Sound - The Physics Perspective

CAS AICP M5 Sound

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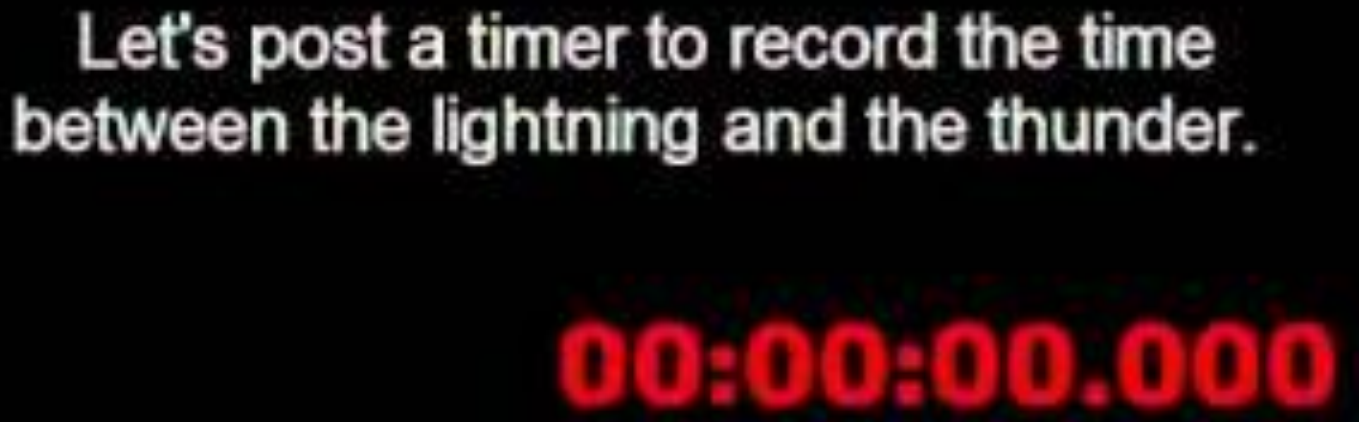
Doppler Effect in Sound

Speed of Sound



Resonance

Interference

No Medium - No Sound

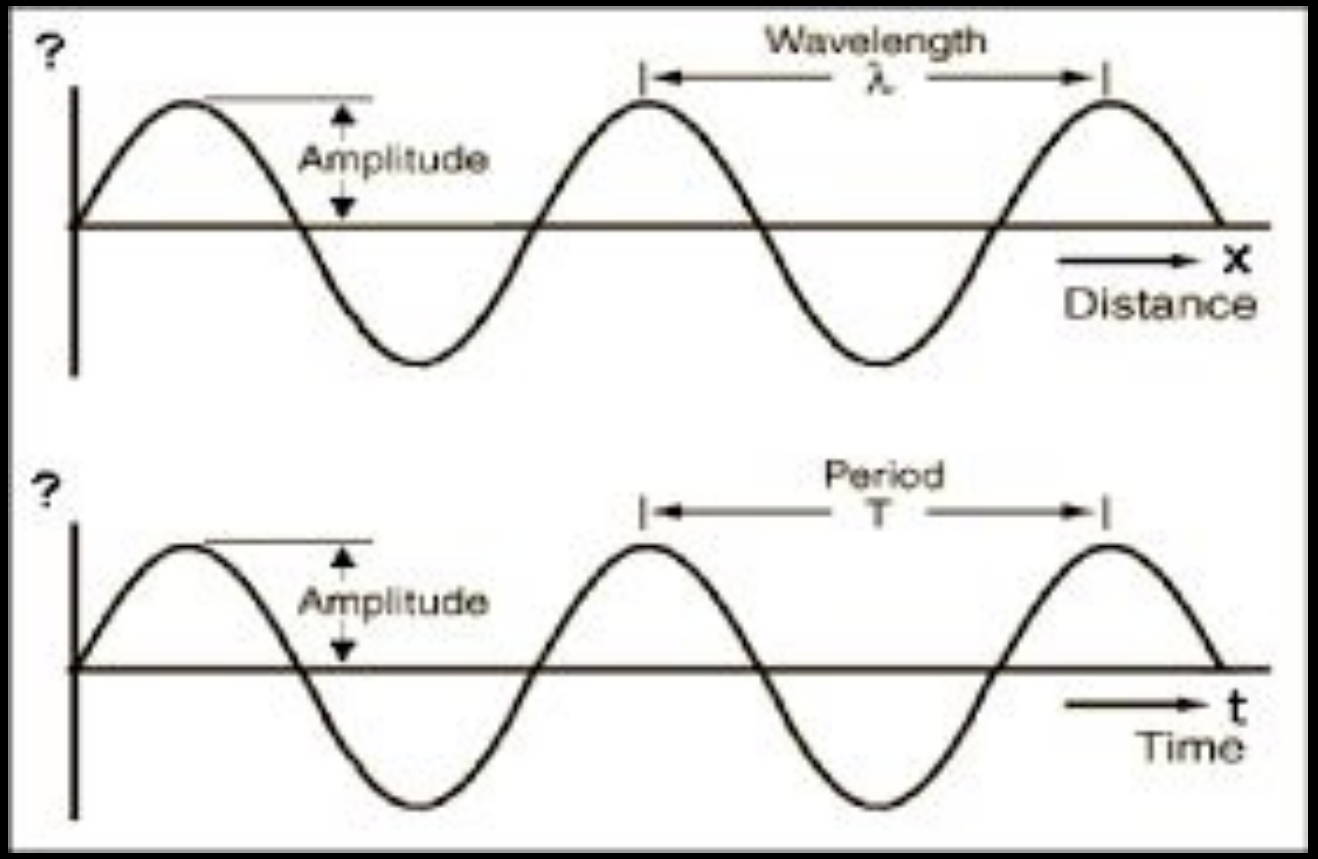
AI Generated Sound - Sportpalast

- Seid ihr bereit, mit dem Führer, als Phalanx der Heimat hinter der kämpfenden Wehrmacht stehend, diesen Kampf mit wilder Entschlossenheit und unbeirrt durch alle Schicksalsfügungen fortzusetzen - bis der Sieg in unseren Händen ist?

- Prompt by Göbbels, Berlin Sportpalast 1943-02-18, generation by udio.com

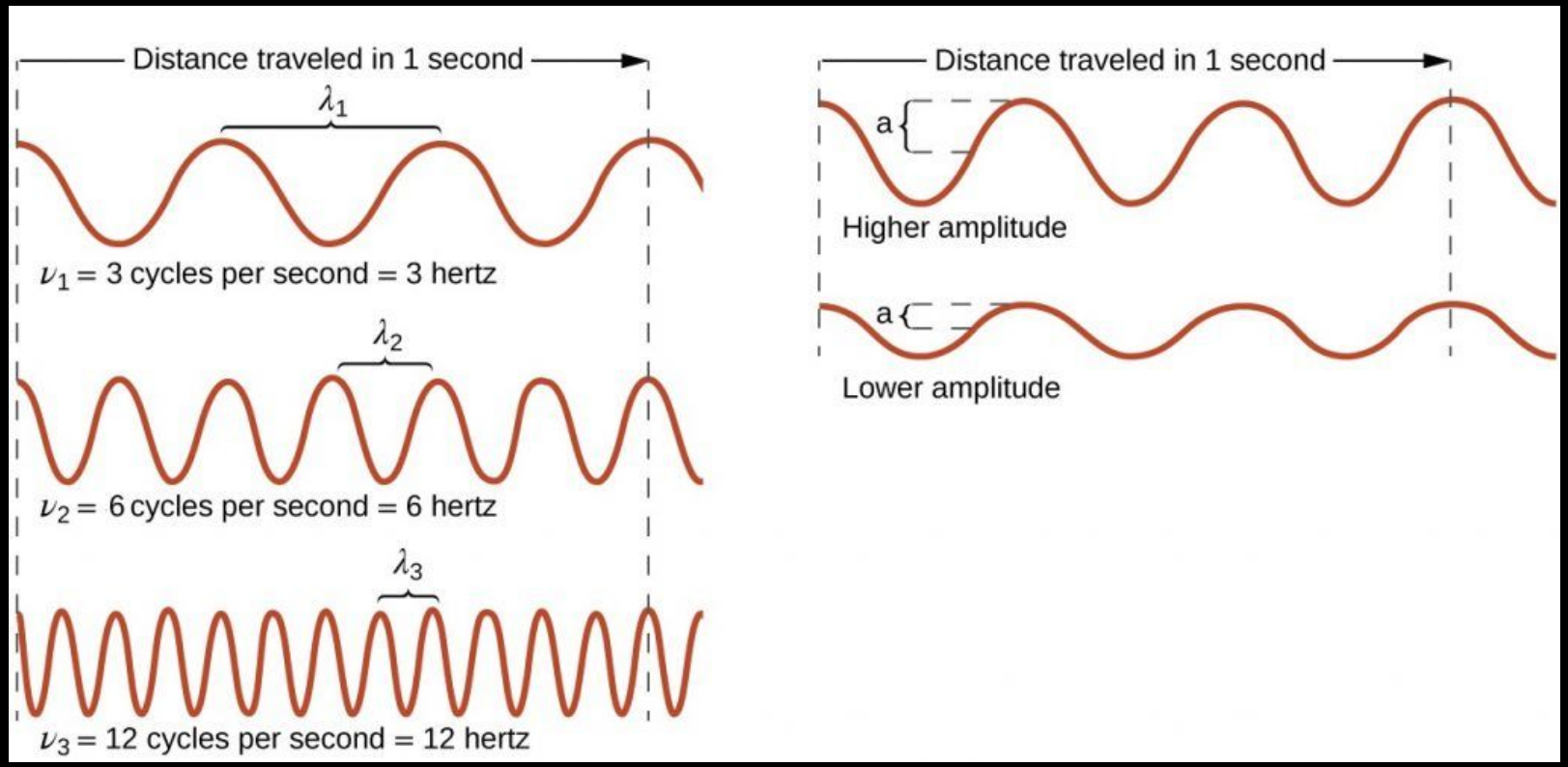
Waves in a medium (for example air)

Wave (theoretical description)

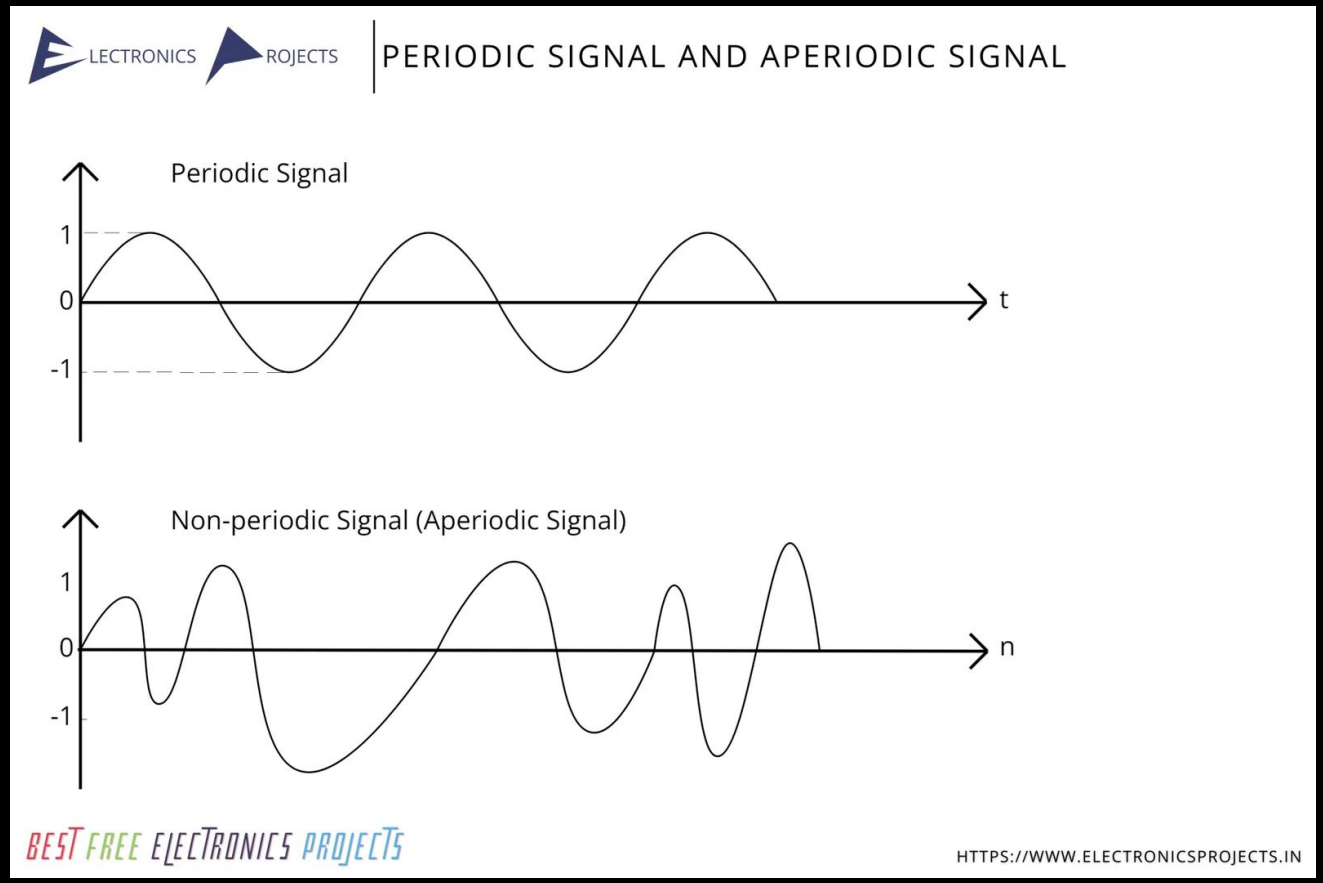


v = x/t so
v = λ/T

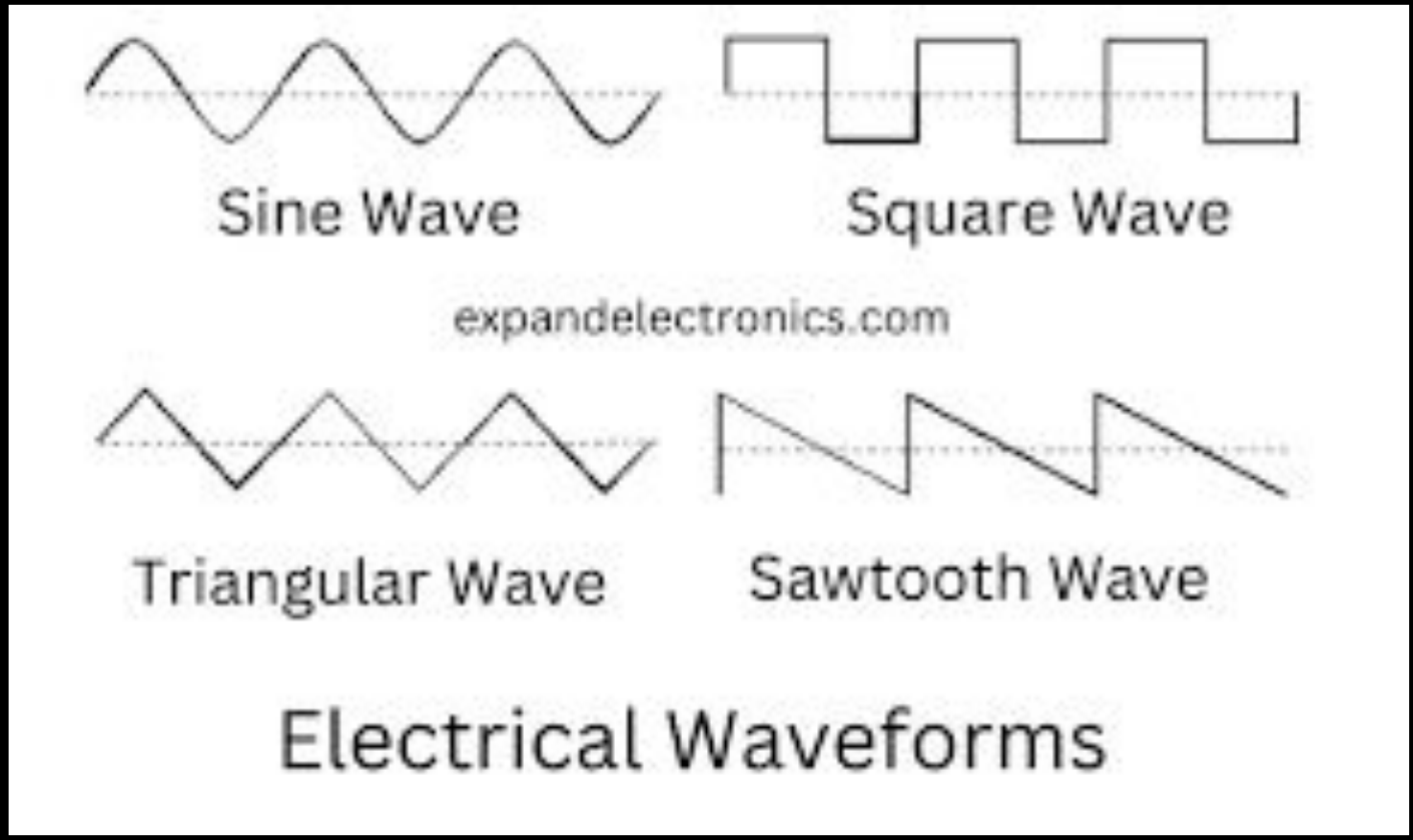
We describe waves with amplitude, wavelength λ (distance between two peaks) and period (T) and frequency (f = 1/T)



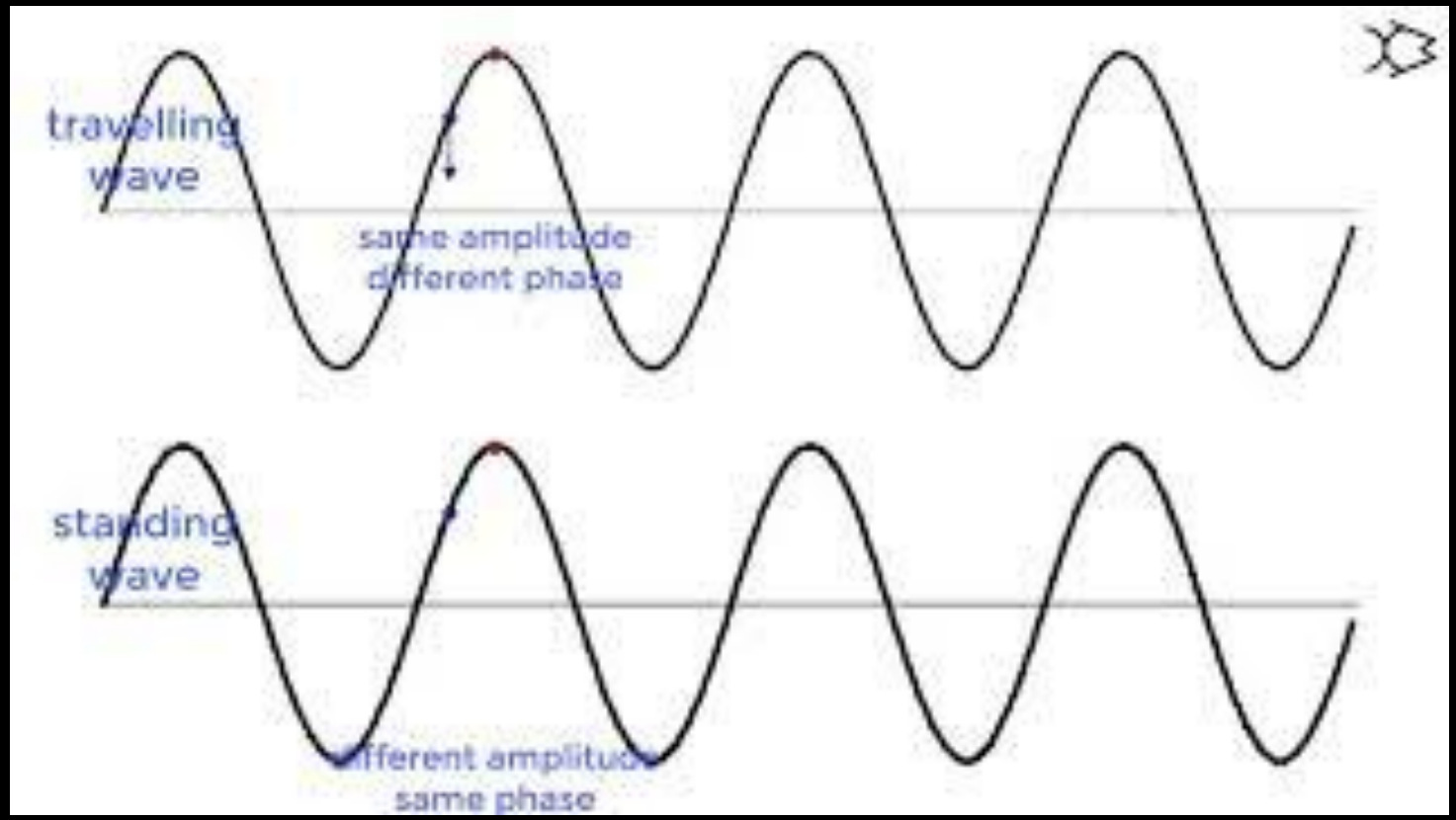
The perceived frequency is called pitch.



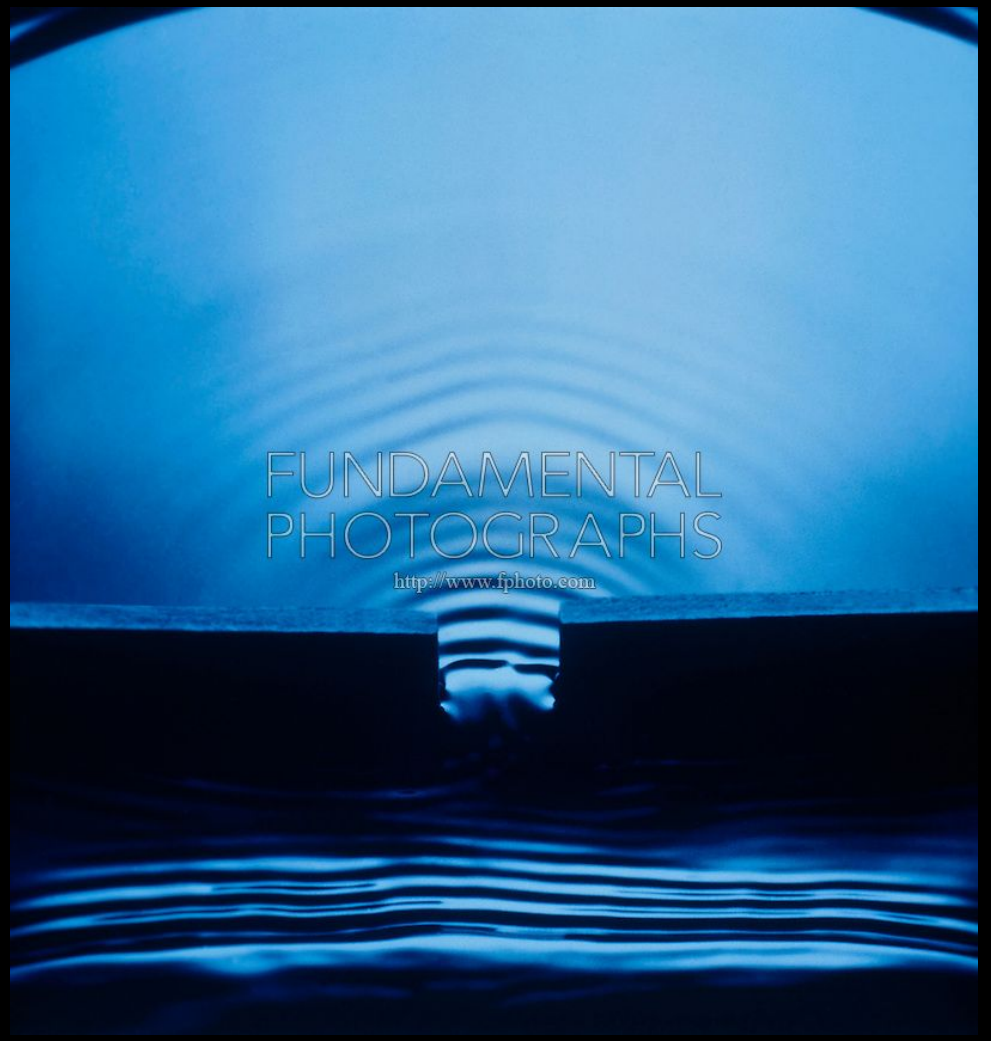
Waves can be periodic or aperiodic



There are many different waveforms



Waves can be travelling or standing (like a string on the guitar)



We often categorize into plane and concentric waves

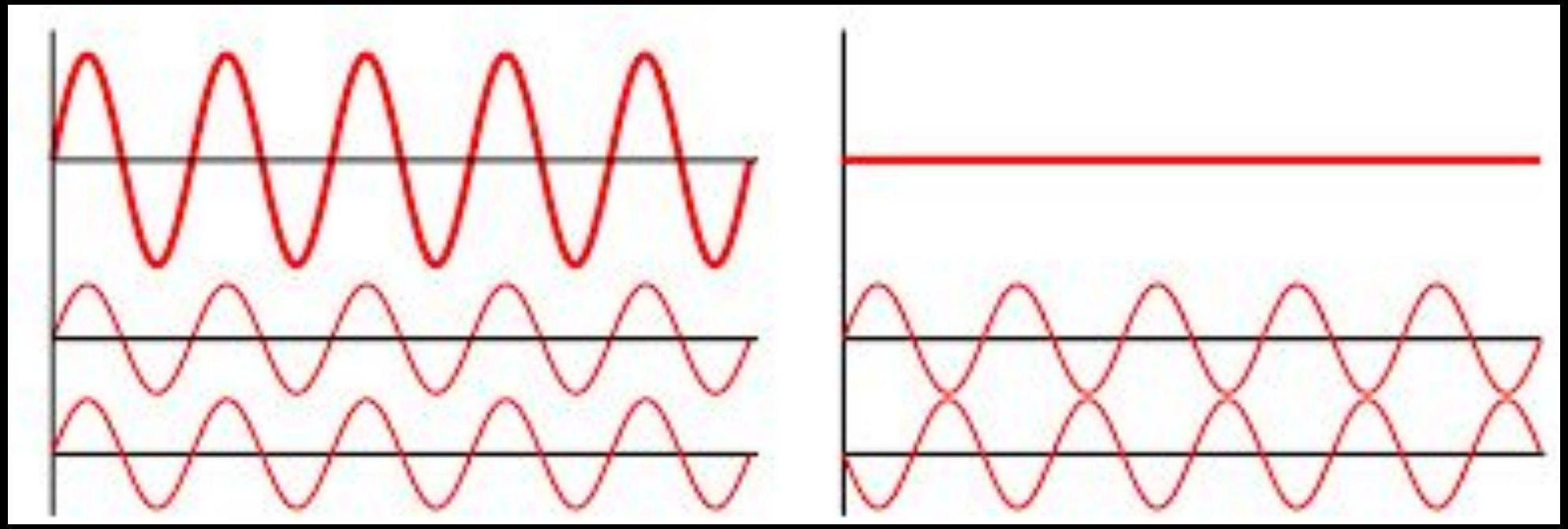
Mathematical description of (sin) waves

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

Any other wave can be described as a superposition (sum) of many sine waves (Fourier expansion). Example square wave:

$$x(t) = \frac{4}{\pi}\sum_{k=1}^{\infty}\frac{1}{2k-1}\sin\left(2\pi\left(2k-1\right)t\right)$$

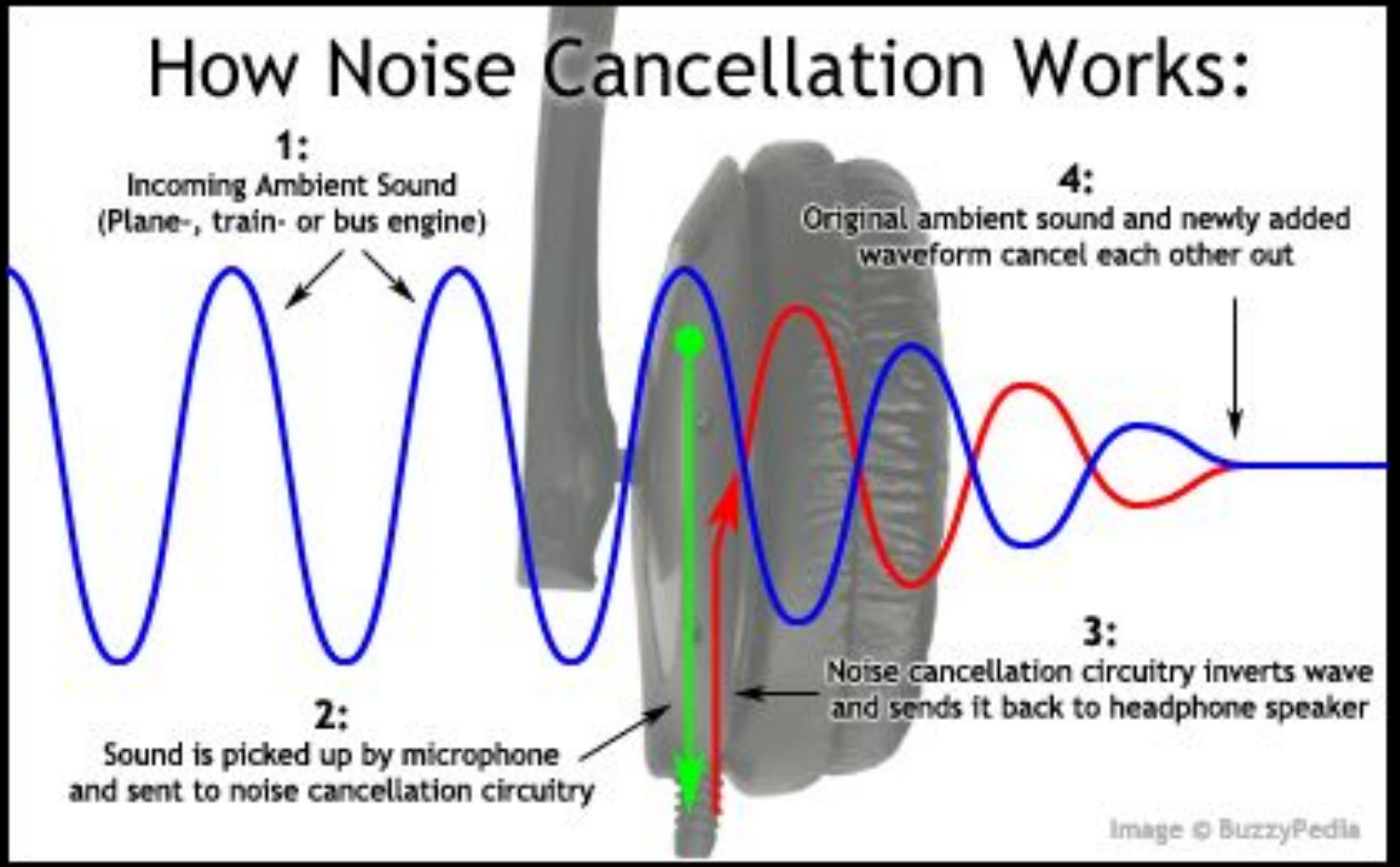
(opposed to particles, waves superimpose, i.e. they add up, both constructively and destructively)

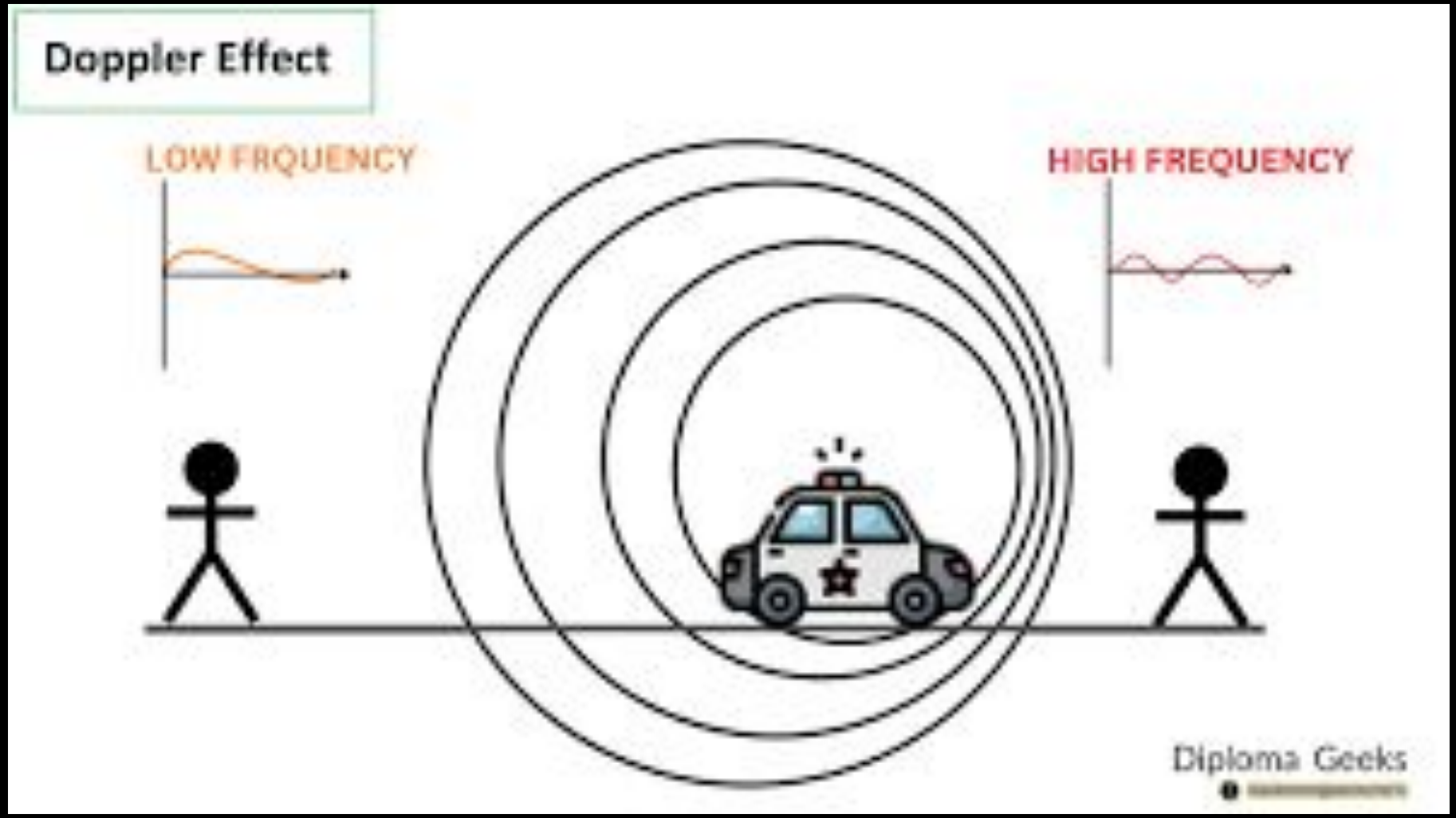


Superposition / Interference

Interference

Interference




Doppler Effect
LOW FRQUENCY
HIGH FREQUENCY
Diploma Geeks

Doppler Effect in Sound

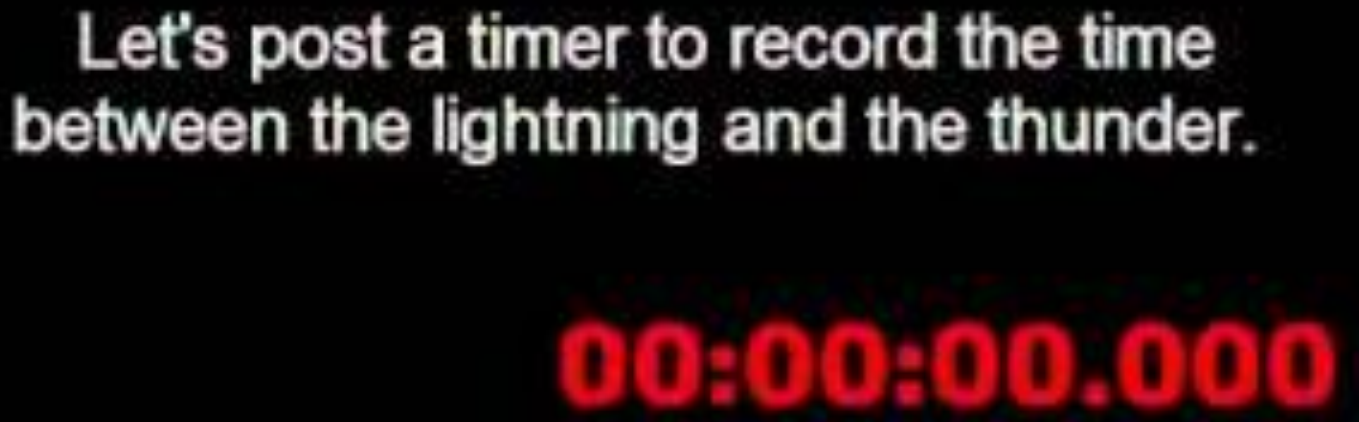
What is sound ?

A longitudinal wave in a medium
(that can be heard)

What can a sound wave do ?

- Absorption
- Reflection (Echo)
- Refraction and Diffraction (direction change)
- Transmission
- Dispersion
- Polarization
- Interference
- Doppler Effect

Speed of Sound



Speed of sound

- in air about 340 m/s
- in water about 1500 m/s
- in glass about 5000 m/s
- in beryllium about 13000 m/s

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Hearing of sound

- Humans can hear from 20 to 20’000 Hz
- Frequencies below 20 we call infrasound
- Frequencies above 20’0000 we call ultrasound
- Dogs can hear up to 30’000
- Dolphins and bats up to 100’000

- Perception range degrades with age, mostly in the high frequency domain

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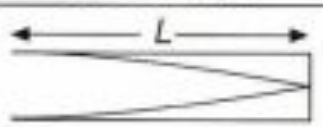
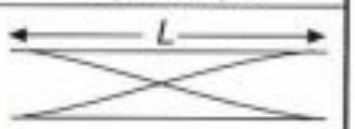
Modes of Vibration of Standing Waves

Mode	String	Closed Pipe	Open Pipe
1st harmonic or fundamental	 $\lambda = 2L$	 $\lambda = 4L$	 $\lambda = 2L$
2nd harmonic or 1st overtone	 $\lambda = \frac{2L}{2}$		 $\lambda = \frac{2L}{2}$
3rd harmonic or 2nd overtone	 $\lambda = \frac{2L}{3}$	 $\lambda = \frac{4L}{3}$	 $\lambda = \frac{2L}{3}$
4th harmonic or 3rd overtone	 $\lambda = \frac{2L}{4}$		 $\lambda = \frac{2L}{4}$
5th harmonic or 4th overtone	 $\lambda = \frac{2L}{5}$	 $\lambda = \frac{4L}{5}$	 $\lambda = \frac{2L}{5}$

Let’s play !

Go to this page with your phone and try out

- Different pitches
    - What are the smallest and biggest frequencies you can hear?
- Different waveforms

Or go to the link with your laptop

https://onlinetonegenerator.com/

Digitizing Sound

- Longitudinal mechanical waves are analog
- When we record sound, with a microphone, it creates an electrical current that is digitized into a on-off signal (squared waveform)
- The on-off (1 or 0) signal can be manipulated by a computer, for example used to train an AI model that can generate a song
- The output on-off signal is then made analog to steer the vibrations of a loudspeaker

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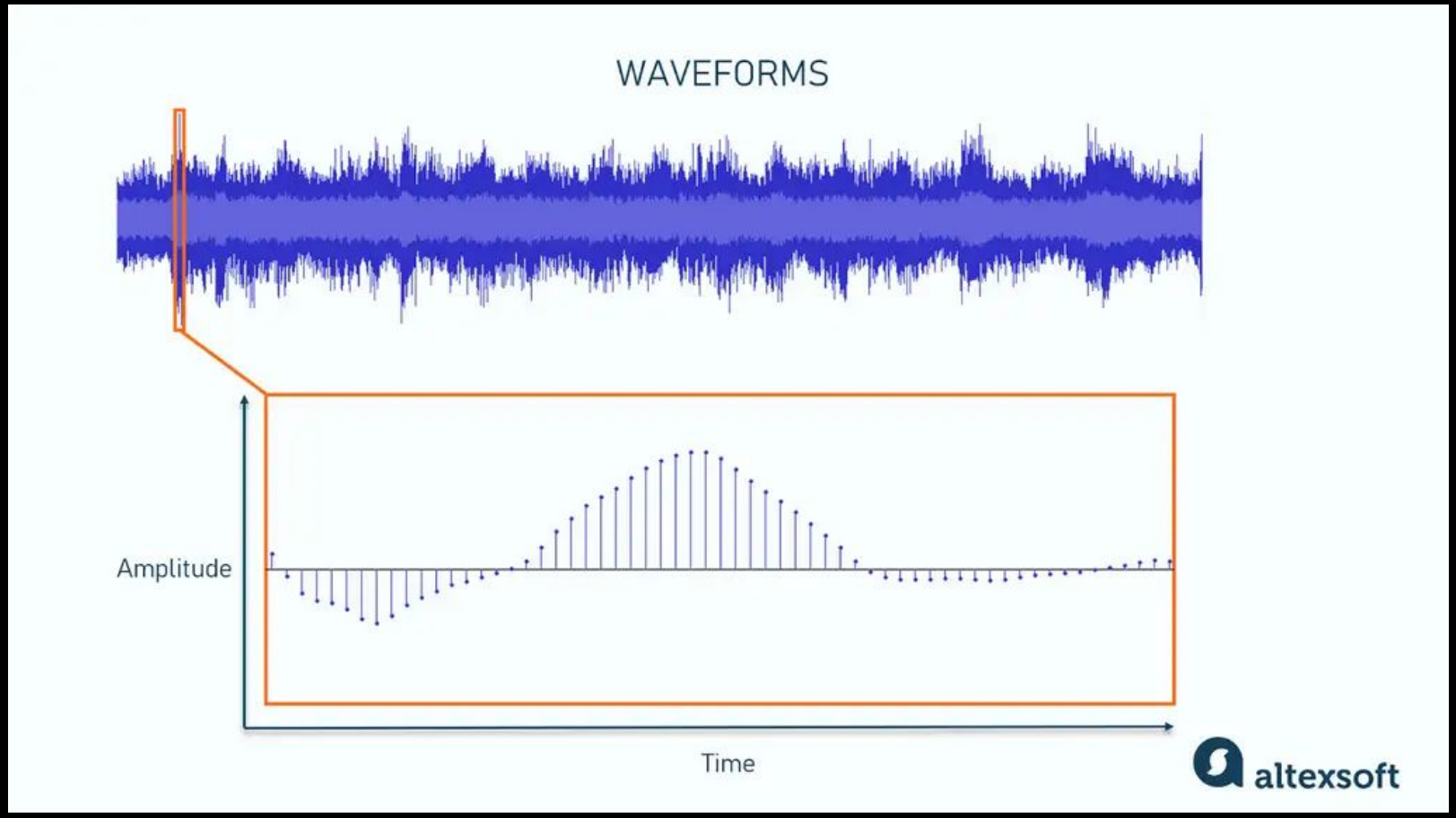
Digitizing

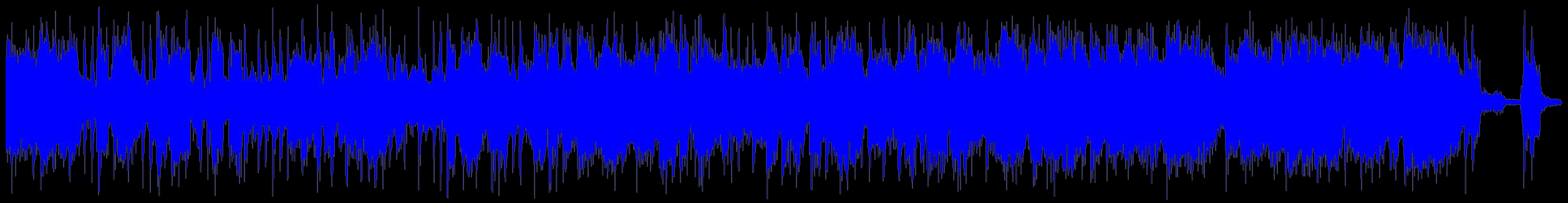

How an analog-to-digital converter works
Analog-to-digital converter
Analog signal
Digital signal

Representation of sound - waveforms



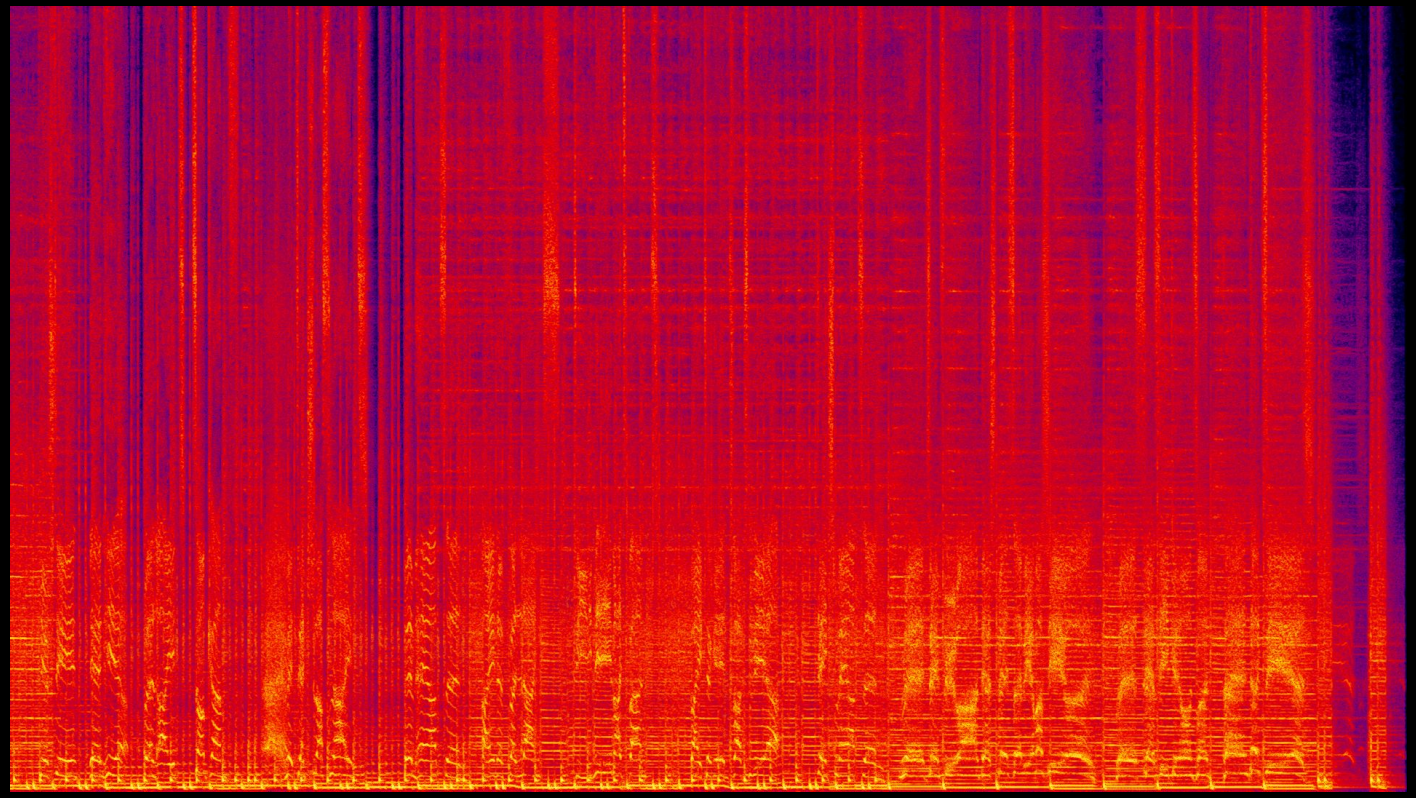
Data heavy - CD typically has 44’000 samples per second

Waveform of Sportpalast



Done with https://audioalter.com/waveform

Spectrogram of Sportpalast



Sound can be represented as pictures and then processed with image techniques

Done with https://audioalter.com/spectrogram

Tool	Best For	Open Source	Architecture	Key Features	Pricing
Suno	Complete songs with vocals	No (Proprietary)	Transformer-based	Text-to-song, v4.5 model, stem separation, multi-language vocals, mobile app	Free plan; paid tiers for commercial use
Stable Audio	Long-form music generation	Yes (Open)	Diffusion Transformer (DiT) on latent representation	Up to 4m 45s generations, 21.5 Hz latent rate, text conditioning	Open model available; commercial license for business use
Music Gen	Customizable music from text	Yes (Open)	Transformer-based autoregressive decoder with EnCodec	Text/melody conditioning, multiple styles, local operation capability	Free and open source (Meta/Facebook Research)
Udio	Professional-quality compositions	No (Propetary)	Likely diffusion-based (not disclosed)	Advanced editing (extending/inpainting/remixing), community sharing, professional output	Free plan; paid subscriptions for downloads
AIVA	Orchestral & cinematic music	No (Proprietary)	Deep learning + reinforcement learning	250+ styles, MIDI editor, trained on classical composers, SACEM recognition	Free (with attribution); Standard & Pro for full rights

Table generated with Claude

Ethical Concerns regarding AI4Sound ?

- Is there a copyright on the generated sound?
- Was sound for the training with copyright?
- Is it a problem that you cannot distinguish your mother's voice from an AI trained voice (fakes)?
- Will human sound artists and makers lose their jobs?
- Sustainability
- Health
- Training bias (low intellectual qualtiy)

- Is This What We Want ?

Summary

- Sound is a (hearable) longitudinal mechanical wave

- Apart from polarization it thus has the typical wave features (in particular superposition / interference)

- Digitized sound can be used to train machine learning models that can then generate new sound like speech and music

Check your learning outcomes

- link to google form : https://forms.gle/XVp5qnexiDCwSjHq7

Exercises

1. Create yourself a GitHub repository for your CAS

2. Play with acoustics using this jupyter notebook
   - https://colab.research.google.com/drive/10-IqNtkEqXM8t1Ts4p34RXH-FBCCne7m?usp=sharing