Problem 17

Didgeridoo

Problem

The 'didgeridoo' is a simple wind instrument traditionally made by the Australian Aborigines from a hollowed-out log. It is, however, a remarkable instrument because of the wide variety of timbres that it produces. Investigate the nature of the sounds that can be produced and how they are formed.

Principle of work

- The player's lips vibrate to produce sound
- The lips' vibrations consist of many frequencies depending on the intention (and ability) of the player
- Didgeridoo amplifies only its characteristic (resonant) frequency and its overtones
- By changing the frequency distribution of the lip vibration the player can modify the timbre

Experiment

Properties of our didgeridoo:

Length: 1.22 m

Internal diameter: 3.5 cm

External diameter: 5.5 cm

Wall thickness: 1 cm

- Both blowing and free end had the same diameter – no flare

- Resinous gum makes playing easier

- How to play: seal the blowing end on the mouth, blow and vibrate the lips

For our experiment we used:

Didgeridoo

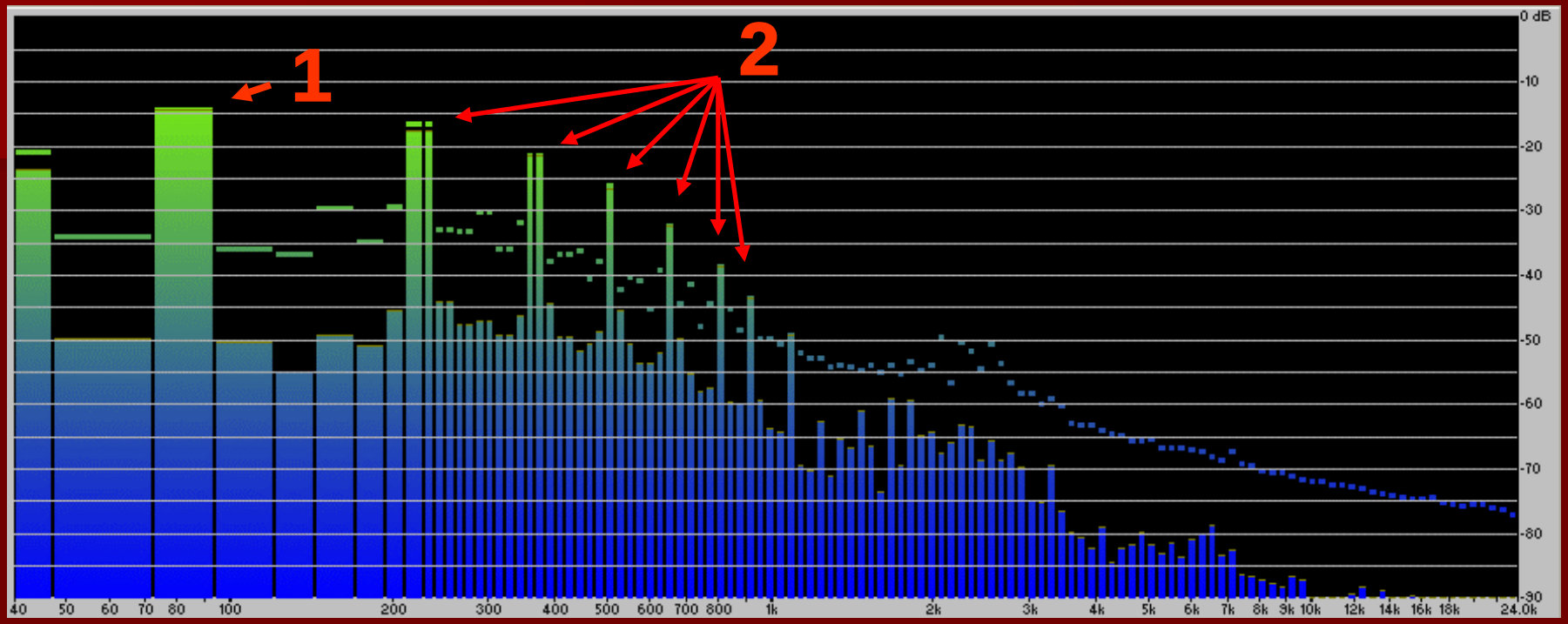
Microphone

Sound spectrometer

Osciloscope

- We measured basic (resonant) frequency and its overtones
- With osciloscope we observed form of the sound waves

Spectrogram:



From the spectrogram we can see:

1. Basic (resonant) frequency
2. Overtones (harmonics)

1. Basic frequency

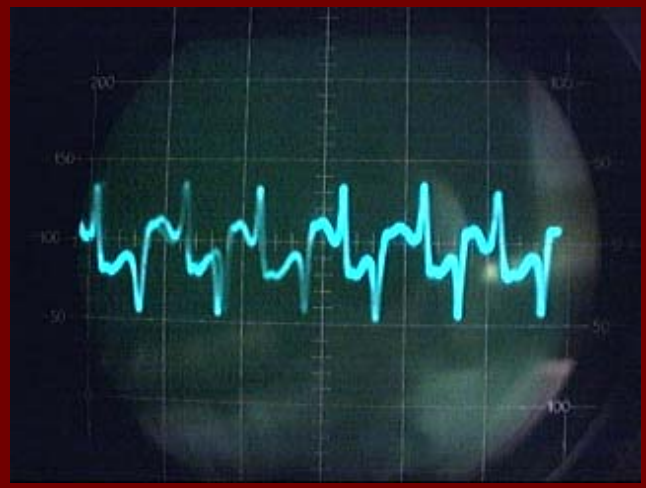
- The resonant frequency of the instrument
- It changes with length
- The lowest frequency we can play
- With pressure variations we can change it for ± 5 Hz
- Always present, although maybe owerpowered by overtones

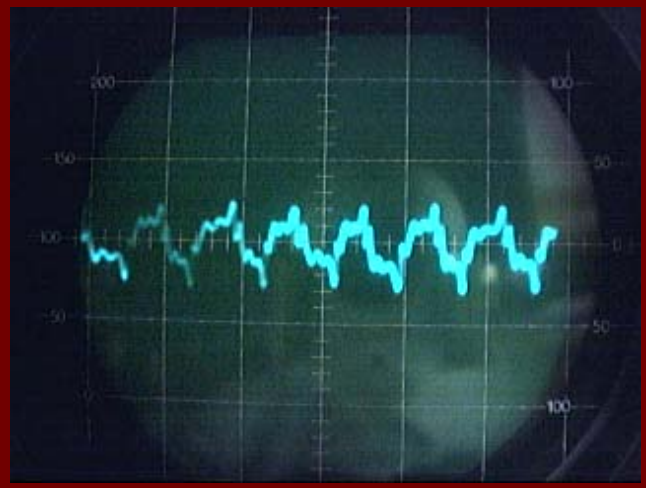
2. Overtones

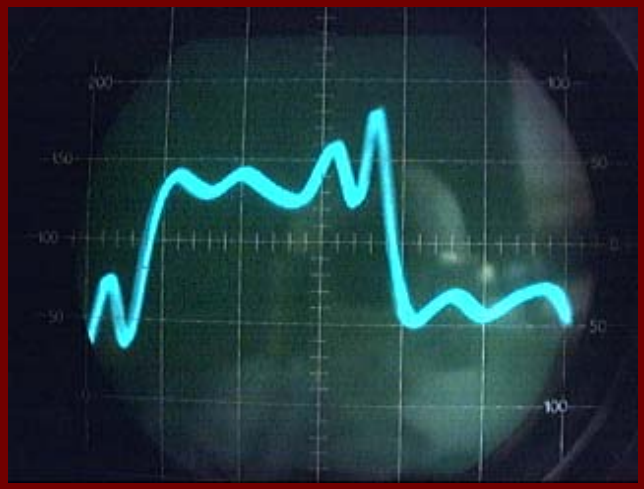
- The main reason for characteristic didgeridoo timbre
- Intensity depends on pressure and mode of lipps vibration
- Many combinations possible
- Sometimes louder than basic frequency

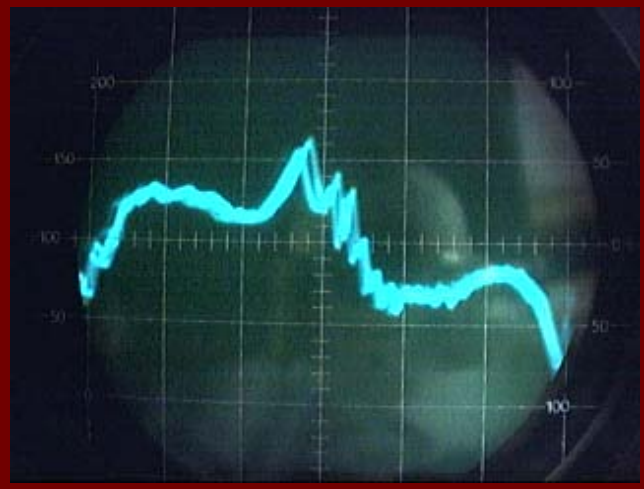
Osciloscope pictures:

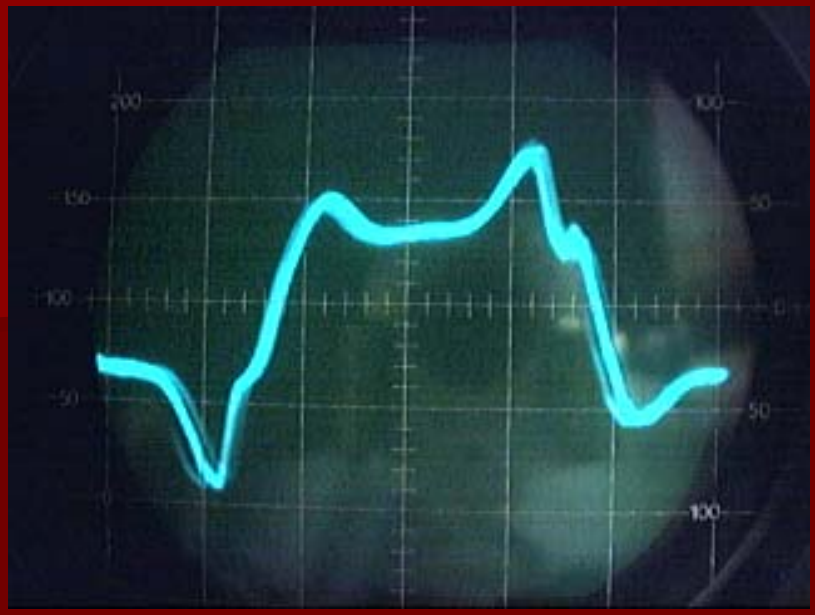
- Different timbres



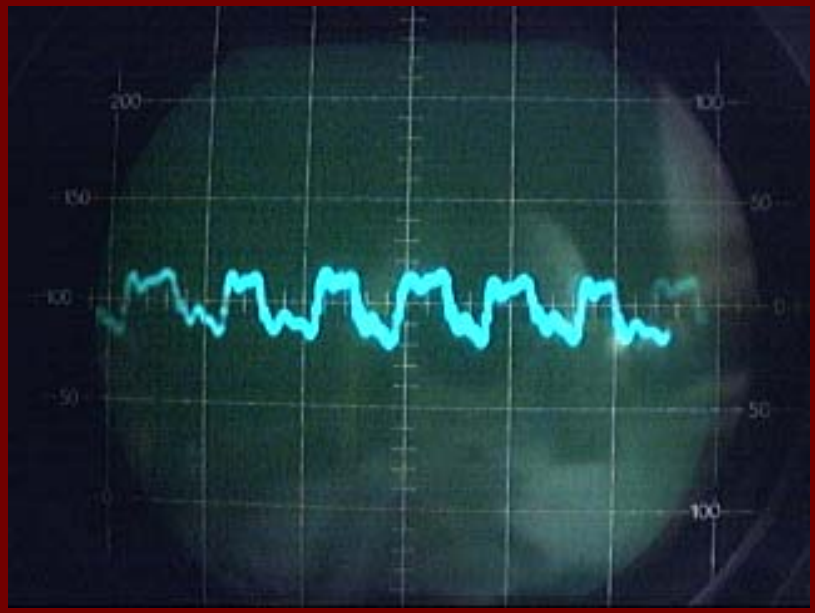








- Didgeridoo sound, with minimum overtones included



- Low amplitude produced with low air pressure

Experimental conclusion

- Measured basic frequency: ~67 Hz
- Overtones change due to:

  Pressure variations

  Variations in lips vibration

  Position of the tongue

- Overtones define the timbre

Explanation

Waves in a tube

- By lips vibration standing wave is formed
- Wave frequency – resonant frequency of the tube
- It depends on:

  length (cyllindrical instruments)

  flare dimensions (conical instrumnents)

Overtones frequency

- Integral multiples of the basic frequency
- Their intensities determine the timbre
- In the general case (flare, boundary effects) we can calculate the frequency f_n:

$$f_n = \left(n - \frac{1}{2}\right)\frac{c}{4L'}\left\{1 + \left[1 + \frac{4(d_2 - d_1)}{\pi^2 d_1 \left(n - \frac{1}{2}\right)^2}\right]^{\frac{1}{2}}\right\}$$

$$L' = L + 0.3d_2$$

n – integer

c – speed of sound

L – length of the instrument

d_1 – diameter of blowing end

d_2 – diameter of larger end

(N. Fletcher, Acoustics Australia, 1996.)

- In our case: $d_1 = d_2$
- Calculated resonant frequency: 69.1 Hz
- Measured frequency: 67 Hz

Overtones amplitude

- For a_n we have:

$$a_n = \frac{\sqrt{\frac{2I}{\rho c}}}{2\pi f_n}$$

I – intensity of sound

ρ – density of air

c – speed of sound

f_n - frequency

Wave form

- Determined by the amplitude in the Fourier series:

$$u(t) = \sum_n \left(a_n \cos 2\pi n f_1 t + b_n \sin 2\pi n f_1 t \right)$$

u – time part of wave function

a_n – amplitude [mm]

n – integer

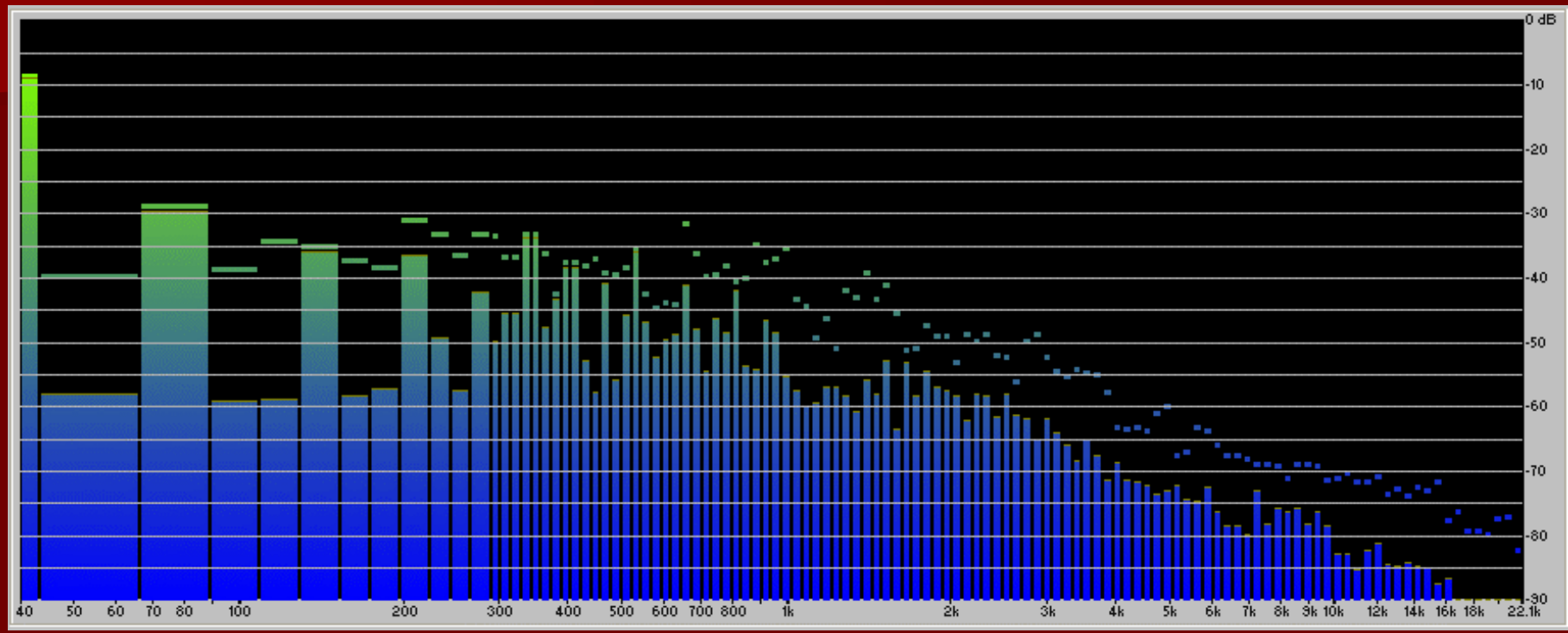
f_1 – resonant frequency

(I. Supek: Teorijska fizika i struktura materije, vol.1)

Fourier analysis

- The amplitude a_n is determined from the spectrogram:

Example of Fourier analysis



$$u(t) = 1.25\cos(2 \cdot 67\pi t) + 0.6\cos(2 \cdot 134\pi t) + 0.4\cos(2 \cdot 201\pi t)$$
$$+ 0.28\cos(2 \cdot 268\pi t) + 0.24\cos(2 \cdot 335\pi t) + \ldots$$

Conclusion

- Didgeridoo timbre consists of:
  - Basic (resonant) tone
  - Overtones
- Timbre is formed by resonant oscillation of the air column
- The timbers depend on the instrument properties
- The player mostly controles the characteristics of the timbre