

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

Threshold of hearing

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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)
- Ratio between two intensity values
- Use an intensity of reference (TOH)

Intensity level

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

Intensity level

$$dB(I_{TOH}) = 10 \cdot \log_{10}\left(\frac{I_{TOH}}{I_{TOH}}\right) = 0$$

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$\log(1) = 0$

Intensity level

- Every ~3 dBs, intensity doubles

Intensity level

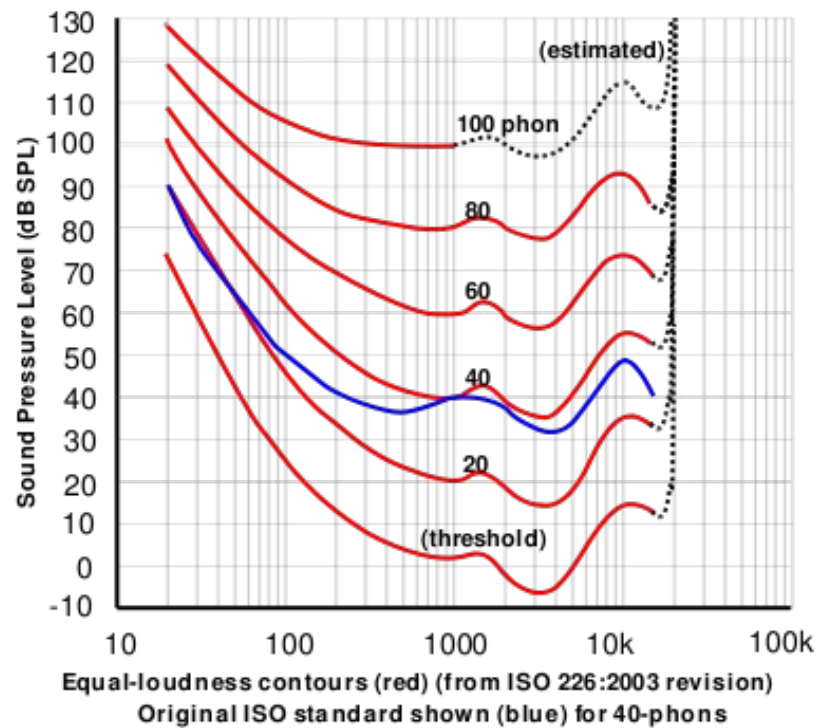
Source	Intensity	Intensity level	× TOH
Threshold of hearing (TOH)	10^{-12}	0 dB	1
Whisper	10^{-10}	20 dB	10^2
Pianissimo	10^{-8}	40 dB	10^4
Normal conversation	10^{-6}	60 dB	10^6
Fortissimo	10^{-2}	100 dB	10^{10}
Threshold of pain	10	130 dB	10^{13}
Jet take-off	10^2	140 dB	10^{14}
Instant perforation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



Timbre

Timbre



Timbre

- Colour of sound

Timbre

- Colour of sound
- 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?

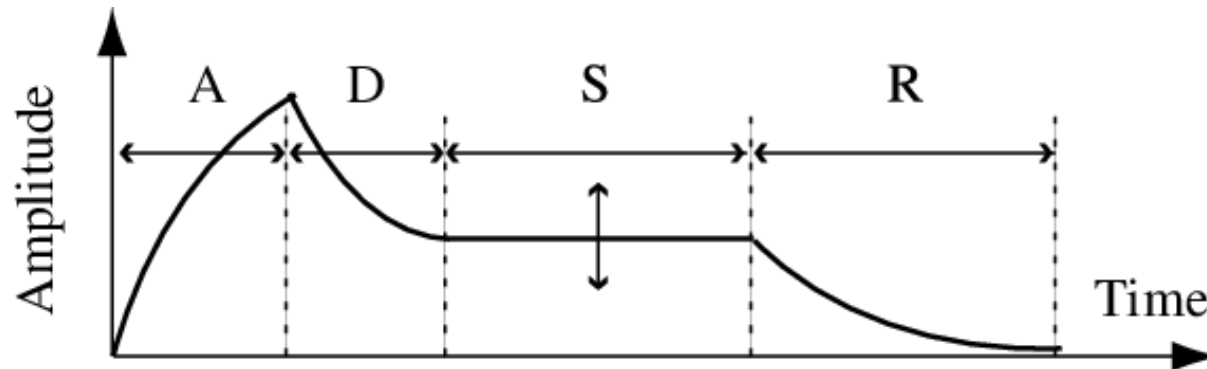
- Timbre is multidimensional

What are the features of timbre?

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

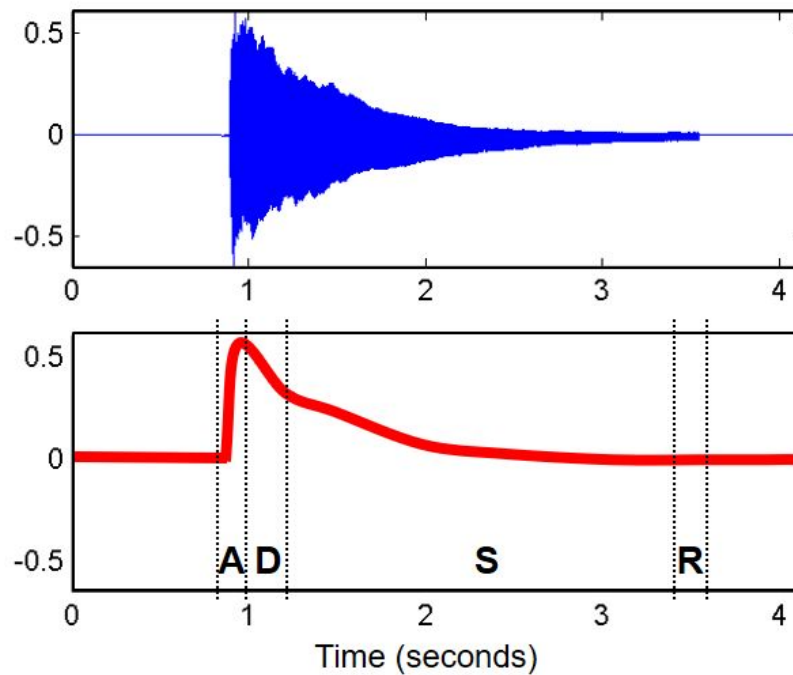
Sound envelope

- Attack-Decay-Sustain-Release Model

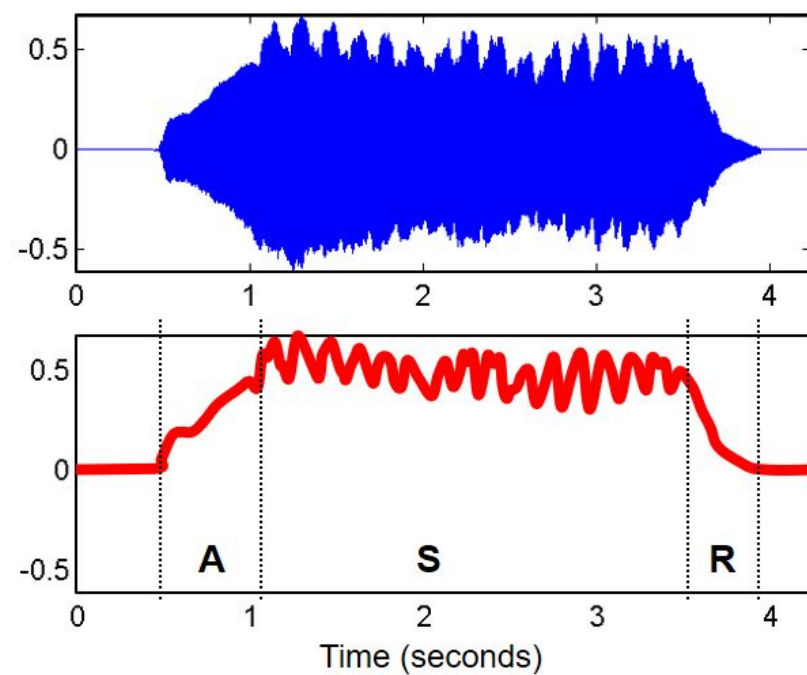


Sound envelope

Piano sound



Violin sound



Complex sound

- Superposition of sinusoids

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- A *partial* is a sinusoid used to describe a sound

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$$f_1 = 440$$

Complex sound

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

Complex sound

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

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



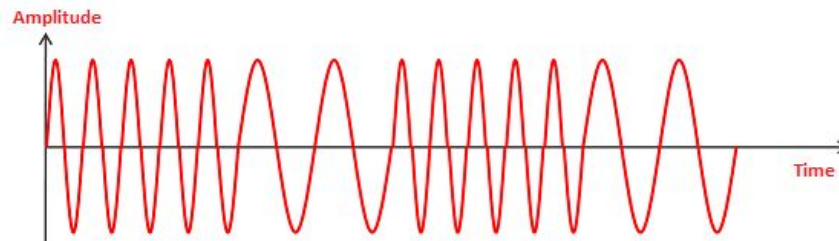
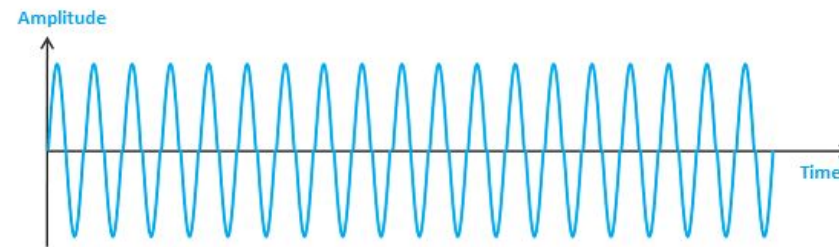
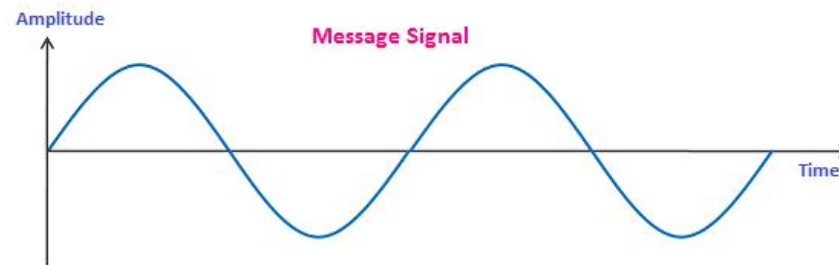
Harmonic content



Frequency modulation

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

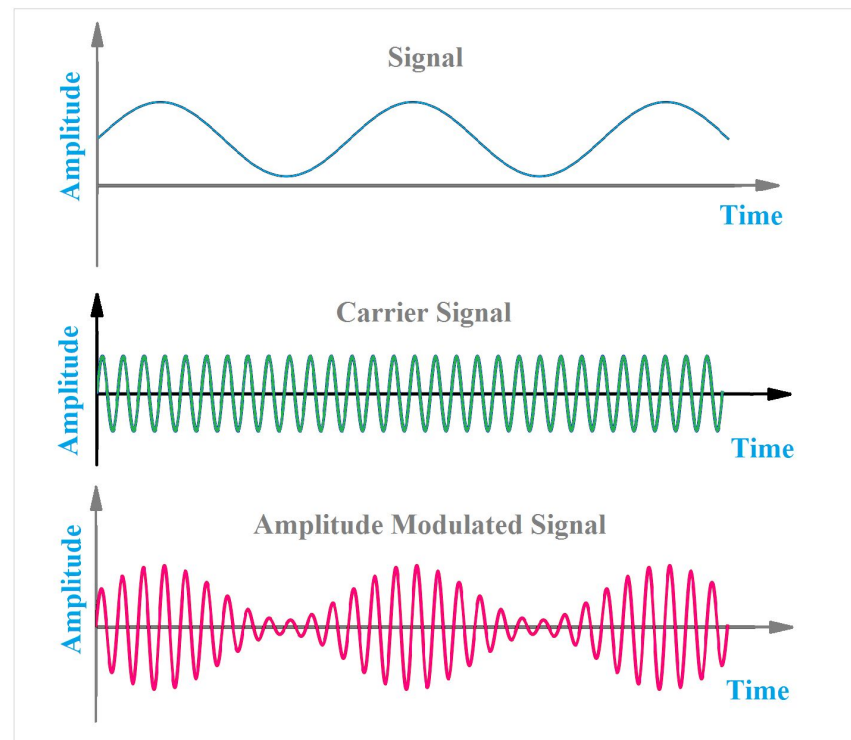
Frequency modulation



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)