intensities, and is based on a logarithmic scale. The main reason it is used so much as the fundamental measurement in acoustics is that the ear itself 'hears' logarithmically and human beings judge the relative loudness of two sounds by the ratio of their intensities, a logarithmic behaviour. The ear also has a phenomenal dynamic range (a famous analogy is that if the ear were a pair of scales, it could measure a fly and an elephant to the same accuracy) and using a logarithmic decibel scale helps keep these enormous numbers under control.

The logarithmic measure is used to compare the quantity of interest with a reference value; a common example is the threshold of hearing (a sound pressure level of 20 micro pascals or a sound power of 1 pico watt.)

For a clearer understanding of the way logarithmic signals work, consider two uncorrelated sounds within a room. If they both individually have the same noise level the summation of these two would give a total noise level that is 3dB greater.

The table below considers some common noise sources and their typical noise level.

| **Acoustic Pressure Pascal** | **Sound Pressure Level dB reference 20 micro pascal** | **Typical noise events** |
|---|---|---|
| 200 | 140 | Threshold of pain |
| 20 | 120 | Loud nightclub<br>Jet take off at 50m<br>Chainsaw operator |
| 2 | 100 | Inside a noisy factory |
| 0.2 | 80 | Motorway at 10m |
| 0.02 | 60 | Normal voice at 1m<br>Open plan office |
| 0.002 | 40 | Private Office<br>Residential area at night |
| 0.0002 | 20 | Rural area at night,<br>TV Studio |
| 0.00002 | 0 | Threshold of human hearing |

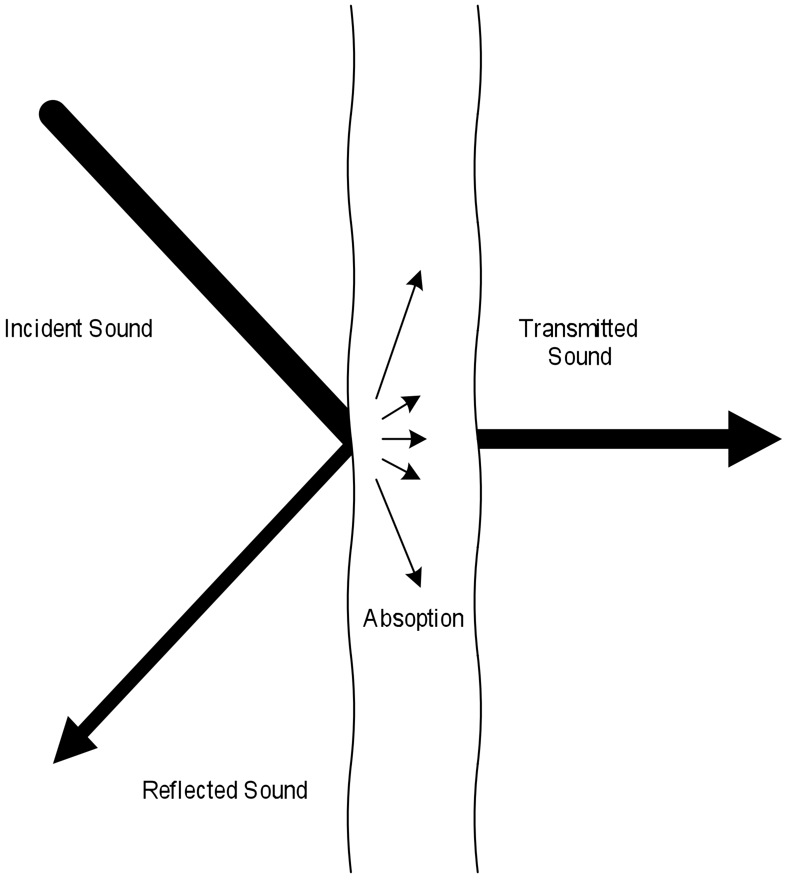
## Building Acoustics

**Reverberation and Reverberation Time**

When an operating noise source in a room is abruptly terminated, the noise from the source will not instantly vanish but will gradually lower in level, or reverberate. Acoustic absorption can be introduced which will subsequently reduce noise generation within a space. Therefore absorption can be used, to a limited degree as a means of noise control.

In 1922, Sabine defined reverberation time as the time required for the sound pressure to drop by 60 dB upon termination and related this reverberation time to be proportional to the room's volume divided by its total sound absorption.

This idea of acoustic absorption can sometimes be confused with the idea of sound insulation. When looking at reverberation we are interested in the sound absorption of materials, which is a measure of the sound that is absorbed by the material generally turned to heat and not reflected. However sound absorbers provide little resistance to sound travelling through them; their main acoustic property is stopping sound waves being reflected when incident upon them. The diagram below describes the effect of a sound wave when incident on a partition. It should be borne in mind that the majority of materials that are good at sound absorption tend not to also be good at sound insulation.




The measure used is the absorption co-efficient which is, basically, a co-efficient between 0 and 1 relating to the proportion of sound that is absorbed. A co-efficient of 1 means that there is no reflected sound.

The effects of this reverberation can be both beneficial and detrimental depending upon the application. Most obviously, concert and opera halls rely on reverberation for performance. During the last four hundred years, composers have, in some respects, written their music for the acoustic environment in which it is to be performed. Gregorian chant is best performed in Cathedrals with long reverberation times; music from the classical-period is normally best performed in halls with reverberation times of between 1.5 and 1.8 seconds, which was the reverberation time of halls of the period. Both these applications are examples that are considerably longer than your average bedroom, which has a reverberation time of about 0.5 seconds.

For more modern applications the use of reverberation inside a room is a fine balancing act. Reverberation is desirable if a weak source of sound is to be audible everywhere in the room, but a short reverberation time is desirable to minimise masking effects, caused by the reverberant components 'leaking' into each other. Short reverberation times can also be used to reduce noise in a space from external or internal sources.

There are also psycho-acoustical effects caused by reverberation. In large open plan offices, for example, it is desirable to keep the reverberant sound field to a minimum, to ensure speech privacy across the open space. However working in an acoustically dead environment can be very distressing over time, leading to a sense of isolation.

**Sound Insulation**

Compared with the concept of reverberation, sound insulation is arguably relatively straightforward. Sound insulation is simply a measure of how well a particular construction keeps sound out. This is essential in designing, say, houses next to a busy road etc. Sound insulation is normally measured in at least octave bands to give some idea of frequency performance. To give materials some kind of common reference though, these octave bands are normally condensed to a single figure. The two most common are $R_w$ and STC, being British and American measures respectively. All you need to know is that the single number is obtained by comparing the tests with a reference curve and allowing for a certain deviation.

I would like to introduce two concepts of sound insulation that will help to explain the noise transmission paths from one place and give an indication of the noise reduction methods required.

- Airborne Sound Insulation:

As the name suggests airborne sound insulation is the process by which sound in the air is reduced by the presence of a wall or floor. Simplistically the airborne sound is incident upon a partition causing vibrations within the wall or floor which will then transmit to the other side and be reradiated into the receiver space.

- Impact Sound Transmission:

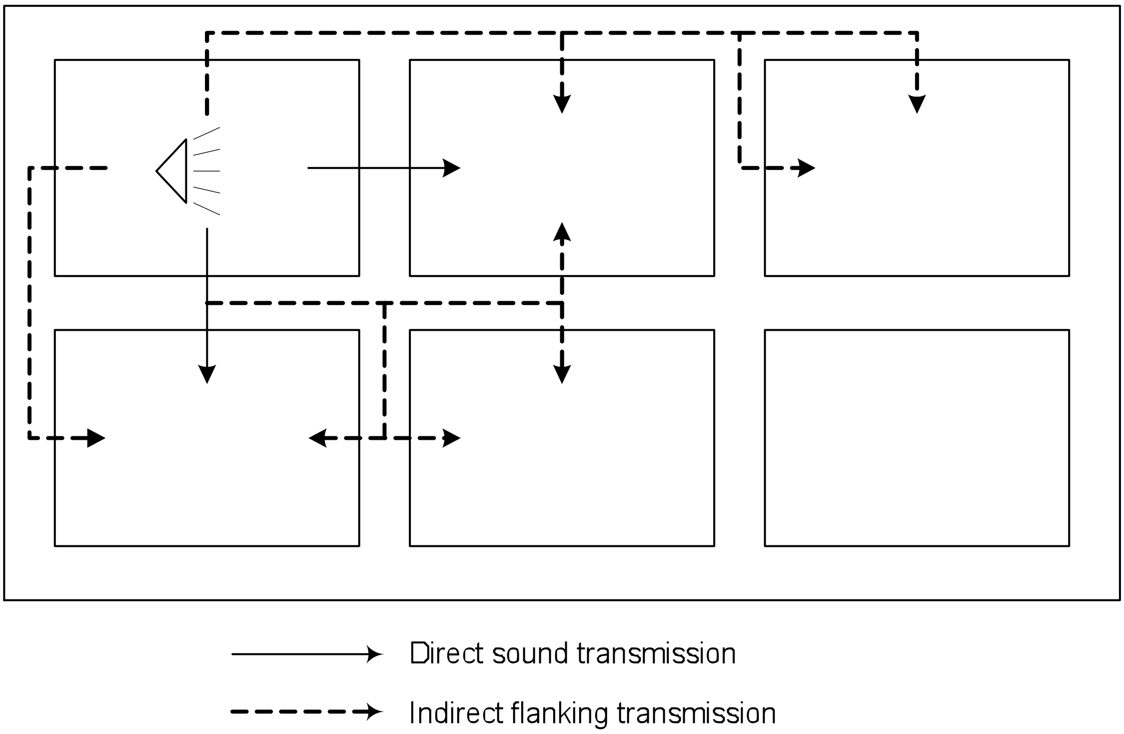
Impact Sound Transmission is the process by which impacting elements – such as door slamming, footsteps – are directly in contact with the structure causing vibrations that are then transmitted through the element as structure-borne sound, re-radiating in other areas of the building.

When trying to design noise control measures both the above will need to be dealt with differently, therefore it is vital to identify the cause of any unfavourable acoustic conditions.

**Flanking Noise Transmission**

Flanking noise transmission occurs when noise is transferred from one place to another indirectly via another continuous path. For example where a lightweight wall is built off a continuous concrete floor, if the mass of the floor is sufficiently light, noise transmission by this path may dominate sound transmission from one space to the other with a reduction over the expected performance of the separating wall in isolation.

To help explain the many different paths sound can take when transmitting through a building structure please refer to the diagram below which indicates some of the paths that may occur in a typical high density residential situation:




**Composite Sound Transmission**

The sound transmission of a given partition can be significantly affected by the introduction of an element with much lower sound insulation performance such as a door or a window. In addition the introduction of said element may also lead to gaps and cracks in the partition which can have a massive impact on the performance of the entire wall. In addition flanking paths such as air-conditioning ductwork can also provide a strong path for sound transmission that also may have gaps and cracks associated with penetrations through walls and floors.

You may think that as the gaps are small in comparison to the area of the partition it will only make a small amount of difference, however this is not the case. Consider a wall that gives a performance of 60dB, assume there is a hole in that wall that is one thousandth times smaller than the area total area of the wall. The loss in the sound insulation of the wall would be 30dB, half the total decibel sound insulation without the presence of the hole.

It is therefore vital that holes in walls and floor are eliminated as much as possible especially where inserted elements can increase the risk of perforation.

## The Control of Noise

**Basic Theory**

The measures that are required to reduce the transmission of sound are generally dependent upon the noise generated, the construction methods of the building and the quality of workmanship of the construction.

The main methods to improve the acoustic performance of the of structures sound insulation include:

**Increasing Mass:**

As the transmission of sound is dependent upon setting up vibration within the structure increasing the mass reduces the ability of the structure to move. As a general rule of thumb doubling the mass will give a 5dB reduction in the sound transmitted.

**Additional Layers:**

Increasing mass is only practicable to a certain degree. Often the most efficient method of increasing the acoustic performance of a wall and a floor is the introduction of additional layers, while maintaining sufficient separation to the original construction by distance or a resilient intermediate layer.

The amount of sound transmitted in a multi-layered construction is dependent on a number of factors. The stiffness of any connection between layers such as a resilient layer on a floor or wall ties between leafs of masonry walls will effect the sound transmitted. It should be borne in mind that even air has its own inherent stiffness that will also need to be considered. In general the stiffer the connection the greater the sound transmission.

The effect of additional layers can be improved utilising absorption in the cavity to absorb sound in the cavities. In addition increasing the width of the cavity and reducing the number of connections across will increase the acoustic performance.

Some care needs to be taken, as depending on the frequency of the noise source in question, additional layers can actually reduce the acoustic performance. The additional layer will act as a mass and the air within the cavity will act as a spring. At certain frequencies the mass will resonate reducing the acoustic benefit of the additional layer.

**Noise Transmission Path**

In order to determine the necessary noise control for a particular noise problem the path for the noise transmission must be determined, i.e. direct or flanking. Though an acoustic consultant has many different methods of determining this transmission path a lot can be done just by listening and trying to work out if the wall, floor or ceiling is radiating noise. Sometimes a stethoscope such as a doctor might use is a good method of doing this.

The method of reducing the noise transfer is to stop the noise getting into the structure in the first place or stopping the noise being re-radiated within the receiver space.

## Examples of Noise Control Measures

**Control of Noise at Source**

If the noise being generated is within a very reverberant space, multiple reflections off walls will increase the noise level within that space. Additional absorption on the walls and ceiling will suppress the reflections thus reducing the noise level.

**Increasing Mass**

As indicated in the Basic Theory increasing mass is one method of improving the acoustic performance of a separating element. In addition increasing mass, on additional layers such as floating floors, suspended ceilings and plasterboard wall partitions, will lower the resonant frequency layer generally providing improvements at mid to higher frequencies.

## Floating Floors and Soft Floor Covering

A common complaint within residential flats is that of footfall noise and impact noise transmitted through the floor. On concrete floors the use of an acoustic underlay will reduce the impact noise at source. Please note that these materials are not suitable for timber floor build-ups.

## Floating Floors

The soft floor covering detailed above is only suitable for the control of footfall noise on concrete floors. It will have no effect on the impact and airborne sound insulation of timber floor nor will it improve the airborne performance of concrete floors.

In order to improve the performance of the floor with a floating layer would require additional mass on a resilient layer. The amount of mass required would be dependent upon frequency range of attenuation that is required, as a general rule the heavier the mass and the softer the resilient layer the lower the resonant frequency of the floating layer.

## Lightweight Walls

To improve the performance of lightweight walls such as timber or metal stud walls with plasterboard linings, additional mass can be applied to the wall surfaces such as additional layers of plasterboard. In addition absorbent fibrous insulation (such as mineral wool) within the cavities of lightweight partitions can significantly improve their performance.

## Masonry walls

For masonry walls however, where the existing mass is already high additional mass is not likely to provide any significant improvement (every doubling in mass is approximately 5dB increase in noise). The only significant method for noise reduction would be the use of additional linings that incorporates an air gap. As with the floating floor the amount of mass or distance of air gap required would be dependent upon the frequency range of attenuation needed. As a general rule the heavier the mass and the larger the air gap the lower the resonant frequency of the air gap. In addition absorbent fibrous insulation (such as mineral wool) within the air gap between linings and the masonry wall can significantly improve their performance.

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