Auditory Demonstrations

The Decibel Scale (Demo 4, Tracks 08-11)

Background: Sound Pressure, Power and Loudness

In a sound wave there are extremely small periodic variations in atmospheric pressure to which our ears respond in a rather complex manner. The minimum pressure fluctuation to which the ear can respond is less than one billionth (10^{-9}) of atmospheric pressure. (This is even more remarkable when we consider that storm fronts can cause the atmospheric pressure to change by as much as 5 to 10% in a few minutes.) The threshold of audibility, which varies from person to person, typically corresponds to a sound pressure amplitude of about $2x10^{-5}N/m2$ at a frequency of 1000 Hz. The threshold of pain corresponds to a pressure amplitude approximately one million (10^6) times greater, but still less than 1/1000 of atmospheric pressure (which is about $10^6 \mu bars$). Because of the wide range of pressure stimuli, it is con[illegible] on a logarithmic scale, called the decibel (dB) scale. Thus we define sound pressure level as:

$$L_p = 20 log p/p_0 \qquad \text{with } p_0 = 2x10^{-5}N/m^2 = 20\mu Pa$$

Another quantity described by a decibel level is sound intensity, which is the rate of energy flow across a unit area. Sound intensity level is defined as:

$$L_i = 10 log I/I_0 \qquad \text{with } I_0 = 10^{-12}W/m^2$$

The relationship between sound pressure level and sound power level depends on several factors, including the geometry of the source and the room. If the sound power level of a source is increased by 10 dB, the sound pressure level also increases by 10 dB, provided everything else remains the same. If a source radiates sound equally in all directions and there are no reflecting surfaces nearby (a free field), the sound pressure level decreases by 6 dB each time the distance from the source doubles.

Loudness is a subjective quality. While loudness depends very much on the sound pressure level, it also depends upon such things as the frequency, the spectrum, the duration, and the amplitude envelope of the sound, plus the environmental conditions under which it is heard and the auditory condition of the listener.

Things to investigate

1. The full dynamic range of the auditory system is about 120dB. However we need much less for our day to day usage. From the above examples, what level difference can you have between a soft and loud speech signal such that they are both comfortable and understandable without excessive effort from the listener?

2. Explain the difference in acoustic behaviour between an anechoic room and the computer lab that you are in. Would you dare estimating the SPL differences when someone is talking to you from 25, 50, 100 and 200 cm in this room?

3. What is the theoretical dynamic range that can be captured using 16[illegible]?

Answers

1. You probably feel comfortable with a 30-40 dB range, but not too much more otherwise the sound will be either hard to understand (too soft) or uncomfortably loud.

2. Anechoic room stops reflection of sound and it is insulated from exterior noise so it is not easy to make judgment in normal room because of noises and reverberation.

3. 16 bits can represent 65536 unique amplitude levels: $2^{16} = 65536$. Dynamic range is defined as the difference between maximum and minimum of signal so: $20 \log 2^{16} = 96.33dB$.

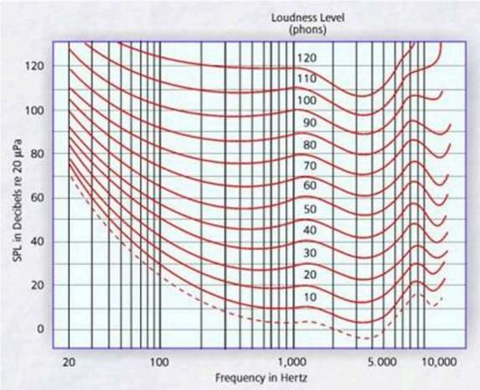
Frequency Response of the ear (Demo 6, Tracks 18)

Introduction

Although sounds with a greater sound pressure level usually sound louder, this is not always the case. The sensitivity of the ear varies with the frequency and the quality of the sound. Many years ago Fletcher and Munson (1933) determined curves of equal loudness for pure tones (that is, tones of a single frequency).

The contours of equal loudness are labeled in units called phons, the level in phons being numerically equal to the sound pressure level in decibels at f = 1000 Hz.

Equal Loudness curves illustrate the frequency dependent relationship between intensity and loudness of a sound. Sound Presure Level (expressed in dB) measures the intensity of a sound; it is a *physical* unit. Loudness on the other hand measures how loud a human perceives a sound; it is a *psychophysical* unit.



The Effect of Spectrum on Timbre (Demo 28 , Tracks 53)

Background

Timbre can be defined as "that attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar." According to this definition, timbre is the subjective correlate of all those sound properties that do not directly influence pitch or loudness. These properties include the overall spectral power distribution, its temporal envelope, rate and depth of amplitude or frequency modulation, and the degree of non-harmonicity of its partials. The timbre of a sound therefore depends on many physical variables.

The concept of timbre plays a very important role in the orchestration of traditional music and in the composition of computer music. There is, however, no satisfying comprehensive theory of timbre perception. Neither is there a uniform nomenclature to designate or classify timbre. This poses considerable problems in communicating or teaching the skills of orchestration and computer score writing to student-composers.

Critical Bands by Masking

Some Background

For many years, it has been known that the cochlea of the inner ear acts as a mechanical spectrum analyzer. Fletcher's pioneering work in the 1940's pointed to the existence of critical bands in the cochlear response. Studying the masking of a tone by broadband (white) noise, Fletcher (1940) found that only a narrow band of noise surrounding the tone causes masking of the tone, and that when the noise just masks the tone, the power of the noise in this band (the critical band) is equal to the powrer in the tone.

Critical bands are of great importance in understanding many auditory phenomema: perception of loudness, pitch, and timbre. Their importance is apttly pointed out by Tobias (1970) in his Foreword to an article on Critical Bands: "Nowhere in auditory theory or in acoustic psychophysiological practice is anything more ubiquitous than the critical band. It turns up in the measurement of pitch, in the study of loudness, in the analysis of masking and fatiguing signals, in the perception of phase, and even in the determination of the pleasantness of music.

The auditory system performs a Fourier analysis of complex sounds into their component frequencies. The cochlea acts as if it [redacted] slightly less than 100Hz at low frequency to about 1/3 of an octave at high frequency. The audible range of frequencies comprises about 24 critical bands. It should be emphasized that there are not 24 independent filters, however. The ear's critical bands are continuous, in that a tone of any audible frequency will find a critical band centered on it.