# Sound and Acoustics I

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# What is sound? Acoustic waves

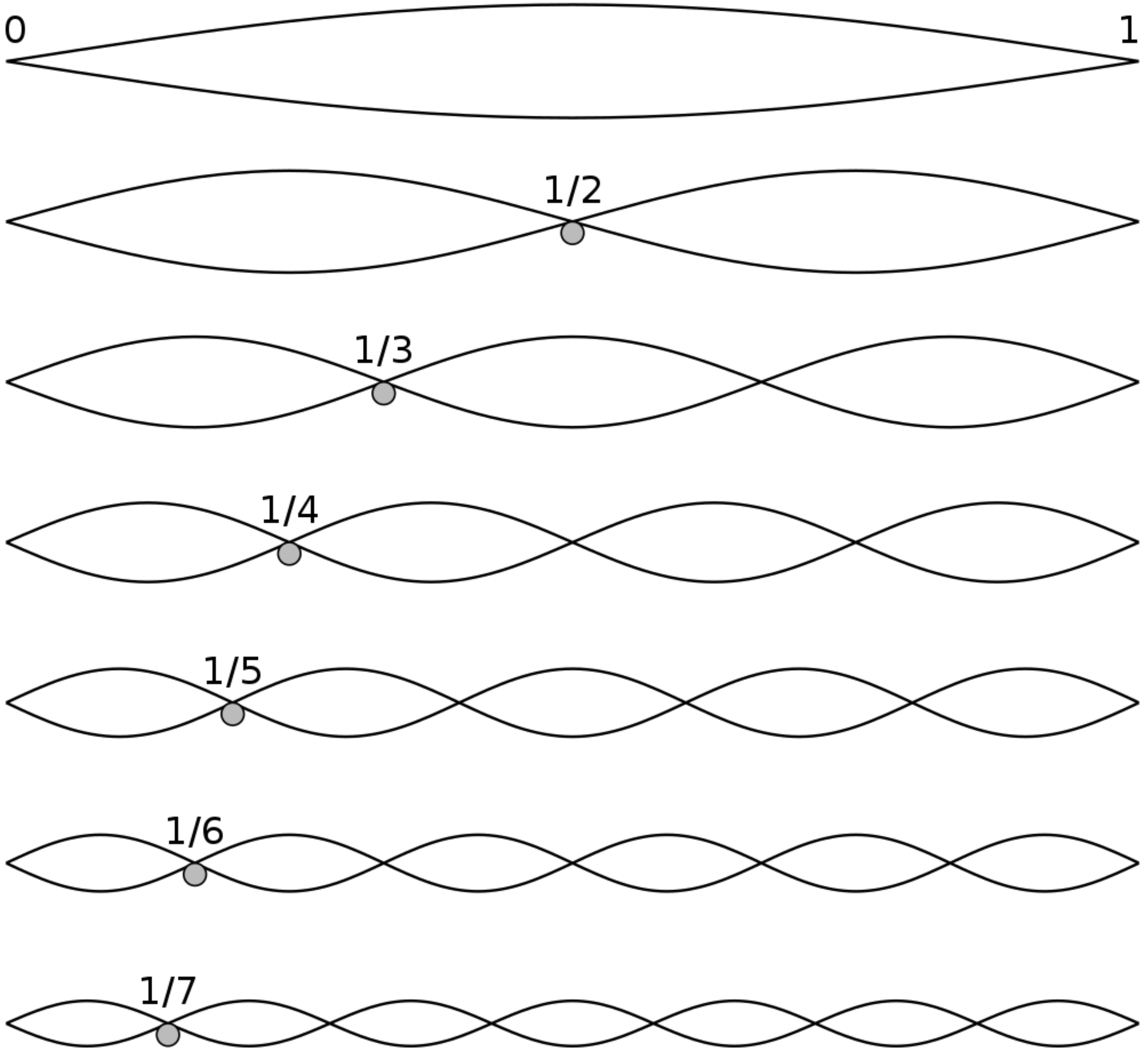
- A sound or acoustic wave is a disturbance that propagates through a medium
- Follows the wave equation: $$\frac{\partial^2 u}{\partial t^2} = c^2 \left( \frac{\partial^2 u}{\partial x_1^2} + \frac{\partial^2 u}{\partial x_2^2} + \cdots + \frac{\partial^2 u}{\partial x_n^2} \right)$$
- Usually a longitudinal (pressure) wave
  - The medium is compressed and rarefied
  - In solids can also be a transverse/shear/strain wave
- Speed of sound depends on material properties

# Standing and traveling waves

- Waves emitted from a point source propagate through space (traveling waves)
- Two waves at the same point in space will interfere
  - If they are in-phase, the amplitude increases (constructive interference)
  - If they are out-of-phase, the amplitude decreases (destructive interference)
- A wave interfering with itself can form a fixed pattern in space known as a standing wave

# The Harmonic Series

- A resonant object vibrating produces a sound wave
- The lowest frequency of that wave is called the *fundamental*
- The object (e.g. a string) can also vibrate at integer fractions of its length (1/2, 1/3, 1/4, etc.) This produces successively higher *overtones*




(Source : Wikimedia, public domain)

# Human Perception of sound

- Human hearing range is 20-20,000 Hz
  - Young people can often hear higher, up to 22,000 Hz. High frequency hearing is lost with age
  - Highest sensitivity in 250 Hz – 5k Hz range
- Human speech has a fundamental frequency in the range of 85-255 Hz

# How do we measure it? Microphones

- A microphone is a device that transforms an acoustic signal into an electrical signal
- Generally involves a moving element connected to an electrical circuit
- Many different types of microphones:
  - Moving capacitor (Condenser)
  - Moving coil around permanent magnet (Dynamic)
  - Moving metal foil in magnetic field (Ribbon)
  - Piezoelectric (Crystal)

# Our microphone: Electret microphone

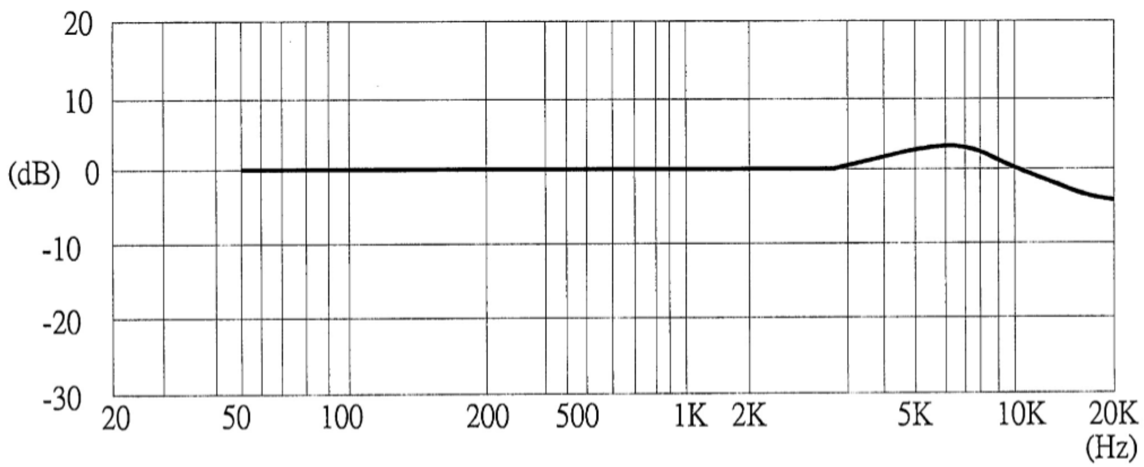
- Condenser-type microphone with a ferroelectric material as the capacitor
  - Static polarization means that it doesn’t require external bias voltage.
  - Moving diaphragm changes the capacitance -> electrical signal
- Usually inexpensive
- Usually omnidirectional with a wide frequency range

# Datasheet

## SPECIFICATIONS

| | | |
|---|---|---|
| directivity | omnidirectional | |
| sensitivity (S) | -44 ±2 dB | f = 1KHz, 1Pa 0dB = 1V/Pa |
| sensitivity reduction (ΔS-Vs) | -3 dB | f = 1KHz, 1Pa Vs = 3.0 ~ 2.0 V dc |
| operating voltage | 3 V dc (standard), 10 V dc (max.) | |
| output impedance (Zout) | 2.2 KΩ | f = 1KHz, 1Pa |
| operating frequency (f) | 20 ~ 20,000 Hz | |
| current consumption (IDSS) | 0.5 mA max. | Vs = 3.0 V dc RL = 2.2KΩ |
| signal to noise ratio (S/N) | 60 dBA | f = 1KHz, 1Pa A-weighted |

**FREQUENCY RESPONSE CURVE**



# Sound and Acoustics II

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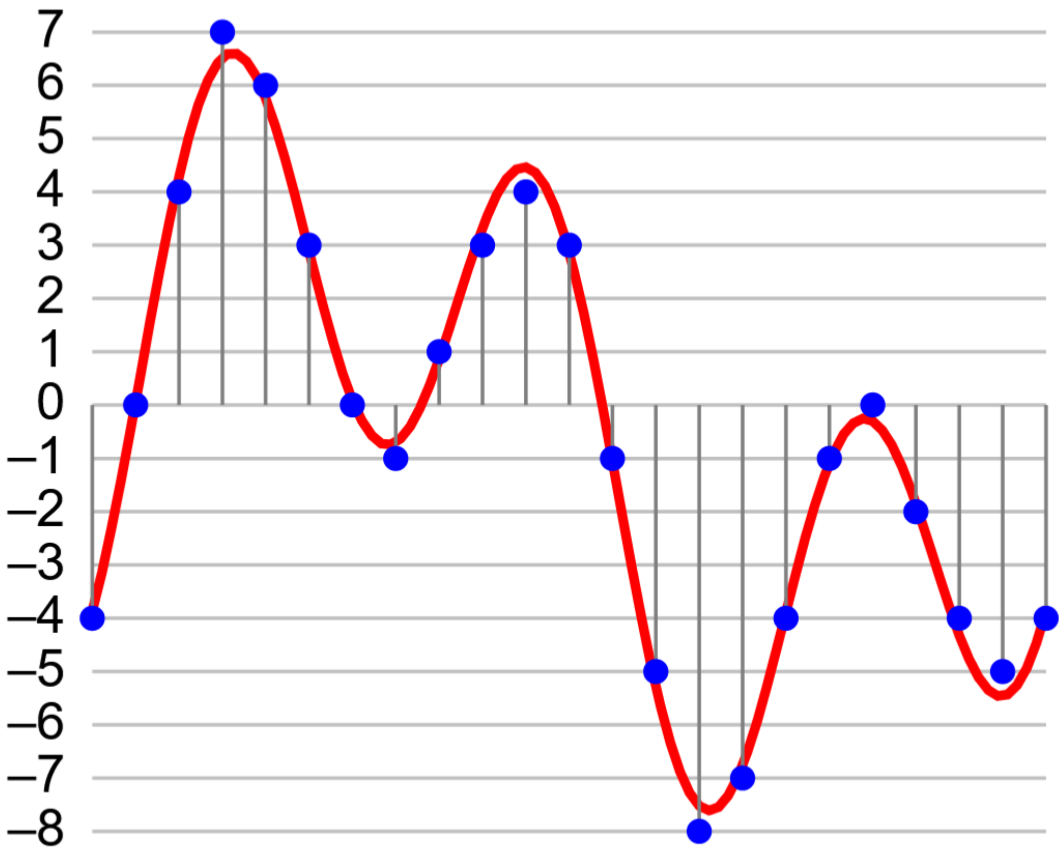
# Sampling

- Process of converting a continuous-time (analog) signal into a discrete-time (digital) signal
- Key factors:
  - Sampling rate – How often you measure the signal
  - Sampling depth – How finely do you measure the amplitude

# Nyquist-Shannon Theorem

- If we have a signal of bandwidth $f_0$, in order to reconstruct it perfectly we need to sample at $f_s >= 2f_0$
- Undersampling (sampling at lower than the *Nyquist rate*) causes a phenomenon known as *aliasing*
  - Aliasing causes a higher-frequency signal to appear lower-frequency
  - Can cause noise, distortion, etc. and leads to imperfect reconstruction

# Signal reconstruction



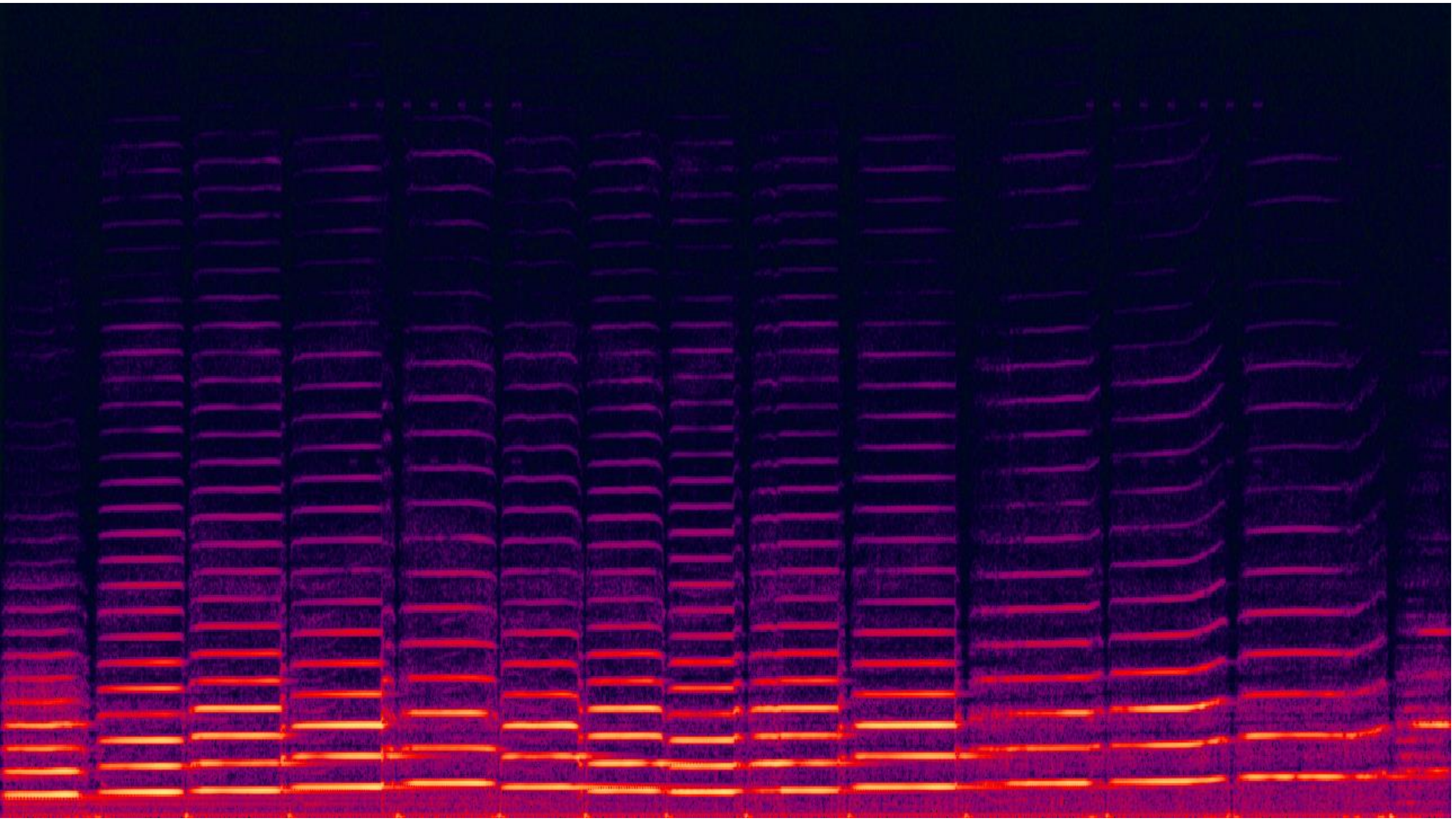

(Source : Wikimedia, [Aquegg])

- Digital signal = amplitude at each sample time
- How to reconstruct the analog signal?
- Most common method: Pulse-code modulation
  - At each sample time, output a voltage equal to the sample amplitude
  - Use a low-pass filter to get rid of aliasing

# Frequency power spectrum / Spectral Density

- Instead of looking at a signal in the time domain, we can look in the frequency domain
  - The transformation for a discrete-time signal is called a Discrete Fourier Transform (DFT) or Fast Fourier Transform (FFT)
- Peaks in the power spectrum correspond to a high amplitude at a given frequency
  - This can be associated with a resonance or other single-frequency emitter
- Different noise types appear differently in the power spectrum
  - White noise has constant power at all frequencies
  - 1/f noise has power inversely proportional to frequency

# Spectrograms



(Source : Wikimedia, Omegatron)

- A spectrogram is a way of visualizing data in *both* frequency and time
- Max frequency determined by sampling rate
- Min frequency determined by integration time
- Often gives you information that you can't get from one alone