Intelligent Signal Processing

Basics of Audio

Angelo Ciaramella

Introduction

- Today we assist to a growing interest in disciplines related to Multimedia
- The affirmation of digital audio came in the early 80s with the Compact Disc (CD)
- Audio digitization has revolutionized the world of music production

Music and sound

- Musical instruments
  - Different and often remarkably similar, developed in different cultures
  - Artistic and popular expressions
- The sound is
  - Entertainment source
  - Information source
- In movies and multimedia shows
  - video information contains 90% of the information
  - sound creates 90% of involvement

Fundamentals of acoustics

- Sound
  - mechanical phenomenon
    - perturbation of a transmission medium (typically air) perceived by the human ear
  - density of a fluid time varying
    - Compression
    - Expansion (rarefaction)

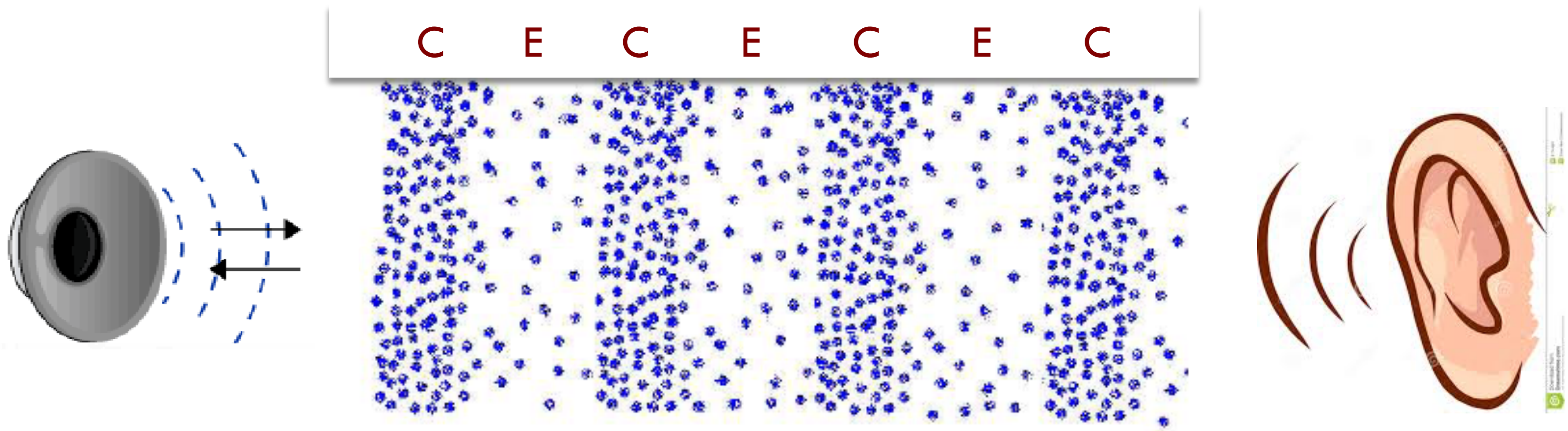
Sound production

- Vibration of solid objects
  - E.g., musical instruments
    - piano, guitar, violin, xylophone, drums, etc.
- All sound sources oscillate
  - Any complete vibration is called cycle
  - A sound signal includes many cycles

Sound propagation

- Any medium, solid, liquid or gaseous, is able to carry the sound
  - it involves molecules of air being compressed and expanded under the action of some physical device
- Nature of the waves
  - Longitudinal waves
    - The axis along which the vibration takes place is the same as the direction of propagation of the wave
  - Transversal waves
    - The axis of the vibration is perpendicular to the direction of wave propagation

Sound propagation



Sound Propagation

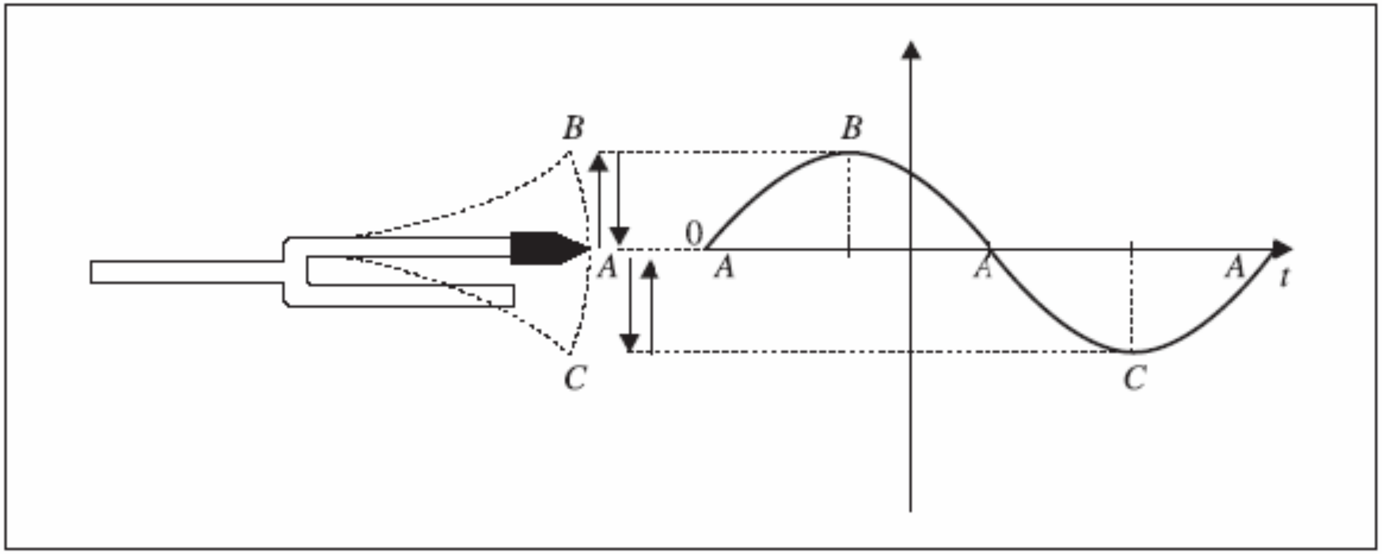
Tuning fork

- A tuning fork is an acoustic resonator in the form of a two-pronged fork
  - It resonates at a specific constant pitch when set vibrating by striking it against a surface or with an object

Example of tuining fork

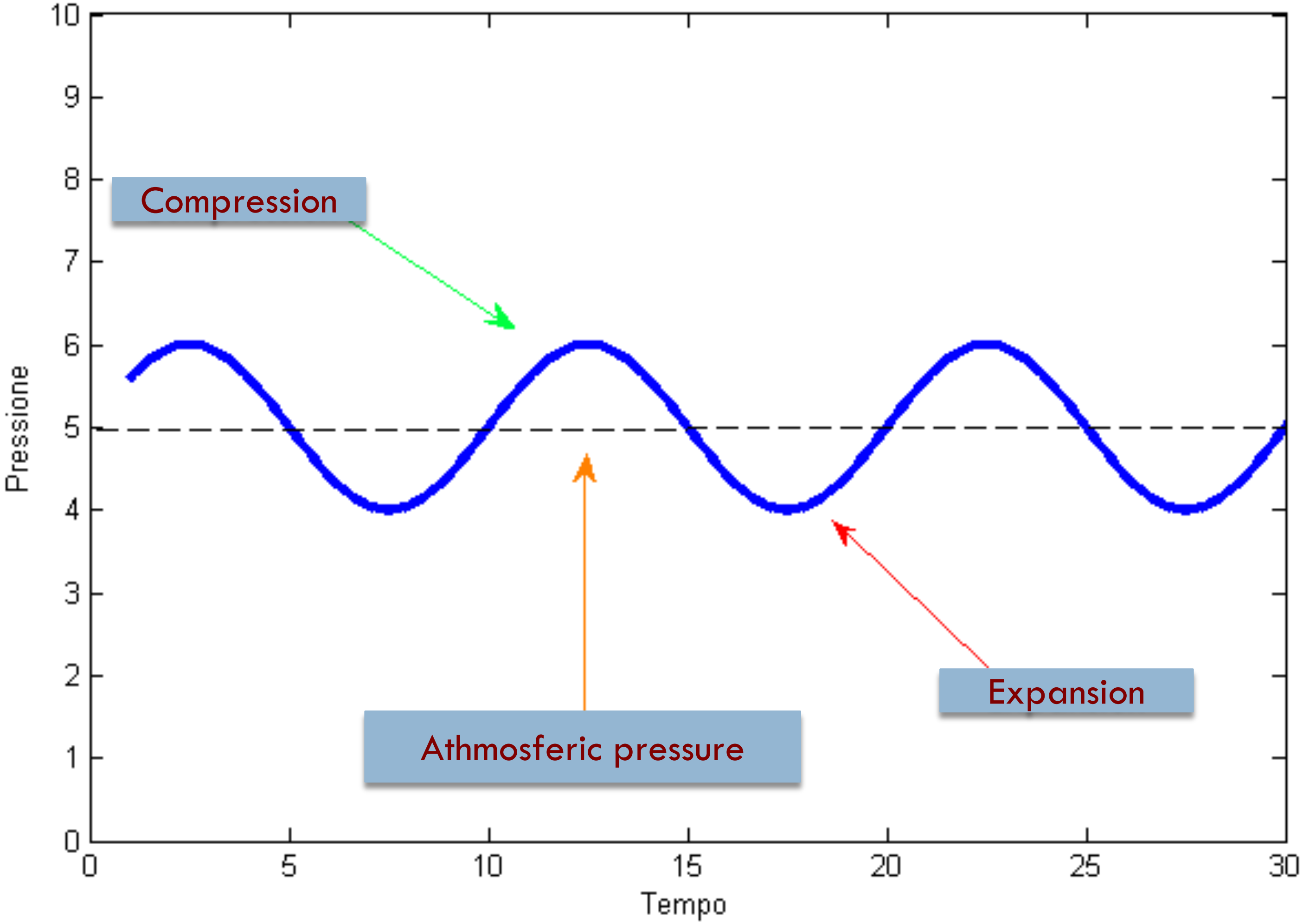
Tuning fork

- The stylus tip of the tuning fork
  - vibrating draws a sinusoidal curve
  - if the axis represent the time the curve of the stylus position is sinusoidal



Sinusoidal generation of the sound

Sound propagation



Sinusoidal propagation of the sound

Sound reception

- The sinusoidal signal achieves our ears
- The ears convert the acoustic signal in a equivalent "electric" (analogic)
- The brain interprets the frequency of the signal (pitch)

The pure tone

- The simplest sound, single frequency (determined by the period) and it does not exist as such in nature

- The tuning fork produces an almost pure tone (fixed frequency that the musician is La)

- The waveforms can be very complicated
  - all can be considered as an extension of pure tone (e.g., Fourier Theorem)

- The waveform of the pure tone coincides with a sinusoidal trigonometric function

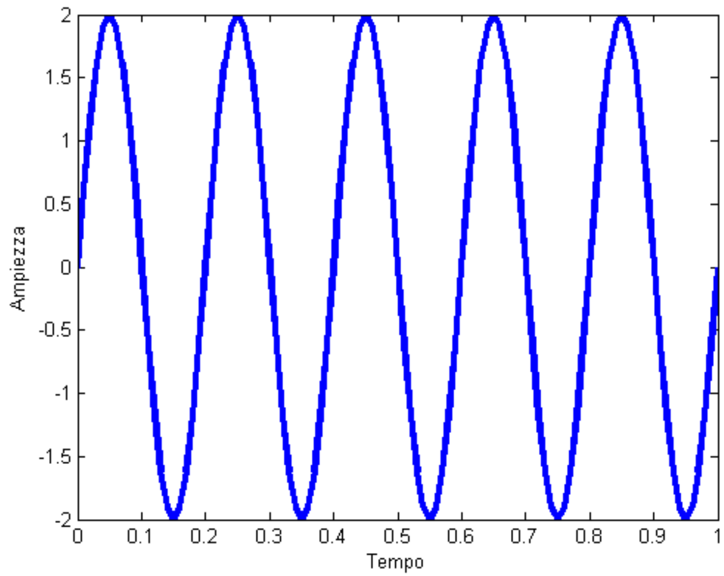
$$y(t) = \mathbf{A}\sin(t)$$

Pure tone properties

- Properties of the pure tone
  - Frequency (f)
  - Angular frequency (ω)
  - Period (T)
  - Wavelength (λ)
  - Amplitude (A)
  - Phase (φ)
  - Initial phase (φ_0)
  - Speed (v)

Frequency

- Frequency
  - the number of cycles accomplished by the wave in a second
  - positive half-wave and a negative half-wave
  - measured in Hz [1 / sec]
  - equal to 1 Hz is a cycle every second



Frequency of # Hz

Experiment

261,6 Hz

293,7 Hz

329,6 Hz

349,2 Hz

392 Hz

440 Hz

493,9 Hz

523,3 Hz

Angular frequency

- The angular frequency is defined as

$$\omega = 2\pi f$$

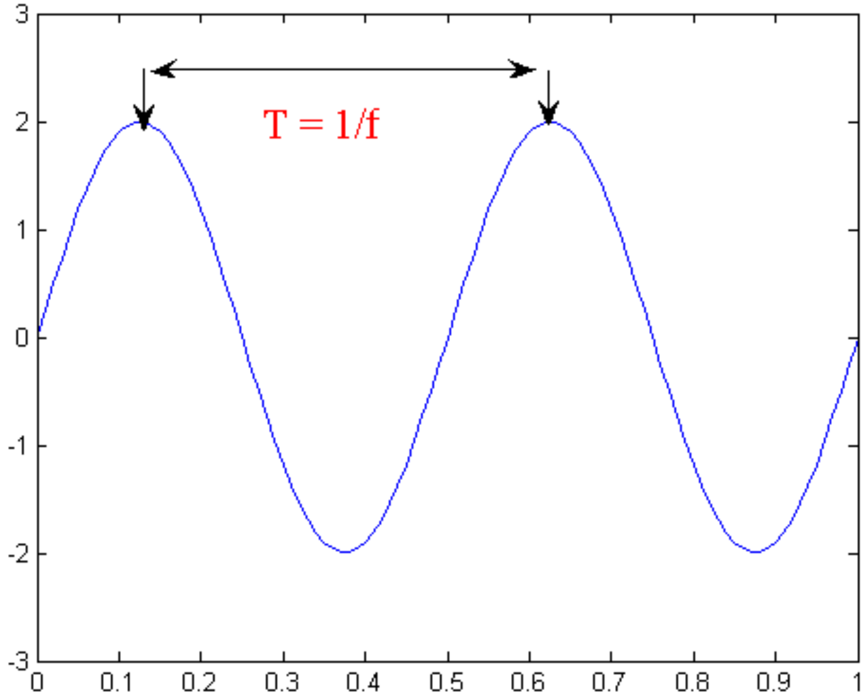
- It is expressed in radians

$$2\pi \equiv 360^{\circ}$$

Period

- The period is the time for achieving a complete cycle

$$T = \frac{1}{f}$$



Example of period

Wavelength

- The distance between two corresponding points along the waveform

$$\lambda = \frac{c}{f}$$

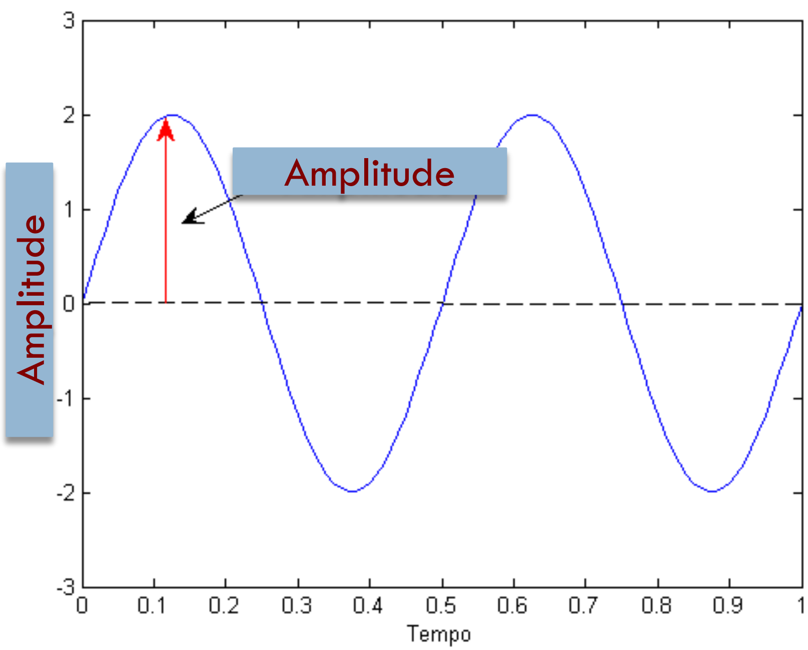
c is the speed of the sound in the considered medium (344 m/sec in air)

- 1 Hz frequency wave, travelling through the air

$$\lambda = \frac{c}{f} \Rightarrow \frac{344m/s}{1/\frac{1}{s}} = 344m$$

Amplitude

- It is the measure of the maximum deviation from the equilibrium position
- Larger amplitudes correspond to higher volumes

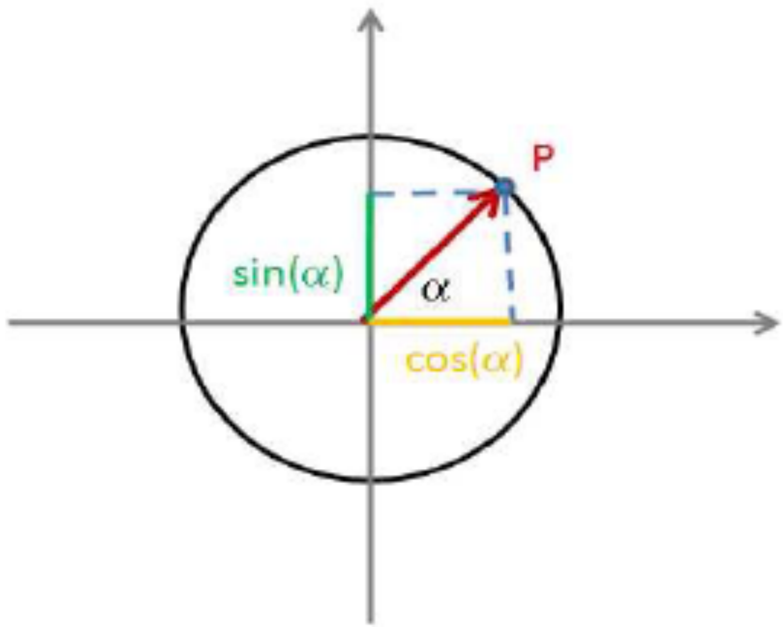


440 Hz
A = 1

440 Hz
A = 10

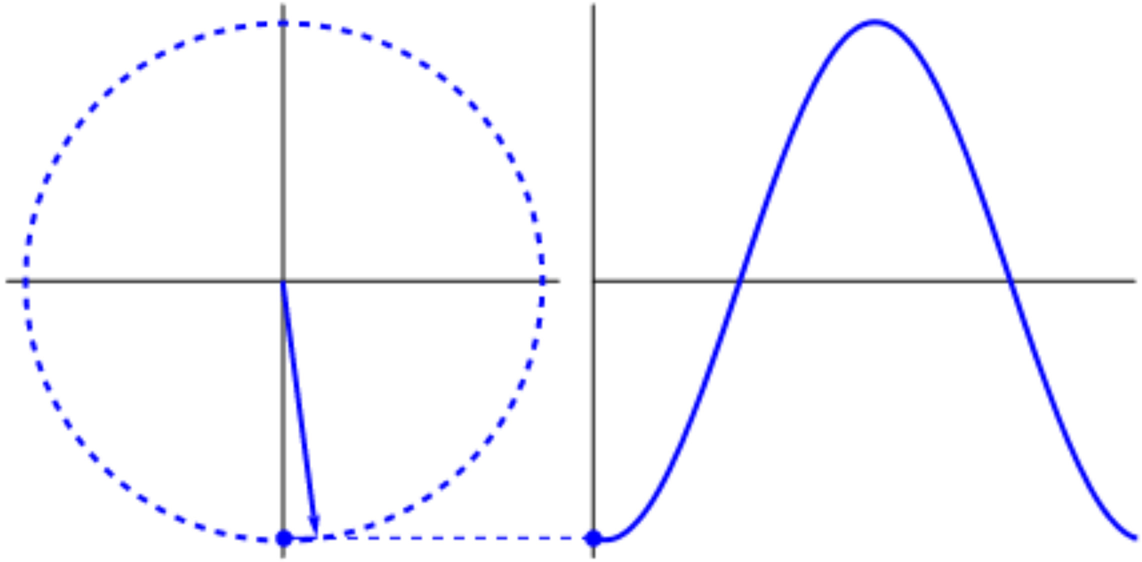
Example of amplitude

Phase



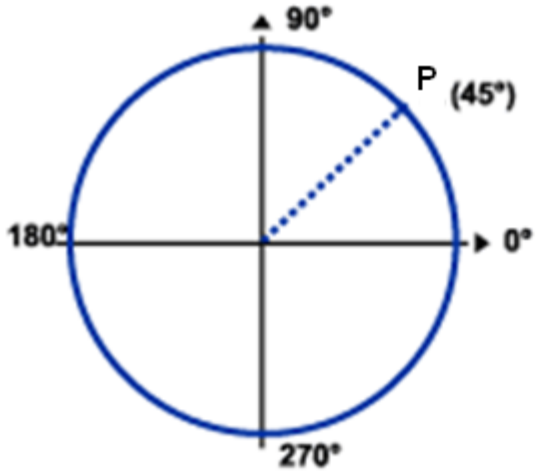
We consider a point moving on a circumference

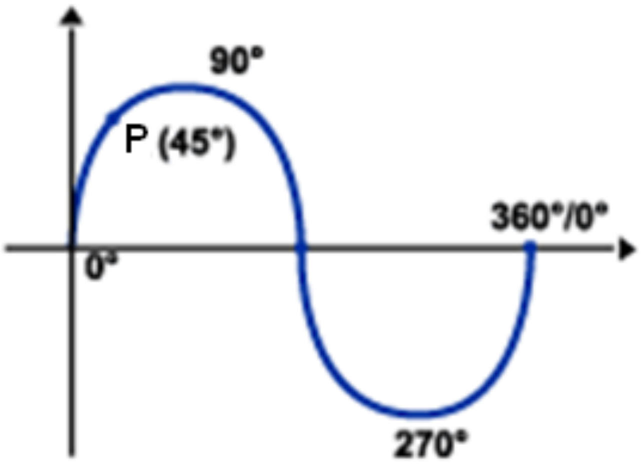
Phase



We consider a point moving on a circumference

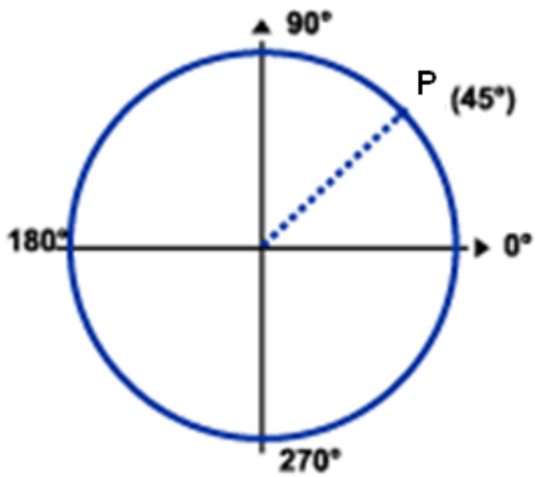
Phase

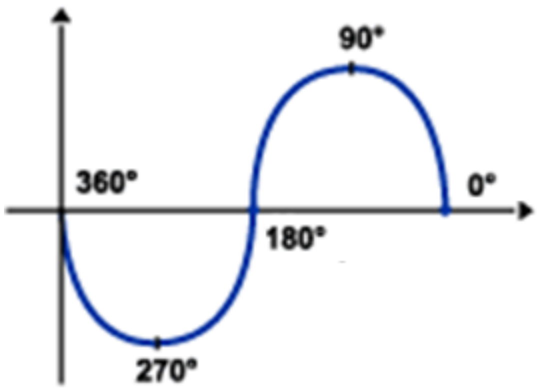




We imagine to rotate the point P counterclockwise and to observe its projection on the y axis

Phase





We imagine to rotate the point P clockwise and to observe its projection on the y axis

Frequency and time

- Alternative interpretation of frequency
  - the number of times that the point P makes a complete turn in a second

- The equation that correlates the phase with time is

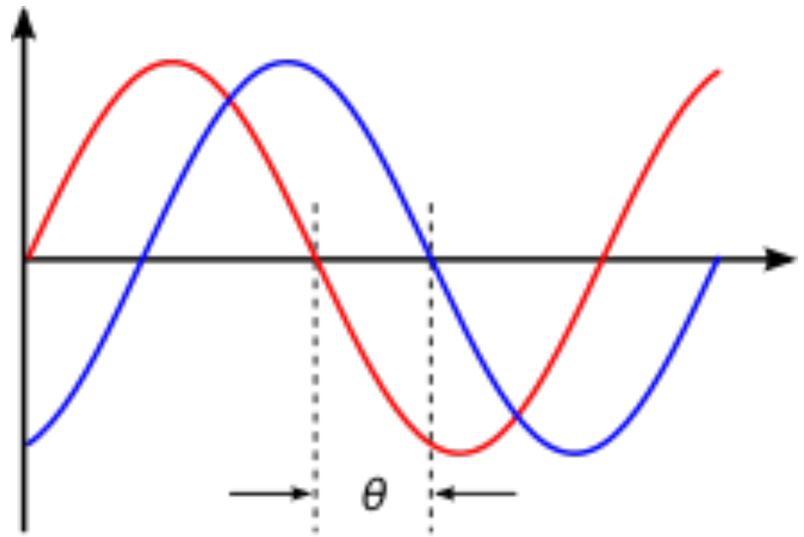
$$\varphi = 2\pi f \Delta t$$

$$\Delta t = t - t_0$$

$$t_0 = 0 \Rightarrow \Delta t = t$$

Initial phase

- The initial phase φ_0 is the offset from where you start to look at the pure tone



Pure tones with different phases

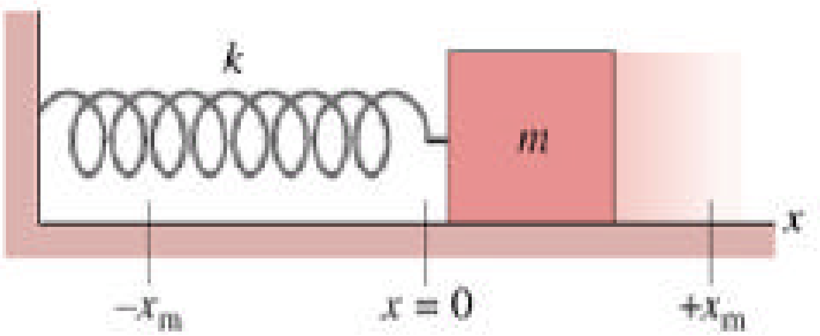
Pure tone equation

- By introduced parameters, the waveform of the pure tone is

$$y(t) = A\sin(\varphi + \varphi_0) = A\sin(2\pi f t + \varphi_0)$$

Oscillating systems

- A body of mass m moves along the x-axis under the action of a ideal spring with elastic constant k and in the absence of dissipative forces



- From the second Newton's law

$$-kx = ma$$

Oscillating systems

- In particular we obtain

$$\frac{d^2x}{dt^2} + \frac{k}{m}x = 0$$

- The solution of the differential equation is

$A = x_m$

$$x(t) = A\cos(\omega t + \phi_0)$$

Initial phase

$$\omega = \sqrt{\frac{k}{m}} = 2\pi f$$

Sound speed

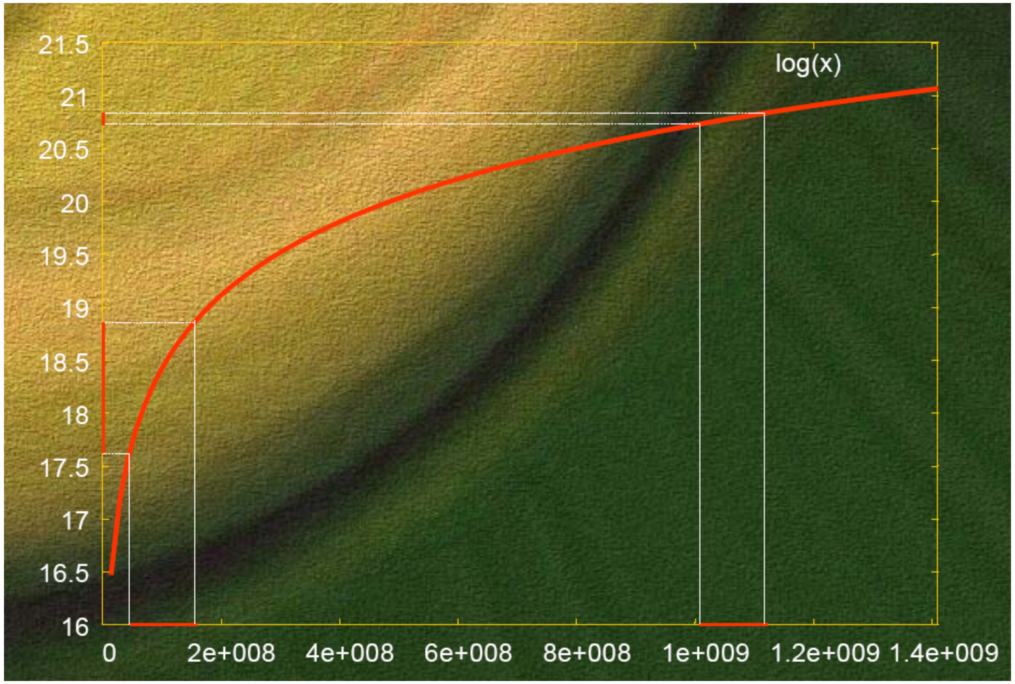
- The sound speed
  - depends on the characteristics of the medium itself
    - in air is about 344 m/s
  - Each medium has a typical sound speed at a constant temperature of 23.24 ° C
- Warmed medium
  - higher speed of sound in the medium
    - to its particles it is transferred to kinetic energy
    - on average for each increment (decrement) by one C degree, the speed increase (decrease) of 0.6 m / s

Sonorous amplitude

- Sonorous amplitude
  - amount of an air particle movement in a point
- Two kinds of misures
  - Sound Pressure level
    - compression and rarefaction of the particles
  - Sound Intensity Level
    - energy carried by the sound

Decibel scale

- Logarithmic scale
  - crushes the reference scale
- The decibel scale is a relative scale
  - it is based on the ratio between two sounds



Sonorous amplitude

Sound power

$$P_{dB} = 10\log_{10}\frac{P_1}{P_0}$$

P_0 is the reference power

Intensity power

$$I_{dB} = 20\log_{10}\frac{I_1}{I_0}$$

I_0 is the reference intensity

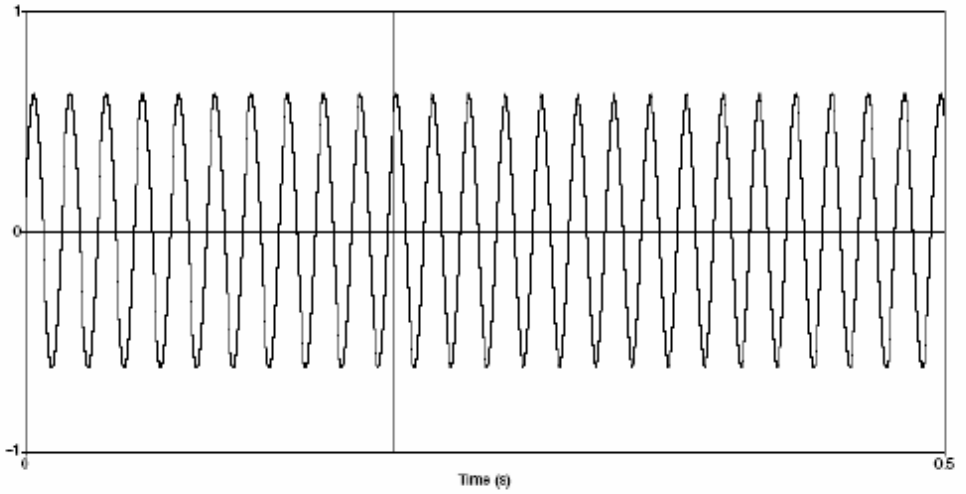
dB and measures

- Measure doubling
  - +3 dB power
  - +6 dB intensity
- for 0 dB the intensity is equal to the reference
- the decibel scale is used for equalization

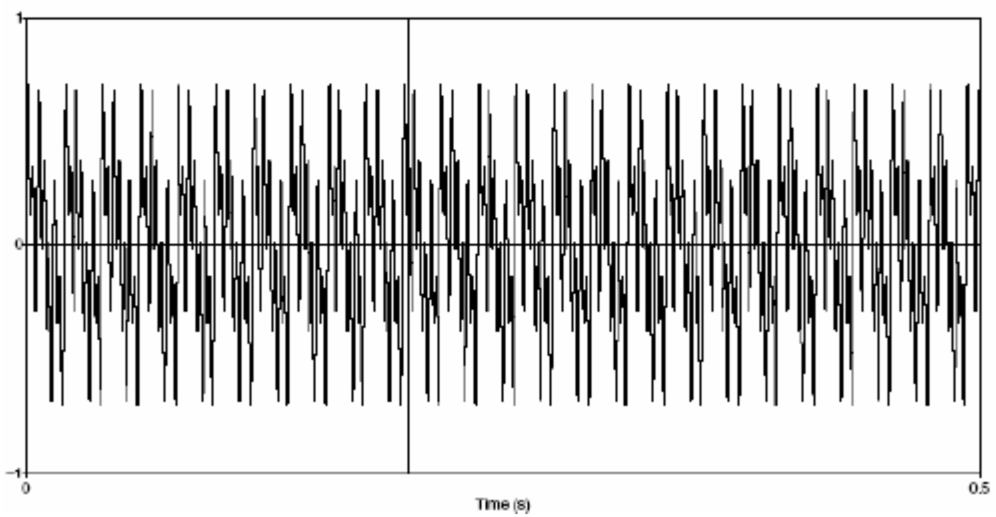
Common sound powers

Sound	P_{db} (dB)	Reaction
Maximum noise produced in the laboratory	210	unbearable sound
Rocket launch (at 50 m)	200	
Eardrum rupture	160	
Taking off jet (at 50 m)	130	
Pain limit	120	physical pain
Rock band in a closed	110	
Lightning flash	110	
Scream (at 1,5 m)	100	
Jackhammer (at 3 m)	90	
Daily city traffic	70-80	
Office or restaurant (crowded)	60-65	useful sounds
Conversation (at 1 m)	50	
Theater or church (empty)	25-30	
Whisper (at 1 m)	15	
Rustle of leaves	10	
Mosquito near ear	10	
Hearing threshold (at 1000 Hz)	0	inaudible

The sound



Pure tone with a 50,72 Hz frequency



Complex sound with a 50,72 Hz fundamental frequency

Frequency band

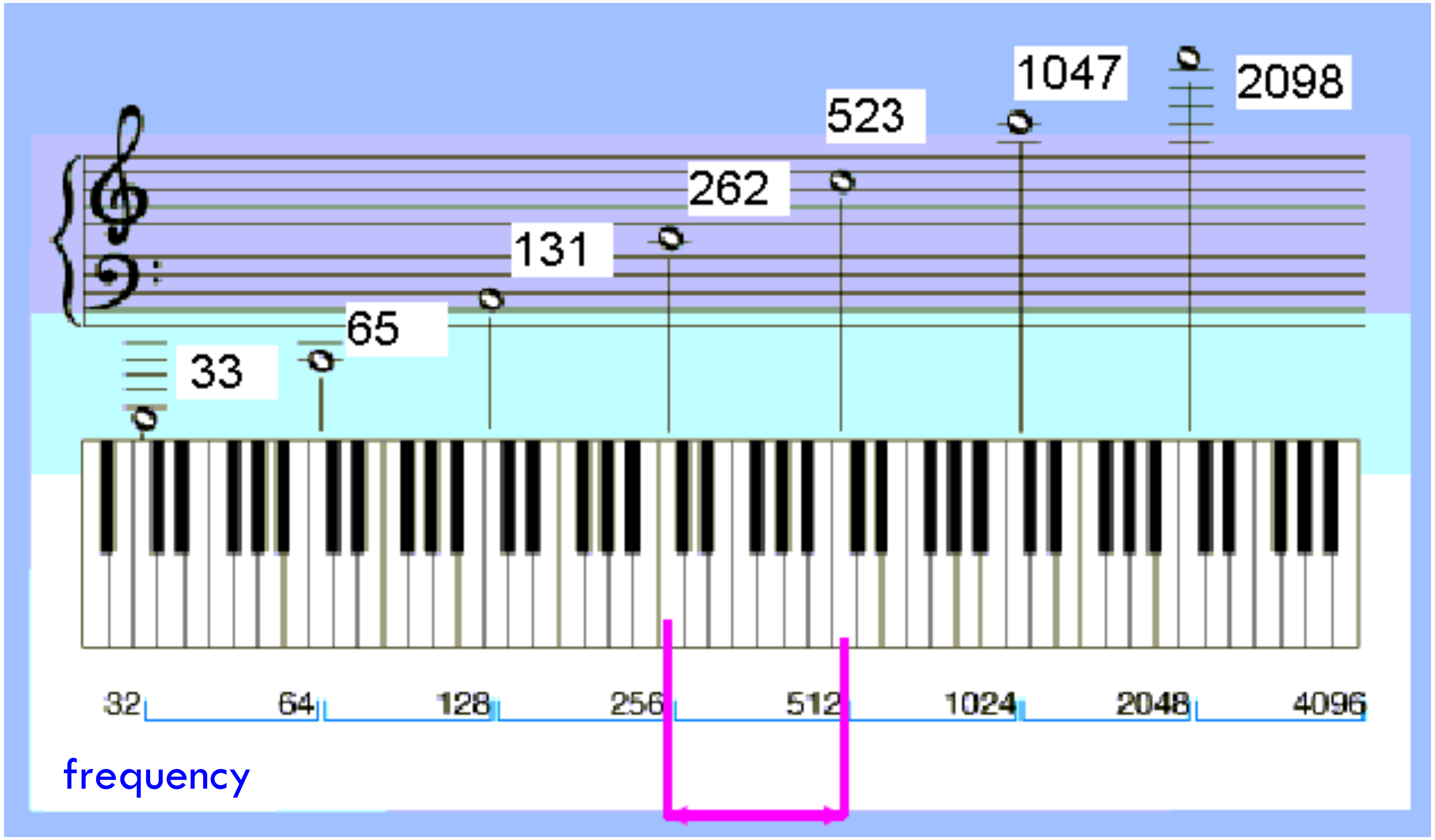
- Band of frequencies for audible sounds
  - from 20 to 20,000 Hz
- infrasound
  - the frequencies below 20 Hz
- ultrasound
  - frequencies higher than 20 KHz
- A complex sound contains many frequencies
  - In nature there are not really periodicals signals

Typical frequencies

Sound	Frequency (Hz)
The lowest note of a piano	27.5
The lowest note of a clarinet	104.8
Middle C of the piano	261.6
The A note after the middle C on the piano	440
The highest note of a piano	4180
Elderly hearing limit	12000
Hearing limit	16000-22000

Table of typical frequencies

The piano



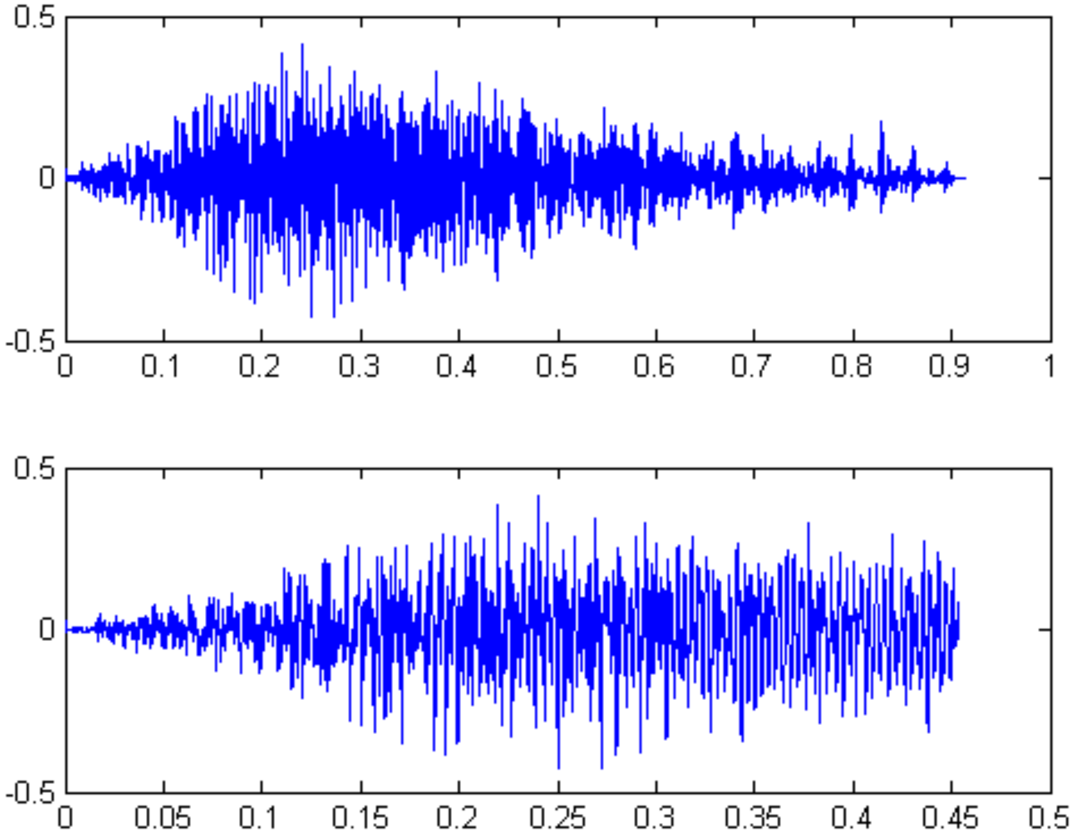
do$_4$	do#$_4$	re$_4$	re#$_4$	mi$_4$	fa$_4$	fa#$_4$	sol$_4$	sol#$_4$	la$_4$	la#$_4$	si$_4$
261,63	277,18	293,66	311,13	329,63	349,23	369,99	392	415,30	440	466,16	493,88

The keyboard of the piano. The frequencies around the middle C (fourth octave) are highlighted (Neo-Latin notation)

Waveform

- Waveform
  - it identifies the source of the sound
  - it describes the behaviour of compressions and rarefactions
- Wafeform perceptive parameter
  - the timbre
    - difference between the same note played by two different instruments
- Two elements contribute to the richness of the timbre of complex waveforms
  - The spectral components in the frequency domain
  - The transients in the time domain (time of start and extension of a vibration)

Real waveforms



Complex waveforms. Lion's roar or earthquake?

Real signals

- Real waveforms
  - varying amplitude in time
    - periodic
    - aperiodic
- Ideally
  - linear superposition of elementary signals (sinusoidal pure tone) with varying frequency, amplitude and phase