

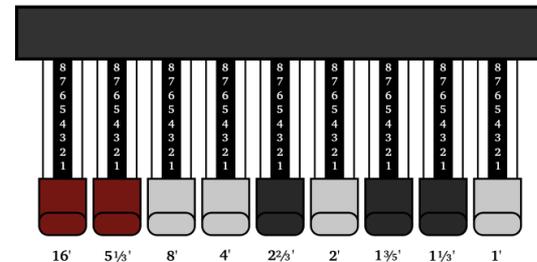
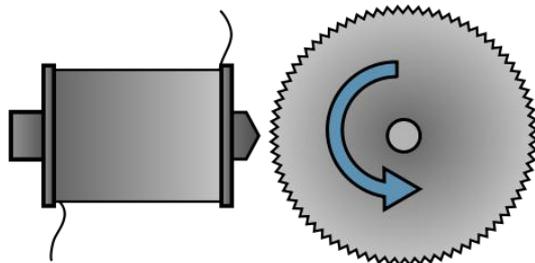


Electronic musical keyboards

- some story...
- a possible project

Hammond organ (~ 1960-70)

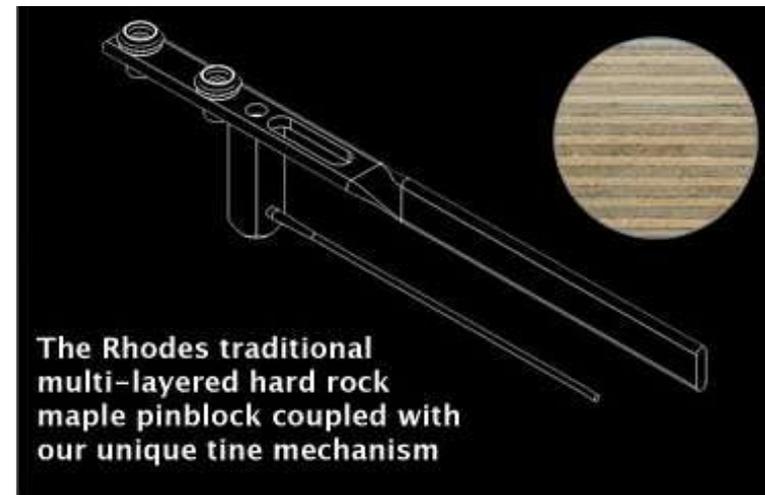
- it's an *electromechanical* organ
- each individual tone is generated by a mechanical tonewheel which rotate in front of an electromagnetic pickups
- 91 tonewheels -> 7.5 octaves
- The component waveform ratios are mixed by sliding drawbars



- modern Hammond organs are all digital ☹️

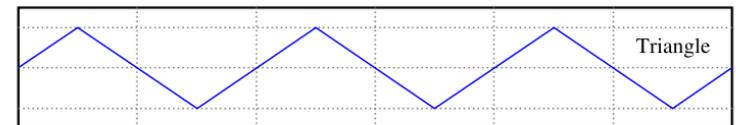
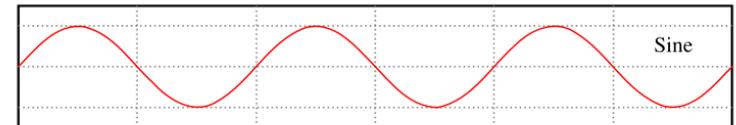
Rhodes piano (~ 1970)

- *Electromechanical* piano
- based on an asymmetrical tuning fork (*diapason*):
- a stiff wire (called a "tine") struck by a felt-tipped (neoprene rubber-tipped after 1970) hammer acting as one side of the tuning fork, and a counterbalancing resonating tone bar above the tine acting as the other side.
- vibrations are then picked up by an electromagnetic pick-up (one for each tine), and amplified



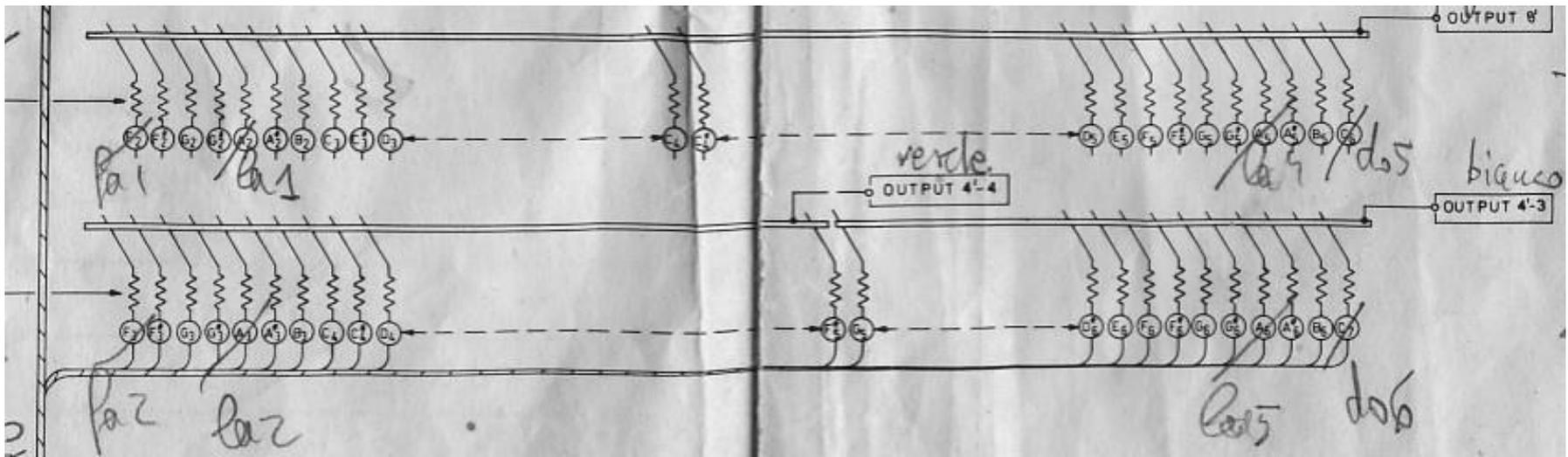
Moog (~ 1970)

- It was a *modular synthesizer*
- The modular synthesizer is a type of synthesizer consisting of separate specialized modules connected by wires (patch cords) to create a so-called patch. E.g.
 - VCO, Voltage-controlled oscillator,
 - VCF, Voltage-controlled filter,
 - VCA, Voltage-controlled amplifier,
 - Envelope generator



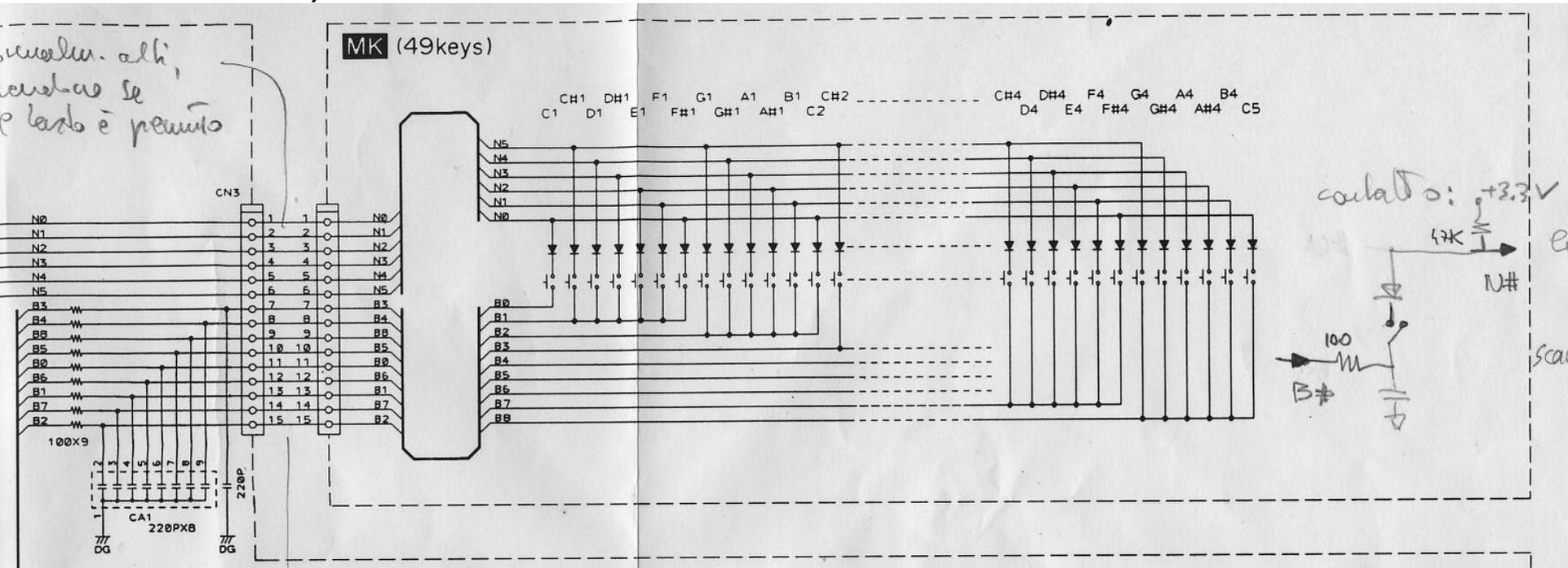
Old electronic keyboards - all analog

- 12 oscillators
- for each oscillator, a cascade of (typically 7) FFs acting as dividers -> square waves
- on the keyboard, one switch for each stop (e.g. 4 switches per key: 8', 4', 2 2/3', 2')
- all the signals for one stop (e.g. 8') are collected together
- and sent to analog filters (mostly low-pass)



modern keyboards

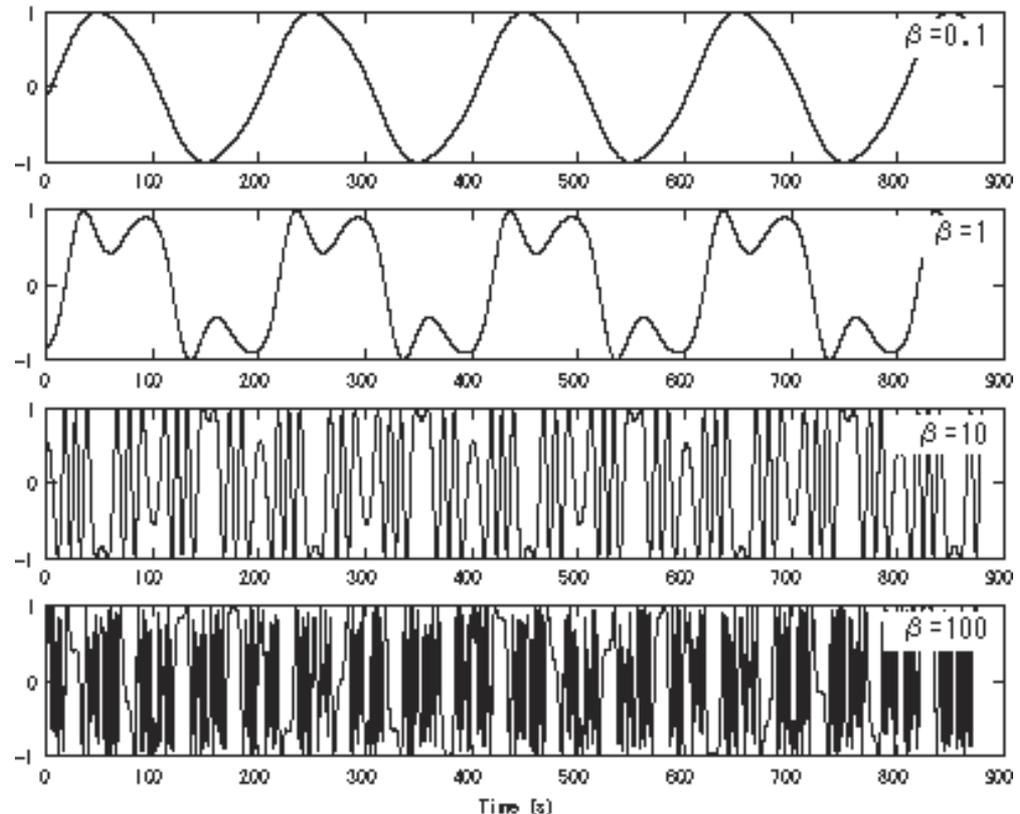
- the pressed keys are read using a row-column scan (as PC keyboards)
- a *Note-On* or *Note-Off* signal is generated for each (de)pressed key
- in dynamic keyboards, *key speed* is also measured (reading the time delay between initial and final key motion) to control volume



frequency modulation (FM) synthesis (1/2)

- the timbre of a simple waveform is changed by *frequency modulating* it with a modulating frequency that is also in the audio range

For synthesizing harmonic sounds, the modulating signal must have a harmonic relationship to the original carrier signal. Otherwise, bell-like dissonant and percussive sounds can be created.

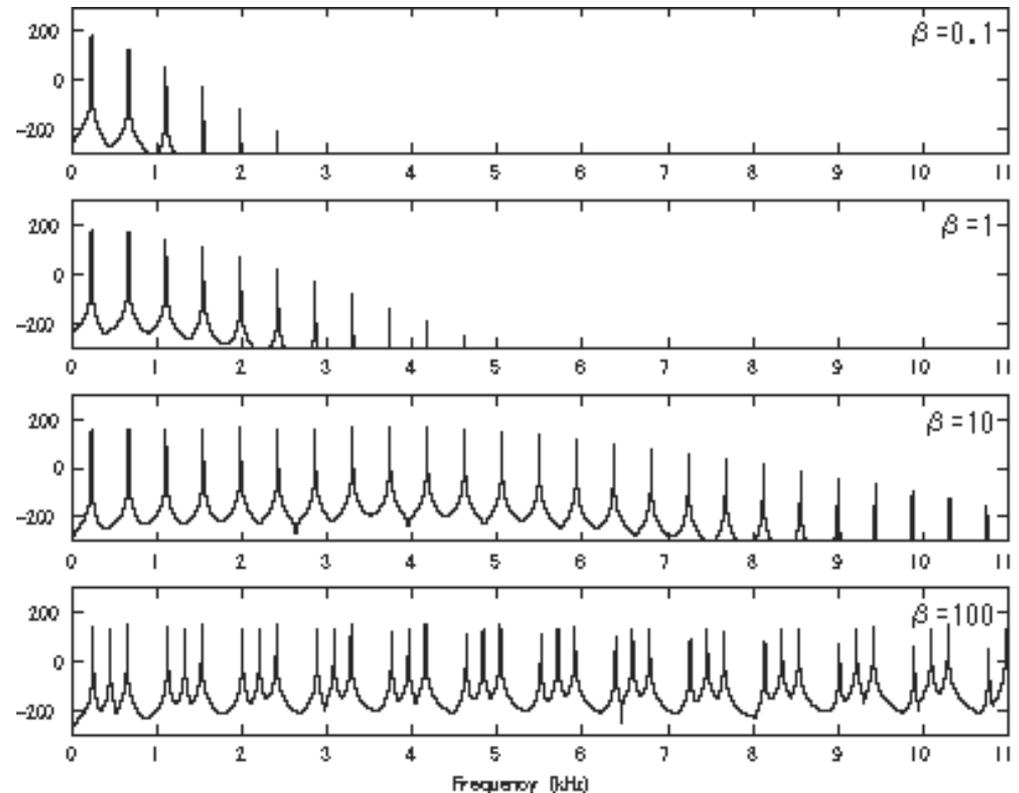


A 220 Hz carrier tone modulated by a 440 Hz modulating tone with various choices of modulation index

frequency modulation (FM) synthesis (2/2)

- invented in 1973 at Stanford University
- digital hardware implementation (actually based on phase modulation) by Yamaha

- Behaviour of the signals in the previous slide
- The harmonic distribution of a simple sine wave signal modulated by another sine wave signal can be represented with Bessel functions

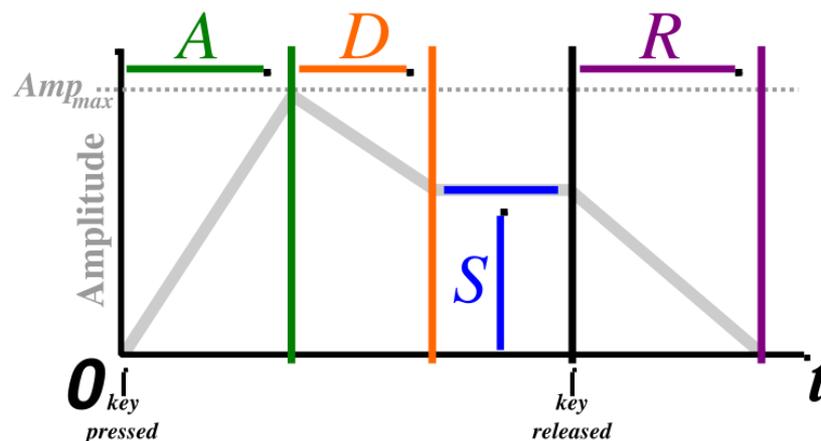


the ADSR envelope

Its function is to modulate some aspect of the instrument's sound — often its loudness — over time.

Four parameters:

- *Attack*: How quickly the sound reaches full volume after the sound is activated (the key is pressed)
- *Decay*: How quickly the sound drops to the sustain level after the initial peak
- *Sustain*: The "constant" volume that the sound takes after decay until the note is released. Note: it's a volume level, not a time period
- *Release*: How quickly the sound fades when a note ends (the key is released)



sample-based synthesis (1/2)

- the seed waveforms are sampled sounds or instruments
- low processing power requirements: most of the nuances of the sound models are contained in the pre-recorded samples rather than calculated in real-time
- when computer memory was expensive, samples had to be as short as possible -> looping a part of the sample (often a single wave), and then using a volume envelope curve to make the sound fade away
- a single recording of an instrument was played back faster or slower to reproduce other pitches

sample-based synthesis (2/2)

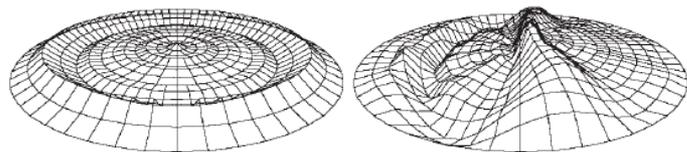
- Multisampling:
 - the original instrument is sampled at regular intervals to cover regions of several adjacent notes (called "*splits*") or for every note
 - the same note may be sampled at several different levels of intensity
- E.g.: Casio Celviano (piano)
 - Tri-element system: three (stereo) samples at three different dynamics levels per note
 - 128 note poliphony
 - Acoustic Resonance System (to simulate the behaviour of the whole acoustic system)

physical modelling synthesis (1/3)

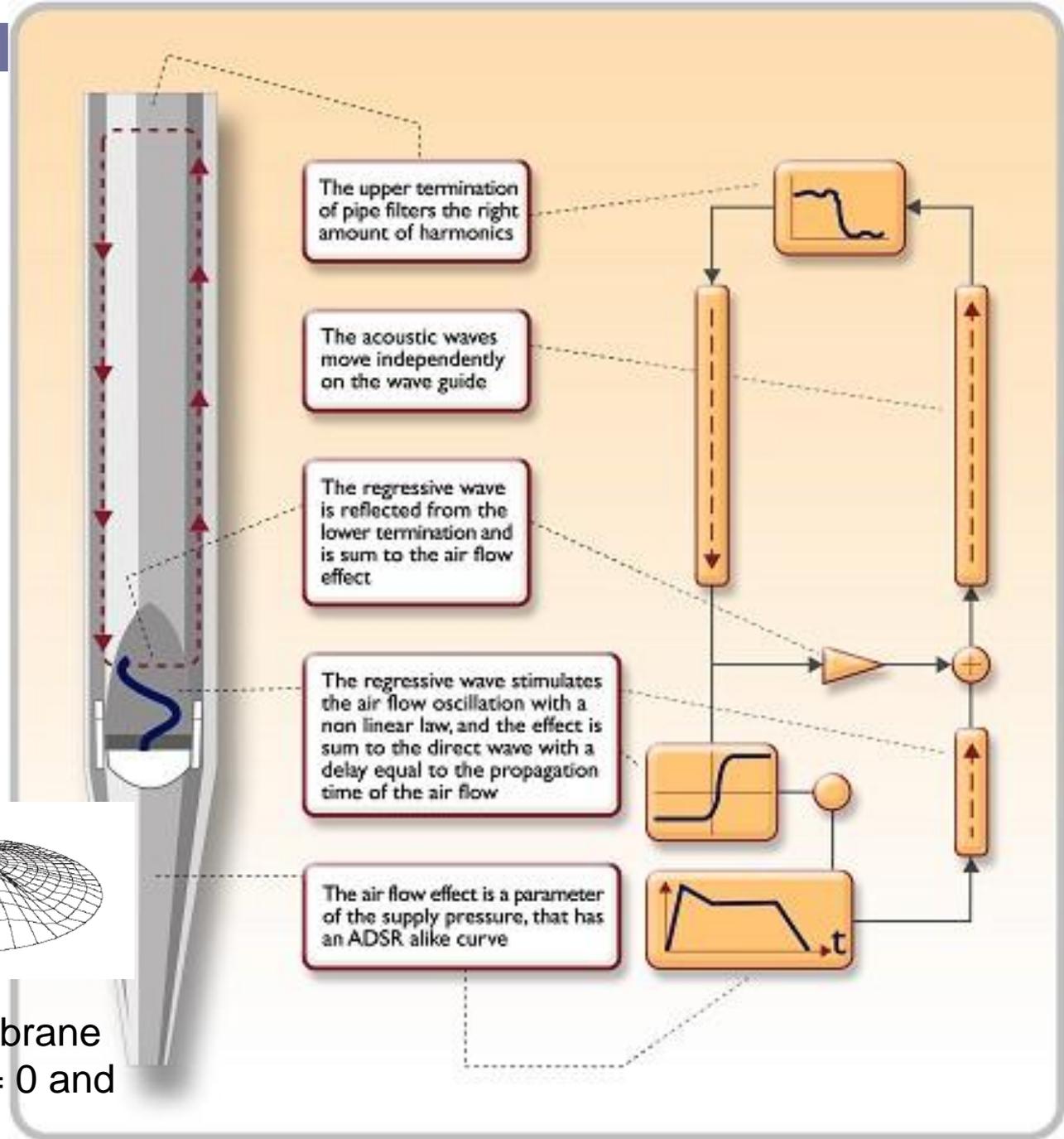
- Digital waveguide synthesis is the synthesis of audio using a digital waveguide.
- Digital waveguides are efficient computational models for physical media through which acoustic waves propagate
- Digital waveguide models therefore comprise
 - digital delay lines to represent the geometry of the waveguide which are closed by recursion
 - digital filters to represent the frequency-dependent losses and mild dispersion in the medium,
 - and often non-linear elements

physical modelling synthesis (2/3)

two examples:
organ pipes,
and drums



Transversal vibrating membrane
with excitation point at $r_0 = 0$ and
 $r_0 = 2/3R$.



physical modelling synthesis (3/3)

- Waveguides such as acoustic tubes may be thought of as three-dimensional, but because their lengths are often much greater than their cross-sectional area, they are modelled as one dimensional waveguides
- Membranes, as used in drums, may be modelled using two-dimensional waveguide meshes
- reverberation in three dimensional spaces may be modelled using three-dimensional meshes

MIDI

- MIDI (Musical Instrument Digital Interface) is an (old, but still used) industry-standard protocol that enables electronic musical instruments, computers, and other equipment to communicate, control, and synchronize with each other
- MIDI does not transmit an audio signal — it transmits *event messages* such as the pitch and intensity of musical notes to play
- both in real time (typically using a serial connection: 31.25 kBaud, current-loop, 5-pin DIN connector) or offline (MIDI files)

A possible project

- An MCU continuously reads the keyboards and generates *Note-On* and *Note-Off* commands
- which are send via SPI (in a MIDI-like way) to another MCU
- which synthesizes the waveforms
- and sends them to the DAC
- Analog signal is sent to the power amplifier and from there to the speakers

workgroups

- On the first MCU
 - keyboard (and also footswitch, for the piano) reading, *Note-On/Off* command generation, serial transmission
- on the second MCU
 - serial port reading
 - slot management (for polyphony)
 - sound generation
 - simple sine
 - FM (s/w implementation)
 - sample based
 - physical modelling (with a very simple model)
 - DAC management (using interrupt or polling)
- Other possible tasks
 - moog
 - waa-waa (using the keyboard joystick)
 - ...