Sound

Frequency – Period – SPL - Spectrum

What is sound? We could say that sound is anything that stimulates our hearing, but this definition is subjective and actually not completely accurate. Scientifically speaking, sound is any change in the static value of atmospheric pressure, regardless of whether we can hear it or not. These changes usually occur from vibrating bodies, such as the diaphragm of a loudspeaker. The air around us exerts a great pressure on our bodies of the order of 100,000 Pa. Being born on a planet with an atmosphere we do not perceive it, unless we move at a faster speed than usual, when for example riding a bicycle. With reference to Figure 1, what matters is the variation of the pressure not its average value P_o which remains almost constant. The changes we are talking about are not dramatic. Even the most deafening sounds do not produce changes in the static pressure greater than 20 Pa. Our ears can perceive very small changes of the order of 0.00002 Pa, therefore the ratio of the highest to the lowest acoustic pressure is 1,000,000:1.

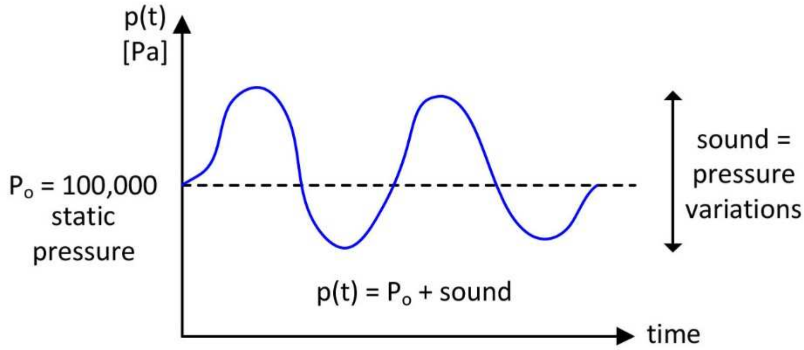

Figure 1: The sound is variations of pressure in the air or another medium.

The basic characteristics of sound are the intensity and the frequency.

The *intensity* is related to the amplitude A of the fluctuation, see figure 2. As we have seen, the range of acoustic pressure variations is enormous. This is the reason we use the logarithm of the pressure to express sound intensity. First, we divide the pressure with the reference pressure p_{ref} = 0.00002 Pa, defined as the minimum change that can be perceived. This mathematical operation gives the *Sound Pressure Level* (SPL). As a ratio of pressures, it is dimensionless and is expressed in decibels (dB).

$$SPL = 20log_{10}\left(\frac{p_{rms}}{p_{ref}}\right) \quad [dB]$$

Do not worry about the logarithm any calculator can handle it. The rms subscript (root mean square) is a kind of average, in order to express the time-varying pressure with a single number. For example, a trumpet produces acoustic pressure that has an rms value of 0.632 Pa at some distance from the instrument. Find the sound pressure level at that point. The calculation proceeds as follows

$$SPL = 20log_{10}\left(\frac{0{,}632}{0{,}00002}\right) = 20log_{10}(31{,}600) = 90dB$$

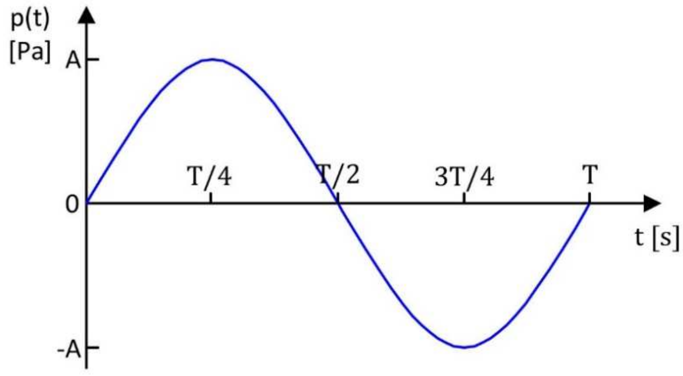

Figure 2: Definition of period and frequency.

Frequency indicates how fast the pressure changes occur, that is how many pressure changes we have per unit of time. Figure 2 depicts a pressure that goes up and down with reference to the static value Po. This means that the zero level corresponds to 100,000 Pa. A full oscillation, moving from zero to maximum then to minimum and back to zero, is completed in T seconds. After that the phenomenon repeats itself in exactly the same way. We call these phenomena *periodic*. The time T is called the *period* and its inverse of it the frequency, measured in cycles per second or Hz.

$$f = \frac{1}{T} \quad [Hz]$$

Our hearing is able to perceive sounds with frequencies ranging from 20 Hz to 20,000 Hz. The sounds that make up our sonic environment are not periodic and they consist of many frequencies. As an example consider a relatively simple sound, the note C5 from a flute. The waveform is shown in figure 3. The sample is almost 1 second (1000 ms) long with a maximum pressure variation 0.2 Pa. It takes some time from the pressure to develop. This buildup of energy in the beginning is called *attack*. The rms value of the sample is equal to 0.08 Pa, which corresponds to a sound pressure level of 72 dB. On the right side of the figure, we have zoomed in the first 150 ms of the waveform. The pressure variations seem to have some kind of repeatability, but not in the strict mathematical sense.

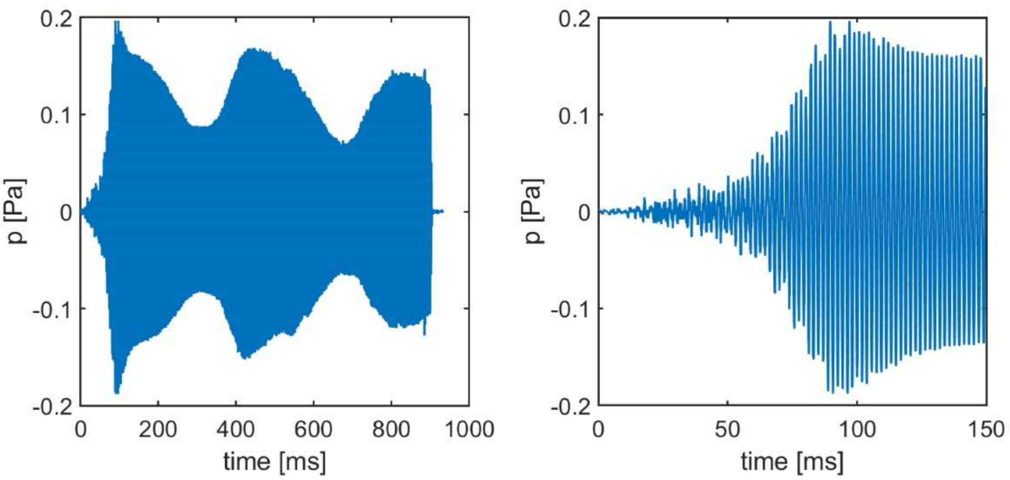

Figure 3: On the left, the full waveform of a flute playing note C5. On the right, the first 150 ms where some kind of periodicity can be seen.

The *spectrum* is the set of frequencies that make up a sound (more generally a signal). There are tools like the FFT algorithm (Fast Fourier Transform) with the aid of which we can calculate the spectrum. The result of this process is depicted in Figure 4, where 5 distinct frequencies can be seen. The lowest is about 523 Hz and is called the *fundamental*. The rest are the *harmonics*. In a sound that has a periodic or almost periodic structure the harmonics are multiples of the fundamental, i.e. the second harmonic has a frequency of 2 x 523 = 1046 Hz, the third harmonic 3 x 523 = 1560 Hz and so on. The more harmonics the spectrum of a sound has, the more complex it is perceived on a subjective basis. There are sounds that do not consist of a fundamental and its harmonics. Any form of noise has a continuous spectrum with no distinguishable frequency components.

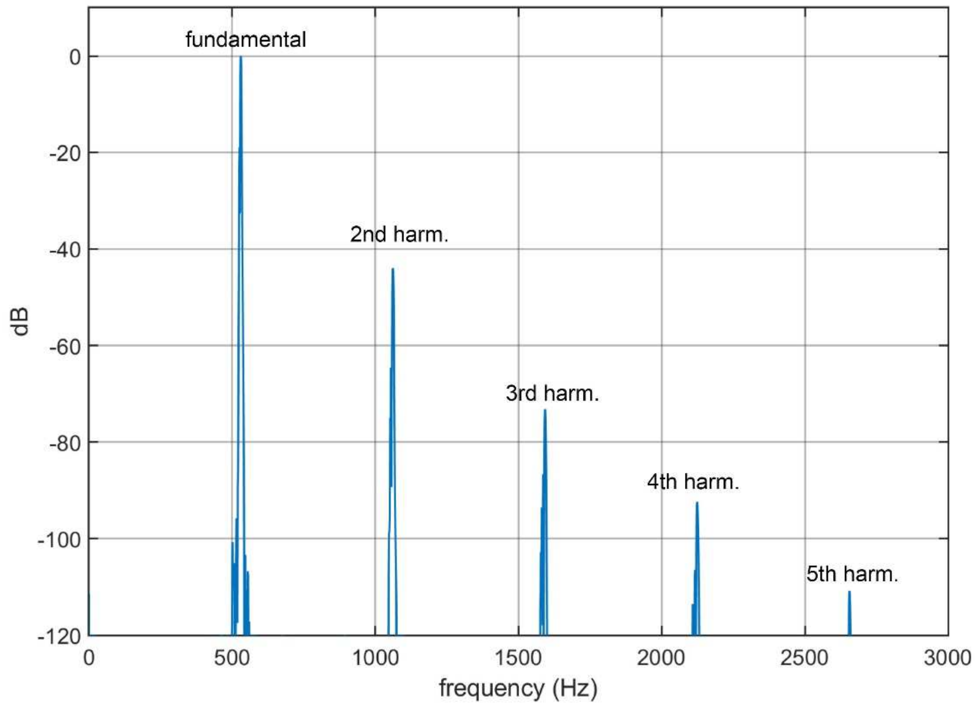

Figure 4: The spectrum of the C5 note contains at least 5 discrete frequencies. The fundamental lies at 523 Hz.

For Echo Diastasis

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