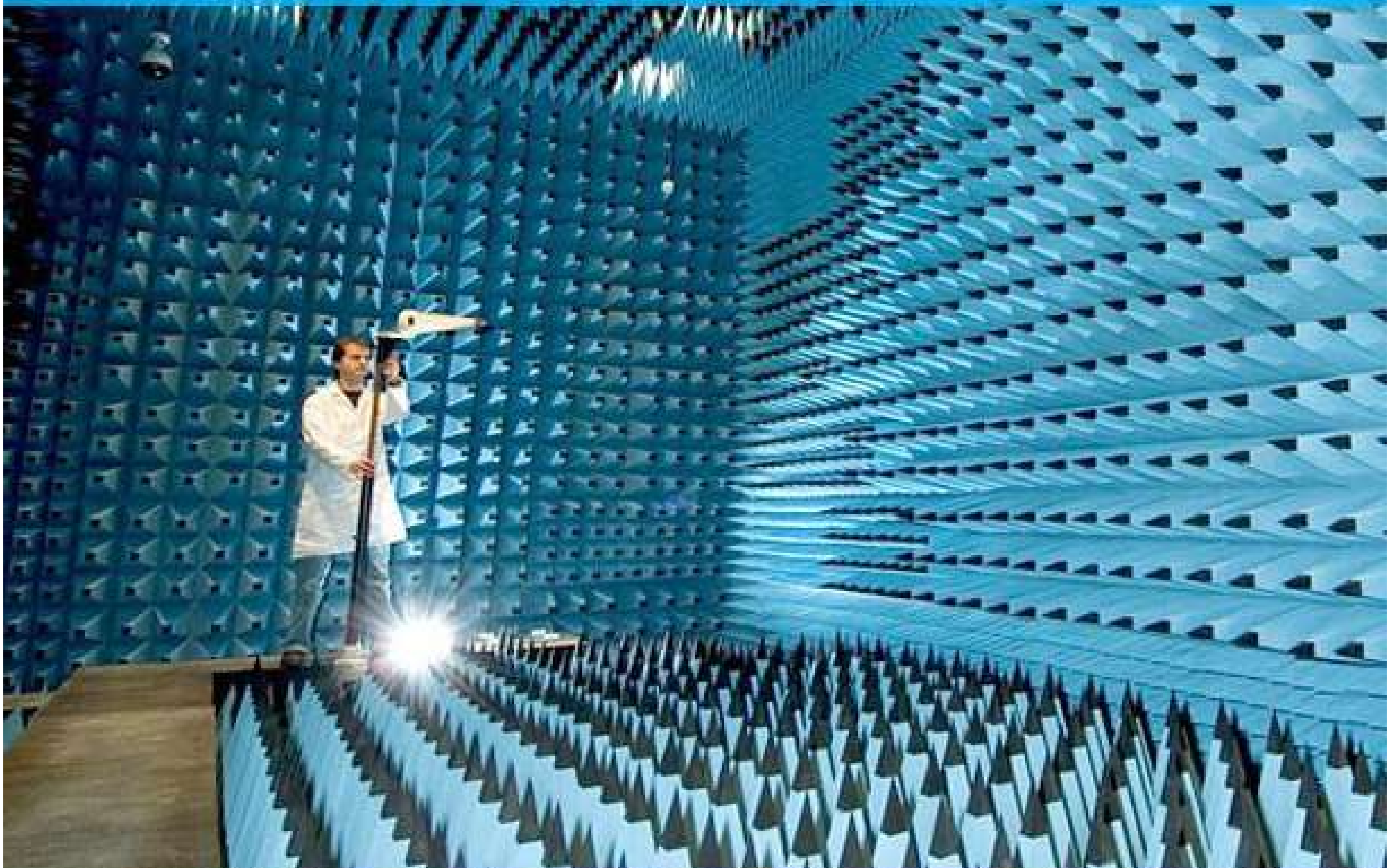
Noise Reduction Techniques & Technology



Jaquelyn Giron

First Edition, 2012

ISBN 978-81-323-4195-6

Published by:
White Word Publications
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

Table of Contents

Chapter 1

Noise Reduction

Noise reduction is the process of removing noise from a signal. Noise reduction techniques are conceptually very similar regardless of the signal being processed, however a priori knowledge of the characteristics of an expected signal can mean the implementations of these techniques vary greatly depending on the type of signal.

All recording devices, both analogue or digital, have traits which make them susceptible to noise. Noise can be random or white noise with no coherence, or coherent noise introduced by the device's mechanism or processing algorithms.

In electronic recording devices, a major form of noise is *hiss* caused by random electrons that, heavily influenced by heat, stray from their designated path. These stray electrons influence the voltage of the output signal and thus create detectable noise.

In the case of photographic film and magnetic tape, noise (both visible and audible) is introduced due to the grain structure of the medium. In photographic film, the size of the grains in the film determines the film's sensitivity, more sensitive film having larger sized grains. In magnetic tape, the larger the grains of the magnetic particles (usually ferric oxide or magnetite), the more prone the medium is to noise.

To compensate for this, larger areas of film or magnetic tape may be used to lower the noise to an acceptable level.

In audio

When using analog tape recording technology, they may exhibit a type of noise known as tape hiss. This is related to the particle size and texture used in the magnetic emulsion that is sprayed on the recording media, and also to the relative tape velocity across the tape heads.

Four types of noise reduction exist: single-ended pre-recording, single-ended hiss reduction, single-ended surface noise reduction, and codec or dual-ended systems. Single-ended pre-recording systems (such as Dolby HX Pro) work to affect the recording medium at the time of recording. Single-ended hiss reduction systems (such as DNR) work to reduce noise as it occurs, including both before and after the recording process as well as for live broadcast applications. Single-ended surface noise reduction (such as CEDAR and the earlier SAE 5000A and Burwen TNE 7000) is applied to the playback of phonograph records to attenuate the sound of scratches, pops, and surface non-linearities. Dual-ended systems (such as Dolby NR and dbx Type I and II) have a pre-emphasis process applied during recording and then a de-emphasis process applied at playback.

Dolby and dbx noise reduction system

While there are dozens of different kinds of noise reduction, the first widely used audio noise reduction technique was developed by Ray Dolby in 1966. Intended for professional use, Dolby Type A was an encode/decode system in which the amplitude of frequencies in four bands was increased during recording (encoding), then decreased proportionately during playback (decoding). The Dolby B system (developed in conjunction with Henry Kloss) was a single band system designed for consumer products. In particular, when recording quiet parts of an audio signal, the frequencies above 1 kHz would be boosted. This had the effect of increasing the signal to noise ratio on tape up to 10dB depending on the initial signal volume. When it was played back, the decoder reversed the process, in effect reducing the noise level by up to 10dB. The Dolby B system, while not as effective as Dolby A, had the advantage of remaining listenable on playback systems without a decoder.

Dbx was the competing analog noise reduction system developed by dbx laboratories. It used a root-mean-squared (RMS) encode/decode algorithm with the noise-prone high frequencies boosted, and the entire signal fed through a 2:1 compander. Dbx operated across the entire audible bandwidth and unlike Dolby B was unusable as an open ended system. However it could achieve up to 30 dB of noise reduction. Since Analog video recordings use frequency modulation for the luminance part (composite video signal in direct colour systems), which keeps the tape at saturation level, audio style noise reduction is unnecessary.

Dynamic Noise Reduction

Dynamic Noise Reduction (DNR) is an audio noise reduction system, introduced by National Semiconductor to reduce noise levels on long-distance telephony. First sold in 1981, DNR is frequently confused with the far more common Dolby noise reduction system. However, unlike Dolby and dbx Type I & Type II noise reduction systems, DNR is a playback-only signal processing system that does not require the source material to first be encoded, and it can be used together with other forms of noise reduction. It was a development of the unpatented Philips Dynamic Noise Limiter (DNL) system, introduced in 1971, with the circuitry on a single chip.

Because DNR is non-complementary, meaning it does not require encoded source material, it can be used to remove background noise from any audio signal, including magnetic tape recordings and FM radio broadcasts, reducing noise by as much as 10 dB. It can be used in conjunction with other noise reduction systems, provided that they are used prior to applying DNR to prevent DNR from causing the other noise reduction system to mistrack.

One of DNR's first widespread applications was in the GM Delco Bose car stereo systems in U.S. GM cars (later added to Delco-manufactured car stereos in GM vehicles as well), introduced in 1984. It was also used in factory car stereos in Jeep vehicles in the 1980s, such as the Cherokee XJ. Today, DNR, DNL, and similar systems are most commonly encountered as a noise reduction system in microphone systems.

Other approaches

A second class of algorithms work in the time-frequency domain using some linear or non-linear filters that have local characteristics and are often called time-frequency filters. Noise can therefore be also removed by use of spectral editing tools, which work in this time-frequency domain, allowing local modifications without affecting nearby signal energy. This can be done manually by using the mouse with a pen that has a defined time-frequency shape. This is done much like in a paint program drawing pictures. Another way is to define a dynamic threshold for filtering noise, that is derived from the local signal, again with respect to a local time-frequency region. Everything below the threshold will be filtered, everything above the threshold, like partials of a voice or "wanted noise", will be untouched. The region is typically defined by the location of the signal Instantaneous Frequency, as most of the signal energy to be preserved is concentrated about it.

Modern digital sound (and picture) recordings no longer need to worry about tape hiss so analog style noise reduction systems are not necessary. However, an interesting twist is that dither systems actually add noise to a signal to improve its quality.

In images

Images taken with both digital cameras and conventional film cameras will pick up noise from a variety of sources. Many further uses of these images require that the noise will be (partially) removed - for aesthetic purposes as in artistic work or marketing, or for practical purposes such as computer vision.

Types

In salt and pepper noise (sparse light and dark disturbances), pixels in the image are very different in color or intensity from their surrounding pixels; the defining characteristic is that the value of a noisy pixel bears no relation to the color of surrounding pixels. Generally this type of noise will only affect a small number of image pixels. When viewed, the image contains dark and white dots, hence the term salt and pepper noise. Typical sources include flecks of dust inside the camera and overheated or faulty CCD elements.

In Gaussian noise, each pixel in the image will be changed from its original value by a (usually) small amount. A histogram, a plot of the amount of distortion of a pixel value against the frequency with which it occurs, shows a normal distribution of noise. While other distributions are possible, the Gaussian (normal) distribution is usually a good model, due to the central limit theorem that says that the sum of different noises tends to approach a Gaussian distribution.

In either case, the noises at different pixels can be either correlated or uncorrelated; in many cases, noise values at different pixels are modeled as being independent and identically distributed, and hence uncorrelated.

Removal

Tradeoffs

In selecting a noise reduction algorithm, one must weigh several factors:

- the available computer power and time available: a digital camera must apply noise reduction in a fraction of a second using a tiny onboard CPU, while a desktop computer has much more power and time
- whether sacrificing some real detail is acceptable if it allows more noise to be removed (how aggressively to decide whether variations in the image are noise or not)
- the characteristics of the noise and the detail in the image, to better make those decisions

Chroma and luminance noise separation

In real-world photographs, the highest spatial-frequency detail consists mostly of variations in brightness ("luminance detail") rather than variations in hue ("chroma detail"). Since any noise reduction algorithm should attempt to remove noise without sacrificing real detail from the scene photographed, one risks a greater loss of detail from luminance noise reduction than chroma noise reduction simply because most scenes have little high frequency chroma detail to begin with. In addition, most people find chroma noise in images more objectionable than luminance noise; the colored blobs are considered "digital-looking" and unnatural, compared to the grainy appearance of luminance noise that some compare to film grain. For these two reasons, most photographic noise reduction algorithms split the image detail into chroma and luminance components and apply more noise reduction to the former; the in-camera noise reduction algorithm used by Nikon's DSLR's, in particular, is known for this.

Most dedicated noise-reduction computer software allows the user to control chroma and luminance noise reduction separately.

Linear smoothing filters

One method to remove noise is by convolving the original image with a mask that represents a low-pass filter or smoothing operation. For example, the Gaussian mask comprises elements determined by a Gaussian function. This convolution brings the value of each pixel into closer harmony with the values of its neighbors. In general, a smoothing filter sets each pixel to the average value, or a weighted average, of itself and its nearby neighbors; the Gaussian filter is just one possible set of weights.

Smoothing filters tend to blur an image, because pixel intensity values that are significantly higher or lower than the surrounding neighborhood would "smear" across the area. Because of this blurring, linear filters are seldom used in practice for noise reduction; they are, however, often used as the basis for nonlinear noise reduction filters.

Anisotropic diffusion

Another method for removing noise is to evolve the image under a smoothing partial differential equation similar to the heat equation which is called anisotropic diffusion. With a spatially constant diffusion coefficient, this is equivalent to the heat equation or linear Gaussian filtering, but with a diffusion coefficient designed to detect edges, the noise can be removed without blurring the edges of the image.

Nonlinear filters

A median filter is an example of a non-linear filter and, if properly designed, is very good at preserving image detail. To run a median filter:

1. consider each pixel in the image
2. sort the neighbouring pixels into order based upon their intensities
3. replace the original value of the pixel with the median value from the list

A median filter is a rank-selection (RS) filter, a particularly harsh member of the family of rank-conditioned rank-selection (RCRS) filters; a much milder member of that family, for example one that selects the closest of the neighboring values when a pixel's value is external in its neighborhood, and leaves it unchanged otherwise, is sometimes preferred, especially in photographic applications.

Median and other RCRS filters are good at removing salt and pepper noise from an image, and also cause relatively little blurring of edges, and hence are often used in computer vision applications.

Software programs

Most general purpose image and photo editing software will have one or more noise reduction functions (median, blur, despeckle, etc.). Special purpose noise reduction software programs include Neat Image, Grain Surgery, Noise Ninja, DenoiseMyImage, GREYCstoration (now G'MIC), and pnmnlfilt (nonlinear filter) found in the open source Netpbm tools. General purpose image and photo editing software including noise reduction functions include Adobe Photoshop, GIMP, PhotoImpact, Paint Shop Pro, and Helicon Filter.

Chapter 2

Active Noise Control and CX (Audio)

Active noise control

Active noise control (ANC) (also known as **noise cancellation**, **active noise reduction (ANR)** or **antinoise**) is a method for reducing unwanted sound.

Explanation

Sound is a pressure wave, which consists of a compression phase and a rarefaction phase. A noise-cancellation speaker emits a sound wave with the same amplitude but with inverted phase (also known as antiphase) to the original sound. The waves combine to form a new wave, in a process called interference, and effectively cancel each other out - an effect which is called phase cancellation. Depending on the circumstances and the method used, the resulting soundwave may be so faint as to be inaudible to human ears.

A noise-cancellation speaker may be co-located with the sound source to be attenuated. In this case it must have the same audio power level as the source of the unwanted sound. Alternatively, the transducer emitting the cancellation signal may be located at the location where sound attenuation is wanted (e.g. the user's ear). This requires a much lower power level for cancellation but is effective only for a single user. Noise cancellation at other locations is more difficult as the three dimensional wavefronts of the unwanted sound and the cancellation signal could match and create alternating zones of constructive and destructive interference. In small enclosed spaces (e.g. the passenger compartment of a car) such global cancellation can be achieved via multiple speakers and feedback microphones, and measurement of the modal responses of the enclosure.

Modern active noise control is achieved through the use of a computer, which analyzes the waveform of the background aural or nonaural noise, then generates a signal reversed waveform to cancel it out by interference. This waveform has identical or directly proportional amplitude to the waveform of the original noise, but its signal is inverted. This creates the destructive interference that reduces the amplitude of the perceived noise.

The active methods (this) differ from passive noise control methods (soundproofing) in that a powered system is involved, rather than unpowered methods such as insulation, sound-absorbing ceiling tiles or muffler.

The advantages of active noise control methods compared to passive ones are that they are generally:

- More effective at low frequencies.
- Less bulky.
- Able to block noise selectively.

The first patent for a noise control system was granted to inventor Paul Lueg in 1934 U.S. Patent 2,043,416, describing how to cancel sinusoidal tones in ducts by phase-advancing the wave and canceling arbitrary sounds in the region around a loudspeaker by inverting the polarity. By the 1950s, systems were created to cancel the noise in helicopter and airplane cockpits including those patented by Lawrence J. Fogel in the 1950s and 1960s such as U.S. Patent 2,866,848, U.S. Patent 2,920,138, U.S. Patent 2,966,549 and Canadian patent 631,136. In 1986, Dick Rutan and Jeana Yeager used prototype headsets built by Bose in their around-the-world flight.

Applications

Applications can be "1-dimensional" or 3-dimensional, depending on the type of zone to protect. Periodic sounds, even complex ones, are easier to cancel than random sounds due to the repetition in the wave form.

Protection of a "1-dimension zone" is easier and requires only one or two microphones and speakers to be effective. Several commercial applications have been successful: noise-cancelling headphones, active mufflers, and the control of noise in air conditioning ducts. The term "1-dimension" refers to a simple pistonic relationship between the noise and the active speaker (mechanical noise reduction) or between the active speaker and the listener (headphones).

Protection of a 3-dimension zone requires many microphones and speakers, making it less cost-effective. Each of the speakers tends to interfere with nearby speakers, reducing the system's overall performance. Noise reduction is more easily achieved with a single listener remaining stationary in a three-dimensional space but if there are multiple listeners or if the single listener moves throughout the space then the noise reduction challenge is made much more difficult. High frequency waves are difficult to reduce in three dimensions due to their relatively short audio wavelength in air. Sinusoidal noise at approximately 1000 Hz is double the distance of the average person's left ear to the right ear; such a noise coming directly from the front will be easily reduced by an active system but coming from the side will tend to cancel at one ear while being reinforced at the other, making the noise louder, not softer. High frequency sounds above 1000 Hz tend to cancel and reinforce unpredictably from many directions. In sum, the most effective noise reduction in three dimensions involves low frequency sounds.

Commercial applications of 3-D noise reduction include the protection of aircraft cabins and car interiors, but in these situations, protection is mainly limited to the cancellation of repetitive (or periodic) noise such as engine-, propeller- or rotor-induced noise.

Antinoise is used to reduce noise at the working environment with ear plugs. Bigger noise cancellation systems are used for ship engines or tunnels. An engine's cyclic nature makes FFT analysis and the noise canceling easier to apply.

The application of active noise reduction produced by engines has various benefits:

- The operation of the engines is more convenient for personnel.
- Noise reduction eliminates vibrations that cause material wearout and increased fuel consumption.
- Quieting of submarines.

CX (audio)

CX is a noise reduction system for recorded analog audio. It was developed by CBS Laboratories (a division of CBS) in the early 1980s, as a competitor to other noise reduction (NR) systems such as Dolby and dbx. The name *CX* was derived from "**C**ompatible e**X**pansion," a feature of the technique.

The CX logo, present on LPs and laserdiscs utilizing CX noise reduction

CX was originally designed by CBS as a noise-reduction technology for vinyl LP records. CX required a special decoder connected to a stereo system, in order to fully reproduce the CX encoded sound on the LP. However, CX-encoded records could also be played without a decoder, with a resulting (claimed acceptable) amount of dynamic range compression.

CBS predicted that CX encoding would become standard on all new LP releases but this never happened. Approximately 50 CX encoded LP titles were released by CBS around 1982. The albums in this series also came in standard, non CX encoded versions. While the implementation of CX with LP's was quite unsuccessful and short-lived, CX would later see success as the NR used for the stereo analog audio tracks on laserdiscs. It was also used for the audio tracks on discs of the RCA SelectaVision CED videodisc system.

Almost all laserdisc (and some CED) players manufactured since the mid-1980s had CX NR capability as a standard feature, with almost all commercial laserdisc releases having

CX encoding on their analog tracks as well. For the LaserDisc system, the CX companding specifications were changed, from 20db of noise reduction to 14db, along with moving the 'knee' where compression/expansion changes from 2:1 to 1:1 from -40db to -28db - other minor changes were made as well. In addition, some of the LD's FM audio encoding specs were changed too, allowing more headroom and better high frequency response at high levels. These changes were made because, at the time of CX's adoption on LD (1981), the vast majority of program sources for mastering, such as 35mm optical and mag film soundtracks, as well as the IVC-9000 and the 1-inch C-Type video tape formats used for LD mastering, had S/N ratio's such that undecoded playback would accentuate their noise to unacceptable levels. By lowering the total amount noise reduction achieved, undecoded playback compatibility was increased. Audible pumping and breathing effects during CX decoded playback were reduced as well.

For the CED VideoDisc, CX companding specifications were unchanged from those of the LP system because the CED system had much higher overall noise levels than the LD format, requiring the full 20db of noise reduction achieved with the unmodified system. The names given by CBS to the two different versions of CX were "CX-20" and "CX-14".

The theory of operation is described in U.S. Patent 4,376,916.

Partial List of CX encoded LP's released by CBS

- Bob Dylan - *Blood on the Tracks* - Columbia Records - (1982 re-issue)
- The Clash - *Sandinista!* - Epic Records - 1980
- Randy Meisner - *Randy Meisner* - Epic Records - 1982
- Freddie Salem & The Wildcats - *Cat Dance* - Epic Records 38018 - 1982
- The Sinceros - *Pet Rock* 1981
- Johnny Mathis - *First 25 Years: Silver Anniversary Album* - Columbia Records - (1981)
- Translator - *Heartbeats And Triggers* - 415 Records/Columbia Records - 1982
- Orchestral Manoeuvres in the Dark - *Orchestral Manoeuvres in the Dark* - DinDisc Limited/Epic Records - 1981
- Frank Marino - *Juggernaut* - Columbia CXAL 38023
- Saxon - *Strong Arm of the Law* - Carrere CXBL 537679
- Saxon - *Denim and Leather* - Carrere CXAL 537685
- Terumasa Hino - *Double Rainbow* - Columbia CX 37420
- T.V. Smith's Explorers - *The Last Words of the Great Explorer* - Epic BL 37432 - 1981
- Santana - *Zebop!* - Columbia CX PC 37158 - 1981
- Deniece Williams - *I'm So Proud* - Columbia Records - 1983
- Johnny Cash - * - Columbia Records - 198?

Chapter 3

Dolby Noise-Reduction System

Dolby NR is the name given to a series of noise reduction systems developed by Dolby Laboratories for use in analogue magnetic tape recording. The first was *Dolby A*, a professional broadband noise reduction for recording studios in 1966, but the best-known is *Dolby B* (introduced 1968), a sliding band system for the consumer market, which helped make high fidelity practical on cassette tapes, and is common on stereo tape players and recorders to the present day. Of the noise reduction systems, *Dolby A* and *Dolby SR* were developed for professional use. *Dolby B*, *C*, and, *S* were designed for the consumer market. All the Dolby variants work by companding, or *comp*ressing the dynamic range of the sound during recording and ex*panding* it during playback.

How Dolby noise reduction works

Dolby noise reduction is a form of dynamic preemphasis employed during recording, plus a form of dynamic deemphasis used during playback, that work in tandem to improve the signal-to-noise ratio. While Dolby A operates across the whole spectrum, the other systems specifically emphasize the audible frequency range where background tape hiss, an artifact of the recording process that is similar to white noise, is most noticeable (usually above 1 kHz).

The Dolby preemphasis boosts the recorded level of the audio signal at these higher frequencies during recording, effectively compressing the dynamic range of that portion of the signal, so that quieter sounds above 1 kHz receive a proportionally greater boost. As the tape is recorded, the relative amplitude of the signal above 1 kHz is used to determine how much pre-emphasis to apply - a low-level signal is boosted by 10 dB (Dolby B) or 20 dB (Dolby C). As the signal rises in amplitude, less and less pre-emphasis is applied until at the "Dolby level" (+3 VU), no signal modification is performed.

The sound is thus recorded at a higher overall level on the tape relative to the tape's overall noise level, requiring the tape formulation to preserve this specially recorded signal without distortion. On playback, the opposite process is applied (deemphasis), based on the relative signal component above 1 kHz. Thus as this portion of the signal decreases in amplitude, the higher frequencies are progressively more sharply attenuated, which also filters out the constant background noise on the tape when and where it would be most noticeable.

The two (pre and de-emphasis) processes are intended to cancel each other out as far as the actual recorded program is concerned. Only de-emphasis is applied to the incoming signal and noise during playback. After playback de-emphasis is complete, apparent noise in the output signal is reduced, and this process should not produce any effect noticeable to the listener. Playback without noise reduction produces a noticeably brighter sound, however.

The calibration of the recording and playback circuitry is therefore critical for faithful reproduction of the original program content, and this is easily offset by poor quality tape, dirty recording/playback heads, or using inappropriate bias levels/frequency for the tape formulation, as well as tape speed, when recording or duplicating. This can manifest itself as muffled-sounding playback, or "breathing" of the noise level as the signal varies.

On some high end consumer equipment, Dolby calibration control is included: for recording, a reference tone at Dolby level may be recorded for accurate playback level calibration on another transport; at playback, the same recorded tone should produce the identical output, as indicated by a Dolby logo marking at +3 VU on the VU meter(s). For accurate off-the-tape monitoring during recording on 3-head decks, both processes must be employed at once, and circuitry provided to accomplish this is marketed under the rubric "Double Dolby".

Dolby A

Dolby *A* was the company's first noise reduction system, presented in 1966. It was intended for use in professional recording studios, where it became commonplace, gaining widespread acceptance at the same time that multitrack recording became standard. The input signal is split into four frequency bands with 12 dB/oct slopes: lowpass @ 80 Hz; bandpass 80 Hz - 3 kHz; highpass @ 3 kHz; highpass @ 9 kHz. The compansion circuit has a threshold of -40dB, with a ratio of 2:1 for a compression / expansion of 10dB, except for the 9 kHz highpass which has only 5dB of gain change. This provides about 10 dB of broadband noise reduction, which increases to a possible 15dB at 15 kHz according to articles written by Ray Dolby in JAES (Oct 1967) and Audio (June / July 1968).

Dolby A also saw some use as the method of noise reduction in optical sound for motion pictures.

Dolby B

Dolby *B* was developed after Dolby *A* and presented in 1968, as a single sliding band system providing about 9 dB noise reduction (A-weighted), primarily for cassettes. It was much simpler than Dolby *A* and therefore much less expensive to implement in consumer products. Dolby *B* recordings are acceptable when played back on equipment that does not possess a Dolby *B* decoder, such as most inexpensive cassette players. However, Dolby *B* provides less effective noise reduction than Dolby *A*, generally by a factor of more than 3 dB.

From the mid 1970s, Dolby *B* became standard on commercially prerecorded music cassettes in spite of the fact that some low-end equipment lacked decoding circuitry, although it allows for acceptable playback on such equipment. Most pre-recorded cassettes use this variant. In the early-1970s, some expected Dolby NR to become normal in FM radio broadcasts and some tuners and amplifiers were manufactured with decoding circuitry. In 1971 WFMT started to transmit programs with Dolby NR, and soon some 17 stations broadcasted with noise reduction, but by 1974 it was already on the decline.

Dolby C

Dolby *C* was introduced in 1980. It provides about 15 dB noise reduction (A-weighted). It is constructed by combining the effect of two Dolby B systems together with an expansion to lower frequencies. The resulting recordings sound much worse when played back on equipment that does not have Dolby *C* noise reduction. Some of this harshness can be mitigated by using Dolby B on playback. It utilises anti-saturation and spectral skewing techniques. Dolby C first appeared on higher end cassette decks in the 1980s.

Dolby SR

The Dolby *SR* (Spectral Recording) system, introduced in 1986, was the company's second professional noise reduction system. It is a much more aggressive noise reduction approach than Dolby *A*. It attempts to maximise the recorded signal at all times using a complex series of filters that change according to the input signal. As a result, Dolby *SR* is much more expensive to implement than Dolby *B* or *C*, but Dolby *SR* is capable of providing up to 25 dB noise reduction in the high frequency range. It is only found on professional recording equipment.

In the motion picture industry, as far as it concerns distribution prints of movies, the Dolby A and SR markings refers to Dolby Surround which is not just a method of noise reduction, but more importantly encodes two additional audio channels on the standard optical soundtrack, giving left, center, right, and surround.

SR prints are fairly well backward compatible with old Dolby A equipment. The Dolby SRD marking refers to Dolby Digital and its variants.

Dolby S

Dolby *S* was presented in 1989. It is found on some Hi-Fi and semi-professional recording equipment. It was intended that Dolby *S* would become standard on commercial prerecorded musicassettes in much the same way that Dolby *B* had in the 1970s, but this never happened, as Dolby *S* came to market at a time when the Compact Cassette was being replaced by the Compact Disc as the dominant mass market music format. Dolby Labs claimed that most members of the general public couldn't differentiate between the sound of a CD and a Dolby *S* encoded cassette. Subsequently, Dolby *S* appeared only on high-end audio equipment.

Dolby *S* is much more resistant to playback problems caused by noise from the tape transport mechanism than Dolby C. Likewise, Dolby S was also claimed to have playback compatibility with Dolby B in that a Dolby S recording could played back on older Dolby B equipment with some benefit being realised. It is basically a cut down version of Dolby *SR* and uses many of the same noise reduction techniques. Dolby *S* is capable of 10 dB of noise reduction at low frequencies and up to 24 dB of noise reduction at high frequencies.

Dolby HX

Developed in 1982, Dolby HX is not a noise reduction system, though it can indirectly decrease noise by allowing signals to be recorded at higher levels than they otherwise could. Using electronic circuitry partly equivalent to that used in noise reduction, HX provides additional dynamic range for high-frequency signals. **HX** or "Headroom eXtension" is a method for further increasing the dynamic range of a cassette tape by dynamically modulating the ultrasonic bias signal, used by all analogue tape decks, to increase the headroom for high-frequency audio signals. This system was modified by Bang & Olufsen for consumer equipment and marketed by Dolby as *Dolby HX Pro*. HX and HX Pro are used only in recording.

Because tape is magnetic, it is inherently non-linear in nature, due to the hysteresis of the magnetic particles. If an analogue signal were recorded directly onto magnetic tape, its reproduction would be extremely distorted, due to this non-linearity.

To overcome this, a high frequency signal, known as bias, is mixed in with the recorded signal, which "pushes" the envelope of the signal into the linear region. With strong signals of fixed frequency and high amplitude, the amount of bias needed is reduced. Due to group and phase delay the audio signal itself creates a variable amount of self-bias. If the added bias remains constant, these high frequency signals become overbiased. This overbias creates distortion as the tape becomes saturated. Dolby HX Pro automatically reduces the bias signal in the presence of strong high frequency signals. This optimises the amount of self bias, reducing distortion caused from saturation of the magnetic tape. By adjusting the bias with respect to group and phase delay the overall distortion of high frequency signals is also greatly reduced. This kind of bias adjustment increases the high frequency dynamic range available. The net effect for the listener is a crisper sounding high frequency reproduction.

Technological obsolescence

Dolby's analogue noise reduction systems, though still used in some professional applications, as well as in the large installed base of consumer tape decks, are becoming increasingly obsolete due to the widespread adoption of digital audio (in the form of compact discs, MP3s, MiniDiscs, and to a lesser extent DAT) in the home for entertainment and professional studios for recording. In other words, Dolby NR is not becoming obsolete for analog recording, but analog recording itself is becoming obsolete as digital recording replaces it.

Chapter 4

Earplug

Silicone rubber earplugs for protection against water, dust etc.

An **earplug** is a device that is meant to be inserted in the ear canal to protect the wearer's ears from loud noises or the intrusion of water, foreign bodies, dust or excessive wind.

Protection from water

Some earplugs are primarily designed to keep water out of the ear canal, especially during swimming and watersports. These may be made of wax or moldable silicone which is custom-fitted to the ear canal by the wearer.

A 2003 study published in Clinical Otolaryngology found that a cotton ball saturated with petroleum jelly was more effective at keeping water out of the ear, easier to use, and more comfortable than wax plugs, foam plugs, EarGuard, Aquafit.

As many have advised, including Jacques-Yves Cousteau, ear plugs are actually harmful to divers, especially scuba divers. Scuba divers breathe compressed air or other gas mixtures, at a pressure matching the water pressure. This pressure is also inside the ear, but not between the eardrum and the earplug, so the pressure behind the eardrum will often burst the eardrum. Skin divers have less pressure inside the ears, but they also have only atmospheric pressure in the outer ear canal. Vented earplugs are the only type of earplug which can be used by divers safely.

Hearing protection

There are mainly three types of earplugs for hearing protection:

- **Foam** earplugs, mainly made of memory foam, which are compressed and put into the ear canal, where they expand to plug it.
- **Silicone** earplugs, which are rolled into a ball and carefully molded to fit over the external portion of the ear canal, providing a snug custom fit for the wearer.
- **Flanged** earplugs, including most types of musicians' or 'Hi-Fi' earplugs, as well as custom molds once they are molded.

NIOSH Mining Safety and Health Research recommends using the roll, pull, and hold method when using memory foam earplugs. The process involves the user rolling the earplug into a thin rod, pulling back on the ear, and holding the earplug deep in the canal with the finger. To get a complete seal, the user must wait about 20 seconds for the earplug to expand inside the canal.

Furthermore, they may be either disposable or nondisposable, with foam and silicone ones generally being disposable or for use a relatively limited number of times, while solid ones generally may be regarded as nondisposable. A variation of the traditional foam earplug is the no-roll foam earplug that uses a built-in central stem to push the foam plugs into the ears. These earplugs achieve a seal due to their tapered shape, rather than expansion after being rolled.

Ear plugs are especially useful to people exposed to excessively noisy devices or environments (80 dB or more).

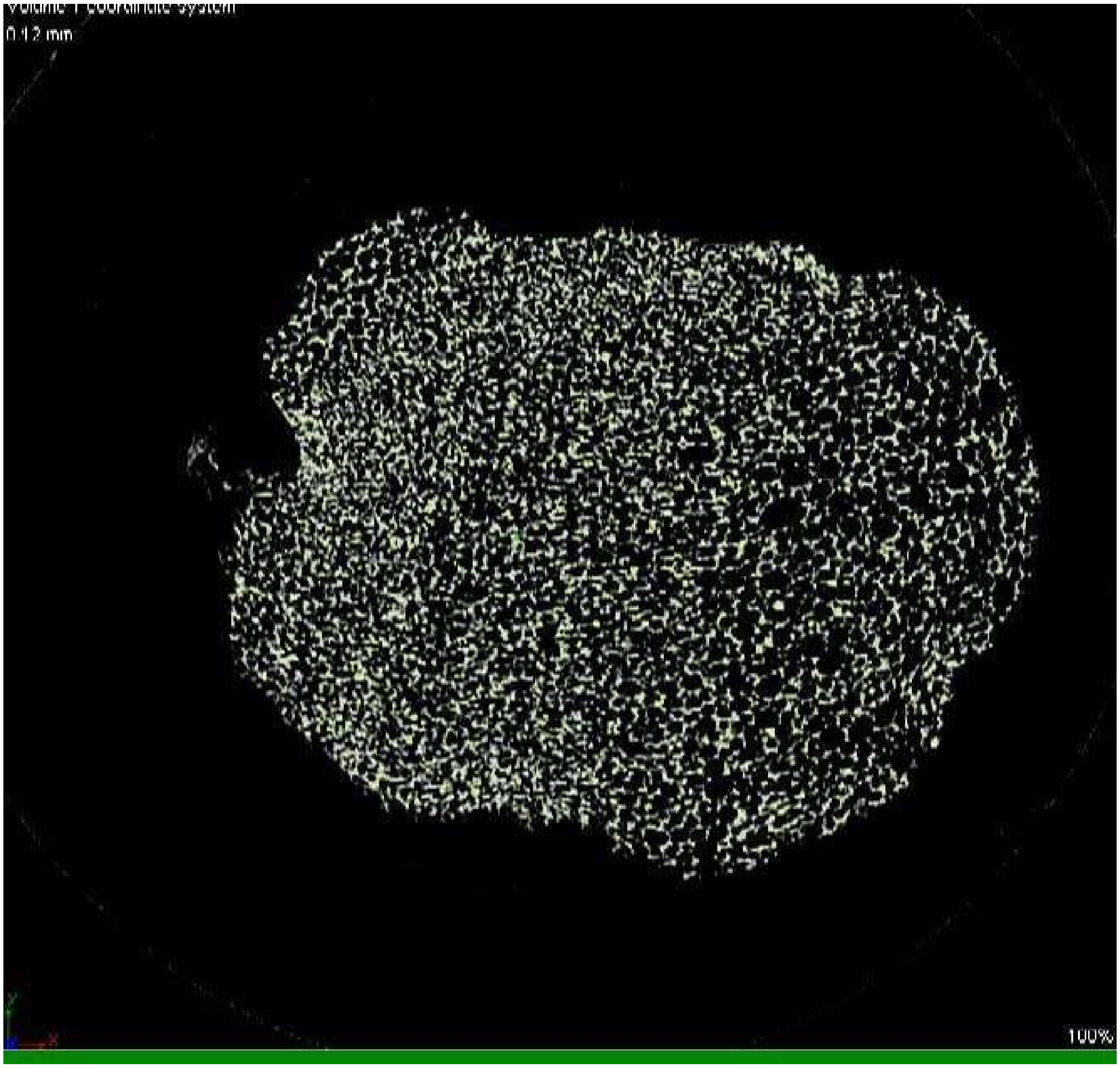
Level of noise in dB(A)	Maximum daily exposure time
85	8 Hours
91	2 Hours
97	30 Minutes
103	7 Minutes

History

The first recorded use of wax earplugs is in the *Odyssey,* wherein Odysseus's crew used wax earplugs to avoid being distracted by the Sirens' songs. In 1907, German company Ohropax, which produced earplugs, was started by German inventor Max Negwer. Current earplug material was discovered in 1967, at National Research in the USA, by Ross Gardner and his team. As part of a project on sealing joints, they developed a resin with energy absorption properties. This E-A-R material was later developed into commercial memory foam earplugs.

'Basic' type plugs

Disposable foam earplugs: with coins for scale (top) and inserted into the wearer's ear.



Flight through a CT-image stack. Ear plug is stuck in a styrofoam cavity that simulates the ear canal. Ear plug adapts to the cavity.

This kind of earplug protection is often worn by industrial workers who work within hearing distance of loud machinery for long periods, and is used by the British Ministry of Defense (MoD) for soldiers to use when firing weapons. Earplugs are rated for their ability to reduce noise. In the United States, the U.S. Environmental Protection Agency mandates that hearing protection be tested to provide a Noise Reduction Rating (NRR) where a panel of ten subjects are tested in a laboratory to determine the attenuation over a range of frequencies. In the European Union, hearing protectors are required to be tested according to the International Organization for Standardization (ISO) acoustical testing standard, ISO 4869 Part 1 and the Single Number Rating (SNR) or High/Middle/Low (HML) ratings are calculated according to ISO 4869 Part 2. In Brazil, hearing protectors are tested according to the American National Standards Institute ANSI S12.6-1997 and are rated using the Noise Reduction Rating Subject Fit NRR(SF). Australia and New

Zealand have different standards for protector ratings yielding a quantity SLC80 (Sound Level Class for the 80th percentile). Canada implements a class system for rating the performance of protectors. Gauger and Berger have reviewed the merits of several different rating methods and developed a rating system that is the basis of a new American National Standard, ANSI S12.68-2007

The various methods have slightly different interpretations, however, each method has an effective percentile associated with the rating for which that percent of the users should be able to achieve the rated attenuation. For instance the NRR is determined by the mean attenuation minus two standard deviations, thus it translates to a 98% statistic. That is at least 98 percent of users should be able to achieve that level of attenuation. The SNR and HML are a mean minus one standard deviation statistic. Therefore, approximately 86% of the users should be able to achieve that level of protection. Similarly, the NRR(SF) is a mean minus one standard deviation and represents an 86% of users should achieve that level of protection. The difference between the ratings lies in how the protectors are tested. NRR is tested with an experimenter-fit protocol. SNR/HML are tested with an experienced subject-fit protocol. NRR(SF) is tested with a naive subject-fit protocol. According to Murphy et al. (2004), these three protocols will yield different amounts of attenuation with the NRR being the greatest and NRR(SF) being the least.

The experimenter-fit NRR should be adjusted per the guidelines of the National Institute for Occupational Safety and Health as the required NRR ratings differ greatly from lab tests to field tests.

To compensate for known differences between laboratory-derived attenuation values and the protection obtrained by a worker in the real world, the labeled noise reduction ratings shall be derated as follows: (1) earmuffs- subtract 25 % from the manufacturers' labeled NRR; (2) slow-recovery formable earplugs subtract 50%; and (3) all other earplugs - subtract 70% from the manufacturers labeled NRR. These derating values shall be used until such time as manufacturers test and label their products in accordance with a subject-fit method such as Method B of ANSI S12.6-1997.

The NRR(SF) used in Brazil does not require derating as it resembles the manner in which the typical user will wear hearing protection.

Most earplugs are elastic ones made of memory foam, that is typically rolled into a tightly compressed cylinder (without creases) by the wearer's fingers and then inserted in the ear canal. Once released, the earplug expands until it seals the canal, blocking the sound vibrations that could reach the eardrum. Other plugs simply push into the ear canal without being rolled first. Sometimes earplugs are connected with a cord to keep them together when not in use. Other common material bases for earplugs are viscous wax or silicone.

Other devices that provide hearing protection include electronic devices worn around and/or in the ear, designed to cancel out the loud noise of a gunshot, while possibly amplifying quieter sounds to normal levels. While rich in features, these electronic devices carry a price over one hundred times their foam counterparts.

Since they reduce the sound volume, earplugs are often used to help prevent hearing loss and tinnitus (ringing of the ears), amongst other ailments.

Noise reduction ratings

Hearing protectors sold in the U.S. are required by the U.S. Environmental Protection Agency (EPA) to have a noise reduction rating (NRR), which is an estimate of the reduction of noise at the ear when protectors are worn properly. However, due to the discrepancy between how protectors are fit in the testing laboratory and how users wear protectors in the real world, the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) have developed derating formulas to reduce the effective NRR.

While the NRR and the SNR (Single Number Rating) are designed to be used with C-weighted noise, which means that the lower frequencies are not de-emphasized, other ratings (NRR(SF) and NRSA) are determined for use with A-weighted noise levels, which have lower frequencies de-emphasized. The National Institute for Occupational Safety and Health recommended and the U.S. EPA mandated that 7-dB compensation between C and A weighting be applied when the NRR is used with A-weighted noise levels.

OSHA has defined in their training manual for inspectors that the adequacy of hearing protection for use in a hazardous noise environment should be derated to account for how workers typically wear protection relative to how manufacturers test the protector's attenuation in the laboratory. For all types of hearing protection, OSHA's derating factor is 50%. If used with C-weighted noise, the derated NRR will become NRR/2. If used with A-weighted noise, OSHA applies the 7-dB adjustment for C-A weighting first then derates the remainder. For example, an protector with 33-dB attenuation would have this derating:

- Derated NRR = (33 – 7)/2

NIOSH has proposed a different scheme for derating based upon the type of protector. For earmuffs, the NRR should be derated by 25%, for slow-recovery foam earplugs the derating is 50% for all other protection, the derating is 70%. NIOSH applies the C-A spectral compensation differently than OSHA. Where OSHA subtracts the 7-dB factor first and derates the result, NIOSH derates the NRR first and then compensates for the C-A difference. For example, a slow recovery foam earplug with a 33-dB NRR would have this NIOSH derating:

- Derated NRR = (33/2) – 7

NIOSH also has different derating percentages for various types of hearing protection. Currently, the derating factor is 70% for premolded plugs, 50% for fast expansion foam plugs (formable plugs) and for muffs is 25%. For example, to find the derated NRR for an earmuff by using the NIOSH derating system, the procedure would go as follows:

- Derated NRR = (Original NRR x (1-.25)) – 7

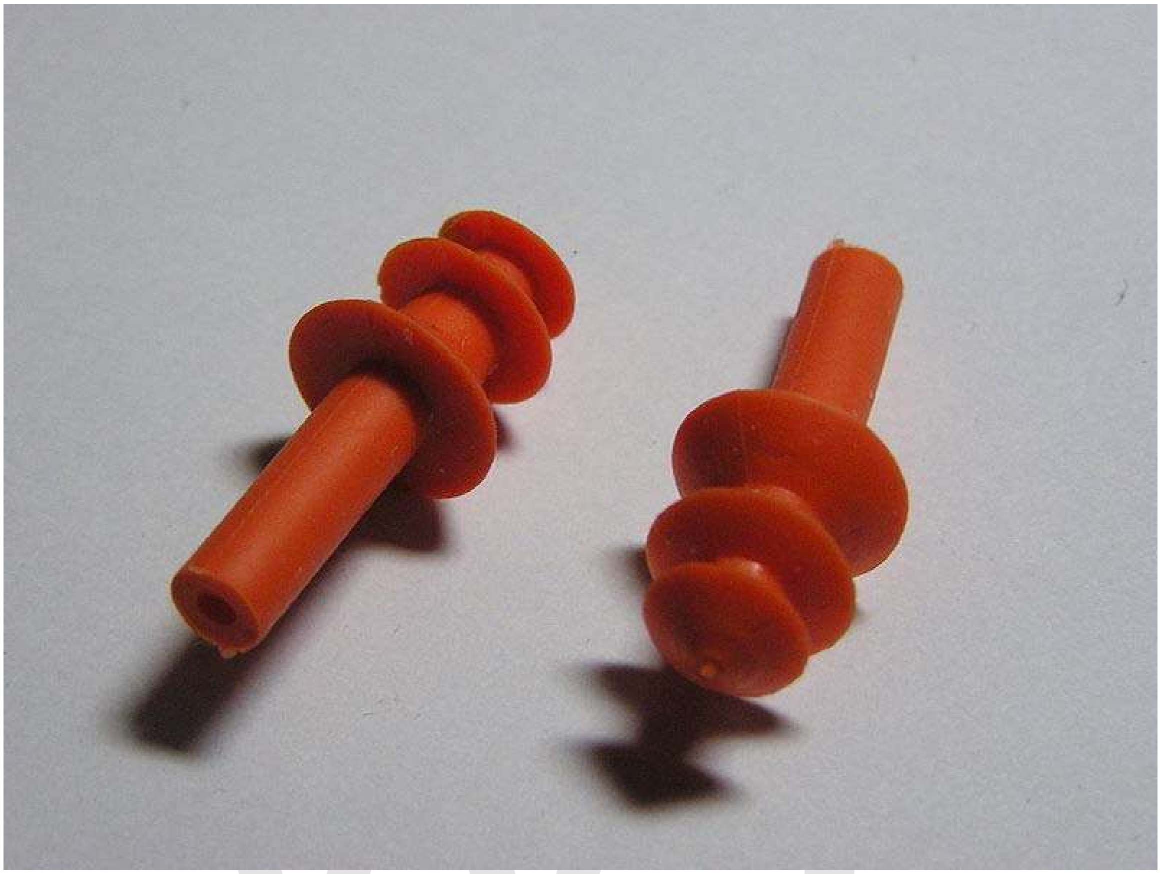
Expected updates

In 2007, the American National Standards Institute published a new standard for noise reduction ratings for hearing protectors, ANSI S12.68-2007. Using the real ear attenuation at threshold data collected by a laboratory test prescribed in ANSI S12.6-2008, the noise reduction statistic for A-weighted noise (NRSA) is computed using a set of 100 noises listed in the standard. The noise reduction rating, rather than be computed for a single noise spectrum the NRSA incorporates variability of both subject and spectral effects. ANSI S12.68 also defines a method to estimate the performance of a protector in an atypical noise environment. Building upon work from the U.S. Air Force and the ISO 4869-2 standard, the protector's attenuation as a function of the difference in C and A-weighted noise level is used to predict typical performance in that noise environment. The derating may be quite severe (10 to 15 decibels) for protectors that have significant differences between low and high frequency attenuation. For "flat" attenuation protectors, the effect of C-A is less. This new system eliminates the need for calculators, relies on graphs and databases of empirical data, and is believed to be a more accurate system for determining NRRs.

Musicians' or 'Hi-Fi' earplugs

Musicians' earplugs. The Grey end caps contain an acoustic transmission line with a damper (attenuator) at the end while the domed flanges form a seal in outer part of the ear canal. The output port can just be seen as a small hole at the near end of the left plug

Musicians who perform music styles noted for their loud nature, especially rock music, often wear earplugs to prevent their own performances from damaging their hearing. Musicians' earplugs are designed to attenuate sounds evenly across the audio band and thus minimise their effect on the user's perception of bass and treble levels. These are commonly used by musicians and technicians, both in the studio and in concert, to avoid overexposure to high volume levels.



Earplugs made from silicone rubber. The hole seen in the left plug is the input port and extends as far as the central flange where the attenuation occurs

They generally achieve this by incorporating a tiny diaphragm to reduce low frequencies, together with absorbent or damping material for high frequencies. This means they can be quite costly, being intended for constant re-use unlike simple earplugs which are disposable. These earplugs usually give an attenuation of only about 20dB and are not intended for protection from very high noise levels (beyond 105 dB).

Example of custom earplugs worn by professional musicians

Some musicians' earplugs are custom-made for the individual listener. An audiologist administers a hearing test and makes molds of the ear. A company then makes a custom ear-piece into which different attenuator capsules can be inserted. These different capsules will provide different levels of attenuation, usually 9, 15, and 25 dB. These types of earplugs will provide the flattest attenuation and the truest isolation from outside noise, as they fit firmly into the individual's ears. They also provide much better protection from very high noise levels. This type of plug is quite popular amongst audio engineers who can safely listen to loud mixes for extended periods of time.

In other activities, hobby motorcyclists and skiers may also choose to use decibel reduction earplugs, to compensate for the ongoing noise of the wind against their head or helmet.

Flight ear protection

Earplugs are available which help to protect ears from the pain caused by airplane cabin pressure changes. Some products contain a porous ceramic insert which reportedly aids equalization of air pressure between the middle and outer ear thereby preventing pain during landings and take-offs.

Sleep

Earplugs for sleeping are made to be as comfortable as possible while blocking external sounds that may prevent or disrupt sleep. Specialized earplugs for such noises as a partner's snoring may have sound-dampening enhancements that enable the user to still hear other noises, such as an alarm clock.

To determine the comfort of earplugs used for sleeping, it is important to try them on while actually lying down. The pressure on the ear between the head and pillow may cause significant discomfort. Furthermore, just tilting the head back or to the side causes significant anatomical changes in the ear canal, mostly a reduction of the ear canal diameter, which may reduce comfort if the earplug is too large.

Health risks

Earplugs are generally safe, but precautions may be needed against a number of possible health risks, with additional ones appearing with long term use:

- Pushing in earplugs into the external ear canal may cause the air pressure to rise in it, in effect pushing against the eardrum and causing pain. This may be caused by pressure on the ear while lying down on the side, and is also the case when completely expanded foam earplugs are pushed further into the ear. To bypass the latter risk, such earplugs are instead removed, compressed and inserted to the desired depth. Vice versa, when pulled out, the resultant negative pressure pulls the eardrum. Therefore, some earplugs are better carefully screwed or jiggled out rather than yanked out. Yawning does not help equalizing this air pressure difference, since it equalizes the pressures between the middle ear and the environment, while this overpressure rather is located in the outer ear, between the eardrum and the earplug.
- If pushed too far into the ear canal, they may push ear wax and debris into the canal and possibly against the ear drum. As a precaution, ear plugs should not be pushed further into the ear canal than they may be grabbed and rotated. Ear wax impacted by earplugs can be removed by irrigation or other remedies, as described there.
- There is a possibility for allergic reactions, but this is likely rare, as earplugs generally are made of immunologically inert materials.

Long-term use

Custom molded plugs are recommended for long-term use, since they are more comfortable and gentle to the skin and won't go too far into the ear canal.

Nevertheless, prolonged or frequently repeated use of ear plugs have the following health risks, in addition to the short term health risks:

- They may cause earwax to build up and plug the outer ear, since it blocks the normal flow of earwax outwards. This can result in tinnitus, hearing loss, discharge, pain or infection. Excess earwax should be carefully removed from the ear, and earplugs should be cleaned regularly with water and mild soap. However, foam type ear plugs are usually designed to be disposable, and will expand and lose their memory property upon drying after washing with water and soap. They will become quite spongy, expand very quickly after being compressed, making them quite problematic in proper insertion into the ear canal. They also lose a large proportion of sound attenuating capability after such washing and drying.
- They may cause irritation of the temporomandibular joint, which is located very close to the ear canal, causing pain. Individually fitted non-elastic earplugs may be less likely to cause this irritation compared with foam ones that expand inside the ear canal.
- Earplugs are also a possible cause of ear inflammation, otitis externa, although the short term use of earplugs when swimming and shampooing hair may actually help prevent it. Still, many pathogenic bacteria grow well on warm, moist, foam-type plugs (polyvinylchloride (PVC) or polyurethane). However, there need also be a loss of integrity of the skin for infection to occur. Hard and poorly fitting ear plugs can scratch the skin of the ear canal and set off an episode. When earplugs are used during an acute episode, disposable plugs are recommended, or used plugs must be cleaned and dried properly to avoid contaminating the healing ear canal with infected discharge.

Custom molds

Noise and decibel reduction earplugs can be molded to fit an individual's ear canal. This is associated with a higher cost, but can help to reduce the discomfort typically experienced after longer use, or if the level of protection or performance is inadequate.

Pressure and flight earplug molds are less common, as they are typically not used as long as other earplugs, and are therefore less in demand.

For best results they are molded in the ear while in the position that they will be used. For instance, if they are to be used for sleeping then they should be molded in the ear while lying down, as different positioning of the jaws causes significant changes to the form of the ear canal, mostly a reduction of the diameter, risking the sleep earplug to be made too large otherwise. These changes can be felt by feeling with a finger just at the entrance to the ear canal while moving the jaws sideways, up and down or anterior and posterior.

Chapter 5

Hearing Conservation Program

Hearing conservation programs are design to prevent noise induced hearing loss. A written hearing conservation program is required by the Occupational Safety and Health Administration (OSHA) “whenever employee noise exposures equal or exceed an 8-hour time-weighted average sound level (TWA) of 85 decibels measured on the A scale (slow response) or, equivalently, a dose of fifty percent.” This 8-hour time-weighted average is known as an exposure action value. While the Mine Safety and Health Administration (MSHA) also requires a hearing conservation program, MSHA does not require a written hearing conservation program. MSHA’s hearing conservation program requirement can be found in 30 CFR § 62.150, and requires has almost the same exact requirements as the OSHA hearing conservation program requirements. Therefore, only the OSHA standard 29 CFR 1910.95 will be discussed in detail.

Program requirements

The OSHA standard contains a series of program requirements.

- **Engineering Controls:** 29 CFR 1910.95(b)(1) requires that “feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels…personal protective equipment shall be provided and used to reduce sound levels…”
- **Monitoring:** 29 CFR 1910.95(d) requires that monitoring be conducted when “any employee’s exposure may equal or exceed an 8-hour time-weighted average of 85 decibels.
- **Testing:** 29 CFR 1910.95(g) requires an “audiometric testing program” for “all employees whose exposures equal or exceed an 8-hour time-weighted average of 85 decibels”.
- **Hearing Protectors:** 29 CFR 1910.95(i) states that “employers shall make hearing protectors available to all employees exposed to an 8-hour time-weighted average of 85 decibels or greater at no cost to the employees”
- **Training:** 29 CFR 1910.95(k) mandates an annual “training program” for “all employees who are exposed to noise at or above an 8-hour time-weighted average of 85 decibels…” and mandates certain aspects of the training that must be

included. This includes the effects of noise on hearing; purpose, advantages, disadvantages, and attenuation of different types of hearing protectors; purpose audiometric testing.

- **Record Keeping:** 29 CFR 1910.95(m) states that employers “shall maintain an accurate record of all employee exposure measurements…”

Sound survey

A sound survey is often completed to determine areas of potential high noise exposure. This type of survey is normally completed using a sound level meter (SLM). There are three types of sound level meters. Type 0 is precision instrument normally used in laboratories. A type 1 is for precision measurements taken in the field. Type 2 sound level meters are less precise than type 1 and are often used to take all-purpose sound level measurements. Noise monitoring is generally completed using a noise dosimeter that integrates “all continuous, intermittent and impulsive sound levels” to determine a person’s noise exposure level.

Surveys must be repeated when there are significant changes in machinery and/or processes that would affect the noise level.

Administrative and engineering controls

Administrative and engineering controls are the preferred method to prevent noise exposure. Normally, administrative and engineering controls do not require personal protective equipment and therefore are normally more protective. However, it is not always feasible to use administrative and engineering controls as the only ways to prevent noise over-exposure. The key is to maintain an 8-hour time-weighted average of less than 85 dBA so that personal protective equipment is not required. On October 19, 2010, the US Department of Labour proposed that the term "feasible" be interpreted as that which is capable of being done, thus enhancing OSHA's ability to enforce this aspect of the standard.

Hearing protection device

If engineering controls fail to maintain an 8-hour time-weighted average below 85 dBA, then a hearing protection device (hpd) is required. There are two general types of hpd’s: earplugs and ear muffs. Each one has its own benefits and drawbacks. The selection of the proper hpd to be worn is commonly done by an industrial hygienist so that the proper amount of noise protection is worn. OSHA requires that hpd be given free of charge.

Earplugs

There are four general classes of earplugs. These include: premolded, formable, custom molded and semi-insert.

-Premolded earplugs do not require the plug to be formed before it is inserted into the ear. This prevents the plugs from becoming soiled before insertion.

-Formable earplugs are made of a variety of substances. However, all each substance shares the common feature of being able to be shaped by the user prior to insertion. One drawback of this is the obvious need for the user to have clean hands while shaping the earplug. They do have the advantage of forming to the users ear, while many premolded earplugs do not accomplish this very well.

-Custom molded ear plugs are unique for each person, since they are cast from each user's own ear canals. Therefore, they provide a personalized fit for each individual.

-Semi-inserts are generally a soft earplug on the end of band. The band aides in maintaining the earplug in position. They are often useful since they can be quickly removed and inserted.

Earmuffs

Earmuffs are another type of hpd. The main difference between earmuffs and earplugs, is that earmuffs are not inserted inside the ear canal. Instead the muffs create a seal around the outside of the ear to prevent noise from reaching the inner ear. Earmuffs are easy to wear and often provide a more consistent fit than an earplug. There are earmuffs available that use the principle of active noise control to help reduce noise exposures. However, earmuffs are not commonly worn by people who have sideburns or glasses, who find earmuffs to be uncomfortable.

Noise reduction ratings

The United States Environmental Protection Agency (EPA) requires that all hearing protection devices be labeled with their associated noise reduction rating (NRR). The NRR provides the estimated attenuation of the hearing protection device. However, it has been found that the "labeled manufacturers' noise reduction ratings (NRRs) substantially overestimated the actual field attenuation performance." To determine the amount of noise reduction afforded by a hearing protection device, OSHA recommends that 7 db be subtracted from the NRR. The NRR is generally given in a C-weighted format, so to obtain the A-weighted reduction, one must subtract 7 db. OSHA also recommends a 50% safety factor, therefore the final OSHA recommended reduction would be (NRR-7)/2.

Audiometric testing program

Audiometric testing is a very important part of a hearing conservation program. Audiometric testing allows for the identification of those that have lost significant hearing. Additionally, the testing allows for the identification of those who are in process of losing their hearing. Audiometric testing is most important in identifying those who have permanent hearing loss. This is called noise-induced permanent threshold shift (NIPTS)

Employee training and education

Proper training and education of those exposed to noise is the key to preventing noise-induced hearing loss. If employees are properly trained on how to follow a hearing conservation program, then the risk of noise-induced hearing loss is reduced. OSHA requires said training to be completed on an annual basis. Proper training is imperative since “even with a very modest amount of instruction attenuation performance can be significantly improved.”

Record keeping

OSHA requires that records of exposure measurements and audiometric tests be maintained. Records are also required to have the following:

- name and job classification
- date of the audiogram
- examiner’s name
- calibration date
- employee’s most recent noise exposure assessment
- background sound pressure levels in audiometric test booths.

Noise exposure measurement records must be maintained for at least 2 years. Audiometric test records must be retained for the duration of the affected employee’s employment. Additionally, employees, former employees, representatives designated by the individual employee and the Assistant Secretary all must have access to these records.

Program evaluation

Proper program evaluation is important in maintaining the health of hearing conservation program. The National Institute for Occupational Safety and Health (NIOSH) has created a checklist to help evaluate the effectiveness of a hearing conservation program. It can be found on their website. NIOSH recommends that fewer than 5% of exposed employees should have a 15 dB Significant Threshold Shift in the same ear and same frequency.

The National Institute for Occupational Safety and Health is pushing a higher emphasis on a hearing loss prevention program rather than a hearing conservation program. While this change may seem superfluous, it is important to note the advancement. Prevention implies a response by the workplace caused by initial signs of employee hearing loss rather than instilling a new set of policies (such as “buy quiet”) and thinking (such as hearing protection training and education) to decrease the possibility of occupational hearing loss from happening in the first place.

The Buy Quiet policy is an easy way to progress towards a safer work environment. Many traditionally noisy tools and machines are now being redesigned in order to manufacture quieter running equipment, so a “buy quiet” purchase policy should not require new engineering solutions in most cases. As a part of the “buy quiet” campaign, the New York City Department of Environmental Protection released a products and vendor guidance sheet in order to assist contractors for achieving compliance with the New York City Noise Regulations.

In order to make these plans effective, employees and administration need to be educated in occupational noise-induced hearing loss prevention. It is also necessary to identify and examine sources of noise first before being able to control the damage it may cause to hearing. For example, the National Institute for Occupational Safety and Health has conducted a study and created a database on handheld power tools for the sound power levels they expose their operators to. This Power Tools Database allows contractors in a trade-skill profession to monitor their exposure limits and allow them preparation to prevent permanent hearing damage

Chapter 6

Helicopter Noise Reduction

Helicopter noise reduction is a topic of research into designing helicopters which can be operated more quietly, reducing the public-relations problems with night-flying or expanding an airport. In addition, it is useful for military applications in which stealth is required: long-range propagation of helicopter noise can alert an enemy to an incoming helicopter in time to re-orient defenses.

Sources of helicopter noise

- Rotor noise
- Engine noise
- Transmission noise

The noise from a rotor can be divided into several distinct sources, which will be described as follows:

Thickness noise

Thickness noise is dependent only on the shape and motion of the blade, and can be thought of as being caused by the displacement of the air by the rotor blades. It is primarily directed in the plane of the rotor.

Loading noise

Loading noise is an aerodynamic adverse effect due to the acceleration of the force distribution on the air around the rotor blade due to the blade passing through it, and is directed primarily below the rotor. In general, loading noise can include numerous types of blade loading: some special sources of loading noise are identified separately.

Blade-vortex interaction (BVI) noise

BVI occurs when a rotor blade passes within a close proximity of the shed tip vortices from a previous blade. This causes a rapid, impulsive change in the loading on the blade resulting in the generation of highly directional impulsive loading noise. BVI noise can occur on either the advancing or retreating side of the rotor disk and its directivity is characterized by the precise orientation of the interaction. In general, advancing side BVI noise is directed down and forward while retreating-side BVIs cause noise that is directed down and rearward. It has been shown that the main parameters governing the strength of a BVI are the distance between the blade and the vortex, the vortex strength at the time of the interaction, and how parallel or oblique the interaction is (Hardin 1987, Malovrh 2005).

Broadband noise

Another form of loading noise, broadband noise consists of various stochastic noise sources. Turbulence ingestion through the rotor, the rotor wake itself, and blade self-noise are each sources of broadband noise.

High-speed impulsive (HSI) noise

HSI noise is caused by transonic flow shock formation on the advancing rotor blade, and is distinct from loading noise. The source of HSI noise is the flow volume around the advancing blade tip, hence it cannot be captured by examining only the acoustic sources on the surface of the blade, HSI noise is typically directed in the rotor plane forward of the helicopter, like thickness noise.

Tail rotor noise

While most noise from a helicopter is generated by the main rotor, the tail rotor is a significant source of noise for observers relatively close to the helicopter, where the higher-frequency noise of the tail rotor has not yet been attenuated by the atmosphere. Tail rotor noise is particularly annoying to the human listener due to its higher frequency (as compared to the main rotor) which places it directly in the band in which the human ear is most sensitive.

Shrouded tail rotor directs noise sideways

Methods of noise reduction

Almost all helicopter engines are located above the aircraft, which tends to direct much of the engine-noise upwards. In addition, with the advent of the turbine engine, noise from the engine plays a much smaller role than it once did. Most research is now directed towards reducing the noise from the main and tail rotors.

A tail-rotor which is recessed into the fairing of the tail (a fenestron) reduces the noise level directly below the aircraft, which is useful in urban areas. In addition, this type of rotor typically has anywhere from 8 to 12 blades (as compared to 2 or 4 blades on a conventional tail rotor), increasing the frequency of the noise and thus its attenuation by the atmosphere. In addition, the placement of the tail rotor within a shroud can prevent the formation of tip vortices. This type of rotor is in general much quieter than its conventional counterpart: the price paid is a substantial increase in the weight of the aircraft, and the weight that must be supported by the tail boom. For example, the Eurocopter EC-135 has such a design.

For smaller helicopters it may be advantageous to use a NOTAR (from NO TAil Rotor) system. In this yaw-control method air is blown out of vents along the tail boom, producing thrust via the Coandă effect.

Some designs have been done to reduce the rotor noise itself, for example the Comanche military helicopter attempted many stealth mechanisms, including attempts to quiet the rotor.

Helicopter pilots can select operating modes which limits the engine torque and other parameters to ensure legal limits are respected to reduce noise. Pilots can disable the restrictions in an emergency to get extra power.

Chapter 7

Noise Barrier

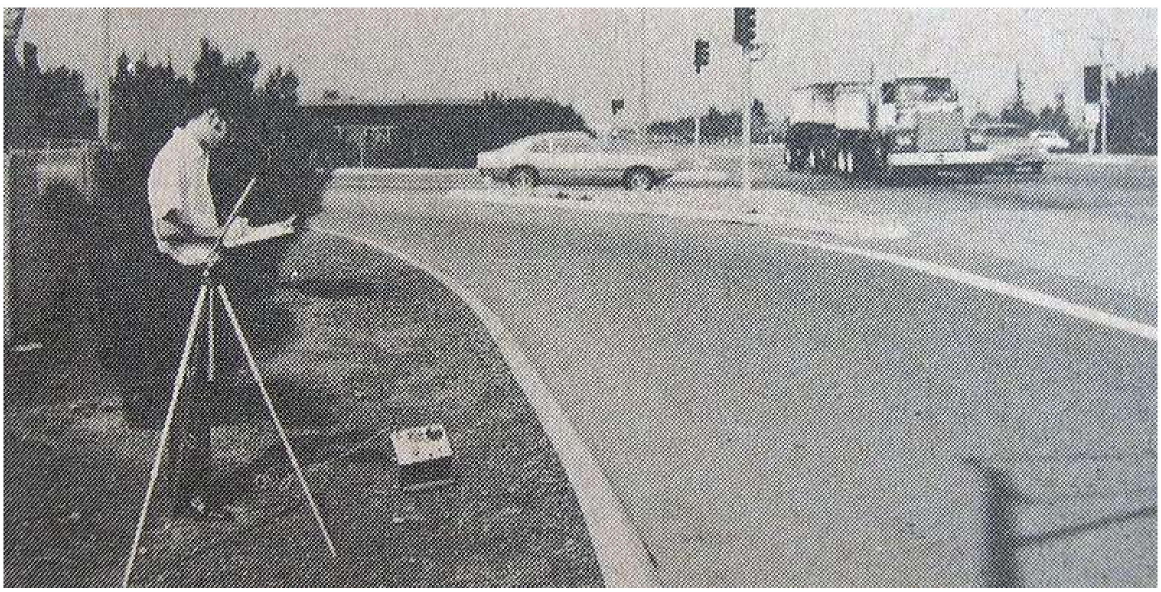
The *sound tube* in Melbourne, Australia, designed to reduce roadway noise without detracting from the area's aesthetics.

A **noise barrier** (also called a **soundwall**, **sound berm**, **sound barrier**, or **acoustical barrier**) is an exterior structure designed to protect sensitive land uses from noise pollution. Noise barriers are the most effective method of mitigating roadway, railway, and industrial noise sources – other than cessation of the source activity or use of source controls.

In the case of surface transportation noise, other methods of reducing the source noise intensity include encouraging the use of hybrid and electric vehicles, improving automobile aerodynamics and tire design, and choosing low-noise paving material. Extensive use of noise barriers began in the United States after noise regulations were introduced in the early 1970s.

History

Noise barriers have been built in the United States since the mid-20th century, when vehicular traffic burgeoned. In the late 1960s, acoustical science technology emerged to mathematically evaluate the efficacy of a noise barrier design adjacent to a specific roadway. By the 1990s, noise barriers that included use of transparent materials were being designed in Denmark and other western European countries.Below, a researcher collects data to calibrate a roadway noise model for Foothill Expressway.



Acoustical scientist measures sound in noise barrier design study, Santa Clara County, Calif.

The best of these early computer models considered the effects of roadway geometry, topography, vehicle volumes, vehicle speeds, truck mix, roadway surface type, and micro-meteorology. Several U.S. research groups developed variations of the computer modeling techniques: Caltrans Headquarters in Sacramento, California; the ESL Inc. group in Palo Alto, California; the Bolt, Beranek and Newman group in Cambridge, Massachusetts, and a research team at the University of Florida. Possibly the earliest published work that scientifically designed a specific noise barrier was the study for the Foothill Expressway in Los Altos, California.

Numerous case studies across the U.S. soon addressed dozens of different existing and planned highways. Most were commissioned by state highway departments and conducted by one of the four research groups mentioned above. The U.S. National Environmental Policy Act effectively mandated the quantitative analysis of noise pollution from every Federal-Aid Highway Act Project in the country, propelling noise barrier model development and application. With passage of the Noise Control Act of 1972, demand for noise barrier design soared from a host of noise regulation spinoff.

By the late 1970s, over a dozen research groups in the U.S. were applying similar computer modeling technology and addressing at least 200 different locations for noise barriers each year. In 1973 Sound Fighter® Systems (SFS), a company based out of Shreveport, LA, started designing, engineering and manufacturing high-performance absorptive sound walls. Sound Fighter® Systems is the oldest established manufacturer of absorptive outdoor noise barriers in America. As of 2006, this technology is considered a standard in the evaluation of noise pollution from highways. The nature and accuracy of the computer models used is nearly identical to the original 1970s versions of the technology.

Theory of design

The acoustical science of noise barrier design is based upon treating a roadway or railway as a line source. The theory is based upon blockage of sound ray travel toward a particular receptor; however, diffraction of sound must be addressed. Sound waves bend (downward) when they pass an edge, such as the apex of a noise barrier. Further complicating matters is the phenomenon of refraction, the bending of sound rays in the presence of an inhomogeneous atmosphere. Wind shear and thermocline produce such inhomogeneities.

The sound sources modeled must include engine noise, tire noise, and aerodynamic noise, all of which vary by vehicle type and speed. The resulting computer model is based upon dozens of physics equations translated into thousands of lines of computer code.

Noise barrier earth berm along Highway 12, Sonoma County, California

Some noise barriers consist of a masonry wall or earthwork, or a combination thereof (such as a wall atop an earth berm). Sound abatement walls are commonly constructed using steel, concrete, masonry, wood, plastics, insulating wool, or composites. In the most extreme cases, the entire roadway is surrounded by a noise abatement structure, or dug into a tunnel using the cut-and-cover method. The noise barrier may be constructed on private land, on a public right-of-way, or on other public land. Because sound levels are measured using a logarithmic scale, a reduction of nine decibels is equivalent to elimination of about 80 percent of the unwanted sound.

Noise barriers can be extremely effective tools for noise pollution abatement, but theory calculates that certain locations and topographies are not suitable for use of any reasonable noise barrier. Cost and aesthetics play a role in the final choice of any noise barrier.

Tradeoffs

This noise abatement wall in The Netherlands has a transparent section at the driver's eye-level to reduce the visual impact.

Disadvantages of noise barriers include:

- Aesthetic impacts for motorists and neighbors, particularly if scenic vistas are blocked.

- Costs of design, construction, and maintenance.
- Necessity to design custom drainage that the barrier may interrupt.

Normally, the benefits of noise reduction far outweigh aesthetic impacts for residents protected from unwanted sound. These benefits include lessened sleep disturbance, improved ability to enjoy outdoor life, reduced speech interference, stress reduction, reduced risk of hearing impairment, and reduction in blood pressure (improved cardiovascular health).

With regard to construction costs, a major factor is the availability of excess soil in the immediate area which could be used for berm construction. If the soil is present, it is often cheaper to construct an earth berm noise barrier than to haul away the excess dirt, provided there is sufficient land area available for berm construction. Generally a four-to-one ratio of berm cross sectional width to height is required. Thus, for example, to build a 6-foot-high (1.8 m) berm, one needs an available width of 24 feet (7.3 m).

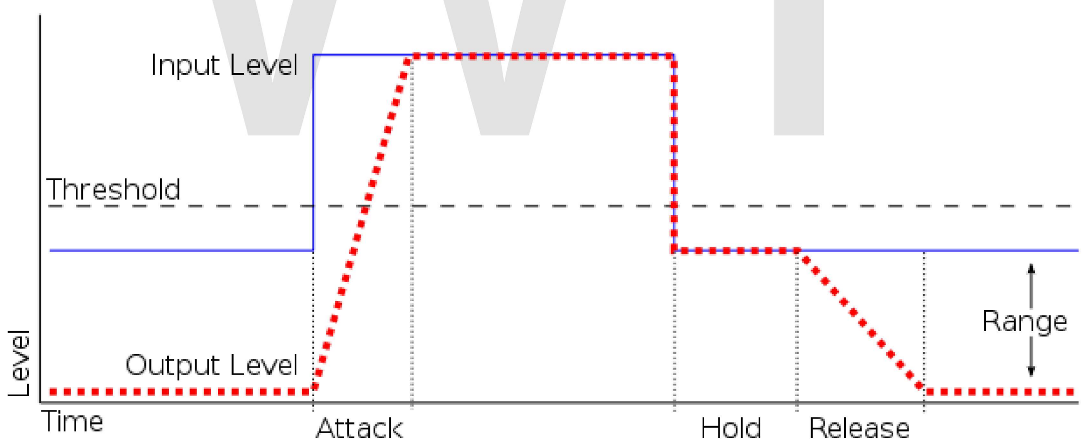
Earth berm noise barriers can be constructed solely of excess earth from grading pads for a residential development it will protect. Thus its entire construction cost is negligible; arguably, it may pay into the project, since offhaul of earth may have been needed. A further nuance of this particular project is that the residential side of the berm is over-excavated, which gives more privacy between highway and homes and also enhances noise benefit. Finally, note the aesthetics of the earth berm which blends with scenic elements of the natural hills of Annadel State Park in the background. It may be a surprise to find out this berm is over six feet in height, since the aesthetics of earth mounding reduce the visual impact of the structure, compared to a soundwall.

As a minor embellishment to noise barrier design, one may note the concept of constructing a louver or cap atop the wall that is directed back toward the noise source. This concept follows the theory that such a design should inhibit shadow zone diffraction filling in sound behind the noise barrier. In actual experience the benefits are slight compared to the benefits of a higher barrier and the costly construction techniques necessary to create and maintain such a device. Variation of the louver design can be found in Denmark, where the designs are also intended to minimize reflected sound. Furthermore, some of the Danish soundwalls are made of transparent materials to minimize the visual impact; such material use, however, compromises the efficacy by reducing mass.

Chapter 8

Noise Gate

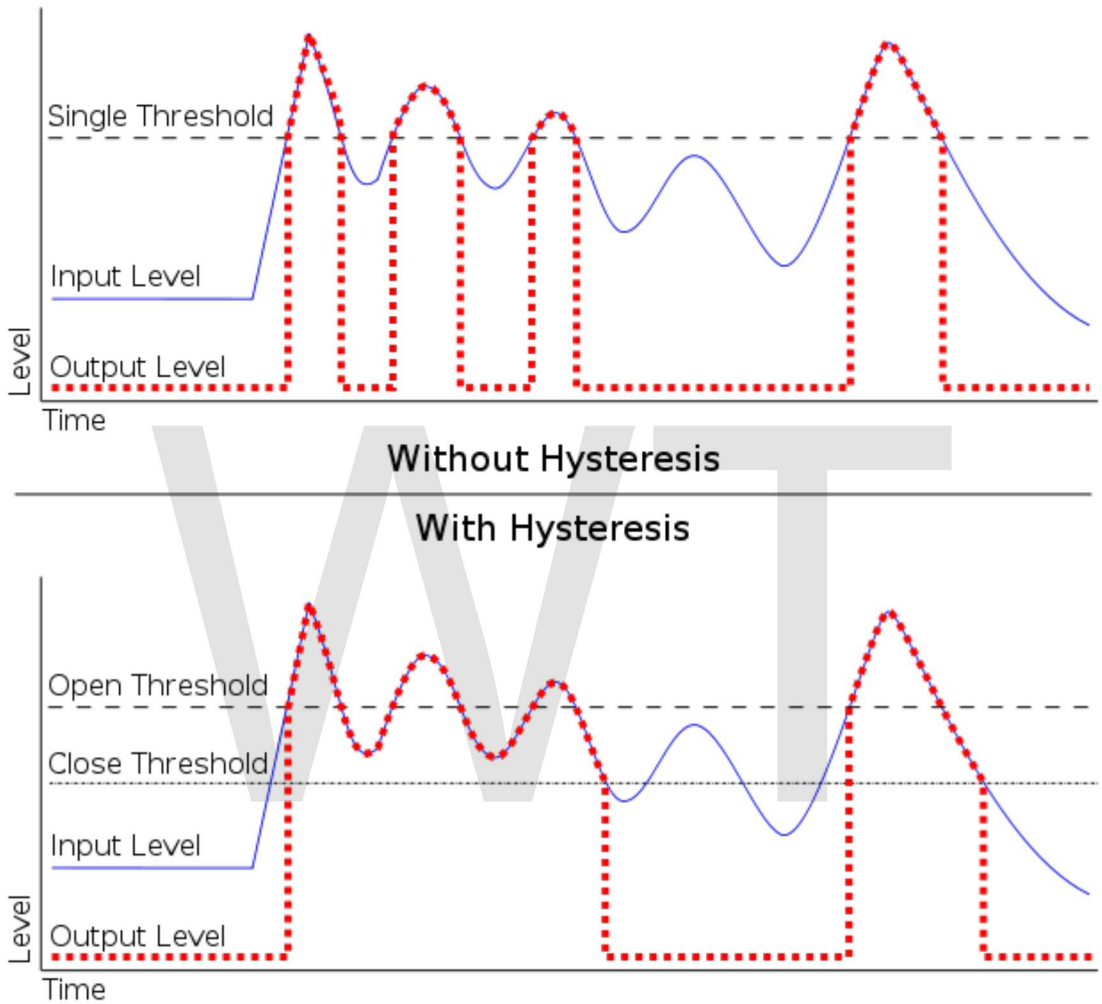
A **Noise Gate** or **gate** is an electronic device or software that is used to control the volume of an audio signal. In its most simple form, a noise gate allows a signal to pass through only when it is above a set threshold: the gate is 'open'. If the signal falls below the threshold no signal is allowed to pass (or the signal is substantially attenuated): the gate is 'closed'. A noise gate is used when the level of the 'signal' is above the level of the 'noise'. The threshold is set above the level of the 'noise' and so when there is no 'signal' the gate is closed. A noise gate does not remove noise from the signal. When the gate is open both the signal and the noise will pass through.



The Attack, Hold, and Release functions of a noise gate.

They are commonly used in the recording studio and sound reinforcement. Rock musicians may also use small portable units to control unwanted noise from their amplification systems. Band-limited noise gates are also used to eliminate background noise from audio recordings by eliminating frequency bands that contain only static.

Noise Gates have a *Threshold* control to set the level at which the gate will open. More advanced noise gates have more features. The *Release* sets the amount of time for the gate to go from open to fully closed. A fast release abruptly cuts off the sound once it has fallen below the threshold, a slower release smoothly changes from open to closed, much like a slow fade out. If the release time is too short a click can be heard when the gate re-opens. Release is the most common control to find on a gate, after Threshold.



A noise gate without hysteresis can open and close undesirably with a fluctuating signal (top). With hysteresis the noise gate does not 'chatter'.

The *Attack* control sets the time for the gate to change from closed to open, much like a fade-in. The *Hold* control allows you to define the amount of time the gate will stay open after the signal falls below the threshold. This is useful during short pauses between words or sentences in a speech signal.

The amount of attenuation when the gate is closed can be set by the *Range* control. Often there will be complete attenuation, that is no signal will pass when the gate is closed. In some circumstances complete attenuation is not desired and the range can be changed.

Advanced gates have a *sidechain*. This is an additional input that allows the gate to be triggered by another audio signal.

A variation of a sidechained noise gate used in electronic music production is a *trigger gate*, *trancegate* or just simply *gate*, where the noise gate is not controlled by audio signal but a preprogrammed pattern resulting in a precisely controlled chopping of a sustained sound.

Noise gates often implement hysteresis, that is, they have two thresholds. One to open the gate and another, set a few dB below, to close the gate. This means that once a signal has dropped below the close threshold, it has to rise to the open threshold for the gate to open, so that a signal that crosses over the close threshold regularly does not open the gate and cause chattering. A longer hold time as described above also helps avoid chattering.

Audio noise reduction

In audio post-processing, noise gating reduces steady noise sources such as rumble from LP records, hiss from audio tape, static from a radio or amplifier, and hum from a power system, without greatly affecting the source sound. An audio signal such as music or speech is broken up into many frequency bands by a collection of overlapping band-pass filters, and if the signal amplitude in any one band is lower than a preset threshold then that band is eliminated from the final sound. This greatly reduces perceptible background noise because only the frequency components of the noise that are within the gated passbands survive.

The technique was implemented in real-time electronics in some audiophile record players as early as the 1980s, and is now commonly used in audio production post-processing, where software to Fourier transform the audio signal can yield a very detailed spectrum of the background noise. Common digital audio editing software packages such as CoolEdit and Audacity include easy-to-use digital noise gating code: the user selects a segment of audio that contains only static, and the amplitude levels in each frequency band are used to determine the threshold levels to be applied across the signal as a whole.

Noise gating works well when the static is steady and either narrowly confined in frequency (e.g. hum from AC power) or well below the main signal level (15 dB minimum is desirable). In cases where the signal merges with the background static (for example, the brushed drum sounds in the Sun King track on the Beatles album Abbey Road) or is weak compared to the noise (as in very faint tape recordings), the noise gating can add artifacts that are more distracting than the original static.

In the context of a multi-microphone recording session, noise gating is employed to reduce the leakage of sound into a microphone from sources other than the one the microphone was intended for. One example involves the mic-ing up of a drumkit. In most multi-mic drum recordings one microphone will be used to capture the snare drum sound and another to capture the kick drum sound. The snare microphone will output a signal composed of a high level snare signal and a lower level kick drum signal (due to the further distance of the kick drum from the snare microphone). If the threshold level of the noise gate is set correctly a snare drum signal can be isolated. To fully isolate the snare drum signal the release rate has to be quite fast which can cause the tail end of the snare sound to be 'chopped off'. This can usually be remedied by the inclusion of one or more 'overhead' microphone(s), which can act as a general 'audio glue' for all the other gated sources.

For vocal applications on stage an optical microphone switch may be used. An infra-red sensor senses if somebody is in front of the microphone and switches on the microphone.

Recording usages

A good example of time-controlled noise gating is the well-known "gated reverb" effect heard on the drums on the Phil Collins hit single "In the Air Tonight", created by engineer-producer Hugh Padgham, in which the powerful reverberation added to the drums is cut off by the noise gate after a few milliseconds, rather than being allowed to decay naturally. This can also be achieved by: sending the 'dry' snare signal to the reverb (or other process) unit, inserting a noise gate on the path of the reverb signal and connecting the snare sound to the side chain of the gate unit. With the gate unit set to 'external sidechain' (or 'external key') the gate will respond to the snare signal level and 'cut off' when that has decayed below the threshold, not the reverberated sound.

It is a common production trick to use spurious combinations of side chain inputs to control longer, more sustained sounds. For example, a hi-hat signal can be used to control a sustained synthesized sound to produce a rhythmic melodic (or harmonic) signal which is perfectly in time with the hi-hat signal. A good example of this use of the device can be found on the Godley & Creme concept album *Consequences*. The album's story required the creation of a number of special sound effects that would convey the impression of natural disasters. For the "Fire" sequence, Godley and Creme used a noise gate, triggered by the sound of multitracked voices, that created the 'voice' of a raging bushfire. During the recording of this segment, each time the voice signal began, it triggered the noise gate to open up another channel, which carried a pre-recorded loop of a crackling sound (created by overdubbing the sound of Bubble Wrap being popped in front of a microphone). The combined voices and crackling created an eerie and quite convincing 'talking fire' effect.

Chapter 9

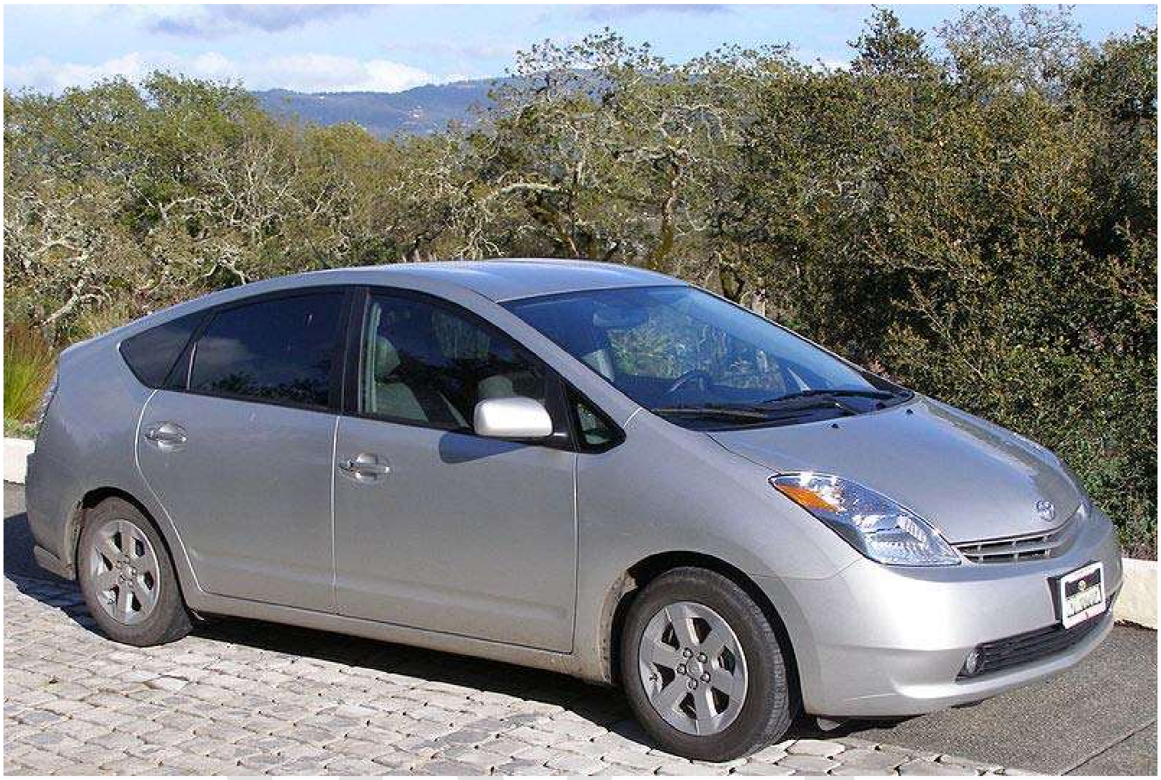
Noise Mitigation

Noise mitigation is a set of strategies to reduce noise pollution. The main areas of noise mitigation or abatement, are: transportation noise control, architectural design, and occupational noise control. Roadway noise and aircraft noise are the most pervasive sources of environmental noise worldwide, and remarkably little change has been effected in source control in these areas since the start of the problem, a possible exception being the development of hybrid and electric vehicles.

Multiple techniques have been developed to address interior sound levels, many of which are encouraged by local building codes; in the best case of project designs, planners are encouraged to work with design engineers to examine tradeoffs of roadway design and architectural design. These techniques include design of exterior walls, party walls and floor/ceiling assemblies; moreover, there are a host of specialized means for dampening reverberation from special purpose rooms such as auditoria, concert halls, dining areas and meeting rooms. Many of these techniques rely upon materials science applications of constructing sound baffles or using sound absorbing liners for interior spaces. Industrial noise control is really a subset of interior architectural control of noise, with emphasis upon specific methods of sound isolation from industrial machinery and for protection of workers at their task stations.

Sound masking is the active addition of noise to reduce the annoyance of certain sounds; the opposite of soundproofing.

Roadway noise mitigation



This Hybrid vehicle can operate 15 to 25 decibels quieter than conventional autos at speeds less than 60 km/h

Source control in roadway noise has provided little reduction in vehicle noise, except for the development of the hybrid vehicle; nevertheless, hybrid use will need to attain a market share of roughly fifty percent to have a major impact on noise source reduction on city streets. (Highway noise is little affected by automobile type, since those effects are aerodynamic and tyre noise related.) Other contributions to reduction of noise at the source are: improved tire tread designs for trucks in the 1970s, better shielding of diesel stacks in the 1980s, and local vehicle regulation of unmuffled vehicles.

The most fertile area for roadway noise mitigation is in urban planning decisions, roadway design, noise barrier design, speed control, surface pavement selection and truck restrictions. Speed control is effective since the lowest sound emissions arise from vehicles moving smoothly at 30 to 60 kilometres per hour. Above that range sound emissions double with each five miles per hour of speed. At the lowest speeds, braking and (engine) acceleration noise dominates. Selection of surface pavement can make a difference of a factor of two in sound levels, for the speed regime above 30 kilometres per hour. Quieter pavements are porous with a negative surface texture and use medium to small aggregates; the loudest pavements have a transversely tined/grooved surface, and/or a positive surface texture and use larger aggregates. Obviously surface friction and roadway safety are important considerations as well for pavement decisions.

When designing new urban freeways or arterials, there are numerous design decisions regarding alignment and roadway geometrics. Use of a computer model to predict future sound levels from line sources has become standard practice since the early 1970s. In this way exposure of sensitive receptors to elevated sound levels can be minimized. An analogous process exists for urban mass transit systems and other rail transportation decisions. Early examples of urban rail systems designed using this technology were: Boston MTA line expansions (1970s), San Francisco Bay Area Rapid Transit System expansion (1981), Houston light rail system (1982), and the Portland, Oregon Beaverton light rail line (1983).

Noise barriers can be applicable for existing or planned surface transportation projects. They are probably the single most effective weapon in retrofitting an existing roadway, and commonly can reduce adjacent land use sound levels by up to ten decibels. A computer model is required to design the barrier since terrain, micrometeorology and other locale specific factors make the endeavor a very complex undertaking. For example, a roadway in cut or strong prevailing winds can produce a setting where atmospheric sound propagation is unfavorable to any noise barrier.

Aircraft noise abatement

A British Airways Airbus A321, on landing approach to London Heathrow Airport, showing proximity to homes.

As in the case of roadway noise, surprisingly little progress has been made in quelling aircraft noise at the source, other than elimination of loud engine designs from the 1960s and earlier. Because of its velocity and volume, jet turbine engine exhaust noise defies reduction by any simple means. The most promising forms of aircraft noise abatement is through land planning, flight operations restrictions and residential soundproofing. Flight restrictions can take the form of preferred runway use; departure flight path and slope; and time of day restrictions. These tactics are sometimes controversial since they can impact aircraft safety, flying convenience and airline economics.

In 1979 the U.S. Congress authorized the FAA to devise technology and programs to attempt to insulate homes near airports. While this obviously does not aid the exterior environment, the program has been effective for residential and school interiors. Some of the first airports at which the technology was applied were San Francisco International Airport, Seattle-Tacoma International Airport, John Wayne International Airport and San Jose International Airport in California. The underlying technology is a computer model which simulates the propagation of aircraft noise and its penetration into buildings. Variations in aircraft types, flight patterns and local meteorology can be analyzed along with benefits of alternative building retrofit strategies such as roof upgrading, window glazing improvement, fireplace baffling, caulking construction seams and other measures. The computer model allows cost effectiveness evaluations of a host of alternative strategies.

In Canada, Transport Canada prepares noise exposure forecasts (NEF) for each airport, using a computer model similar to that used in the US. Residential land development is discouraged within high impact areas identified by the forecast.

In 1998 the flight paths in all of Scandinavia were changed as the new Oslo-Gardermoen Airport was opened. These new paths were straighter, reducing fuel use, and disturbing fewer people. However, vociferous protests came from people who were not disturbed before and they took legal action (NIMBY effect).

Architectural solutions

Beyond the interior acoustics cited above under aircraft noise, there has been a steady trend to design quieter buildings with regard to sources within and without the structure itself. In the case of construction of new (or remodeled) apartments, condominiums, hospitals and hotels many states and cities have stringent building codes with requirements of acoustical analysis, in order to protect building occupants. With regard to exterior noise, the codes usually require measurement of the exterior acoustic environment in order to determine the performance standard required for exterior building skin design. The architect can work with the acoustical scientist to arrive at the best cost effective means of creating a quiet interior (normally 45 dBA). The most important elements of design of the building skin are usually: glazing (glass thickness, double pane design etc.), roof material, caulking standards, chimney baffles, exterior door design, mail slots, attic ventilation ports and mounting of through the wall air conditioners.

Regarding sound generated inside the building, there are two principal types of transmission. Firstly, airborne sound travels through walls or floor/ceiling assemblies and can emanate from either human activities in adjacent living spaces or from mechanical noise within the building systems. Human activities might include voice, amplified sound systems or animal noise. Mechanical systems are elevator systems, boilers, refrigeration or air conditioning systems, generators and trash compactors. Since many of these sounds are inherently loud, the principal design element is to require the wall or ceiling assembly to meet certain performance standards (typically Sound transmission class of 50), which allows considerable attenuation of the sound level reaching occupants.

The second type of interior sound is called Impact Insulation Class (IIC) transmission. This effect arises not from airborne transmission, but rather from transmission of sound through the building itself. The most common perception of IIC noise is from footfall of occupants in living spaces above. This type of noise is more difficult to abate, but consideration must be given to isolating the floor assembly above or hanging the lower ceiling on resilient channel.

Both of the above transmission effects may emanate either from building occupants or from building mechanical systems such as elevators, plumbing systems or heating, ventilating and air conditioning units. In some cases it is merely necessary to specify the best available quieting technology in selecting such building hardware. In other cases shock mounting of systems to control vibration may be in order. In the case of plumbing systems there are specific protocols developed, especially for water supply lines, to create isolation clamping of pipes within building walls. In the case of central air systems, it is important to baffle any ducts that could transmit sound between different building areas.

Designing special purpose rooms has more exotic challenges, since these rooms may have requirements for unusual features such as concert performance, sound studio recording, lecture halls. In these cases reverberation and reflection must be analyzed in order to not only quiet the rooms but prevent echo effects from occurring. In these situations special sound baffles and sound absorptive lining materials may be specified to dampen unwanted effects.

Industrial noise mitigation

This situation classically is thought to involve primarily manufacturing settings where industrial machinery produces intense sound levels, not uncommonly in the 75 to 85 decibel range. While this circumstance is the most dramatic, there are many other office type environments where sound levels may lie in the range of 70 to 75 decibels, entirely composed of office equipment, music, public address systems, and even exterior noise intrusion. The latter environments can also produce noise health effects provided that exposures are long term.

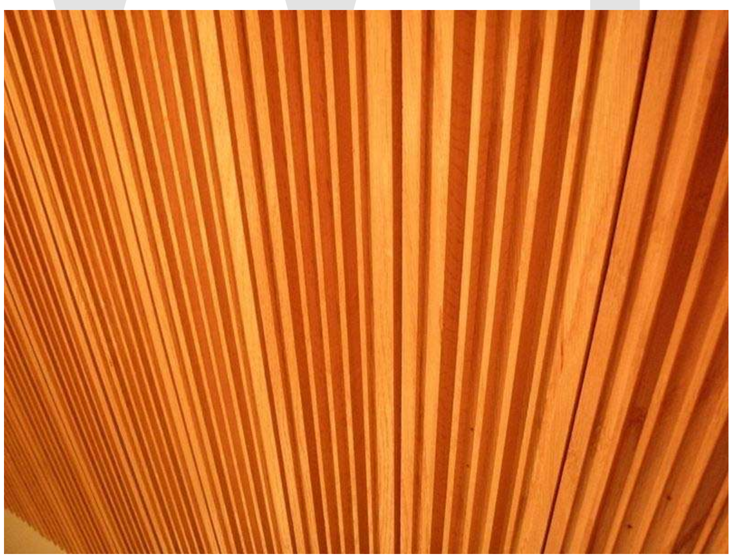
In the case of industrial equipment, the most common techniques for noise protection of workers consist of shock mounting source equipment, creation of acrylic glass or other solid barriers, and provision of ear protection equipment. In certain cases the machinery itself can be re-designed to operate in a manner less prone to produce grating, grinding, frictional or other motions that induce sound emissions.

In the case of more conventional office environments, the techniques in architectural acoustics discussed above may apply. Other solutions may involve researching the quietest models of office equipment, particularly printers and photocopy machines. One source of annoying, if not loud, sound level emissions are certain types of lighting fixtures (notably older fluorescent globes). These fixtures can be retrofitted or analyzed to see whether over-illumination is present, a common office environment issue. If over-illumination is occurring, de-lamping or reduced light bank usage may apply.

Chapter 10

Soundproofing

A anechoic chamber, showing acoustic damping tiles used for noise absorption.



Sound reflection board

Soundproofing is any means of reducing the sound pressure with respect to a specified sound source and receptor (noise control). There are several basic approaches to reducing sound: increasing the distance between source and receiver, using noise barriers to reflect or absorb the energy of the sound waves, using damping structures such as sound baffles, or using active antinoise sound generators.

Two distinct soundproofing problems may need to be considered when designing acoustic treatments - to improve the sound within a room, and reduce sound leakage to/from adjacent rooms or outdoors. Soundproofing can suppress unwanted indirect sound waves such as reflections that cause echoes and resonances that cause reverberation. Soundproofing can reduce the transmission of unwanted direct sound waves from the source to an involuntary listener through the use of distance and intervening objects in the sound path.

Distance

The energy density of sound waves decreases as they spread out, so that increasing the distance between the receiver and source results in a progressively lesser intensity of sound at the receiver. In a normal three dimensional setting, with a point source and point receptor, the intensity of sound waves will be attenuated according to the inverse square of the distance from the source.

Damping

Damping means to reduce resonance in the room, by absorption or redirection (reflection or diffusion). Absorption will reduce the overall sound level, whereas redirection makes unwanted sound harmless or even beneficial by reducing coherence. Damping can reduce the acoustic resonance in the air, or mechanical resonance in the structure of the room itself or things in the room.

Absorption

Absorbing sound spontaneously converts part of the sound energy to a very small amount of heat in the intervening object (the absorbing material), rather than sound being transmitted or reflected.

There are several ways in which a material can absorb sound. The choice of sound absorbing material will be determined by the frequency distribution of noise to be absorbed and the acoustic absorption profile required.

Porous absorbers

Porous absorbers, typically open cell rubber foams or melamine sponges, absorb noise by friction within the cell structure.

Porous open cell foams are highly effective noise absorbers across a broad range of medium-high frequencies. Performance is less impressive at low frequencies.

The exact absorption profile of a porous open cell foam will be determined by a number of factors including the following:

- Cell size
- Torosity
- Porosity
- Material thickness
- Material density

Resonant absorbers

Resonant panels, Helmholtz resonators and other resonant absorbers work by damping a sound wave as they reflect it.

Unlike porous absorbers, resonant absorbers are most effective at low-medium frequencies and the absorption of resonant absorbers is always matched to a narrow frequency range.

Reflection

In an outdoor environment such as highway engineering, embankments or panelling are often used to reflect sound upwards into the sky.

Diffusion

If a specular reflection from a hard flat surface is giving a problematic echo then an acoustic diffuser may be applied to the surface. It will scatter sound in all directions.

Room within a room

A room within a room (RWAR) is one method of isolating sound and stopping it from transmitting to the outside world where it may be undesirable.

Most vibration / sound transfer from a room to the outside occurs through mechanical means. The vibration passes directly through the brick, woodwork and other solid structural elements. When it meets with an element such as a wall, ceiling, floor or window, which acts as a sounding board, the vibration is amplified and heard in the second space. A mechanical transmission is much faster, more efficient and may be more readily amplified than an airborne transmission of the same initial strength.

The use of acoustic foam and other absorbent means is less effective against this transmitted vibration. The user is advised to break the connection between the room that contains the noise source and the outside world. This is called acoustic de-coupling. Ideal de-coupling involves eliminating vibration transfer in both solid materials and in the air, so air-flow into the room is often controlled. This has safety implications, for example proper ventilation must be assured and gas heaters cannot be used inside de-coupled space.

Noise cancellation

Noise cancellation generators for active noise control are a relatively modern innovation. A microphone is used to pick up the sound that is then analyzed by a computer; then, sound waves with opposite polarity (180° phase at all frequencies) are output through a speaker, causing destructive interference and cancelling much of the noise.

Residential soundproofing

Residential soundproofing aims to decrease or eliminate the effects of exterior noise. The main focus of residential soundproofing in existing structures is the windows. Curtains can be used to damp sound either through use of heavy materials or through the use of air chambers known as honeycombs. Single-, double- and triple-honeycomb designs achieve relatively greater degrees of sound damping. The primary soundproofing limit of curtains is the lack of a seal at the edge of the curtain. Double-pane windows achieve somewhat greater sound damping than single-pane windows. Significant noise reduction can be achieved by installing a second interior window. In this case the exterior window remains in place while a slider or hung window is installed within the same wall openings.

Noise barriers as exterior soundproofing

Since the early 1970s it has become common practice in the United States (followed later by many other industrialized countries) to engineer noise barriers along major highways to protect adjacent residents from intruding roadway noise. The technology exists to predict accurately the optimum geometry for the noise barrier design. Noise barriers may be constructed of wood, masonry, earth or a combination thereof. One of the earliest noise barrier designs was in Arlington, Virginia adjacent to Interstate 66, stemming from interests expressed by the Arlington Coalition on Transportation. Possibly the earliest scientifically designed and published noise barrier construction was in Los Altos, California in 1970.

Chapter 11

Noise-Canceling Microphone and Noise-Cancelling Headphones

Noise-canceling microphone

A **noise-canceling microphone** is a microphone designed to filter out ambient noise from the desired sound, especially useful in noisy environments.

Technical detail

The development is a special case of the differential microphone topology most commonly used to achieve directionality. All such microphones have at least two ports through which sound enters; a front port normally oriented toward the desired sound and another port that's more distant. The microphone's diaphragm is placed between the two ports; sound arriving from an ambient sound field reaches both ports more or less equally. Sound that's much closer to the front port than to the rear will make more of a pressure gradient between the front and back of the diaphragm, causing it to move more. The microphone's proximity effect is adjusted so that flat frequency response is achieved for sound sources very close to the front of the mic – typically 1 to 3 cm. Sounds arriving from other angles are subject to steep midrange and bass rolloff. Commercially and militarily useful noise-canceling microphones have been made since the 1940s by Roanwell, Electro-Voice and others.

Alternative technologies

Another technique uses two or more microphones and active or passive circuitry to reduce the noise. The primary microphone is closer to the desired source (like a person's mouth). A second mic receives ambient noise. In a noisy environment, both microphones receive noise at a similar level, but the primary mic receives the desired sounds more strongly. Thus if one signal is subtracted from the other (in the simplest sense, by connecting the microphones out of phase) much of the noise is canceled while the desired sound is retained. Other techniques may be used as well, such as using a directional primary mic, to maximize the difference between the two signals and make the cancellation easier to do.

The internal electronic circuitry of an active noise-canceling mic attempts to subtract noise signal from the primary microphone. The circuit may employ passive or active noise canceling techniques to filter out the noise, producing an output signal that has a lower noise floor and a higher signal-to-noise ratio.

Applications

- Call center headsets
- Helicopter pilot headsets
- Race car driver headsets
- Shipboard communications
- Voxtec's Phraselator

Noise-cancelling headphones

Showing 13.5φEX Headphone with noise cancellation from Sony Walkman Series NW-S705F

Noise-cancelling headphones reduce unwanted ambient sounds (i.e., acoustic noise) by means of active noise control (ANC). This involves using one or more microphones placed near the ear, and electronic circuitry which uses the microphone signal to generate an "antinoise" signal. When the antinoise signal is produced by the speaker driver in the headphone, destructive interference cancels out the ambient noise as heard within the enclosed volume of the headphone.

Noise cancellation makes it possible to enjoy music without raising the volume excessively. It can also help a passenger sleep in a noisy vehicle such as an airliner.

Retail noise-cancelling headphones typically use ANC to cancel the lower-frequency portions of the noise; they depend on more traditional methods such as soundproofing to prevent higher-frequency noise from reaching the ear. This approach is preferred because it reduces the demand for complicated electronic circuitry and at higher frequencies, where active cancellation is less effective. To truly cancel high frequency components (coming at the ear from all directions), the sensor and emitter for the cancelling waveform would have to be adjacent to the user's eardrum, which is not technically feasible.

History

By the 1950s, systems were created to cancel the noise in helicopter and airplane cockpits including those patented by Lawrence J. Fogel in the 1950s and 1960s such as U.S. Patent 2,866,848 (filed in 1954), U.S. Patent 2,920,138, U.S. Patent 2,966,549 and Canadian patent 631,136. Dr. Amar Bose (founder of the Bose Corporation) began work on his noise-cancelling headphones in 1978 on board an aeroplane. During the international flight, he was provided with a set of headphones from the airline and almost immediately realized how dissatisfied he was with their quality and the loud engine noise. After nearly a decade of research, Bose would commercially market the first noise-cancelling headphones.

Noise-cancellation technology was also developed to protect the hearing of pilots participating in the first non-stop around-the-world flight. Noise-cancelling in aviation headsets is now commonly available.

Currently, most noise-cancelling headsets use analog technology. This is in contrast to other forms of active noise and vibration control in which digital processing is the standard method.

A number of airlines supply noise-canceling headphones in their business and first class cabins. Noise-cancelling is particularly effective against airplane engine noise. In these cases, the headphones are about the same size as normal headphones. The actual electronics, located in the plane handrest, take the sound from the microphone behind the headphone, invert it, and add it back into the audio signal.

Limitations

Circumaural headphones enclose the wearer's ear completely. This provides passive noise isolation so that electronic noise cancellation circuitry can perform better.

Noise-canceling headphones have several limitations (that vary from vendor to vendor):

- They consume power, usually supplied by a USB port or a battery that must occasionally be replaced or recharged. Without power the headsets function like a regular headset or do not function at all, however, some such as the Solitude X, originally developed for military intelligence operations, employ a "pass through" system to allow the headphones to continue to operate normally, even if the battery power is expended.
- They work well for sounds that are continuous, such as the hum of a refrigerator or the sound in an airplane cabin, but are rather ineffective against speech or other rapidly changing audio signals.
- They may introduce additional noise, usually in the form of high-frequency hiss.
- The noise-cancelling circuitry required for them to operate inherently reduces audio quality.
- Early models were generally bulkier than traditional headphones. However, newer models tend to incorporate the batteries in pre-existing space. While this usually reduces the bulk, it does not reduce the extra weight of noise-cancelling headphones compared to traditional headphones.

Chapter 12

Sound Transmission Class

Sound Transmission Class (or **STC**) is an integer rating of how well a building partition attenuates airborne sound. In the USA, it is widely used to rate interior partitions, ceilings/floors, doors, windows and exterior wall configurations. Outside the USA, the Sound Reduction Index (SRI) ISO standard is used.

The STC rating figure very roughly reflects the decibel reduction in noise that a partition can provide.

Rating methodology

The ASTM test methods have changed every few years. Thus, STC results posted before 1999 may not produce the same results today, and the differences becomes wider as one goes further back in time –the differences in the applicable test methods between the 1970s and today being quite significant.

The STC number is derived from sound attenuation values tested at sixteen standard frequencies from 125 Hz to 4000 Hz. These transmission-loss values are then plotted on a sound pressure level graph and the resulting curve is compared to a standard reference contour. Acoustical engineers fit these values to the appropriate *TL* Curve (or *T*ransmission *L*oss) to determine an STC rating. The measurement is only accurate for speech sounds but much less so for amplified music, mechanical equipment noise, transportation noise or any sound with substantial low-frequency energy below 125 Hz. Sometimes, acoustical labs will measure TL at frequencies below the normal STC boundary of 125 Hz, possibly down to 50 Hz or lower, thus giving additional valuable data to evaluate transmission loss at very low frequencies, such as a subwoofer-rich home theater system would produce. Alternatively, Outdoor-Indoor Transmission Class (OITC) is a standard used for indicating the rate of transmission of sound between outdoor and indoor spaces in a structure that considers frequencies down to 80 Hz (Aircraft/Rail/Truck traffic) and is weighted more to lower frequencies.

STC is roughly the decibel reduction in noise a partition can provide, abbreviated 'dB'. The dB scale is a logarithmic one and the human ear perceives a 10dB reduction in sound as roughly halving the volume - a 40 dB noise subjectively seems half as loud as a 50 dB one. If an 80dB sound on one side of a wall/floor/ceiling is reduced to 50dB on the other side, that partition is said to have an STC of 30. This number does not apply across the range of frequencies, since the STC value is derived from a curve-fit of many datapoints. Any partition will have less TL at lower frequencies. For example, a wall with an STC of 30 may provide over 40dB of attenuation at 3000 Hz but only 10dB of attenuation at 125 Hz.

Sound damping techniques

Typical interior walls in homes (2 sheets of 1/2" drywall on either side of a wood stud frame) have an STC of about 33. When asked to rate their acoustical performance, people often describe these walls as "paper thin". They offer little in the way of privacy. Adding absorptive insulation (i.e. fiberglass batts) in the wall cavity increases the STC to 36-39, depending on stud and screw spacing. Doubling up the drywall in addition to insulation can yield STC 41-45, provided the wall gaps and penetrations are sealed properly.

Note that doubling the mass of a partition does not double the STC. Doubling the mass (going from two total sheets of drywall to four, for instance) typically adds 5-6 points to the STC. Breaking the vibration paths by decoupling the panels from each other will increase transmission loss much more effectively than simply adding more and more mass to a monolithic wall/floor/ceiling assembly.

Structurally decoupling the drywall panels from each other (by using resilient channel,steel studs, a staggered-stud wall, or a double stud wall) can yield an STC as high as 63 or more for a double stud wall, with good low-frequency transmission loss as well. Compared to the baseline wall of STC 33, an STC 63 wall will transmit only 1/1000 as much sound energy, seem 88 percent quieter and will render most frequencies inaudible.

Due to their high mass, concrete and concrete block walls have good TL values (STC's in the 40s and 50s for 4-8" thickness) but their weight, added complexity of construction and poor thermal insulation tend to limit them as viable materials in most residential wall construction, except in temperate climates and hurricane or tornado prone areas. Various insulation options can result in higher STC ratings, however any insulation tends to add little, compared to other aspects of wall construction.

Materials which can improve STC's in walls include mass-loaded vinyl (MLV), standard drywall, "soundproof" drywall, such as QuietRock, Supress, SoundBreak and ComfortGuard or damping compounds such as Green Glue.

It must be noted that acoustical performance values such as STC are measured in specially constructed acoustical chambers and field conditions such as lack of adequate sealing, outlet boxes, back-to-back electrical boxes, medicine cabinets, flanking paths and structure-borne sound can diminish acoustical performance. The as-built 'field-STC' (FSTC) is usually lower than the laboratory-measured STC.

Legal and practical requirements

Section 1207 of International Building Code 2006 states that separation between dwelling units and between dwelling units and public and service areas must achieve STC 50 (STC 45 if field tested) for both airborne and structure borne. However, not all jurisdictions use the IBC 2006 for their building or municipal code. In jurisdictions where IBC 2006 is used, this requirement may not apply to all dwelling units. For example, a building conversion may not need to meet this rating for all walls.

In serious cases (for instance, a bedroom adjacent to a home theater room, and an inconsiderate nocturnal neighbor, to boot) a partition to reduce sounds from high-powered home theater or stereo should ideally be STC 70 or greater, and show good attenuation at low frequencies. An STC 70 wall can require detailed design and construction and can be easily compromised by 'flanking noise', sound traveling around the partition through the contiguous frame of the structure, thus reducing the STC significantly. STC 65 to 70 walls are often designed into luxury multifamily units, dedicated home theaters, and high end hotels.

Sound Transmission Class (or STC) is an integer rating of how well a building partition attenuates airborne sound. In the USA, it is widely used to rate interior partitions, ceilings/floors, doors, windows and exterior wall configurations. Outside the USA, the Sound Reduction Index (SRI) ISO standard is used.

STC	**What can be heard**
25	Normal speech can be understood quite easily and distinctly through wall
30	Loud speech can be understood fairly well, normal speech heard but not understood
35	Loud speech audible but not intelligible
40	Onset of "privacy"
42	Loud speech audible as a murmur
45	Loud speech not audible; 90% of statistical population not annoyed
50	Very loud sounds such as musical instruments or a stereo can be faintly heard; 99% of population not annoyed.
60+	Superior soundproofing; most sounds inaudible

STC	**Partition type**
33	Single layer of 1/2" drywall on each side, wood studs, no insulation (typical interior wall)
45	Double layer of 1/2" drywall on each side, wood studs, batt insulation in wall
46	Single layer of 1/2" drywall, glued to 6" lightweight concrete block wall, painted both sides

54	Single layer of 1/2" drywall, glued to 8" dense concrete block wall, painted both sides
55	Double layer of 1/2" drywall on each side, on staggered wood stud wall, batt insulation in wall
59	Double layer of 1/2" drywall on each side, on wood stud wall, resilient channels on one side, batt insulation
63	Double layer of 1/2" drywall on each side, on double wood/metal stud walls (spaced 1" apart), double batt insulation
72	8" concrete block wall, painted, with 1/2" drywall on independent steel stud walls, each side, insulation in cavities

STC partition ratings taken from: "Noise Control in Buildings: A Practical Guide for Architects and Engineers"; Cyril M. Harris, 1994

Chapter 13

Acoustic Quieting

Acoustic quieting is the process of making machinery quieter by damping vibrations to prevent them from reaching the observer. Machinery vibrates, causing sound waves in air, hydroacoustic waves in water, and mechanical stresses in solid matter. Quieting is achieved by absorbing the vibrational energy or minimizing the source of the vibration. It may also be redirected away from the observer.

One of the major reasons for the development of acoustic quieting techniques was for making submarines difficult to detect by sonar. This military goal of the mid- and late-twentieth century allowed the technology to be adapted to many industries and products, such as computers (e.g. hard drive technology), automobiles (e.g. motor mounts), and even sporting goods (e.g. golf clubs).

Aspects of Acoustic Quieting

When the goal is acoustic quietening, a number of different aspects might be considered. Each aspect of acoustics can be taken alone or in concert so that the end result is that the reception of noise by the observer is minimized.

Acoustic quieting might consider...

- **Noise generation:** by limiting the noise at its source,
- **Sympathetic vibrations:** by acoustic decoupling,
- **Resonations:** by acoustic damping or changing the size of the resonator,
- **Sound transmissions:** by reducing transmission using many methods (depending whether the transmission is through air, liquid, or solid), or
- **Sound reflections:** by limiting the reflection using many methods, e.g. by using acoustic absorption (deadening) materials, trapping the sound, opening a "window" to let sound out, etc.

By analyzing the entire sequence of events, from the source to the observer, an acoustic scientist can provide many ways to quieten the machine. The challenge is to do this in a practical and inexpensive way. The scientist might focus on changing materials, using a damping material, isolating the machine, running the machine in a vacuum, or running the machine slower.

Methods of Quieting

Mechanical Acoustic Quieting

- **Sound isolation**: Noise isolation is isolating noise to prevent it from transferring out of one area, using barriers like deadening materials to trap sound and vibrational energy. Example: In home and office construction, many builders place sound-control barriers (such as fiberglass batting) in walls to deaden the transmission of noise through them.

A sound proof room, showing acoustic damping tiles used for noise absorption and soundproofing.

- **Noise absorption**: In architectural acoustics, unwanted sounds can be absorbed rather than reflected inside the room of an observer. This is useful for noises with no point source and when a listener needs to hear sounds only from a point source and not echo reflections. Example: In a recording studio, sound proofing is accomplished with bass traps and anechoic chambers. Wallace Sabine, an American physicist, is credited with studying sound reverberations in 1900, and Carl Eyring revised his equations in 1930 for Bell Labs. Another example is the ubiquitous use of dropped ceilings and acoustical tiles in modern office buildings with high ceilings. Submarine hulls have special coatings that absorb sound.
- **Acoustic damping**: Isolating vibrations to prevent them from transferring beyond the device into another material. Damping mounts have progressed in the industry to offer vibrational resistance in many degrees of freedom. Recent advances include shock isolators damping in at least six degrees of freedom. Acoustic damping also has uses in seismic shock protection of buildings. Motors and rotating shafts are commonly fitted with these mounts at the points where they contact the building or the chassis of a large machine.
- **Acoustic decoupling**: certain parts of a machine can be built to keep the frame, chassis, or external shafts from receiving unwanted vibrations from a moving part. Example: Volkswagen has registered a patent for an "acoustically decoupled underbody for a motor vehicle.". Another example: Western Digital has registered a patent for an "acoustic vibration decoupler for a disk drive pivot bearing assembly."

- **Preventing stalls**: Whenever a machine undergoes an aerodynamic stall, it will abruptly vibrate.
- **Preventing cavitation**: When a machine is in contact with a fluid, it may be susceptible to cavitation. The sounds of gas bubbles imploding is the source of the noise. Ships and submarines which have screws that *cavitate* are more vulnerable to detection by sonar.
- **Preventing water hammer**: In hydraulics and plumbing, water hammer is a known cause for the failure of piping systems. It also generates considerable noise. A valve that abruptly opens or shuts is the most common cause for water hammer.
- **Shock absorption**: Just as automotive shock absorbers are used to prevent mechanical shocks from reaching the passengers in a car, they are also important for quieting shocks.
- **Reduction of resonance**: Essentially any piece of metal or glass has certain frequencies to which it is susceptible to resonate. A machine that resonates would make a tremendous noise. Resonance also occurs in enclosures, such as when echoes reverberate in an ocarina or the pipe of a pipe organ.
- **Material selection**: By choosing nonmetallic components, the transmission of sound and vibrations can be minimized. For example: instead of using rigid brass fittings, a machine using flexible plastic pipe fittings may be much quieter. In some cases air can be evacuated from a machine and sealed hermetically, the vacuum inside becoming a barrier to sound transmission.

Quieting for Specific Observers

- **Underwater acoustics**: All of the above types of acoustic quieting apply to submarines. Additionally, a submarine may employ a tactic that prevent sounds from reaching a listener at a particular ocean depth. Operating below the depth of the sound channel axis, where the speed of sound in water is the lowest, a submarine can prevent detection by surface ships.
- **Sound refraction**: Just as a submarine can use refraction to hide its acoustic signature from surface vessels, the same principle of sound refraction can be used to prevent certain observers from hearing the noise. For example, an outdoor observer close to the ground will have sound waves refracted **toward him** when the ground is *cooler* than the ambient air and **away from him** when the ground is *hotter* than the air.
- **Sound Redirection**: One of the obvious ways to reduce the received sound level of an observer is to place the observer out of the path of the highest amplitude sounds. For example, if we mark off a circle around a jet engine and make sound power level observations along that circle, we would expect that the sound is loudest directly in line with the jet's exhaust. Observations perpendicular to the exhaust would be significantly quieter.
- **Hearing protection**: An observer may be forced to wear ear plugs in areas of high ambient noise levels. This may be the only quieting method available in areas of noise pollution, such as an open-air firing range or an airport.

Electronic Quieting

- **Electronic vibration control**: Electronics, sensors, and computers are now employed to reduce vibration. Using high speed logic, vibrations can be damped quickly and effectively by counteracting the motion before it exceeds a certain threshold.
- **Electronic noise control**: Electronics, sensors, and computers are also employed to cancel noise by using phase cancellation which matches the sound amplitude with a wave of the opposite polarity. This method employs the use of an active sound generating device, such as a loudspeaker to counteract ambient noise in an area. Workers in noisy environments may favor this method over ear plugs.
- **Noise reduction**: In sound and video equipment, noise reduction is the process of removing noise from a signal. This is strictly for electronic noise or noise which has been detected and put into electronic form.
- **Noise canceling**: If both the noise and the signal are received by an electronic or digital medium, noise can be filtered from the signal electronically and retransmitted without the noise. Helicopter pilots rely on this technology to speak on the radio.

Chapter 14

Sound Masking

Sound masking is the *addition* of natural or artificial sound (commonly, though inaccurately, referred to as "white noise" or "pink noise") into an environment to cover-up unwanted sound by using auditory masking. This is in contrast to the technique of active noise control. Sound masking reduces or eliminates awareness of pre-existing sounds in a given area and can make a work environment more comfortable, while creating speech privacy so workers can better concentrate and be more productive. Sound masking can also be used in the outdoors to restore a more natural ambient environment.

Sound masking can be explained by analogy with light. Imagine a dark room where someone is turning a flashlight on and off. The light is very obvious and distracting. Now imagine that the room lights are turned on. The flashlight is still being turned on and off, but is no longer noticeable because it has been "masked". Sound masking is a similar process of covering a distracting sound with a more soothing or less intrusive sound.

Building interiors

Sound masking can be used anywhere to ensure speech privacy or reduce distractions. Sound masking is typically used in selected workspaces but it can also be helpful in residential environments. The most common sound masking installations are:

- **Open office plans -** open offices can be either too quiet (where someone dropping a pen in the next cubicle is distracting) - or too noisy (where the conversations of others in the office make it impossible to concentrate). Open offices can benefit from sound masking because the added sound covers existing sounds in the area - making workers less distracted and more productive.

- **Private offices -** private offices and other enclosed spaces often appear to provide privacy but actually do not. Many times, walls are lightweight and do not extend to the ceiling deck - only to the ceiling tile. In these cases, sound can easily travel through partitions or over the walls. Sound masking can be provided in adjacent private offices, or in hallways outside of private offices, to ensure that confidential conversations remain confidential.

- **Public spaces -** sound masking is useful for reception areas, pharmacies, waiting rooms, and financial institutions. Sound masking is provided in the area where conversations should not be heard - not necessarily in the area where the conversation is taking place. For instance, a psychiatrist does not want those in the waiting room to overhear a private conversation with a patient, so sound masking is provided in the waiting area: not in the psychiatrist's office.

Sound masking may also be used to hide other unwanted noise, such as the intermittent sounds from machinery. In an office this could be sound of elevators and compressors. Sound masking may render conversations unintelligible by nearby listeners and may thus help compliance with HIPAA and GLBA regulations.

Sound masking is being used to protect confidential privacy in areas where sensitive or classified conversations are being held. The applications, among others, are in government, military, military contractors, corporate board rooms, and legal offices. The requirements for this type of masking are more stringent. The sound must be guaranteed to be continuous during room use, performance must be verified, and the equipment must be able to protect windows, doors, walls, and ducts with vibration maskers instead of loudspeakers.

Exteriors

A number of cases exist where sound masking has been successfully installed for exterior applications, the most common target of concern being roadway noise. In one example application, a large artificial waterfall was constructed as part of the garden exterior of an urban hotel in Santa Rosa, California. The waterfall cascades down an extensive wall approximately four meters in height and functions both for sound masking and as a physical barrier to road noise.

Sound masking systems

In-plenum

The plenum is the space between a dropped ceiling and the upper deck for the floor. In-Plenum sound masking systems, which employ a network of loud speakers located completely within the plenum, were the first such systems developed – they have been in use since the 1960’s. Plenum-based speakers typically range from 10 to 25 centimetres (3.9 to 9.8 in) in diameter. The industry standard spacing of plenum speakers is 4.6 metres (15 ft) or less on centers. Speakers in the plenum generally face upwards, towards the upper deck. This is done to reflect sound from the speakers to broaden, as much as possible, the footprint from the speaker in the work area.

The actual pattern of the received acoustic energy in the workspace from speakers in the plenum is complicated by a number of factors, all of which cause spatial variability in the sound masking field in the workspace. First, because loud speakers actually radiate in all directions, some energy at low frequencies is radiated downwards. Thus some sound variability occurs directly below the speakers. Second, dropped ceilings have a wide range of acoustical "transparency" or transmission loss (their degree of sound penetration directly to the space below). Some common lightweight office ceilings tiles, particularly those made of fiberglass, have a high degree of transparency, which increases sound variability below the speakers. Third, the plenum is acoustically complicated by the presence of HVAC ducts, large beams and other structural members which act to “compartmentalize” the masking sound and cause scattering and reflections. This scattered sound can also cause spatial variability. Fourth, when less transparent acoustical tiles, e.g. mineral fiber tiles, are used, a reverberant acoustic build-up occurs in the plenum that can cause significant "overflow" from the intended treated space, e.g. an open plan office, into spaces where sound masking may not be needed or wanted, e.g. private offices or conference rooms. Finally, when the plenum is used as a vehicle for return-air for the HVAC system, the ceiling necessarily has vents or open-air returns. If these returns are untreated, they will act as direct transmitters of the acoustic field from the plenum to the office area and create additional variability.

Treating the open-air returns is straightforward, but does add cost to the installation. Properly tuned and adjusted, plenum-based systems, when used in conjunction with treated open-air returns, have been shown to provide uniformity within many target sound masked spaces. Uniformity can be achieved by adjusting the acoustic output of individual or small groups of speakers. Adjustments routinely include changes in output volume and output spectra of individual speakers. To provide this adjustment capability, additional system electronics for individual speakers or for small groups of speakers are required.

Direct field

Direct Field sound masking systems have been in use since the late 1990’s. The masking acoustics is called “direct field” because the sound from any specific masking speaker travels directly to a listener without interacting with any other reflecting or transmitting feature. Initially used as an accessory for open office cubicles, direct field systems have been fully integrated into at least one open office furniture system and have been designed to be installed both in dropped ceilings and in offices without any absorptive ceiling systems. When installed in dropped ceilings, direct field systems use speakers that are mounted facing down, When a ceiling tile is not available, they are mounted facing down on any available structure, sending the masking noise directly into the intended space. Direct field masking requires speakers that are, in effect, omni-directional, meaning that they transmit energy equally in essentially all directions. The use of omni-directional speakers, spaced appropriately for the work area (typically on a grid equal to the ceiling height), provides sound masking that is evenly distributed. Using direct field speakers eliminates issues of spatial uniformity and “overflow” due to plenum conditions and open air returns. Because the plenum and ceiling materials are not acoustically involved, individual speakers do not have to be adjusted to counteract plenum conditions, so no tuning is required and electronic complexity is minimized. Also, because the sound from direct field speakers does not have to interact with the ceiling tile, the amount of energy required to produce a sound masked space is reduced.

In Open Ceilings

In many installations, particularly warehouses that have been converted to office space, the masking speakers are hung in a similar manner to those above suspended ceilings. Typically, the speakers are mounted higher and the spacing between them is often closer. The space generally has a very high structural ceiling, so the sound created is quite diffuse (occupants cannot locate the speakers easily by listening).

Under Raised Floors

In offices that utilize raised floors, masking speakers can be placed under them. Special speakers have been designed to accommodate even very shallow cavities, otherwise normal masking speakers can be used there. Listener acceptance is very high with this type of design as the sound is very diffuse.

Advances in Sound Masking

Sound masking has been in use for many years. It is likely that Roman villas with interior fountains had the benefit of masking the sound of chariots. Even today, fountains are used in malls to provide humidity, a pleasant environment, and sound masking. Due to increasing use of sound masking as a privacy tool, electronic methods have had a number of improvements that enhance the performance and acceptability of them: Equipment has been designed to protect sensitive conversations. Masking has been applied successfully in hospitals and other medical facilities. Masking speakers have been successfully located in open ceilings, above suspended ceilings, face-down in suspended ceilings and under raised floors. Most professionals have converged on a preferred spectrum and level of masking for both open and closed offices that balances the need for privacy with occupant acceptability. Most modern equipment is now capable of handling these requirements. Many systems have an initial ramp function. This function permits the user to increase the masking level automatically to the desired level over many days. Persons moving into a new office prefer slow changes and this function accommodates the acoustical aspect. Some systems have a power ramp function. When building power fails and then is turned on, the sound masking level would jump up quite noticeably, possibly creating a negative response. This function acts similar to the initial ramp function but acts in minutes rather than days. Some systems have a level scheduling function. This permits the user to have the sound masking level vary each day based on office use. If the office is fully occupied, the masking is at its highest level. As occupancy is low early in the workday, and persons are preparing to leave in the afternoon, the level can be reduced. During night hours the level is set low so security guards can hear any suspicious sound as they tour the office. Some systems have an adaptive function. In this system, a sound detector captures the sound, separates the activity sound (typically speech) from the background (sound masking) and adjusts the masking so the difference between the two is kept constant. Essentially, the system applies sound masking only when it is needed.

Attributes of Successful Sound Masking Systems

Sound masking level. For open offices, depending on design, the level can vary from 43 dB(A) to 48 dB(A) and for closed offices, the masking levels can vary from none to 44 dB(A). Adjust of levels must be done in small increments of level near 1 dB..

Sound masking spectrum contour. The frequency distribution of sound masking levels, at a minimum, cover the frequency range of speech which is 160 to 8000 Hz. Most experienced practitioners design a spectrum contour that decreases with frequency at about 4 dB per octave, requiring more low frequency sound than high. That particular shape of the contour has been found to be acceptable to occupants. The level of that contour is set to provide the desired privacy, so a balance between performance and acceptability can be achieved.

Spatial uniformity. Unlike most sound systems that call attention to themselves, sound masking is designed to be background (not recognized), just as the background sounds outdoors are not recognized. This is achieved by having sound masking uniform throughout a room. Uniformity is best achieved by having an intervening material (suspended ceiling, raised floor)between the masking speaker and the listener.

Invisibility. In keeping with the concept of being background, it is desirable to have the sound masking system invisible. The control equipment should be in a separate room. Putting speakers behind an intervening material hides them.

Sound diffusion. When sound is diffuse (arriving from all directions about equally), most people are not even aware of it. The quiet outdoor background is an example. The sound from an airport is just the opposite; the sound can be identified and disliked. Diffusion is greatly improved by use of an intervening material.

Applicability. Masking systems need to accommodate the many locations in which masking speakers are put. They include under raised floors, above suspended ceilings, in open ceiling plenums, above discontinuous suspended ceiling tiles, and on walls.

Portability. The system must be able to be moved to a new facility with minimum cost.

Phasing. When two masking speakers have the same signal, but are separated from each other, a person at the mid-point between them can sense a “swishing” sound. This is caused by level changes at various frequencies caused by phase shifts. When strongly noticeable, it is considered to be objectionable. This effect is most pronounced in a commercial facility with persons moving about. An intervening material can eliminate this effect. If there is no intervening material, special design is required to eliminate it.

The Relationship of Sound Masking to Speech Privacy

Many times an owner has an office noise problem and has heard that sound masking will solve it. This idea is true in many cases, but not always. Sound masking is only one of three factors that permit speech privacy to be achieved. If the other factors are insufficient, sound masking may not be a solution.

The Three Factors

1. Speech Level

The louder people speak the more they can be heard by others. Fortunately, people in offices tend to moderate their voices, although occasionally there are people with naturally loud voices. Much information about voice levels has been accumulated so that masking system designers have a good idea about speech levels.

2. Sound Attenuation

As the speech travels out it decays to lower levels; it is attenuated. There are three components that create the loss: blocking the speech, absorbing the speech, and natural spreading. The first component is composed of structures as walls or workstation panels that block the passage of speech through them. The second component is composed primarily of fibrous materials, such as ceiling tiles that reduce reflections from them. The third component is determined by distance from the speaker.

3. Background Level

The speech of a person is reduced in level when it finally reaches a listener. If that level is greater than the background level, it can be heard. The object of sound masking is to raise that level so that the amount of speech that is heard is reduced to the point that it causes no distraction.

The Privacy Index

Speech intelligibility has been the subject of much study for over many years and has resulted in a measure called Articulation Index (AI). It is a number from zero to one, with one representing full comprehension of speech, or 100%. The Privacy Index (PI) is inversely related to AI, PI is equal to 100(1-AI) (*this is also the difference between the AI percentage and 100*). It ranges from zero (no privacy) to 100 (complete privacy). Generally, for office settings, a PI below 80 is unsatisfactory, in that conversations and other noises are easily noticed or overheard. ASTM E 1130 Defines PI.

Privacy Type and Privacy Index

- *SECRET Complete protection of conversations. PI=100+ Grade: A+*
- *CONFIDENTIAL Others cannot understand. PI=95-100 Grade: A*
- *NORMAL Very few distractions. PI=80-95 Grade: B*
- *TRANSITIONAL Many distraction. PI=60-80 Grade: C*
- *NONE Complete distraction. PI=0-59 Grade: F*

Recommended Open Office Levels

- *Panel Height: less than 150 centimetres (59 in) Level: 48 dB(A)*
- *Panel Height: near 150 centimetres (59 in) Level: 47 dB(A)*
- *Panel Height: near 170 centimetres (67 in) Level: 46 dB(A)*
- *Panel Height: near 180 centimetres (71 in) Level: 45 dB(A)*
- *Panel Height: near 200 centimetres (79 in) Level: 44 dB(A)*

Recommended Open Office Spectrum when at 47 dB(A)

- *160 Hz Level: 46 dB*
- *200 Hz Level: 45 dB*
- *250 Hz Level: 44 dB*
- *315 Hz Level: 43 dB*
- *400 Hz Level: 41 dB*
- *500 Hz Level: 40 dB*
- *630 Hz Level: 39 dB*
- *800 Hz Level: 37 dB*
- *1000 Hz Level: 36 dB*
- *1250 Hz Level: 35 dB*
- *1600 Hz Level: 33 dB*
- *2000 Hz Level: 32 dB*
- *2500 Hz Level: 30 dB*
- *3150 Hz Level: 28 dB*
- *4000 Hz Level: 26 dB*
- *5000 Hz Level: 23 dB*
- *6300 Hz Level: 20 dB*
- *8000 Hz Level: 18 dB*

Recommended Closed Office Spectrum when at 44 dB(A)

- *160 Hz Level: 41 dB*
- *200 Hz Level: 40 dB*
- *250 Hz Level: 40 dB*
- *315 Hz Level: 39 dB*
- *400 Hz Level: 38 dB*
- *500 Hz Level: 37 dB*
- *630 Hz Level: 35 dB*
- *800 Hz Level: 33 dB*
- *1000 Hz Level: 31 dB*
- *1250 Hz Level: 29 dB*
- *1600 Hz Level: 26 dB*
- *2000 Hz Level: 24 dB*
- *2500 Hz Level: 22 dB*
- *3150 Hz Level: 20 dB*
- *4000 Hz Level: 17 dB*

- *5000 Hz Level: 15 dB*
- *6300 Hz Level: 12 dB*
- *8000 Hz Level: 10 dB*

Set above levels if above existing background level.

Sound Masking and the Privacy Index

How does sound masking fit into the Privacy graph? As an example, the design of an open office workstation starts with two people separated a few meters apart in sight of each other. Building a workstation means moving on the horizontal axis. The Privacy Index is near 10, so they have no privacy from each other. A furniture system with panels is added. If the panels block sound well and are high enough, the Privacy Index moves along the curve to near 50. A big, beneficial, improvement physically, but nothing much happens to the occupants privacy. Ceiling tiles are added, and the speech reflecting from the ceiling is reduced. If the sound absorbing qualities are good, the Privacy Index moves to 75. Occupants begin to notice an improvement, but as can be seen in the table the goal of Normal Privacy (little distraction) is still not met. Adding sound masking then can bring privacy to the goal. This process is known as the “ABC’s” of speech privacy: Absorb speech (ceiling), Block speech (panels), Cover speech (masking). It is the steep part of the privacy curve that gives the most performance and getting there is merely setting up the conditions. This description tends to make sound masking the hero, but the additions can be done in any order; it is the balance of the three factors that is most important.

Most of the privacy dollars are spent getting to the bend in the curve; the rest is spent to achieve the desired privacy.

The failure of masking to provide privacy for nearby persons can also be seen with this graph. To be acceptable to occupants, the level must be restricted to that which is acceptable and this means an improvement of about 15 PI points. In adding sound masking to a poorly designed office, the PI goes from 10 to 25 for them, not worthwhile. This does not mean to imply masking cannot be effective for others in the room. In customer service areas, for example, the panels are very low so the above situation applies for nearby persons. But as the speech travels outward, the level is reduced an acceptable amount for more distant persons, and then sound masking can be effective. The distance beyond which sound masking is beneficial is called the Radius of Distraction. People beyond this radius have good privacy which they did not have before.

Health Effects

The possibility of a detrimental influence on occupants' health has always been a concern in connection with sound masking. There are three types of effects of sound: physical, physiological, and psychological. Physical effect are things that produce direct damage, for example, very high sound levels, at or above 130 dB. The physiological effects occur at about 70 dB and above. At lowest sound levels, these include a slight dilation of the pupils of the eye and slight galvanic skin response, but no permanent effect. Street noises, bus, train, or aircraft transportation noises are typically above 70 dB. Since sound masking is operated at 47 dB, well below 70 dB, physiological responses are not to be expected. Psychological response is the only remaining concern and can occur at any level. Dripping faucets at 20-30 dB for example can result in annoyance and then complaints. Annoyance in a commercial environment is caused by transient sounds intruding on the listener. It is the purpose of masking to reduce the degree of intrusion of these sounds. A quote from the classic book The Effects of Noise on Man by K. Kryter may illuminate the potential problem:

The general finding that the performance of the more anxious personality types is more affected by noise than that of non-anxious types would attest to the existence of a stimulus-contingency factor. A possible teaching of much of the data presented in this book is that other than as a damaging agent to the ear (physical), noise will not harm the organism or interfere with mental or motor performance.

Chapter 15

dbx (Noise Reduction)

dbx is a family of noise reduction systems developed by the company of the same name. The most common implementations are dbx Type I and dbx Type II for analog tape recording and, less commonly, vinyl LPs. A separate implementation, known as dbx-TV, is part of the MTS system used to provide stereo sound to North American and certain other TV systems. The company – dbx, Inc. – was also involved with Dynamic Noise Reduction (DNR) systems.

History

The Panasonic RQ-J20X portable cassette player from 1982 was the first device to implement the dbx integrated circuit

The original dbx Type I and Type II systems were based on so-called "linear decibel companding" - compressing the signal on recording and expanding it on playback. It was invented by David E. Blackmer of dbx, Inc. in 1971.

A miniature dbx Type II decoder on an integrated circuit was created in 1982 for use in portable and car audio, although only a few devices took advantage of it, such as certain Panasonic portable cassette players and Sanyo car stereos. dbx marketed the **PPA-1 Silencer**, a decoder that could be used with non-dbx players such as the Sony Walkman. A version of this chip also contained a Dolby B-compatible noise reduction decoder, described as *dbx Type B noise reduction*; this was possible after the Dolby patent (but not the trademark) had expired.

How dbx works

dbx Type I and Type II are types of "companding noise reduction". Companding noise reduction works by first compressing the source material's dynamic range (in this case by a factor of two) in anticipation of being recorded on a relatively noisy medium (magnetic tape, for example).

- Upon playback, the encoded material, now contaminated with noise, is passed through an expander which restores the original dynamic range of the source material.
- The contaminating signal (tape hiss) is heavily attenuated and/or "masked" by the dynamic expansion process, resulting in a significant reduction in perceived noise.

Because dbx Type I and Type II are broadband (single-band) companders (unlike Dolby-A's four bands), they are susceptible to audible noise modulation and other artifacts. To deal with this, both Type I and II use very strong high-frequency pre-emphasis of the audio signal in both the recording path and the control signal path. This causes the compander to 'back off' the gain in certain circumstances and reduce the audibility of noise modulation – even with this pre-emphasis, noise modulation can become audible when using very noisy media to begin with, such as the Compact Cassette format. In the control signal path, the dbx Type II process rolls off the high and low frequency response to desensitize the system to frequency response errors – since the roll-off is *only* in the control path, it does *not* affect the audible sound.

The dbx Type-II "disc" setting on consumer dbx decoders adds an additional 1–3 dB of low-frequency roll-off in both the audio path and control path. This protects the system from audible mistracking due to record warps and low-frequency rumble.

The dbx Type I system is meant to be used with recording media that have a S/N, before noise reduction, of at least 60 db and a -3 db frequency response of at least 30 Hz to 15 kHz. dbx Type-II is for more noisy media that have a lower S/N and much more restricted frequency response. Both systems use 2:1 companding and provide exactly the same amount of NR and dynamic range improvement – in other words, they provide the same end results, but are not at all compatible with each other.

dbx artifacts

A sometimes noticeable artifact of dbx was "breathing", as its compander rapidly increased and decreased the volume level of the background noise along with the music, which was most noticeable in quiet musical passages; this was a greater issue with dbx than with Dolby because its compander was more aggressive and worked across the frequency spectrum.

Lack of DBX acceptance in marketplace

Although it brought extraordinary dynamic range to the lowly cassette tape, dbx noise reduction did not achieve widespread popularity in the consumer marketplace, as compressed recordings did not sound acceptable when played back on non-dbx equipment; Dolby B was already widely used when dbx was introduced. Although Dolby noise reduction also used some companding, the level of compression and expansion was very mild, so that the sound of Dolby-encoded tapes was acceptable to consumers when played back on non-Dolby equipment.

- dbx Type I was widely adopted in professional recording, and Tascam incorporated dbx Type II in their Portastudio four-track cassette recorders.
- Tascam's Portastudio family of 4 track cassette recorders became an industry standard for small recording studios before being replaced by digital audio tape many years later.
- An advantage of dbx Type I and Type II compared to Dolby noise reduction is that it did not require calibration with the output level of the tape deck, which could cause incorrect tracking with Dolby B and C, leading to muffled high tones.
- However, due to dbx's high compression and strong high-frequency preemphasis, dbx-encoded tapes were, unlike Dolby B, practically unplayable on non-dbx systems, sounding very harsh when played back undecoded. Undecoded dbx playback also exhibited large amounts of dynamic error, with audio levels going up and down constantly, making it a very fatiguing experience.

While dbx Type-II NR was eventually designed into a self-contained LSI chip, it was never cheap due to the extremely high precision required of the dbx VCAs and the RMS signal analysis, leading to further reluctance of manufacturers to use the dbx chips in their products.

dbx on vinyl

dbx was also used on vinyl records, from 1973 until around 1982, and over 1100 albums were released with dbx encoding, which were known as **dbx discs**. When employed on LPs, the dbx Type-II system reduced the audibility of dust and scratches, reducing them to tiny pops and clicks (if they were audible at all) and also completely eliminated record surface noise. dbx encoded LPs had, in theory, a dynamic range of up to 120db. In addition, dbx LPs were produced from only the original master tapes, with no copies being used, and pressed only on heavy, virgin vinyl. Most were released in limited quantities with premium pricing. Until the CD format came along in 1982, dbx LPs were the quietest and highest fidelity mass-market audio format available to consumers.

In practice, dbx companders contain electronic noise below about -60db which is about halfway from the theoretical range. This meant that even with the best all-analog mastering, dbx discs still did not achieve the full 90db range.

dbx with pro reel tape recorders

the dbx k9 noise reduction card was designed to fit into the pro dolby-A series A-361 frames, already in wide use in pro reel-to-reel recording studios of the time.

dbx for television

dbx-TV noise reduction, while having elements in common with Type I and Type II, is different in fundamental ways, and was developed by Mark Davis (then of dbx, now of Dolby Labs) in the early 1980s.

dbx-TV is included in multichannel television sound (MTS), the U.S. standard for stereo analog television transmission. Every TV device that decoded MTS originally required the payment of royalties, first to dbx, Inc., then to THAT Corporation which was spun off from dbx in 1989 and acquired its MTS patents in 1994; however, those patents expired worldwide in 2004.

dbx in film production

dbx noise reduction, capable of more than 20db of noise reduction, was used in the re-recording of the film Apocalypse Now in 1979. Dolby A-type noise reduction, capable of only 10-12db of noise reduction, was used only at the final stage for the mastering of the film's soundtrack to 70mm prints.

A modified version of dbx was also used in the Colortek stereo film system. In addition, dbx Type-II noise reduction was used in the Model-II and Model-III variants of MCA's Sensurround Special Effects System on the optical audio track and was a cornerstone of the entire system. MCA's Sensurround+Plus, used on the film Zoot Suit, employed dbx Type-II with the 4-track magnetic sound format on 35mm film prints, providing the motion picture with a stereo soundtrack capable of wide dynamic range and freedom from noise.

dbx for program delivery via the NPR Public Radio Satellite System

The first generation PRSS was a single channel per carrier system that had about 40dB of analog (recovered) signal to noise. dbx modules that were set for 3:1 were used to increase the dynamic range of the system. Typically this worked well but for some low frequencies the distortion exceeded 10 percent THD. Also the dbx modules varied in how they tracked the compressed audio so the expanded audio was not an exact representation of what was compressed at the uplink. Many of these problems were resolved when the PRSS moved to a digital delivery system.

Chapter 16

Architectural Acoustics and Noise Regulation

Architectural acoustics

Architectural acoustics is the science of noise control within buildings. The first application of architectural acoustics was in the design of opera houses and then concert halls. More widely, noise suppression is critical in the design of multi-unit dwellings and business premises that generate significant noise, including music venues like bars. The more mundane design of workplaces has implications for noise health effects. Architectural acoustics includes room acoustics, the design of recording and broadcast studios, home theaters, and listening rooms for media playback.

Building skin envelope

This science analyzes noise transmission from building exterior envelope to interior and vice versa. The main noise paths are roofs, eaves, walls, windows, door and penetrations. Sufficient control ensures space functionality and is often required based on building use and local municipal codes. An example would be providing a suitable design for a home which is to be constructed close to a high volume roadway, or under the flight path of a major airport, or of the airport itself.

Inter-space noise control

The science of limiting and/or controlling noise transmission from one building space to another to ensure space functionality and speech privacy. The typical sound paths are room partitions, acoustic ceiling panels (such as wood dropped ceiling panels), doors, windows, flanking, ducting and other penetrations. An example would be providing suitable party wall design in an apartment complex to minimise the mutual disturbance due to noise by residents in adjacent apartments.

Interior space acoustics

This is the science of controlling a room's surfaces based on sound absorbing and reflecting properties. Excessive reverberation time, which can be calculated, can lead to poor speech intelligibility.

Sound reflections create standing waves that produce natural resonances that can be heard as a pleasant sensation or an annoying one. Reflective surfaces can be angled and coordinated to provide good coverage of sound for a listener in a concert hall or music recital space. To illustrate this concept consider the difference between a modern large office meeting room or lecture theater and a traditional classroom with all hard surfaces.

Interior building surfaces can be constructed of many different materials and finishes. Ideal acoustical panels are those without a face or finish material that interferes with the acoustical infill or substrate. Fabric covered panels are one way to heighten acoustical absorption. Finish material is used to cover over the acoustical substrate. Mineral fiber board, or Micore, is a commonly used acoustical substrate. Finish materials often consist of fabric, wood or acoustical tile. Fabric can be wrapped around substrates to create what is referred to as a "pre-fabricated panel" and often provides the good noise absorption if laid onto a wall. Prefabricated panels are limited to the size of the substrate ranging from 2 by 4 feet (0.61 × 1.2 m) to 4 by 10 feet (1.2 × 3.0 m). Fabric retained in a wall-mounted perimeter track system, is referred to as "on-site acoustical wall panels" This is constructed by framing the perimeter track into shape, infilling the acoustical substrate and then stretching and tucking the fabric into the perimeter frame system. On-site wall panels can be constructed to accommodate door frames, baseboard, or any other intrusion. Large panels (generally, greater than 50 square feet or 4.6 square meters) can be created on walls and ceilings with this method. Wood finishes can consist of punched or routed slots and provide a natural look to the interior space, although acoustical absorption may not be great.

There are three ways to improve workplace acoustics and solve workplace sound problems – the ABCs.

- A = Absorb {via drapes, carpets, ceiling tiles, etc.)
- B = Block (via panels, walls, floors, ceilings and layout)
- C = Cover-up (via sound masking)

While all three of these are recommended to achieve optimal results, C = Cover-up by increasing background sound produces the most dramatic improvement in speech privacy – with the least disruption and typically the lowest cost.

Mechanical equipment noise

Building services noise control is the science of controlling noise produced by:

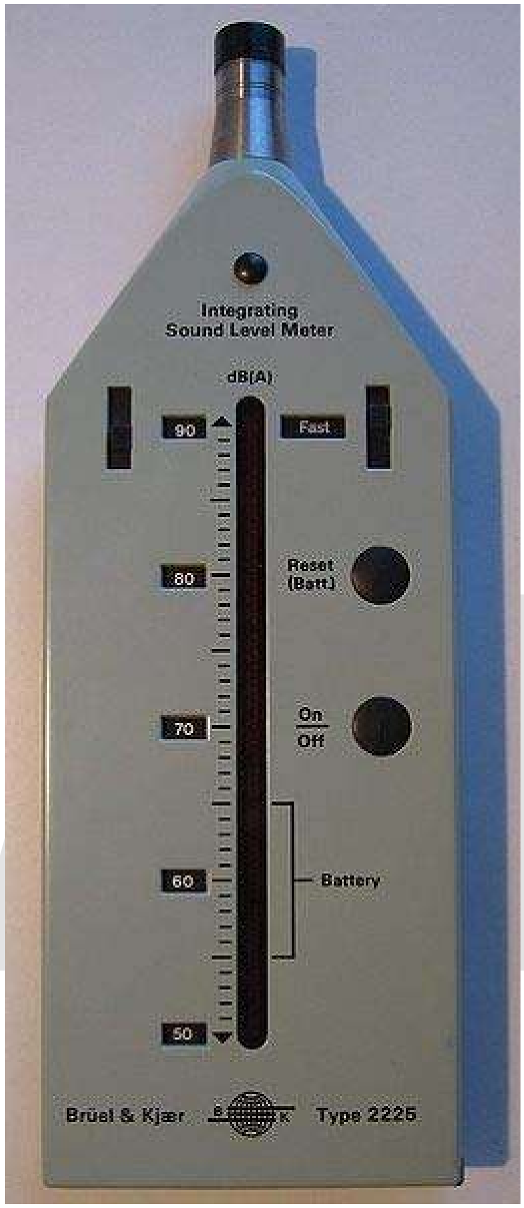
- ACMV (air conditioning and mechanical ventilation) systems in buildings, termed HVAC in North America
- Elevators
- Electrical generators positioned within or attached to a building
- Any other building service infrastructure component that emits sound.

Inadequate control may lead to elevated sound levels within the space which can be annoying and reduce speech intelligibility. Typical improvements are vibration isolation of mechanical equipment, and sound traps in ductwork. Sound masking can also be created by adjusting HVAC noise to a predetermined level.

Noise regulation

Noise regulation includes statutes or guidelines relating to sound transmission established by national, state or provincial and municipal levels of government. After the watershed passage of the United States Noise Control Act of 1972, other local and state governments passed further regulations. Although the UK and Japan enacted national laws in 1960 and 1967 respectively, these laws were not at all comprehensive or fully enforceable as to address generally rising ambient noise, enforceable numerical source limits on aircraft and motor vehicles or comprehensive directives to local government.

History of noise regulation



Sound level meter, a basic tool in measuring sound.

United States initial legislation

In the 1960s and earlier, few people recognized that citizens might be entitled to be protected from adverse sound level exposure. Most concerted actions consisted of citizens groups organized to oppose a specific highway or airport, and occasionally a nuisance lawsuit would arise. Things in the United States changed rapidly with passage of the National Environmental Policy Act (NEPA) in 1969 and the Noise Pollution and Abatement Act, more commonly called the Noise Control Act (NCA), in 1972. Passage of the NCA was remarkable considering the lack of historic organized citizen concern. However, the United States Environmental Protection Agency (EPA) had testified before

Congress that 30 million Americans are exposed to non-occupational noise high enough to cause hearing loss and 44 million Americans live in homes impacted by aircraft or highway noise. NEPA requires all federally funded major actions to be analyzed for all physical environmental impacts including noise pollution, and the NCA directed the EPA to promulgate regulations for a host of noise emissions. Many city ordinances prohibit sound above a threshold intensity from trespassing over property line at night, typically between 10 p.m. and 6 a.m., and during the day restricts it to a higher sound level; however, enforcement is uneven. Many municipalities do not follow up on complaints. Even where a municipality has an enforcement office, it may only be willing to issue warnings, since taking offenders to court is expensive. A notable exception to this rule is the City of Portland, Oregon, which has instituted an aggressive protection for its citizens with fines reaching as high at $5000 per infraction, with the ability to cite a responsible noise violator multiple times in a single day.

Japan

Japan actually passed the first national noise control act, but its scope was much more limited than the U.S. law, addressing mainly workplace and construction noise.

Follow-up on initial U.S. laws

Initially these laws had a significant effect on thoughtful study of transportation programs and also federally-funded housing programs in the United States. They also gave states and cities an impetus to consider environmental noise in their planning and zoning decisions, and led to a host of statutes below the federal level. Awareness of the need for noise control was rising. In fact, by 1973 a national poll of 60,000 U.S. residents found that sixty percent of people considered street noise to have a "disturbing, harmful or dangerous" impact. This trend continued strongly throughout the 1970s in the U.S., with about half of the states and hundreds of cities passing substantive noise control laws. Noise regulation subsided sharply in 1981, when Congress ended funding for the NCA. EPA had pre-empted lower levels of government from regulating sources, so states could not legislate standards such as for truck noise emissions. Thus, in areas where the federal government had failed to promulgate clear standards (such as aircraft noise), no further progress could be made except by the Federal Aviation Administration (FAA), which has an inherent conflict of interest regarding noise regulation.

Nevertheless some states continued to act. California carried out an ambitious plan to require its cities to establish a "Noise Element of the General Plan," which provides guidance for land planning decisions to minimize noise impacts on the public. Many cities throughout the U.S. also have noise ordinances, which specifies the allowable sound level that can cross property lines. These ordinances can be enforced with local police powers.

Europe and Asia

Several European countries emulated the U.S. national noise control law: Netherlands (1979), France (1985), Spain (1993), and Denmark (1994). In some cases unlegislated innovations have led to quieter products exceeding legal mandates (for example, hybrid vehicles or best available technology in washing machines). In any case, the legacy of the NCA has transformed irreversibly the way people think about noise and the intrinsic right to be protected from adverse sound levels.

Beyond the U.S. activities the European countries generally lag by 10 to 20 years. For example, Britain's National Environmental Protection Act of 1990 is stimulating research in the year 2006 aimed at setting certain definitive noise standards. Russia, China and undeveloped countries lag even further behind.

National controls in the U.S. program

After the passage of the NCA, EPA promulgated regulations setting maximum noise limits on a gamut of motor vehicles, industrial machinery and household appliances. The Agency conducted extensive testing and consulted with industry on the practicality of manufacturing quieter devices. EPA's efforts had an influence on the future of a quieter generation of machines. However, roadway noise and aircraft noise account for the lion's share of noise emissions, and the EPA standards for those vehicles pre-empted states from further regulating. In the case of aircraft noise, FAA had veto power over EPA recommendations, so those standards never pushed the envelope.

In the case of motor vehicles, states could not exact a greater standard for enforcement against an individual vehicle, and interstate commerce priorities meant that guidelines for total noise exposure along federally funded highways remained guidelines rather than strict standards. Despite these drawbacks, states and the public at large had a superb weapon in the review of proposed major transportation systems in the form of NEPA and the NCA. In many cases courts were able to enforce the intent of those laws to secure the redesign of roadways and transit systems to provide more noise mitigation or to select an alternative of lesser impact than the original project; in many other cases, the highway agencies simply listened to public input and acoustical scientists before finalizing highway and transit designs.

In the case of airport expansions, courts consistently upheld the sovereignty of the FAA over the EPA, in allowing air traffic needs to be met over environmental concerns. Thus airports were required to study impacts of air traffic and facilities expansions and provide detailed noise contour maps, but in the final analysis the EPA exposure guidelines only advisory in nature. To respond to the shortcomings of the voluntary guidelines, FAA created a well funded program to insulate thousands of homes in the vicinity of major airports. The program was based upon computer modeling of alternative insulation strategies, calculated on a house-by- house basis. While this program did nothing to mitigate exterior sound levels, it benefited residential interiors significantly.

U.S. State and local planning

States passed two different types of legislation starting in the 1970s, echoing the federal lead in noise control. First, many states, with California in the vanguard on a state level, began requiring each municipality and county to have a Noise Element of the General Plan, a substantial noise data base and blueprint for making land use decisions in that jurisdiction. The Noise Element became an integral part of the municipal or county General Plan, especially in California. This document compiled a comprehensive set of measurements setting forth existing sound levels, frequently in the form of sound level contour maps to illustrate where varying sound levels fall relative to land use categories. The Noise Element further states goals for each land use class and even numerical planning standards in order to evaluate future development proposals with regard to noise pollution. Technical analysis of urban highway noise had advanced by the early 1970s to allow intricate analysis of urban planning decisions in order to plan and design urban highways and support associated noise regulations.

Cities and counties in the U.S., who either fell under state mandates or who voluntarily chose to control noise through land use decisions, were active in categorizing sound levels and seeking development strategies that would minimize the number of persons exposed to harmful levels of (primarily) motor vehicle noise. Portland, Oregon continues to innovate through its almost 35 year old Noise Control Office at the City's Bureau of Development Services. Today its code is still one of the only comprehensive codes in the U.S. that not only regulates based on a given decibel level, but also includes sound limitations based on the specific pitch or frequency of the given noise.

Local noise ordinances in U.S. and Europe

Local ordinances are principally aimed at construction noise, power equipment operated by individuals and unmuffled industrial noise penetrating residential areas. Thousands of U.S. cities have prepared noise ordinances that give noise control officers and police the power to investigate noise complaints and enforcement power to abate the offending noise source, through shutdowns and fines. In the 1970s and early 1980s there was even a professional association for noise enforcement officers called NANCO, "National Association of Noise Control Officials." Today only a handful of properly trained Noise Control Officers remain in the United States. A typical noise ordinance sets forth clear definitions of acoustic nomenclature and defines categories of noise generation; then numerical standards are established, so that enforcement personnel can take the necessary steps of warnings, fines or other municipal police power to rectify unacceptable noise generation. Ordinances have achieved certain successes but they can be thorny to implement. Many European cities are still treating noise as the U.S. did in the 1960s, as a nuisance and not as a numerical standard to be achieved.

Building codes

In the case of construction of new (or remodeled) apartments, condominiums, hospitals and hotels, many U.S. states and cities have stringent building codes with requirements of acoustical analysis, in order to protect building occupants from exterior noise sources and sound generated within the building itself.. With regard to exterior noise, the codes usually require measurement of the exterior acoustic environment in order to determine the performance standard required for exterior building skin design. The architect can work with the acoustical scientist to arrive at the best cost-effective means of creating a quiet interior (normally 45 dBA). The most important elements of design of the building skin are usually: glazing (glass thickness, double pane design, etc.), roof material, caulking standards, chimney baffles, exterior door design, mail slots, attic ventilation ports and mounting of through the wall air conditioners. A special case of building skin design arises in the case of aircraft noise, where the FAA has funded extensive work in residential retrofit.

Regarding sound generated inside the building, there are two principal types of transmission. First, airborne sound travels through walls or floor/ceiling assemblies and can emanate from either human activities in adjacent living spaces or from mechanical noise within the building systems. Human activities might include voice, amplified sound systems or animal noise. Mechanical systems are elevator systems, boilers, refrigeration or air conditioning systems, generators and trash compactors. Since many of these sounds are inherently loud, the principle of regulation is to require the wall or ceiling assembly to meet certain performance standards (typically Sound Transmission Class of 50), which allows considerable attenuation of the sound level reaching occupants.

The second type of interior sound is called Impact Insulation Class (IIC) transmission. This effect arises not from airborne transmission, but rather from transmission of sound through the building itself. The most common perception of IIC noise is from footfall of occupants in living spaces above. This type of noise is somewhat more difficult to abate, but consideration must be given to isolating the floor assembly above or hanging the lower ceiling on resilient channel. Commonly a performance standard of IIC equal to 50 is specified in building codes. California has generally led the U.S. in widespread application of building code requirements for sound transmission; accordingly, the level of protection for building occupants has increased markedly in the last several decades.

U.S. occupational safety regulations

The U.S. Occupational Safety and Health Administration has established maximum noise levels for occupational exposure, beyond which mitigation measures or personal protective equipment is required.

Entertainment equipment standards

Noise Criteria (NC) are noise level guidelines applicable to cinema and home cinema. For this application, it is a measure of a room's ambient noise level at various frequencies. For example, in order for a theater to be THX certified, it must have an ambient sound level of NC-30 or less. This helps to retain the dynamic range of the system.

- NC 40: Significant but not a dooming level of ambient noise; the highest "acceptable" ambient noise level. 40 decibels is the lower sound pressure level of normal talking; 60 being the highest.
- NC 30: A good NC level; necessary for THX certification in cinemas.
- NC 20: An excellent NC level; difficult to attain in large rooms and sought after for dedicated home cinema systems. For example; for a home cinema to be THX certified, it has to have a rating of NC 22.
- NC 10: Virtually impossible noise criteria; 10 decibels is associated with the sound level of calm breathing.