Advanced Physics Lab - Acoustics

Advanced Physics Lab, PHYS 3600
Don Heiman, Northeastern University, 2021

This Week

1a-INTRO-a & 1b-INTRO-b: Introduction to the Course
motivation, boiler plate (syllabus/labs)
Fermi questions, exercises

2-ERRORS: Errors and Uncertainties
accuracy, precision, round off, propagation of errors

3-OPTICS: Optical Properties
EM spectrum, photo detectors, light emitters

4-SEMICOND: Semiconductors
band gap, Fermi energy, resistivity, Hall effect

5-ACOUSTICS:
sound, beats, Fourier transform, music

6-EXPERIMENTS: Intro to Lab Experiments
Virtual tour my research lab

Acoustics and Fourier Transform

Advanced Physics Lab, PHYS 3600

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- **Sound**
  intensity, decibels
- **Beats**
- **Fourier Transform**
  convert time axis to freq axis
  FFT, Lorentzian function
- **Music**
  even-tempered scale
  timbre

"Physics of the Blues"

Former College of Science Dean

Murray Gibson on YouTube

Acoustics

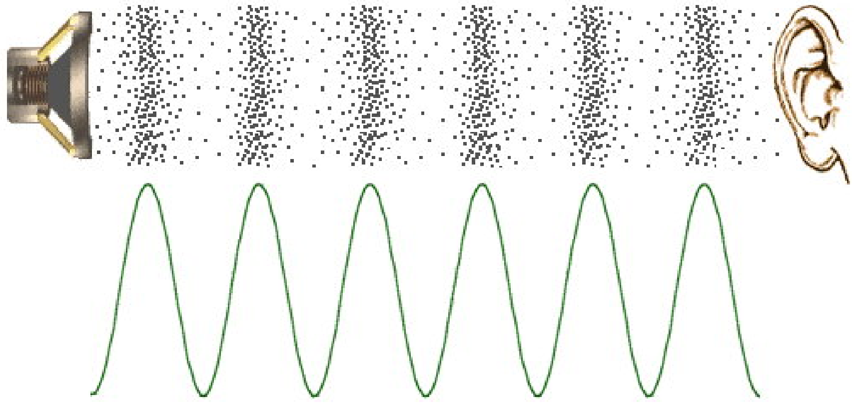
Acoustics is the Science of Sound

Many areas of acoustics

- Musical
- Medical (ultrasound imaging)
- Architectural ("study" rooms, concert halls)
- Noise pollution

Sound is a longitudinal compression wave

Compressions are along the direction of the wave



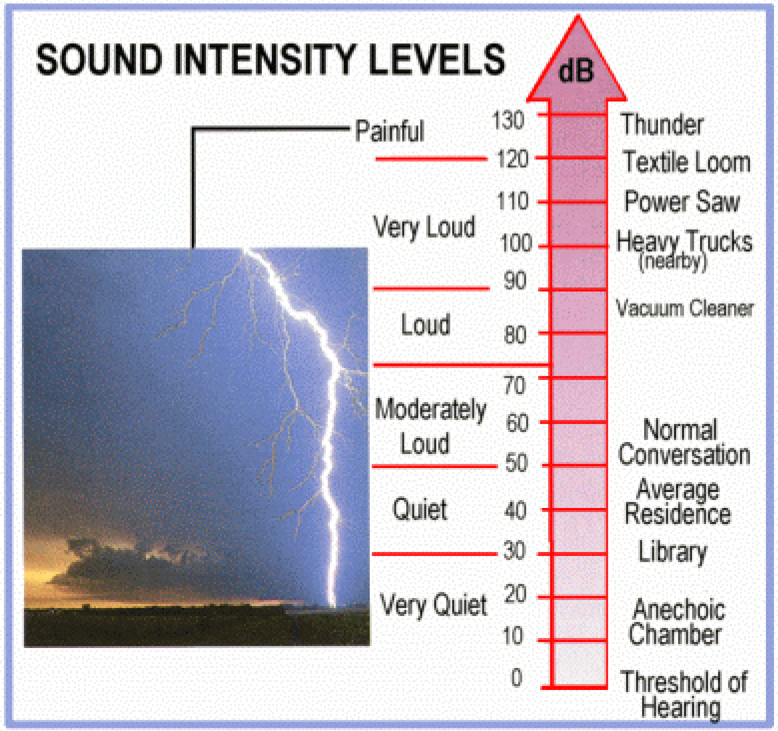
Sound Intensity

Our hearing, and also sight,
responds on a logarithmic scale of intensity.

Decibel Intensity Scale
Intensity in dB
Power in (W/cm^2)

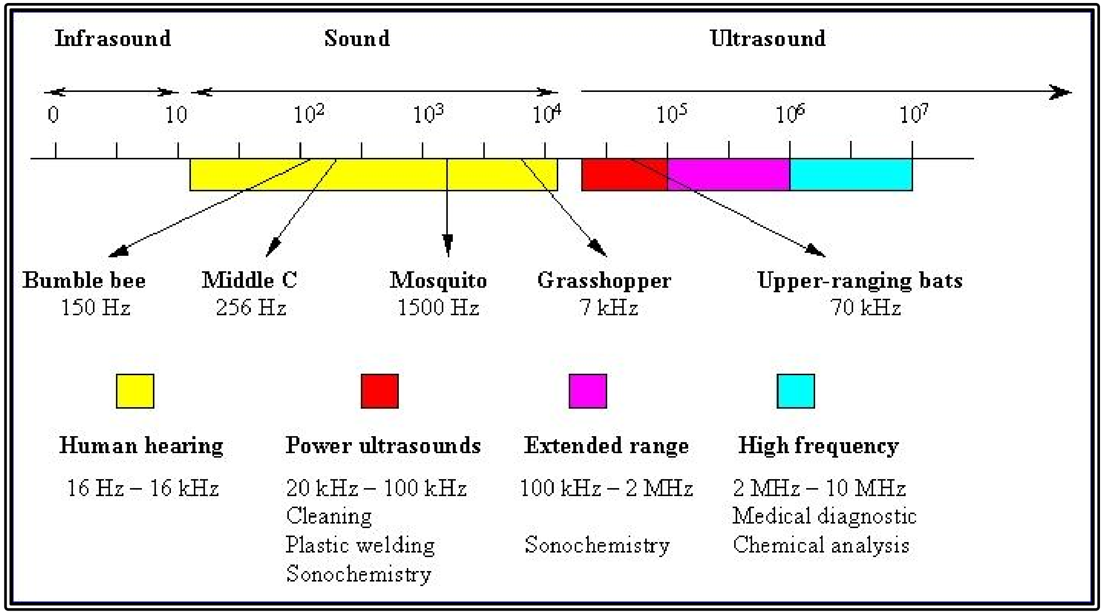
$$P = P_o\, 10^{db/10}$$

dB	P/P_o	Quality
0	10^{-12}	threshold of hearing
20	10^{-10}	whisper (at 1m)
60	10^{-6}	normal conversation
80	10^{-4}	traffic noise
120	1	threshold of pain
140	100	jet aircraft taking off



Sound Frequency

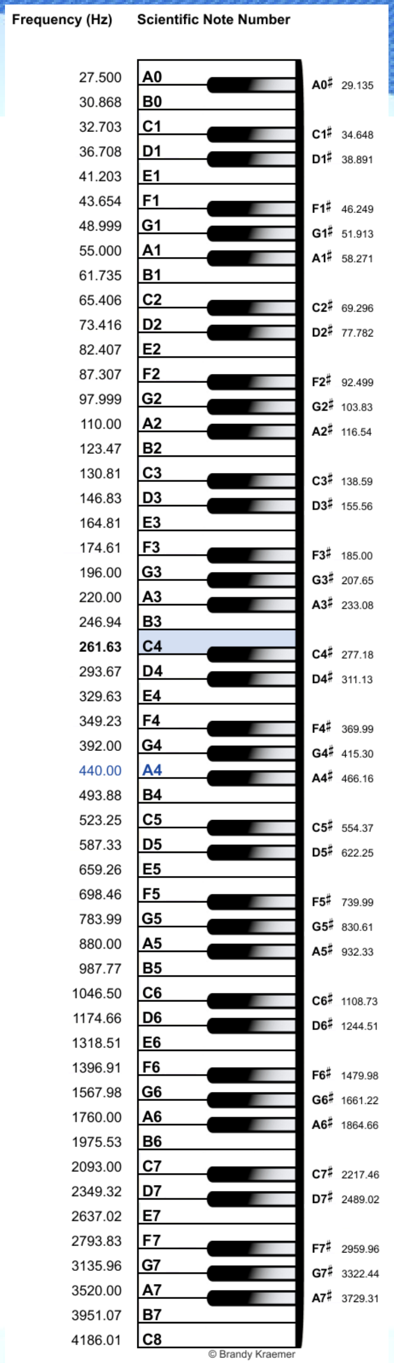
We also detect frequencies also on a logarithmic scale.



Hearing Ranges

Humans:	12 to 20,000 Hz
Dogs:	40 to 60,000 Hz
Mice:	1,000 to 70,000 Hz
Dolphins:	74 to 150,000 Hz
Bats:	20 to 150,000 Hz

Pianos span only
27-4186 Hz
of fundamental frequencies,
but much higher harmonics.



Speed of Sound

The speed of sound depends on the material properties.

Speeds

Gas ~ slow
Liquid ~ medium
Solid ~ fast

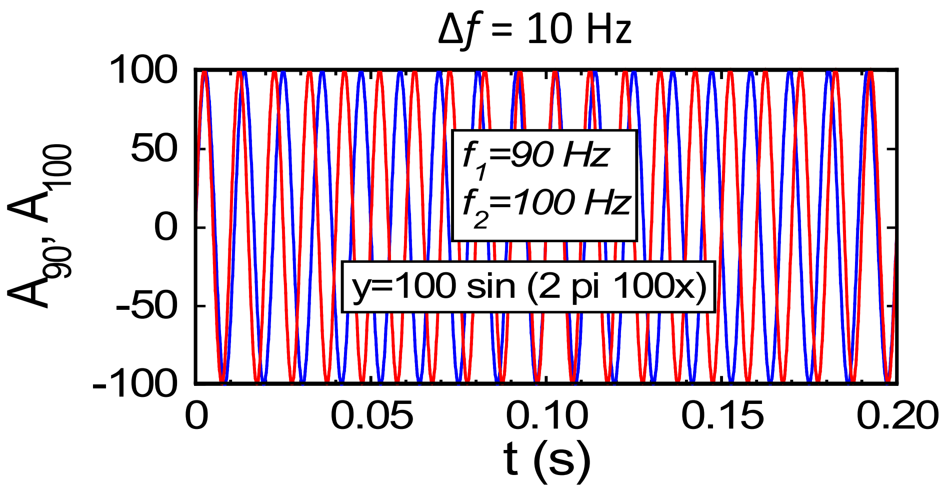
Distance of Lightning
v ~ 1000 ft/s

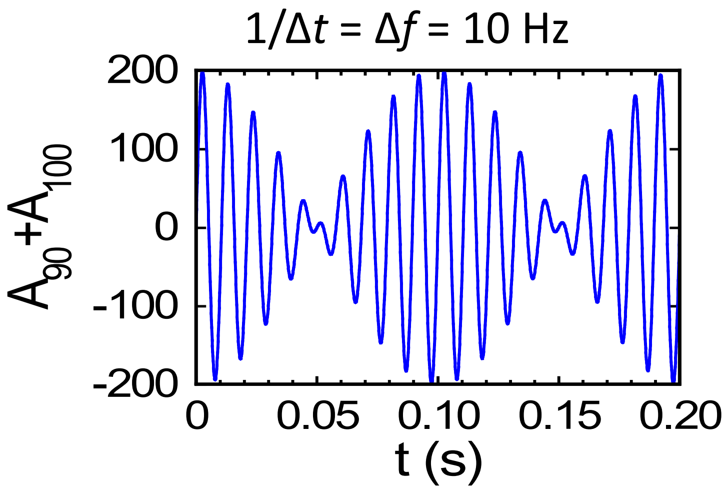
Count the seconds from the flash to the sound

	Medium	Speed (m/s)
GAS	Air (0 ^{o}C)	331
	Air (20 ^{o}C)	343
	Helium	965
	Hydrogen	1284
LIQUIDS	Water (0 ^{o}C)	1402
	Water (20 ^{o}C)	1482
	Seawater	1522
SOLIDS	Aluminum	6420
	Steel	5941
	Granite	6000

Beats

Two waves of different frequencies generate a "Beat" frequency, equal to the difference of the two frequencies.





sin (ωt) = sin (2π*f* t)

ω – radians/sec

f – cycles/sec (Hertz)

ω = 2π*f*

$A(t) = \sin(2\pi f_1 t) + \sin(2\pi f_2 t)$

$A(t) = 2 \sin[2\pi (f_1+f_2)/2\ t] \cos[2\pi (f_1-f_2)/2\ t]$

Average $\langle f \rangle = (f_1+f_2)/2$

Beat $f_{beat} = f_1 – f_2$

(there are 2 maxima per cycle, # maxima per second is f_1-f_2)

Fourier Transform

Discrete Fourier Transform

$$A(t) = \sum_{f=0}^{n-1} B(f)\, e^{-i2\pi ft/n}$$

$$B(f) = \frac{1}{n}\sum_{t=0}^{n-1} A(t) e^{i2\pi ft/n}$$

$$e^{i2\pi ft} = cos(2\pi ft) + i\, sin(2\pi ft)$$

$$A(t) = \int_{-\infty}^{\infty} B(f) e^{i2\pi f \cdot t} df$$

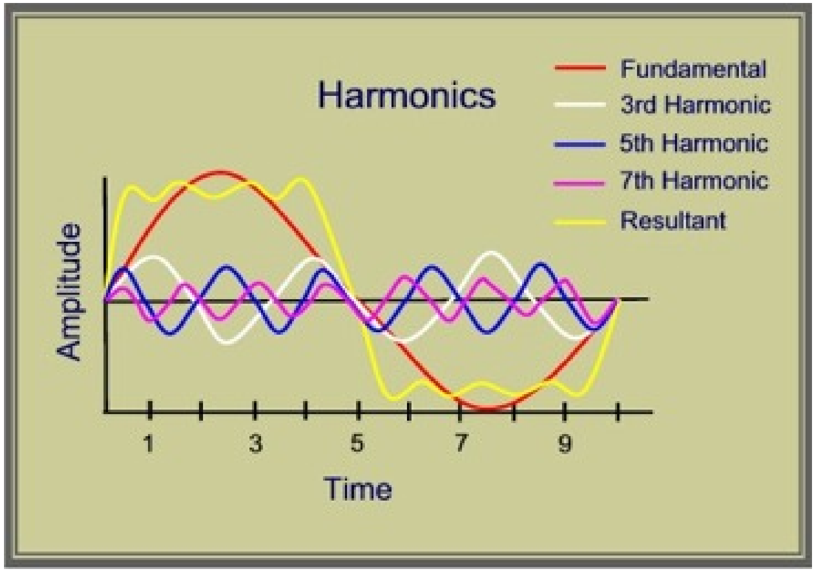
$$B(f) = \int_{-\infty}^{\infty} A(t) e^{-i2\pi f \cdot t} dt.$$

Construct any arbitrary A(t)

By adding a series of sine waves

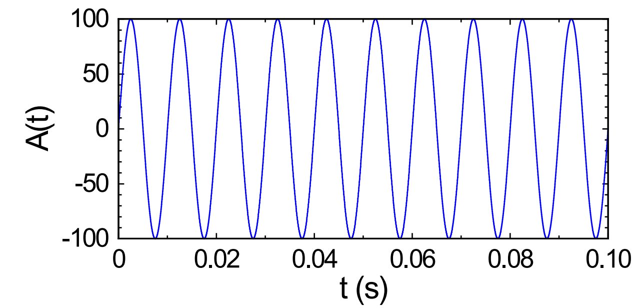
that have a set of harmonic

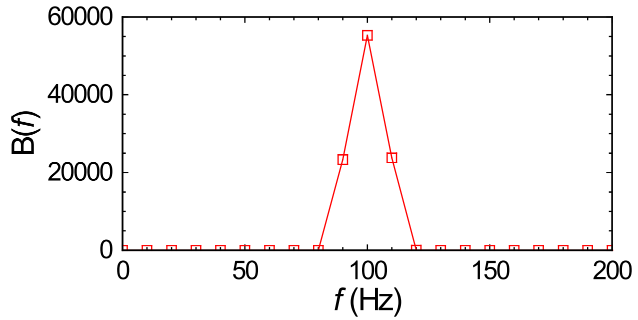
frequencies f_o, $2f_o$, $3f_o$......

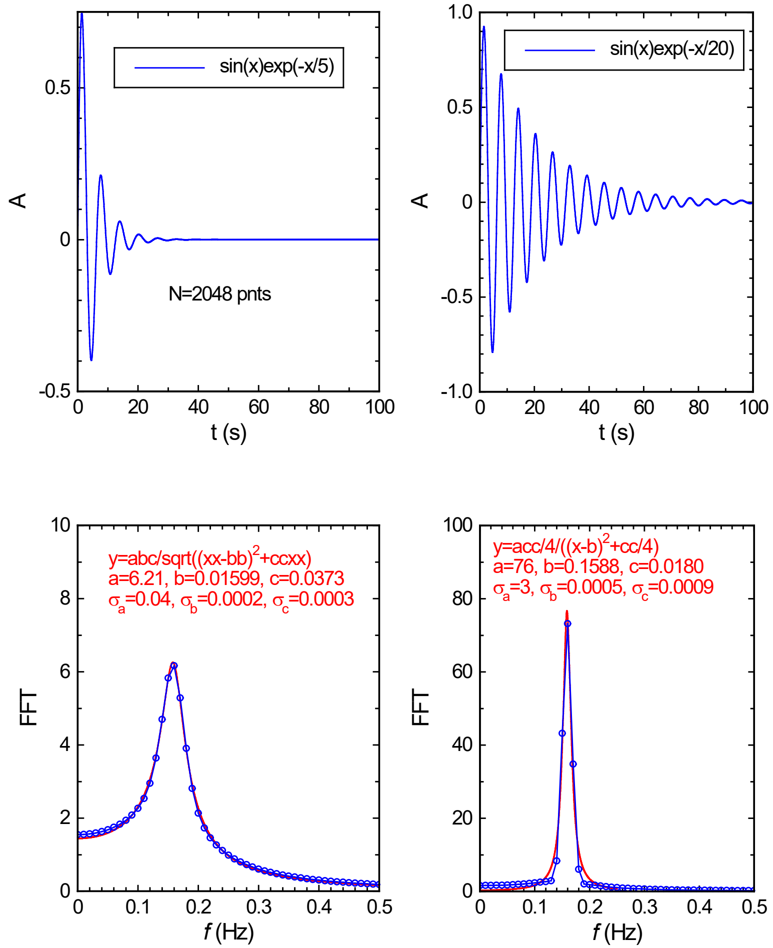


Fourier Transform

Measure sound versus time, then convert sound to frequency axis







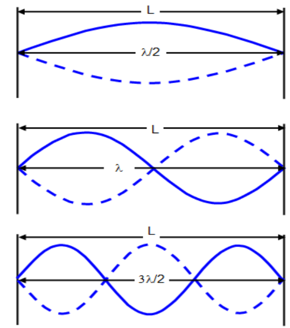
Music - Frequency

Harmonics

f_o – fundamental

$n\,f_o$ – overtones, $n>1$

A-440 , A-880 (n=2) octave

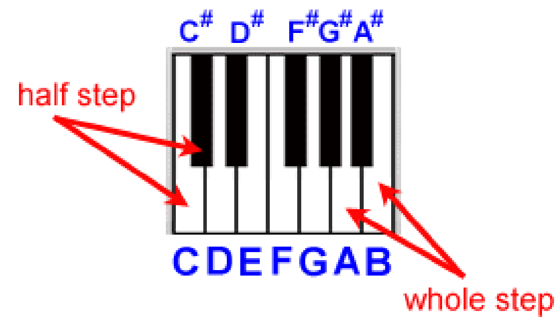


Set middle C

"scientific scale" $f_o = 2^8 = 256$ Hz

"set A-440" $f_o = 440$ (441) Hz

$f_c = 261.63$ Hz



Even-tempered Scale

12 tone equal temperament

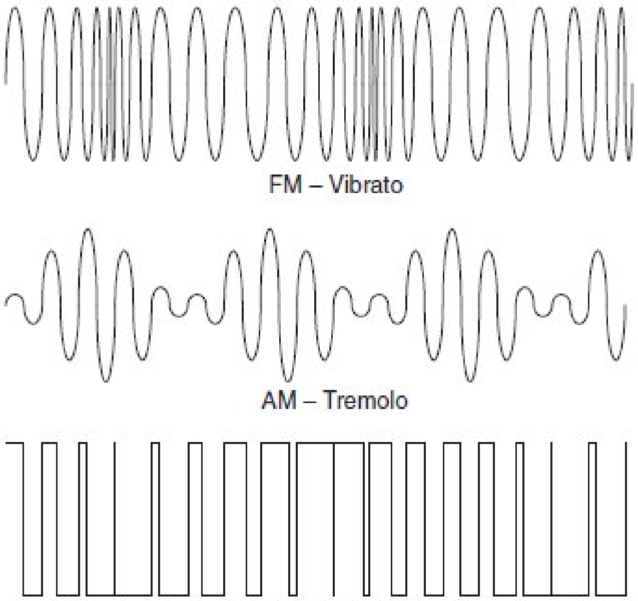
$f_m = f_o\, 2^{m/12}$

$2^{1/12} = 1.0595$

Vibrato and Tremolo

Vibrato – Δf (FM) - guitar whammy bar, singers

Tremolo – ΔA (AM) - singers



FM – Vibrato

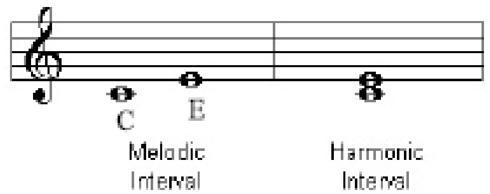
AM – Tremolo

PWM – Pulse width modulation

Intervals and Cords

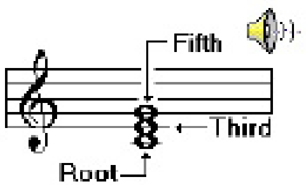
B. Melodic and Harmonic Intervals

In a *melodic interval* the notes are played in succession. In a *harmonic interval* both (or several) notes are sounded simultaneously. The two notes here are C and E. The lower note is middle-C.



C. Musical Chord

Three or more notes sounded simultaneously form a chord. Traditionally, chords have been built by superimposing two or more thirds. For example, notes C-E-G form a chord or major triad. The note upon which the chord is founded is called the root. The other notes are called by the name of the interval they form in relation to the root name. This cord is the C-cord.



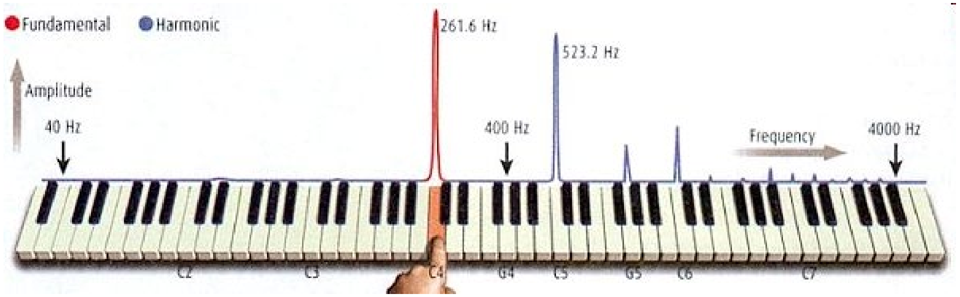
See http://www.teoria.com/

Notes on Timbre

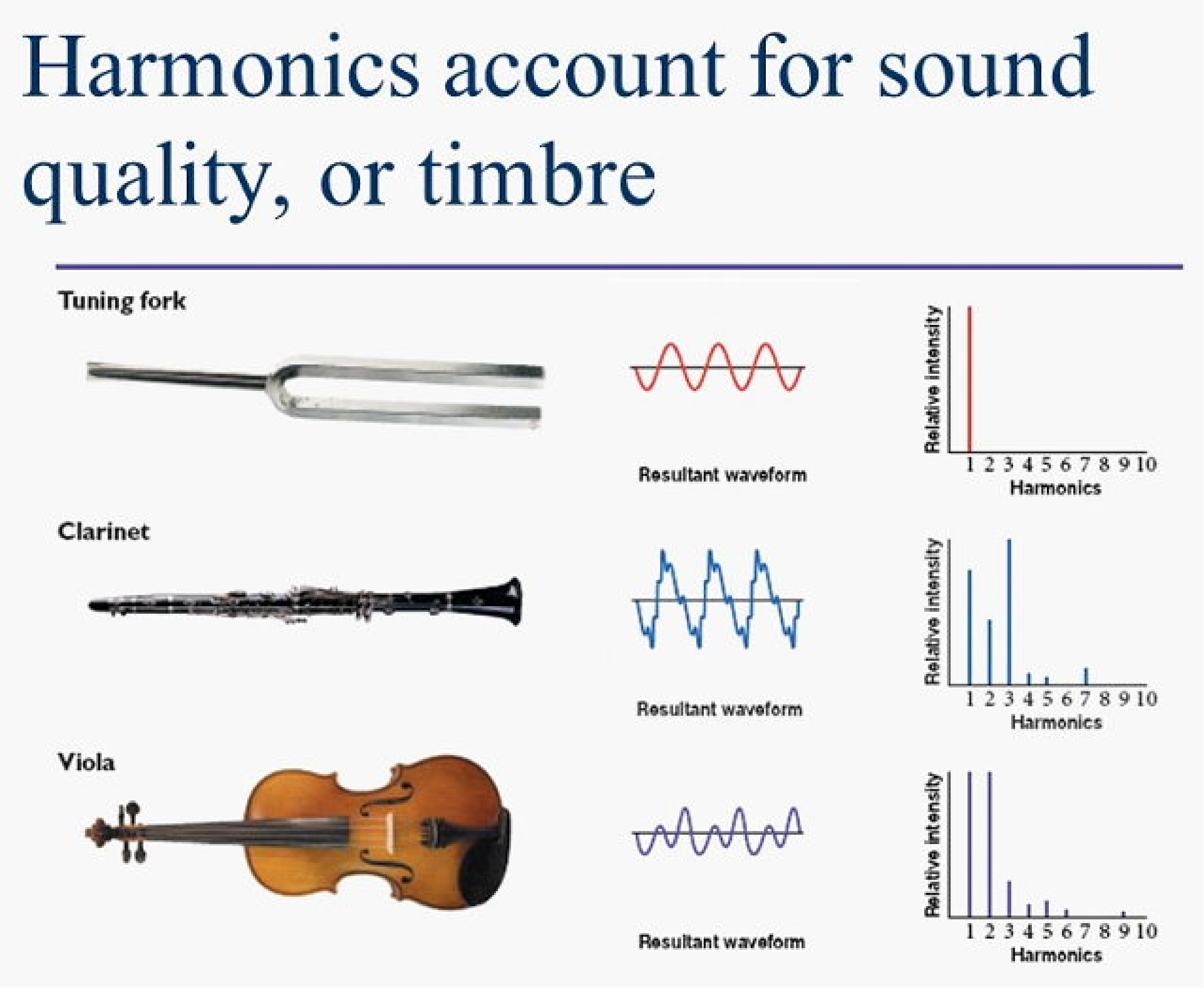
When two different instruments produce the same note or pitch, why do they sound very different?

This difference is related to musical "timbre," usually pronounced "tamber" as in the first syllable of the word tambourine. For example, the note A-440 played on a guitar sounds much different than the same note played on a trumpet.

The main difference in the sound comes from the set of *harmonics* (multiples of the fundamental frequency). Most instruments don't produce a single frequency, instead, they produce acoustic vibrations at the fundamental frequency, *fo*, and also at the harmonics, 2*fo*, 3*fo*, 4*fo*, etc.



Notes on Timbre

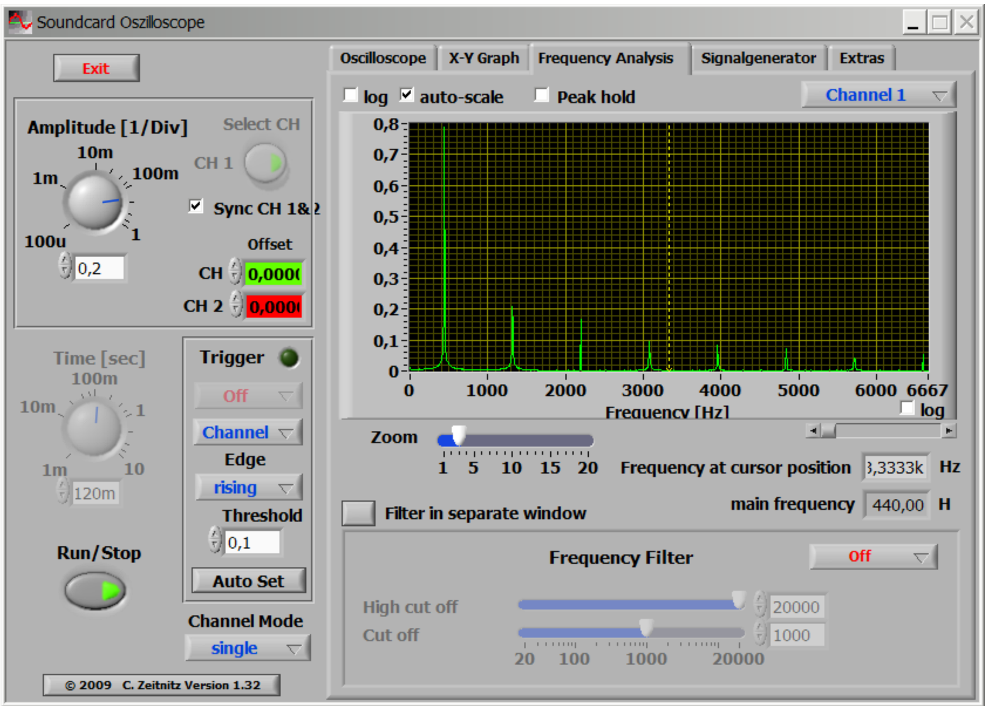


https://slideplayer.com/slide/7655825/

Real-time FFT

SoundCard Oscilloscope

https://www.zeitnitz.eu/scope_en



Examples

- whistle vs time
- whistle vs frequency
- chirp vs frequency
- log and db scales
- add 2 frequencies, beats
- voice harmonics
- guitar harmonics

End of Acoustics Module

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