Aalto University
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Communication acoustics
Ch 6: Musical Instruments and Sound Synthesis

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This chapter

- Acoustic music instruments
  - Types
  - Basic operation principle
  - Examples: guitar, trumpet
- Sound synthesis
  - Frequency- and time-domain models of musical instruments
  - Synthesizers

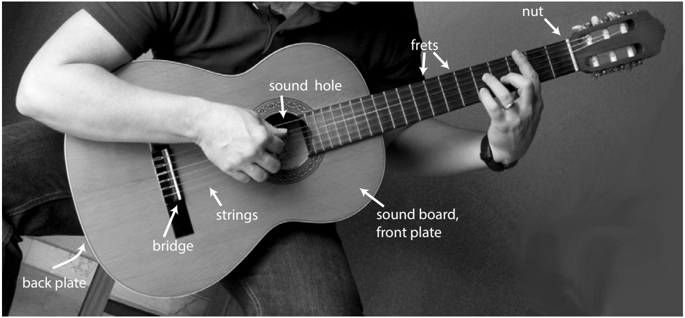
Acoustic instruments

- Idiophones
  - Instument body makes the sound
  - Xylophone, church bell, rattle
- Membranophones
  - Membrane is the main vibrating unit
  - Drums
- Chordophones
  - String is the main vibrating unit
  - Guitar, piano, violin, harp
- Aerophones
  - Air column is the main vibrating unit
  - Trumpet, pipe organ, flute

How sound is generated

- Excitation
  - The player of then instrument applies a force to a part of the instrument
  - Something starts to vibrate
  - The repetition frequency of vibration is often controlled by the player
- Resonance
  - Often the vibration is led to resonant structures in instrument
  - Colors the sound, and helps to radiate more sound
- Radiation
  - Often the main source of radiation is the resonator or the air column

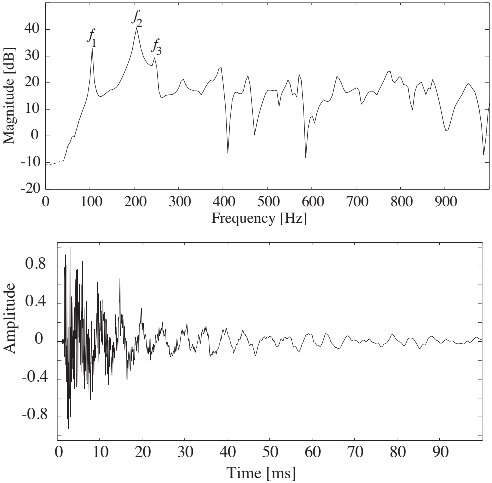
Example 1: Guitar



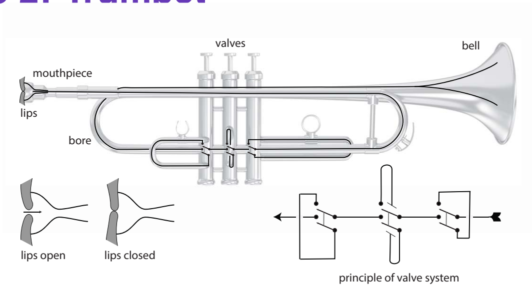
- Chordophone, player plucks the strings causing vibration
- The length of string defines directly f_0
- Guitar body, both air volume and plates, act as resonators
- Sound is radiated mostly from sound hole and sound board

Link to string movement video | Link to bass string movement video

Guitar body response



Example 2: Trumpet



- Aerophone, air column is the main vibrating unit
- The vibrations in player's lips coupled to modes of the column
- Frequencies of modes follow roughly harmonic spectrum

(notes of valveless trumpet in C)

- Length of air column is changed with valves
- Sound is radiated mostly from the bell

Synthesis of musical sounds

- Frequency-domain models of instruments
- Time-domain models of instruments
- Other music sound synthesis methods (not models of instruments)

Frequency-domain models of music instruments

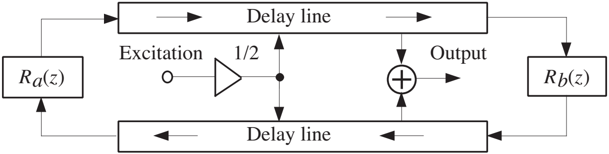
- Excitation is modeled as input signal $X(j\omega)$
- Vibrating unit(s) and resonators are modeled as $H_i(j\omega)$
- Output: $Y(j\omega) = X(j\omega)\prod_i H_i(j\omega)$
- Computationally efficient
- Valid if system is LTI (linear and time invariant)
- Many instruments not: trumpet (excitation coupled to modes), piano (hammer strucks many times, excitation depends on string position)
- Some instruments yes: Guitar

Time-domain models of music instruments

- The vibrating unit is modeled with time-domain approach, such as a delay line or a mesh of nodes
- Resonators can be modeled with IIR or FIR filters
- Computationally laborious methods

Time-domain model of guitar string

- String is modeled as a delay line
- Damping in each end
- Excitation is given as input signal
- Excitation can be convolved with body response as in the demo below
- Output is taken out from the position of guitar microphones



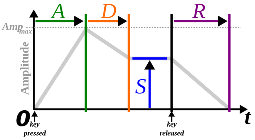
Click to hear guitar model playing Bach

Other methods to synthesize musical sounds

- Sampling, record musical notes and play them back upon request from user
- Additive synthesis, add up sinusoids to obtain desired sound
- Subtractive synthesis, generate spectrally rich sound, and filter it to get needed sound
- Non-linear synthesis, e.g., frequency-modulation (FM) synthesis (Yamaha DX 7)

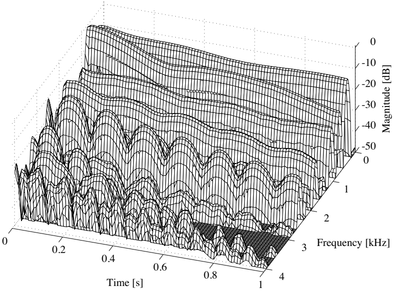
Envelope of musical sounds

- In synthesizers: attack - decay - sustain - release



From: http://en.wikipedia.org/wiki/Synthesizer#ADSR_envelope

- In real instruments similar, but each harmonic of a real instrument has its own temporal envelope



References

These slides follow corresponding chapter in: Pulkki, V. and Karjalainen, M. Communication Acoustics: An Introduction to Speech, Audio and Psychoacoustics. John Wiley & Sons, 2015, *where also a more complete list of references can be found*.