# Digital Sound Capstone

DXARTS 460 – Spring 2011

Instructor: Stelios Manousakis

# Lecture 1

## Fundamentals of Acoustics:

Frequency | Amplitude | Spectrum

# Acoustics

- ***Acoustics*** is the study of the physics of the production, transmission, and reception of sound, as a **physical phenomenon.**

- It quantifies the energy, time variation, frequency content and location of a sound.

- Many different sub-disciplines of acoustics:

  - aeroacoustics
  - architectural/vibration acoustics
  - bioacoustics
  - biomedical acoustics
  - speech communication
  - underwater acoustics
  - physical acoustics
  - acoustic engineering

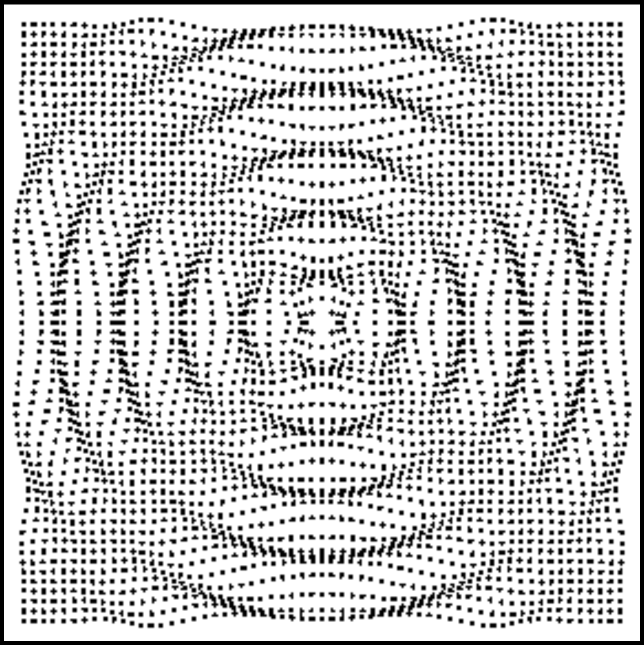
# Acoustics: what is sound?

- Sound is produced by a vibrating source.
- The vibrations disturb molecules in a medium that is adjacent to the source (air, water, solid) by alternately pulling apart and pushing together the molecules in synchronism with the vibrations.
- The sound source produces small regions in the air in which the air pressure is lower than average (rarefactions) and small regions where it is higher (compressions).

# Waves

- The energy of a sound event occurring at an isolated point expands in a 3-dimensional sphere, moving away from the source

- When energy is transported through a medium, the medium often oscillates as a result, depending on its elasticity. The energy is transported by means of the medium's oscillations, which are called ***waves***.



# Waves

- Sound waves are an example of ***longitudinal waves,*** which are waves that oscillate back and forth along the same axis as the wave's propagation. These are opposed to ***transverse waves,*** waves that oscillate perpendicularly to the direction of travel (picture a vibrating bass string)

- ***Travelling waves*** are moving, making a disturbance that varies across distance and time

- ***Standing waves*** are the result of interference of two travelling waves and appear to stay in one place (e.g. the vibrations of a bass string).

- Sound waves are also an example of a ***vibrating system*** (pendulum, water): their motion is repetitive.

# Acoustic properties of sound

Some physical properties of sound waves are

- velocity (or speed and direction)

- frequency
- wavelength
- period

- amplitude
- intensity

- spectrum

# Velocity of sound

- The velocity (speed towards a direction) of sound depends on many factors, including ***density*** and ***elasticity*** of the transmitting material.

- Solids are more elastic, therefore sound travels faster in them.

- Raising temperature decreases density, therefore increasing velocity.

- In air, in a dry room, at 20°C (68°F), at sea level: 343m/s (1125ft/s).

  Same room at 0°C (32°F): 331m/s (1086ft/s)

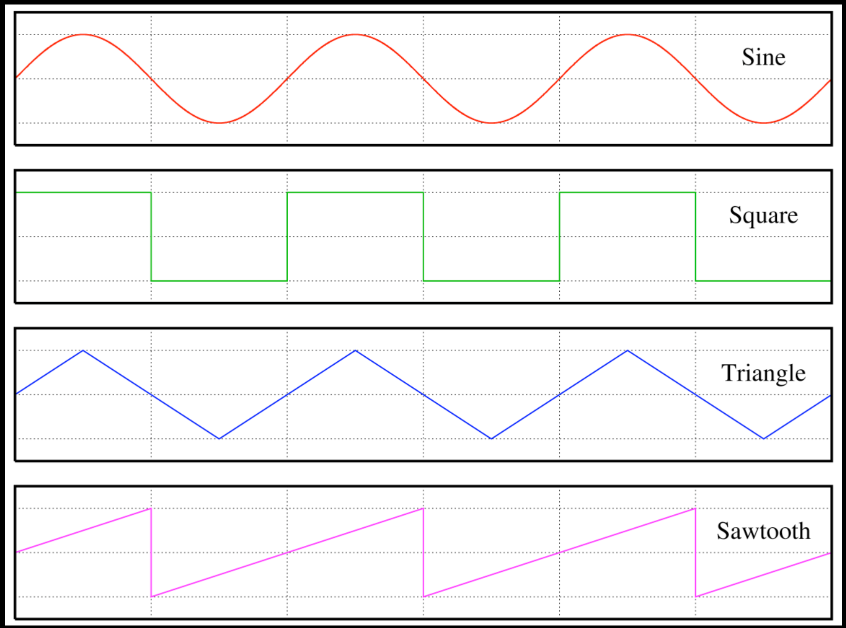
  In breath (not dry), at ~25°C (77°F): 346m/s (1135ft/s)

# Waveforms | Period

- The pattern or shape of pressure variations in time produced by a sound is known as the ***waveform*** of the sound

- Waveforms made up of repeating patterns are called ***periodic***. The shape of a cycle of a periodic waveform has a large effect on the way it sounds.

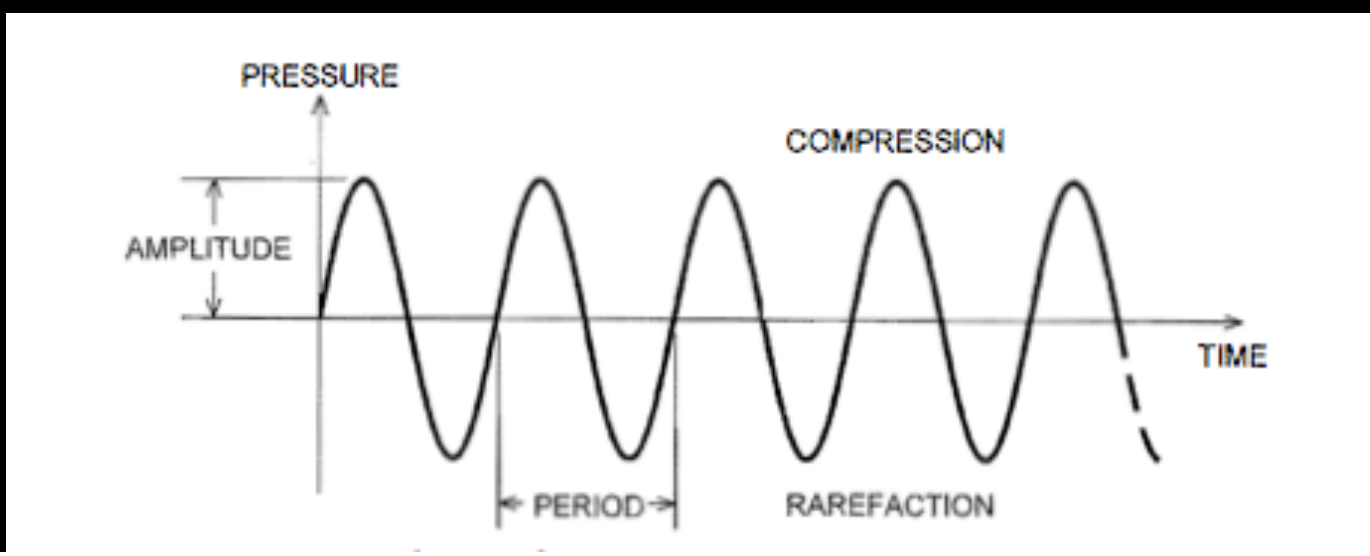
- The smallest complete unit of the pattern is known as a ***cycle**,* and the amount of time occupied by a single cycle is known as a ***period**.*



# Frequency

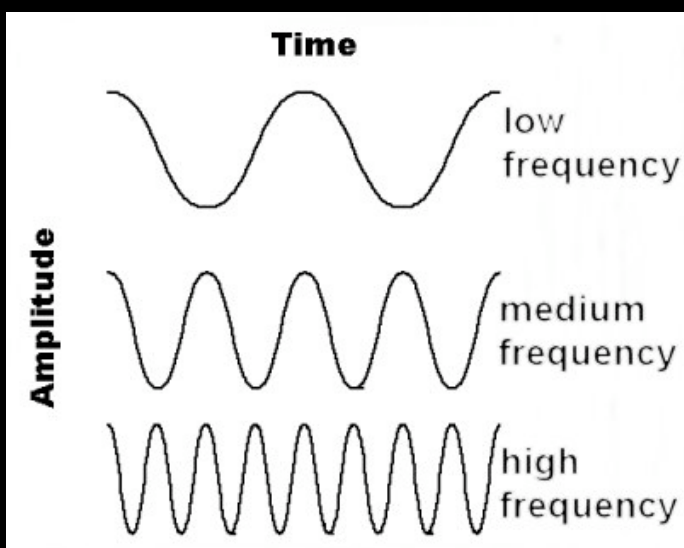
- The rate at which the cycles of a periodic waveform repeat is called the ***frequency*** of the waveform
- It is measured in ***cycles per second*** or ***Hertz*** (Hz)
- ***Frequency*** is the mathematical inverse of ***period***, and so a waveform with a period of 1 ms has a frequency of 1000 Hz (i.e., there are 1000 repetitions of a cycle each second)

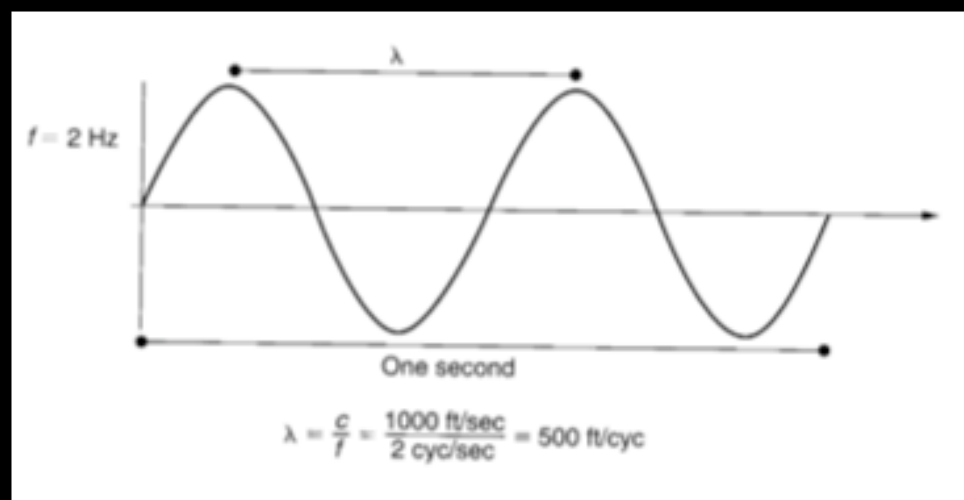
  >>> Frequency = 1 / period (1cycle / 0.001seconds = 1000Hz)



# Wavelength

- The ***wavelength*** is the distance between corresponding points from cycle to cycle and is the inverse of the frequency.
- Longer wavelengths correspond to lower frequencies, shorter wavelengths to high frequencies, and vice-versa.
- Wavelength = Speed of sound / Frequency

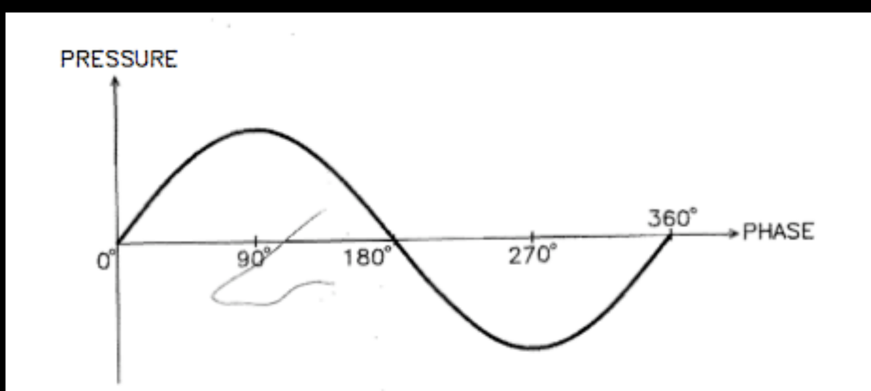


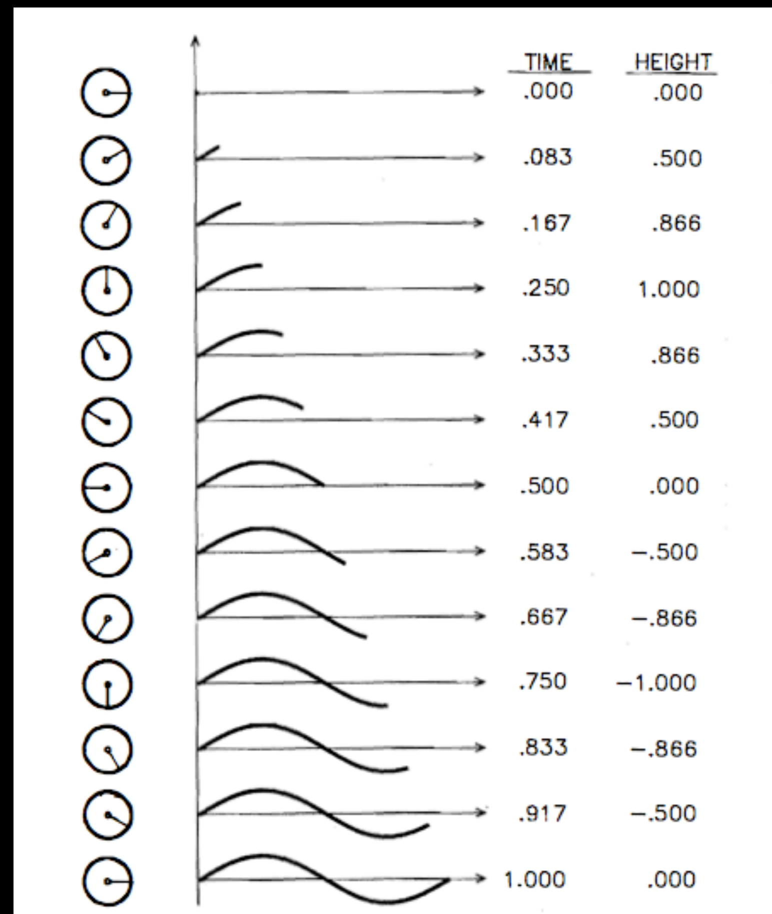



# Phase

- ***Phase*** is the position of a wave at a certain time of the cycle, measured as an angle from a reference position.

- If two waves are half wavelength out of phase, their combined positive and negative polarities will cancel each other out entirely!

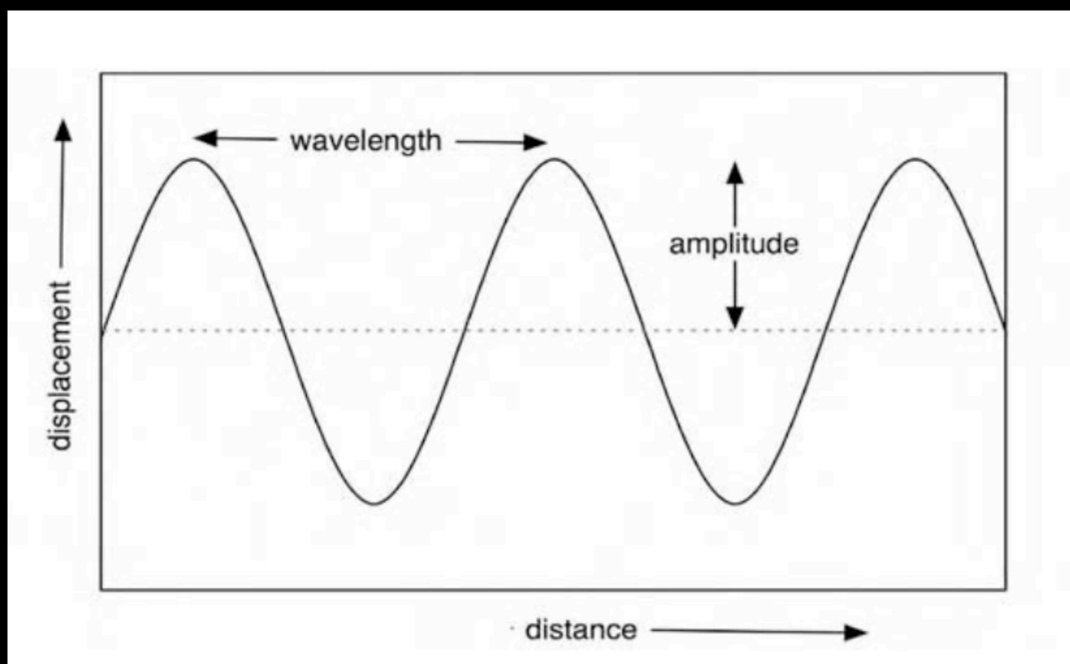


# Amplitude

- ***Amplitude*** is the amount of change, positive or negative, in atmospheric pressure caused by the compression/rarefaction cycle of a sound.
  In other words, how high or low the wave's oscillations are.

- Amplitude is indicative of the amount of acoustic energy in a sound.



# Amplitude | SPL | SWL

- **Amplitude** is the degree of oscillation of air particles. It describes how much *work (force * distance)* oscillating particles perform on the point (e.g., the eardrum).

- It is indicative of the amount of acoustic energy in a sound and is the most important factor in the perceived *loudness* of a sound. It refers to changes in ***sound pressure level*** (SPL).

- Amplitude is measured in Newtons per square meter (N/m2)–that is, as a *force* applied over an area.

- Our ears are as sensitive as to detect fluctuations in pressure of 0.00002 N/m2

- ***Sound power level*** (SWL, or PWL) is a measure of the total power radiated in all directions by a source. Remember that what is traveling is an expanding sphere of kinetic energy that displaces molecules as it passes over them.

- **Sound power levels** (SWL) and **sound pressure levels** are closely related, but not synonymous.

# Intensity

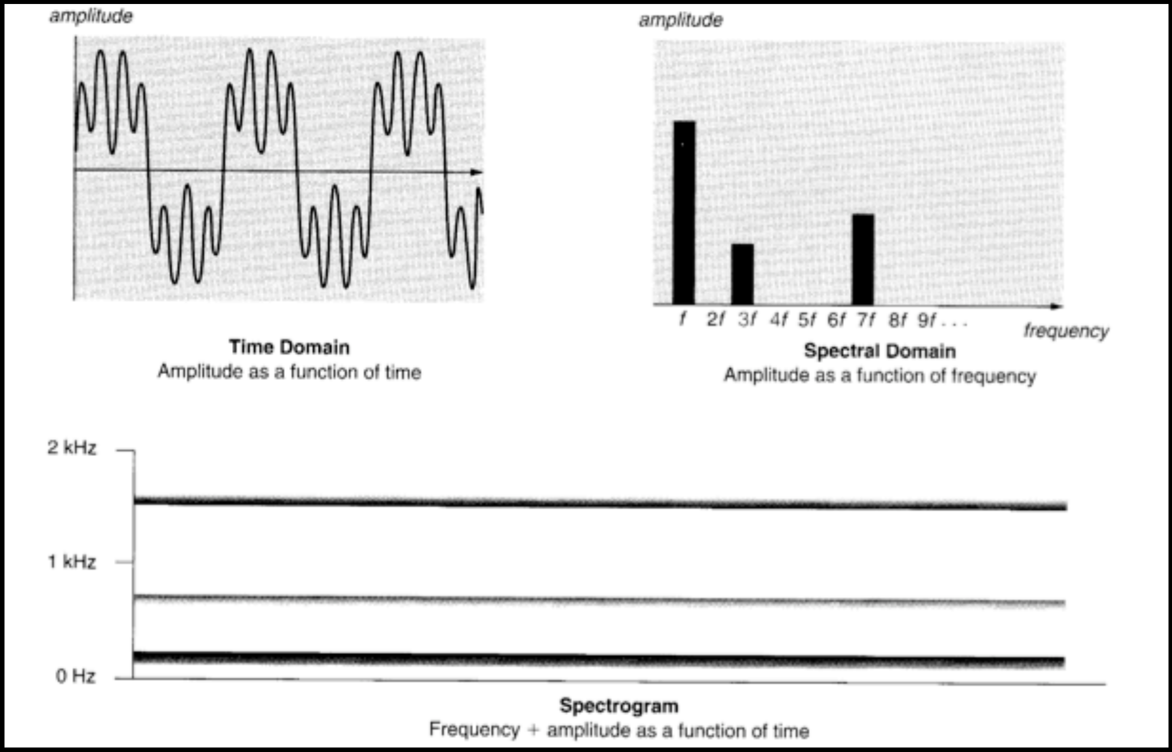
- ***Intensity*** is a measure of the *power* in a sound that actually contacts an area such as the eardrum (unlike sound power, intensity has a direction): it characterizes the ***rate*** at which energy is delivered in the audible sensation associated with amplitude.

- More about that when we talk about psychoacoustics...

# Spectrum | time & frequency domains

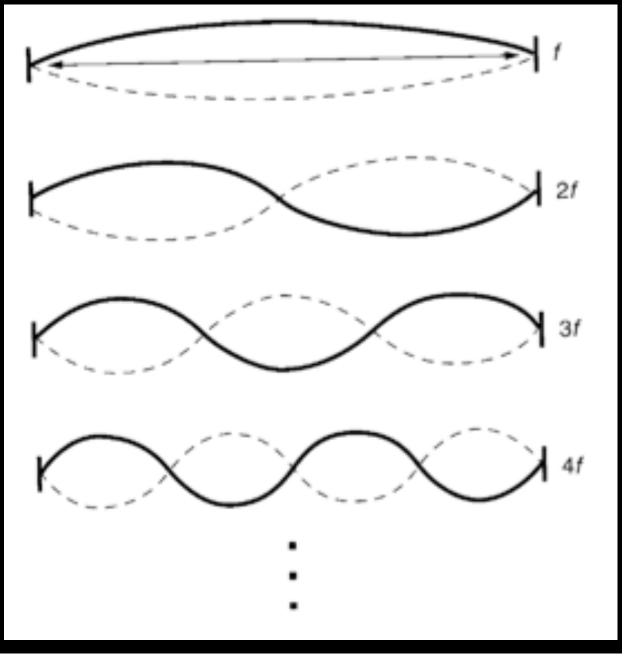
- Sounds are typically complex in nature, composed of many frequencies. This set of frequencies and their correspondent amplitudes is called ***spectrum.***

- Any signal can be described either by its ***pattern of amplitude versus time*** (its **waveform**) or by its ***distribution of energy versus frequency*** (its ***spectrum***).



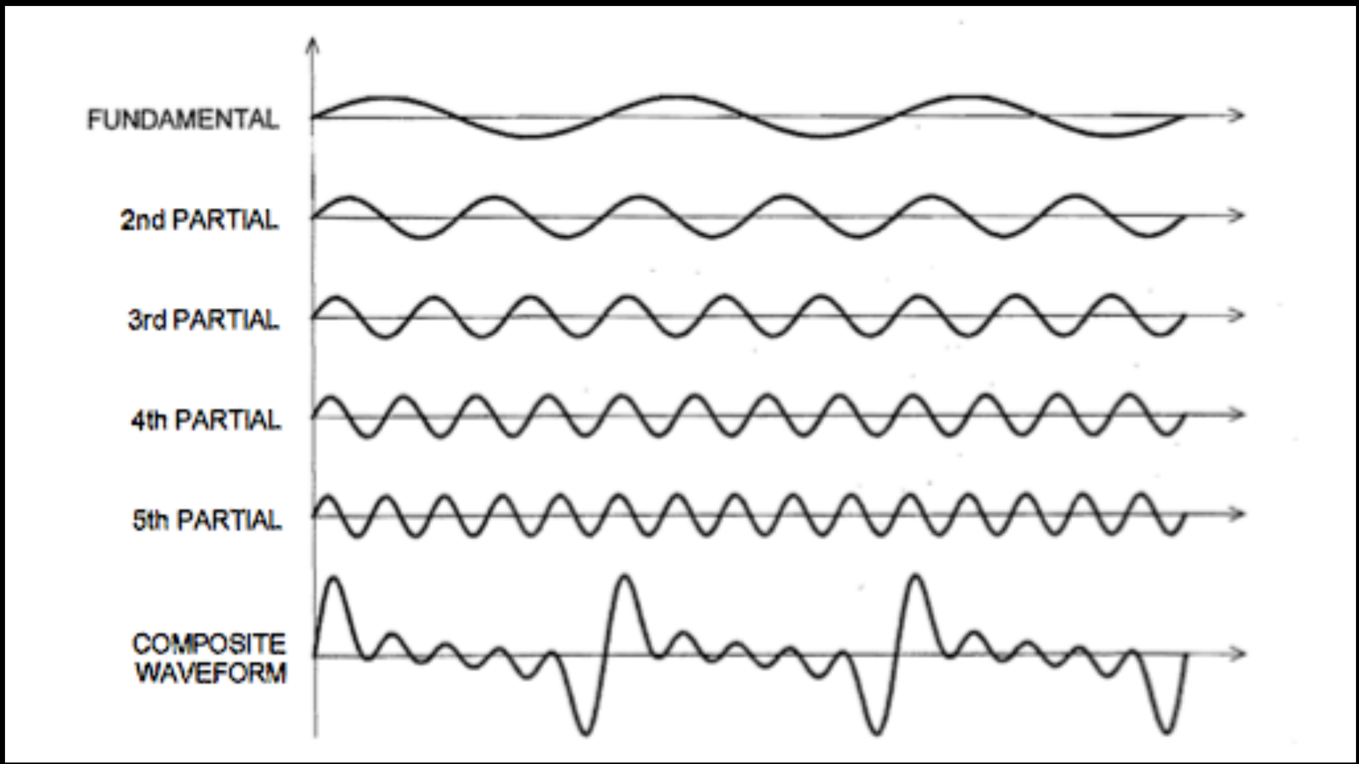
# Harmonic Spectrum

- Spectral components are sometimes called the ***partials*** of a waveform.
- ***Harmonics*** refer to that set of partials that are integer multiples of the ***fundamental*** frequency – is the greatest common divisor of those partials.
- We call a spectrum that is composed of frequencies that are related harmonically (that is, as whole-number multiples), a ***harmonic spectrum*** .



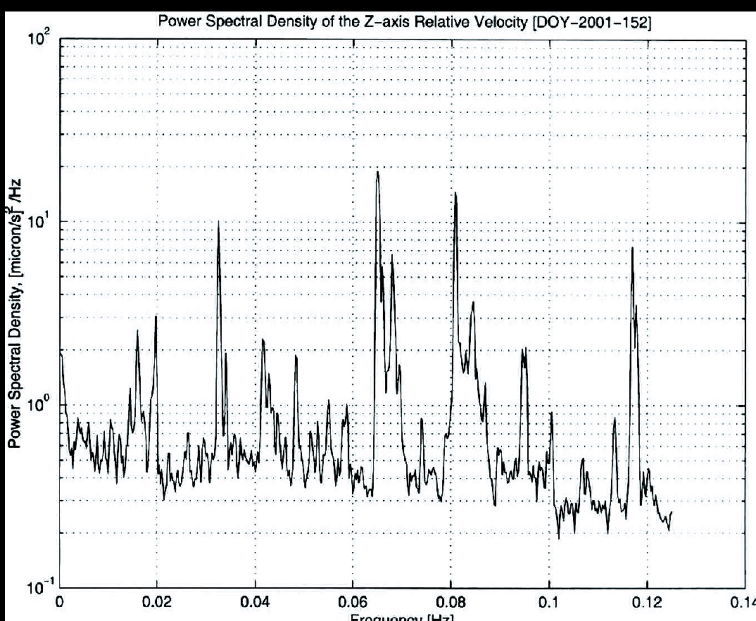
# Harmonic Spectrum

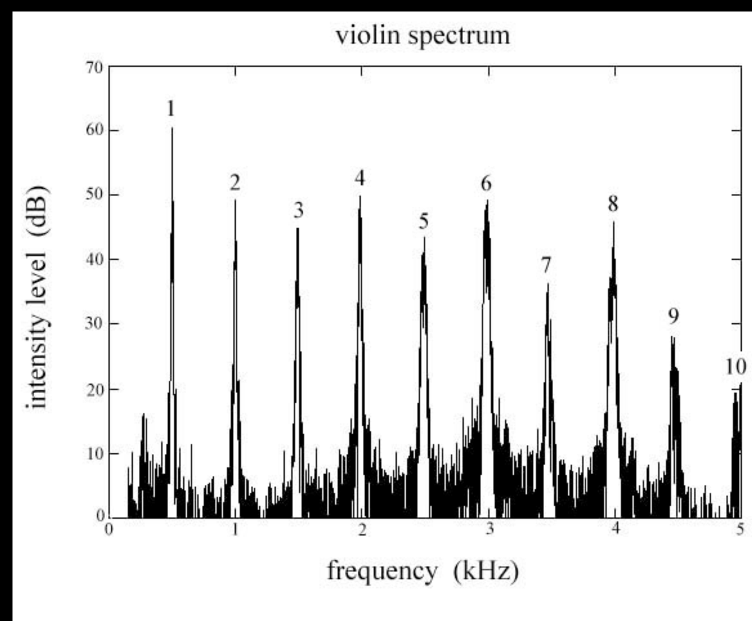
- E.g:
  if the fundamental frequency is 100 Hz, the second harmonic is at 200 Hz, the third harmonic is at 300 Hz, and so on, up to the fifth harmonic at 500 Hz. (***f*** * 1; ***f*** * 2; ***f*** * 3, etc)



# Harmonic and inharmonic spectra

- We hear harmonic spectra as sounds with a clear pitch.
- However, very often, natural sounds and sounds of musical instruments produce ***inharmonic*** partials in addition to the harmonic series.
- Inharmonic partials add a ***noise component*** to a pitch.



# Terminology recapitulation

- Acoustics: study of sound as a physical phenomenon
- Sound: molecules vibrating and traveling in waves
- Physical properties of sound:
  - Velocity: speed of sound towards a direction
  - Waveform: the pressure vibration pattern of sound in time
  - Frequency: the rate of pattern repetition
  - Period: the amount of time of a single pattern cycle
  - Wavelength: the length of a cycle
  - Phase: the position in the cycle
  - Amplitude: the amount of atmospheric pressure change
  - Intensity: power of a sound on an area
- Spectrum: a frequency domain representation of a sound wave

# Bibliography


- ***Acoustics and Psychoacoustics***. David Howard, Jamie Angus, Focal Press; 4th Edition, 2009.
- ***Audio In Media.*** Stanley Alten, Wadsworth Publishing; 6 edition, 2001.
- ***Computer Music: Synthesis, Composition, and Performance.*** Charles Dodge and Thomas A. Jerse, Wadsworth Publishing Co Inc; 2nd Revised edition edition, 1997.
- ***Essentials of Music Technology***. Mark Ballora, Prentice Hall, 2002.
- ***Introduction to Computer Music.*** **Nick** Collins, John Wiley & Sons, 2009.
- ***Musimathics: The mathematical foundations of music.*** Gareth Loy, MIT Press, 2006
- ***The Digital Musician.*** Andrew Hugill, Routledge, 2007.


NOTE: All images were taken from these books and the internet.