# Intensity, loudness, and timbre

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# The power of sound!

# Sound power

- Rate at which energy is transferred
- Energy per unit of time emitted by a sound source in all directions
- Measured in watt (W)

# Sound intensity

- Sound power per unit area
- Measured in $W/m^2$

1 Watt

= 100 W

# Threshold of hearing

- Human can perceive sounds with very small intensities

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$$TOH = 10^{-12} W/m^2$$

# Threshold of pain

$$TOP = 10 \cdot W/m^2$$

# Intensity level

- Logarithmic scale
- Measured in decibels (dB)
- Ration between two intensity values
- Use an intensity of reference (TOH)

# Intensity level

$$dB(I) = 10 \cdot log_{10}(\frac{I}{I_{TOH}})$$

# Intensity level

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**log(1) = 0**

# Intensity level

- Every ~3 dBs, intensity doubles

# Intensity level

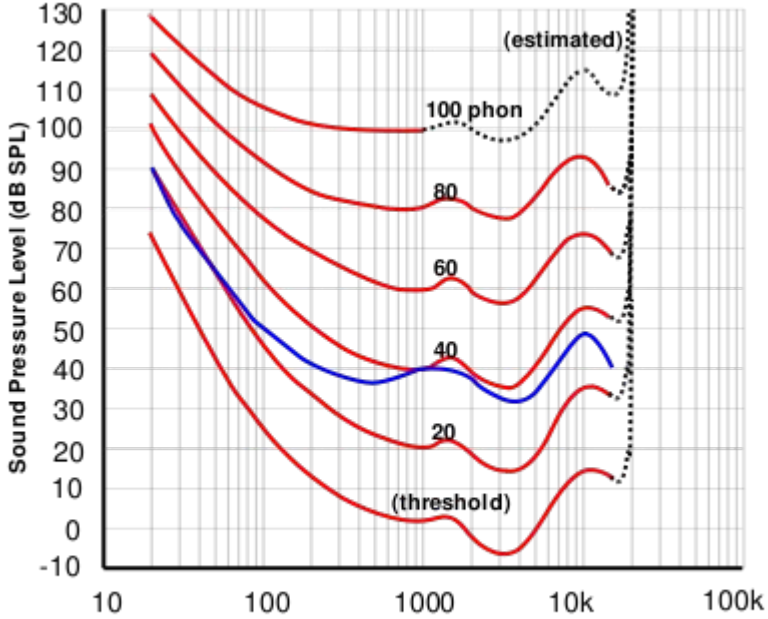
| Source | Intensity | Intensity level | × TOH |
|---|---|---|---|
| Threshold of hearing (TOH) | $10^{-12}$ | **0 dB** | 1 |
| Whisper | $10^{-10}$ | **20 dB** | $10^{2}$ |
| Pianissimo | $10^{-8}$ | **40 dB** | $10^{4}$ |
| Normal conversation | $10^{-6}$ | **60 dB** | $10^{6}$ |
| Fortissimo | $10^{-2}$ | **100 dB** | $10^{10}$ |
| Threshold of pain | 10 | **130 dB** | $10^{13}$ |
| Jet take-off | $10^{2}$ | **140 dB** | $10^{14}$ |
| Instant perforation of eardrum | $10^{4}$ | **160 dB** | $10^{16}$ |

Table 1.1 from [Müller, FMP, Springer 2015]

# Loudness

- Subjective perception of sound intensity
- Depends on duration / frequency of a sound
- Depends on age
- Measured in *phons*

# Equal loudness contours




Equal-loudness contours (red) (from ISO 226:2003 revision)
Original ISO standard shown (blue) for 40-phons

# Timbre

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- Colour of sound

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- Diff between two sounds with same intensity, frequency, duration

# Timbre

- Colour of sound
- Diff between two sounds with same intensity, frequency, duration
- Described with words like: bright, dark, dull, harsh, warm

# What are the features of timbre?

- Timbre is multidimensional

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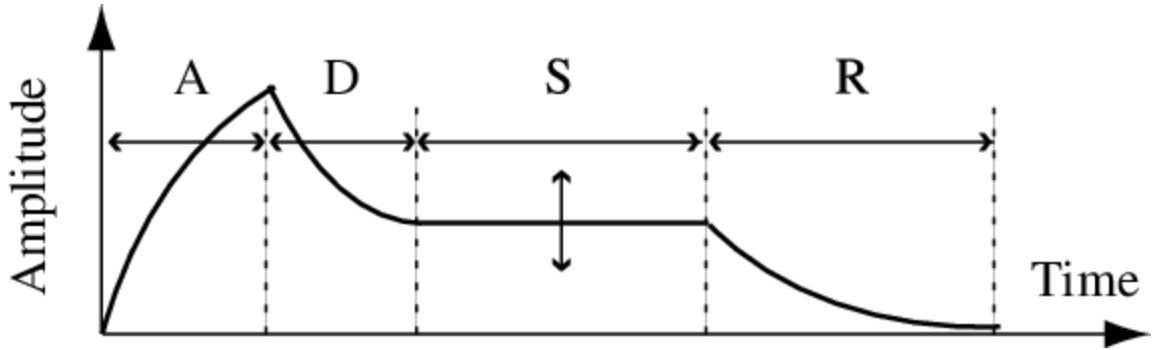
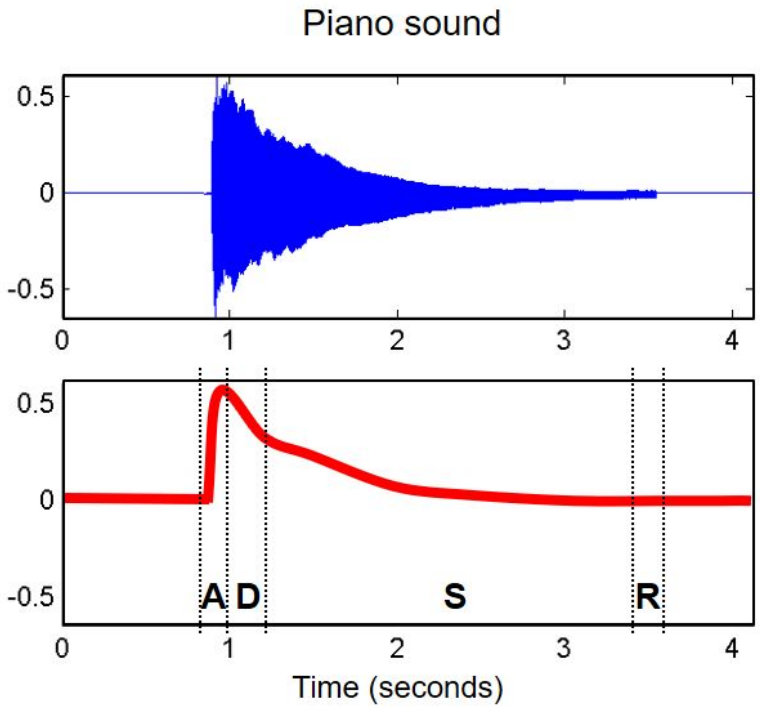
- Timbre is multidimensional
- Sound envelope
- Harmonic content
- Amplitude / frequency modulation

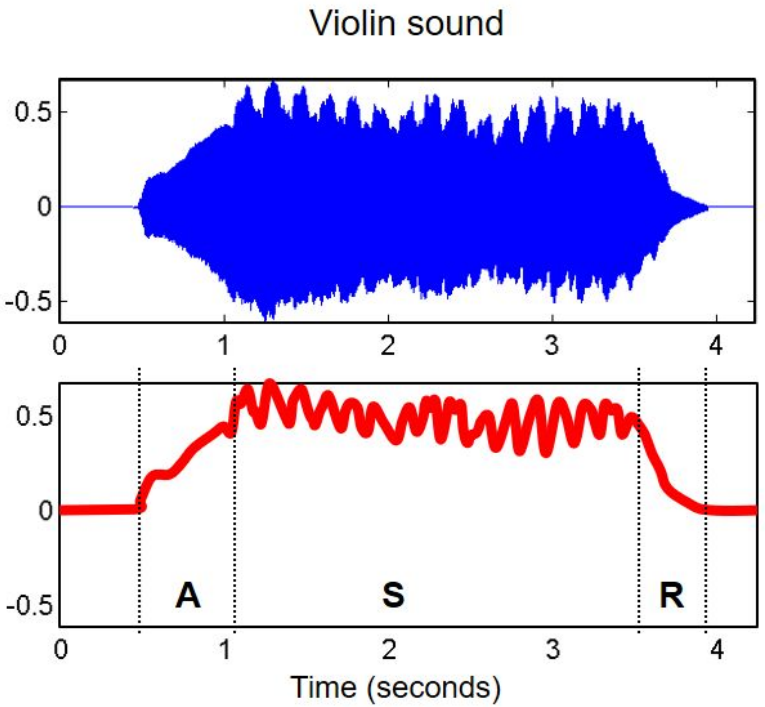
# Sound envelope

- Attack-Decay-Sustain-Release Model



# Sound envelope



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$$f_1 = 440$$

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$$f_1 = 440, f_2 = 2 \cdot 440 = 880$$

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$$f_1 = 440, f_2 = 2 \cdot 440 = 880, f_3 = 3 \cdot 440 = 1320, ...$$

# Complex sound

- Superposition of sinusoids
- A *partial* is a sinusoid used to describe a sound
- The lowest partial is called *fundamental frequency*
- A harmonic partial is a frequency that’s a multiple of the fundamental frequency
- *Inharmonicity* indicates a deviation from a harmonic partial

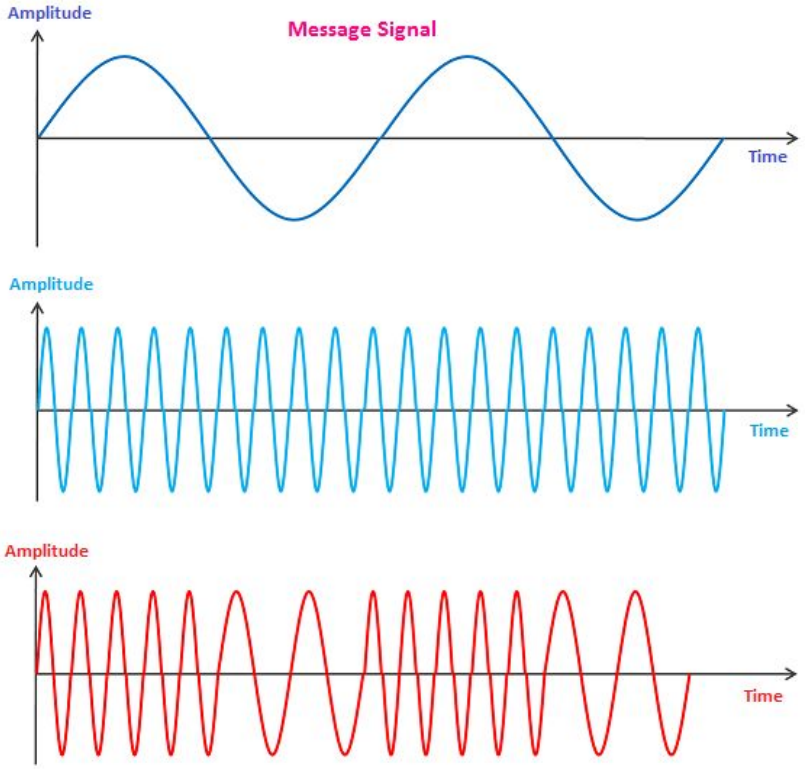
# Harmonic vs inharmonic instruments

# Harmonic content

# Frequency modulation

- AKA *vibrato*
- Periodic variation in frequency
- In music, used for expressive purposes

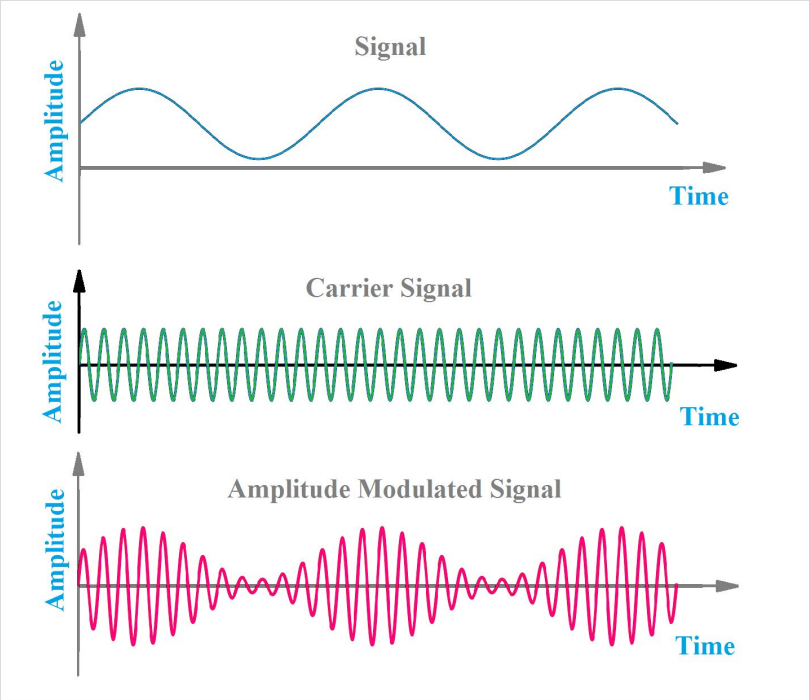
# Frequency modulation



# Amplitude modulation

- AKA *tremolo*
- Periodic variation in amplitude
- In music, used for expressive purposes

# Amplitude modulation



# Timbre recap

- Multifactorial sound dimension
- Amplitude envelope
- Distribution of energy across partials
- Signal modulation (frequency/amplitude)

# Sound recap

- Sound is a wave
- Frequency, intensity, timbre
- Pitch, loudness, timbre

# What’s up next?

- Introducing audio signal
- Audio to Digital Conversion (ADC)
- Digital to Audio Conversion (DAC)

# Join the community!

thesoundofai.slack.com