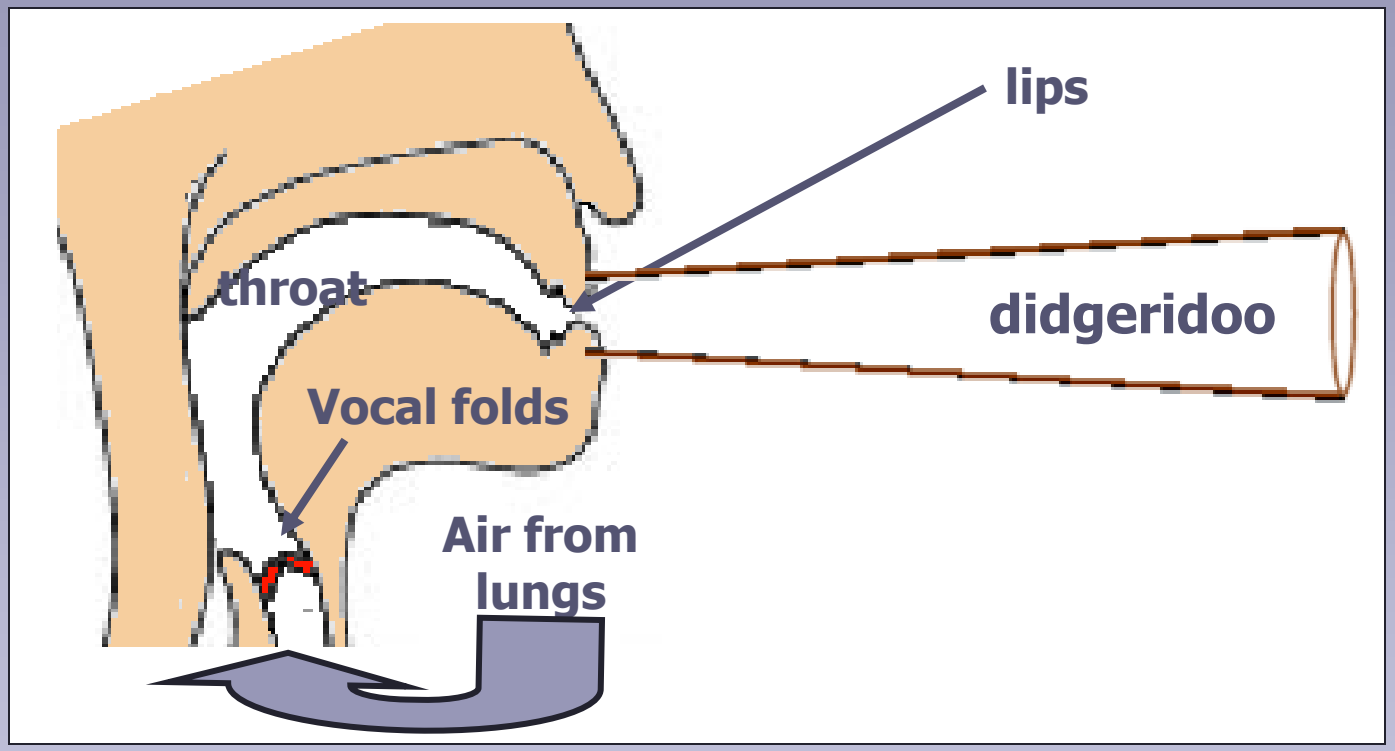
17. „Didgeridoo"

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.

What is a „didgeridoo”?

Scheme of didgeridoo :



- instrument’s interior is chamfered by termites;
- sometimes irregular shape of the pipe (twisted, conical);
- beeswax mouthpiece

What is responsible for interesting and remarkable sound of didgeridoo ?

What is responsible for the sound of didgeridoo?

sound waves modified by the instrument

1st case: smooth interior, straight didj

2nd case: smooth interior, widened didj

3nd case: rough interior

sound waves created with player's vocal folds and throat

motion of player's lips, tongue and cheeks – sounding mechanism

lip valve – vibration analysis

Changing the volume and shape of a resonant cavity (throat) by cheeks and tongue

What is responsible for the sound of didgeridoo?

sound waves amplified by the instrument

1st case: smooth interior, straight didj

Didgeridoo – pipe of an opened or closed end ?

We can suppose, that didgeridoo is a tube closed on one end by lips – in that case standing wave will appear when we raise oscillations of frequencies defined by the equation:

$$f = \frac{(2n+1)c}{4(L+\Delta l)} \qquad (n = 0,1,2,3\ldots),$$

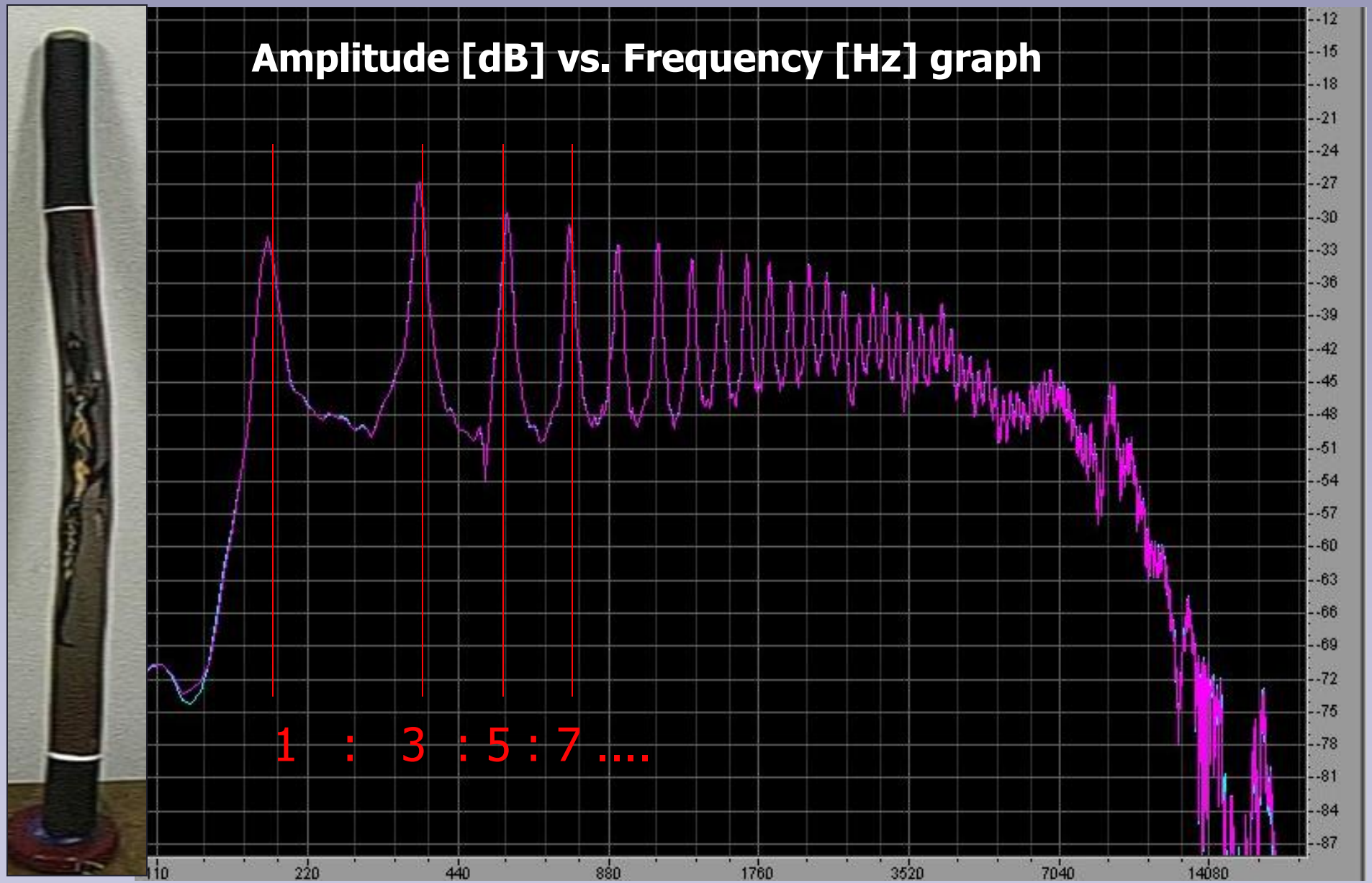
After deeper analysis, we can say, that it is not completely sealed by mouth – other harmonic frequencies (of course they will be weaker resonated) will appear – they are defined by equation:

$$f_{\lambda/2} = \frac{nc}{2(L+\Delta l)} \qquad (n = 1,2,3\ldots),$$

c – sound velocity in air, $\Delta l = \frac{8a}{3\pi}$ **- entry correction**

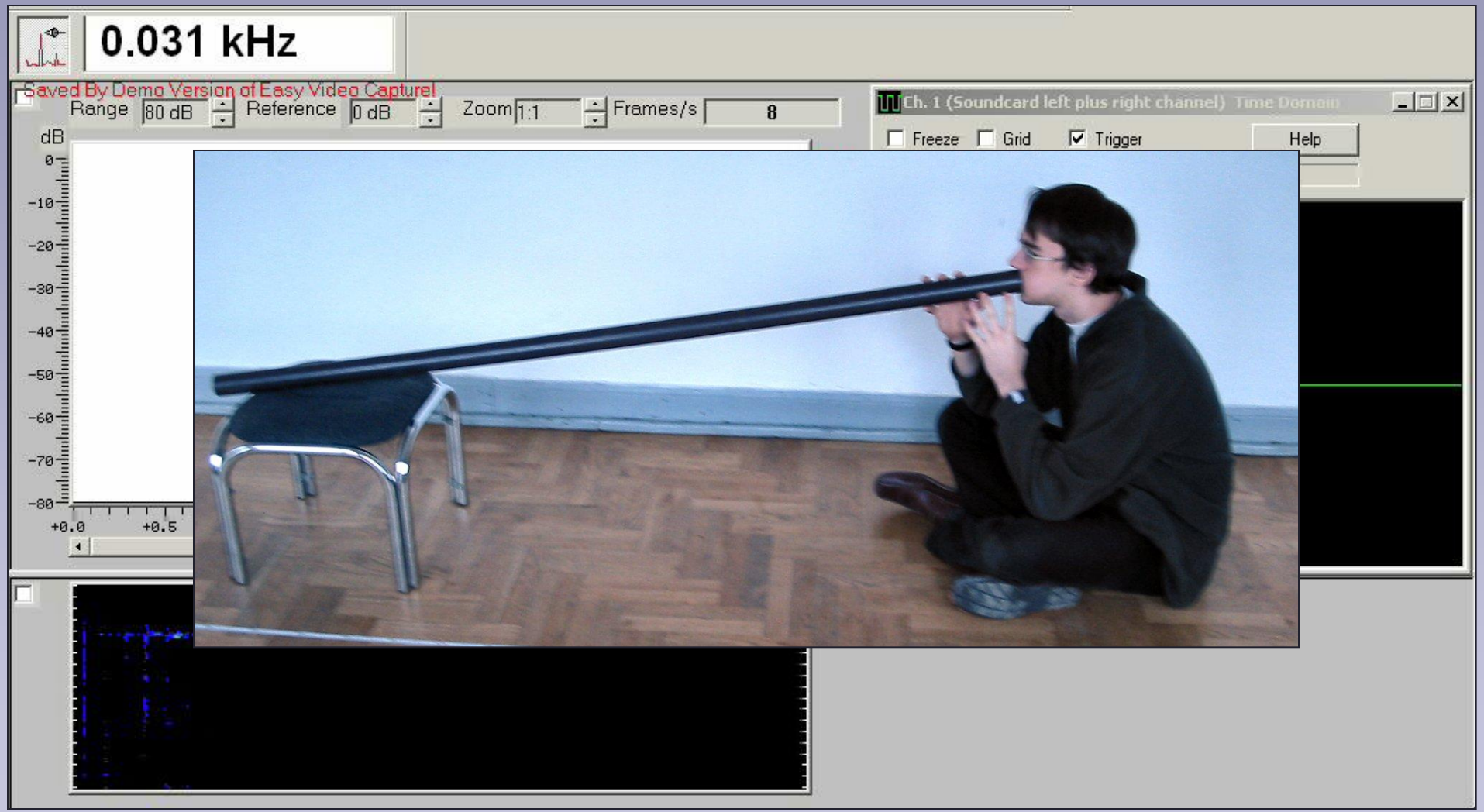
***L* – resonator's length,** **(a – pipe radius)**

White noise transimission through didgeridoo with smooth interior



PCV pipes - experiments

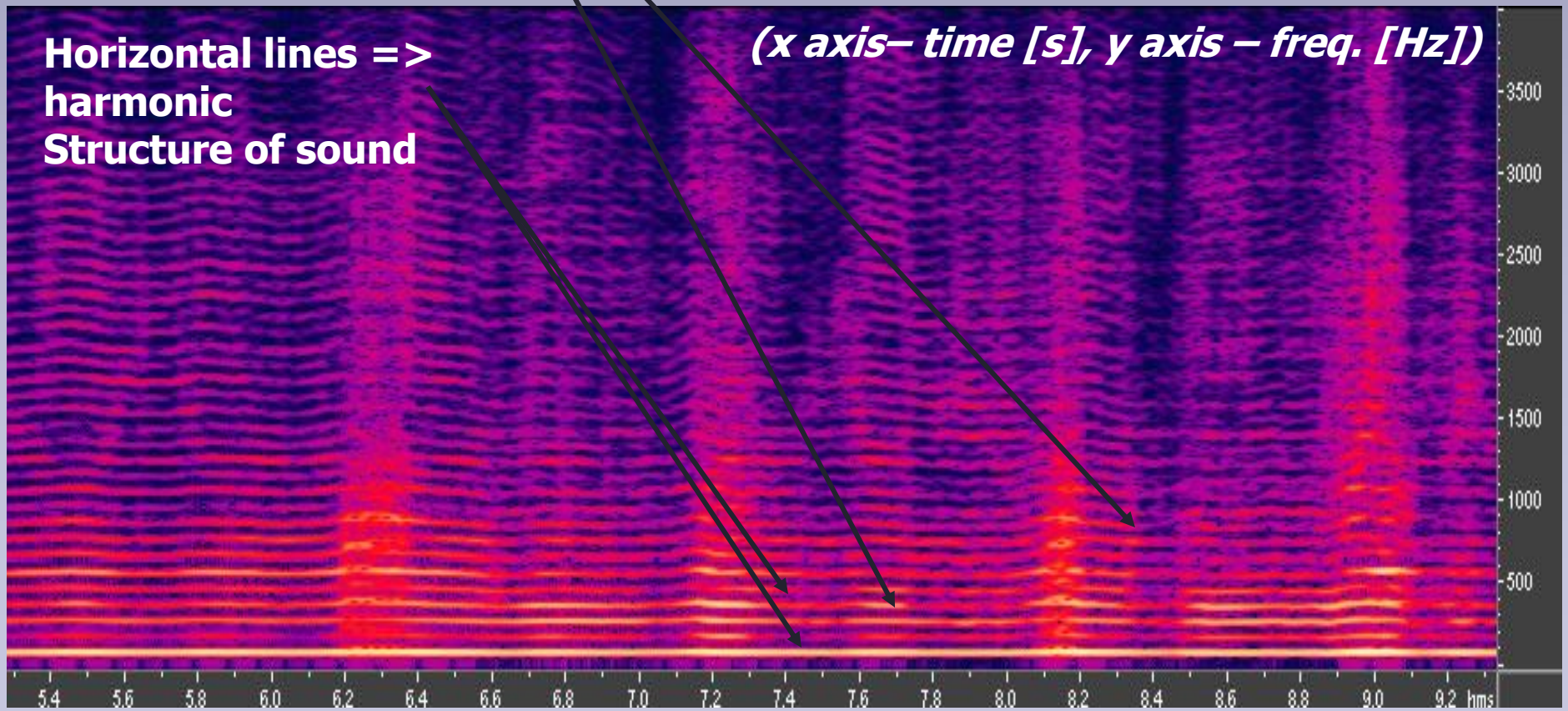
Fundamental frequency:



Long, straight PCV pipe: **L = 1,7 m** **d_{OUT} = 4,4 cm** **d_{IN} = 5 cm**

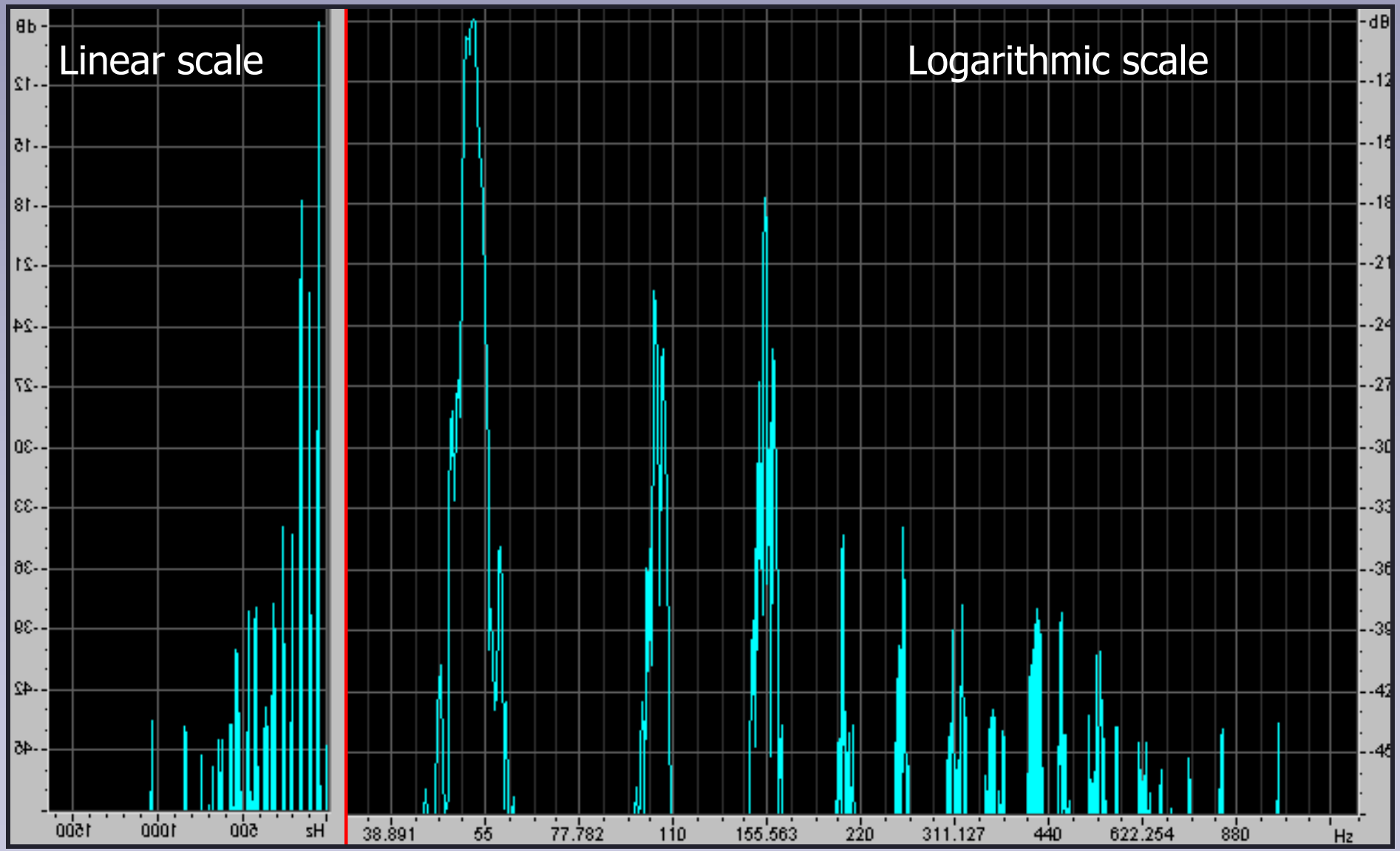
Spectral view of sound

Irregular areas=> effects of play (changes of cheeks shape, position of tongue etc.)



Frequency characteristic

Amplitude [dB] vs. Frequency [Hz] graph for PCV pipe

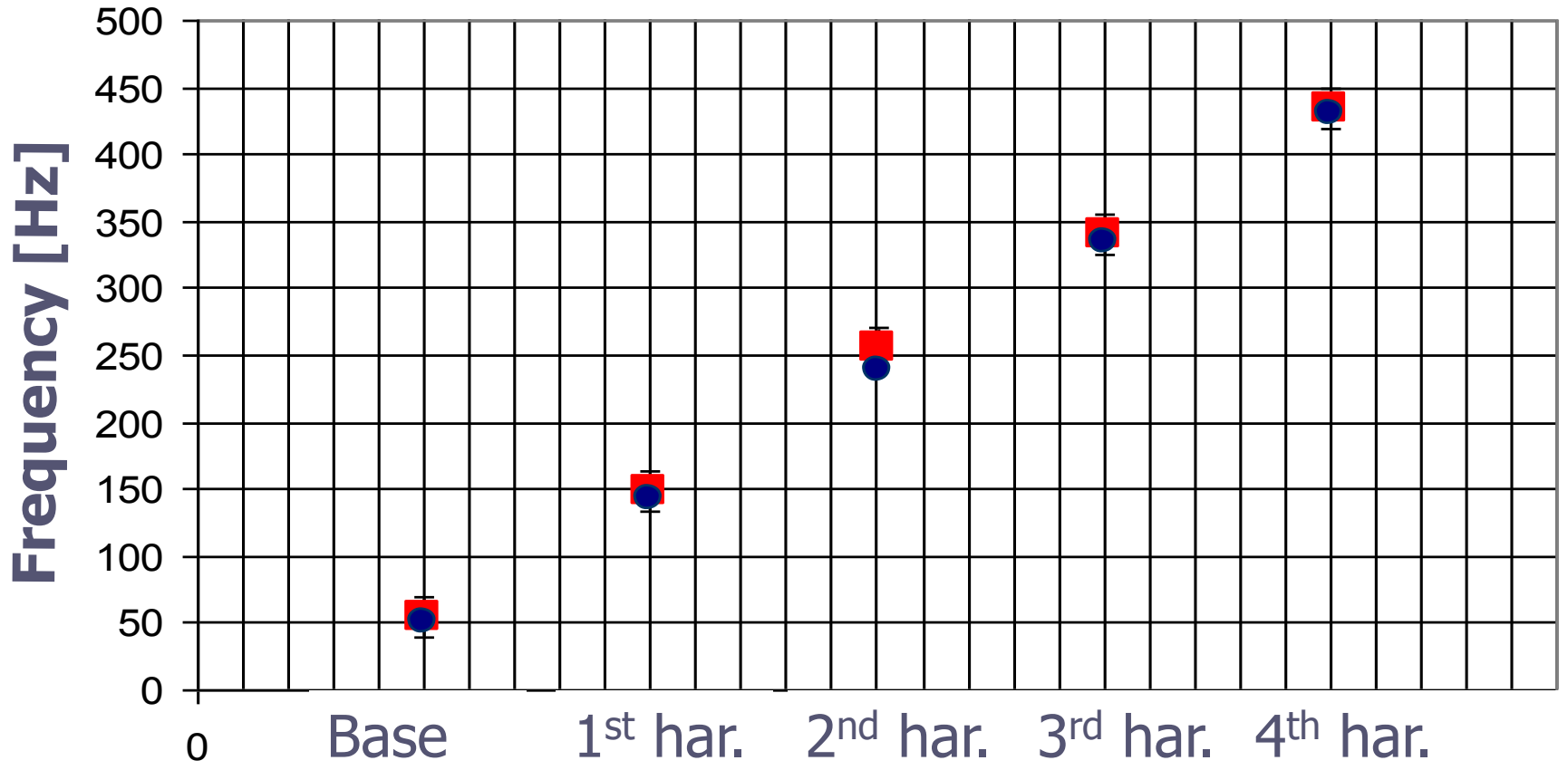


PCV pipe – experimental results

Theoretical values calculated from equation:

$$f_n = \frac{(2n+1)c}{4(L+\frac{8a}{3\pi})} \qquad (n = 0,1,2,3\ldots)$$

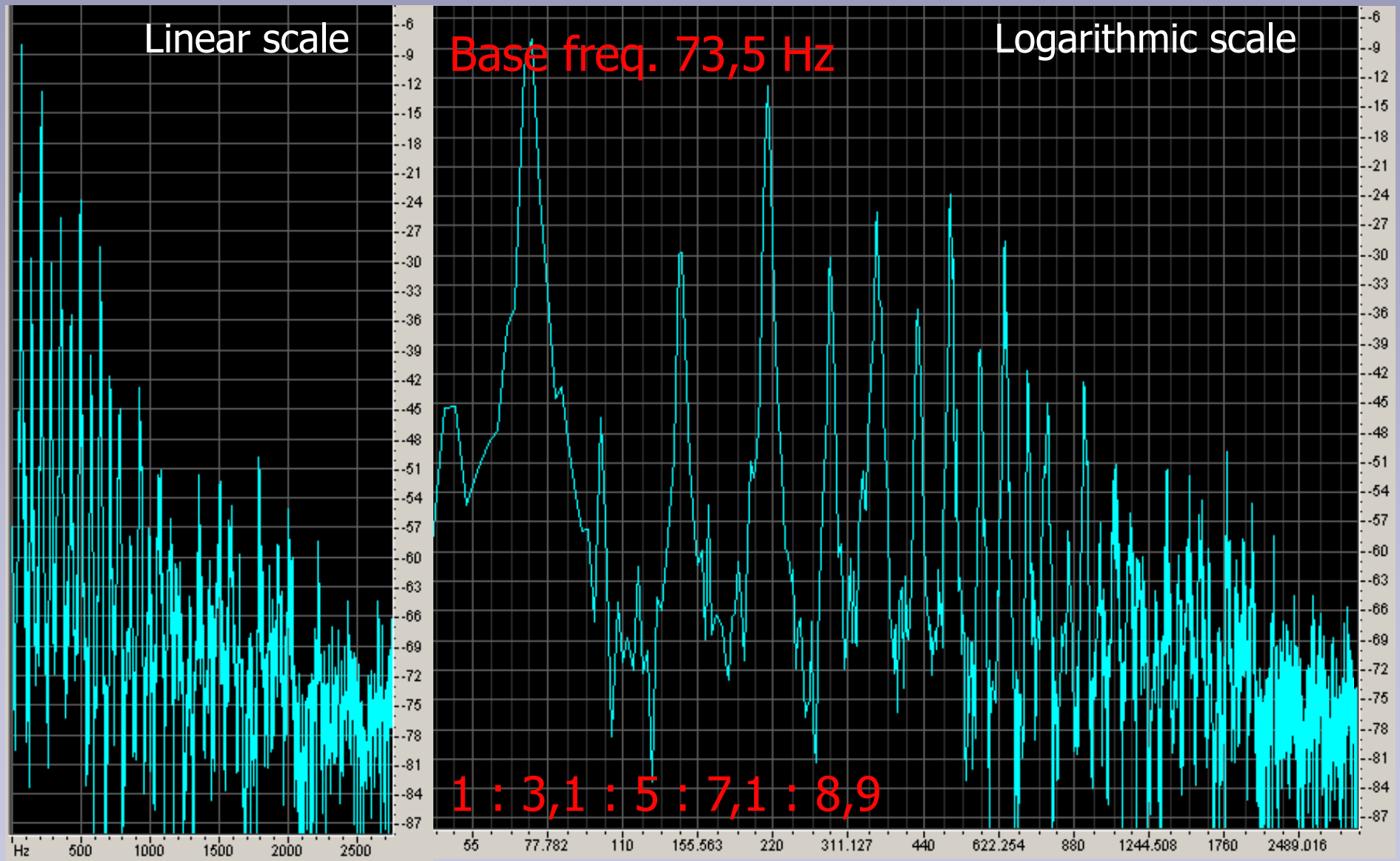
Theoretical and **experimental** harmonic frequencies



Didgeridoo - experiments

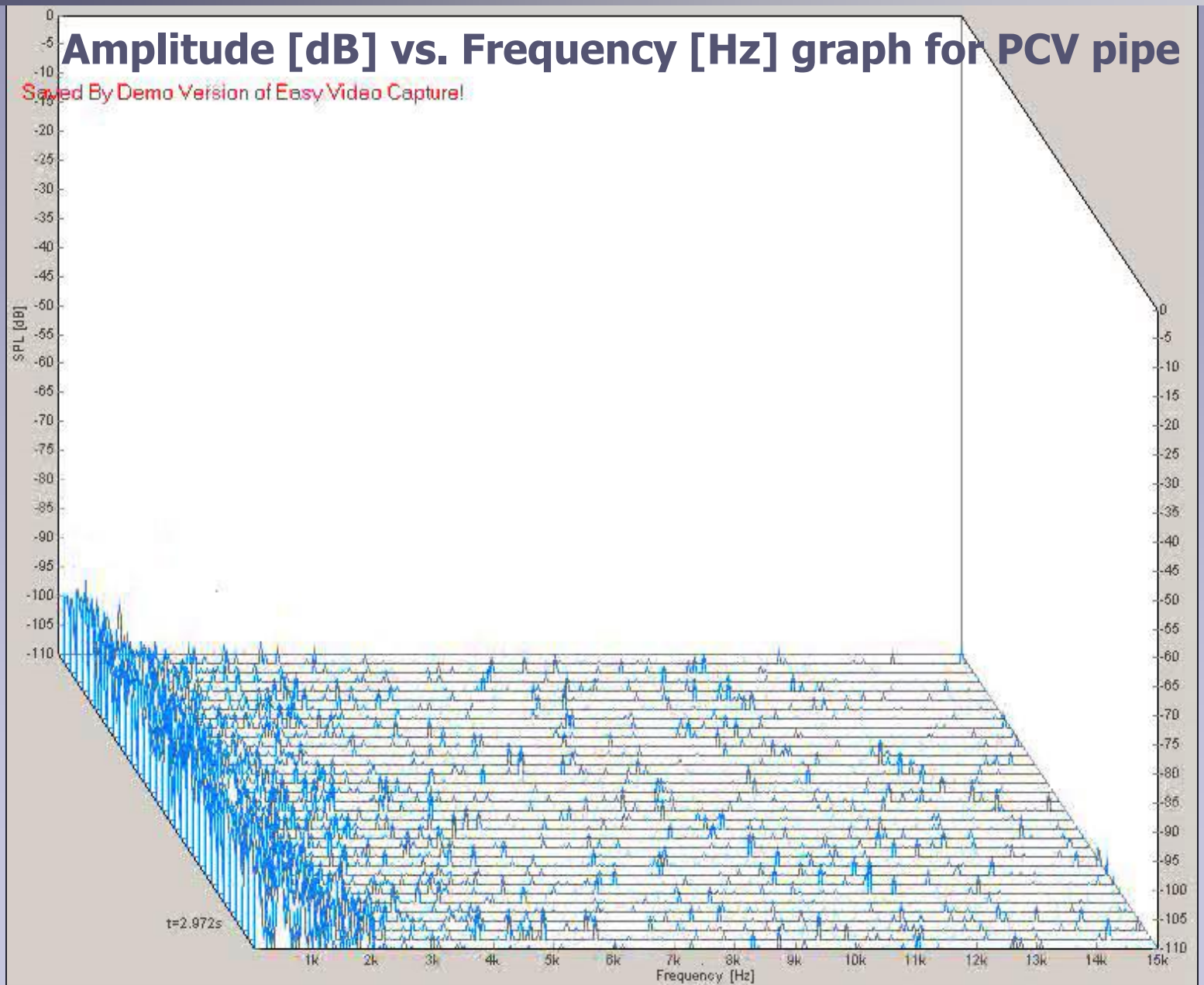
Frequency characteristic - 1

Amplitude [dB] vs. Frequency [Hz] graph for 1st play



Frequency characteristics

dB



Hz

What is responsible for the sound of didjeridu?

sound waves amplified by the instrument

2nd case: smooth interior, widened didj

Didgeridoo vs Bessel's horn

A better assumption for didgeridoo, which sometimes widens on the end, will be a Bessel's horn. In that horn resonant frequencies are equal:

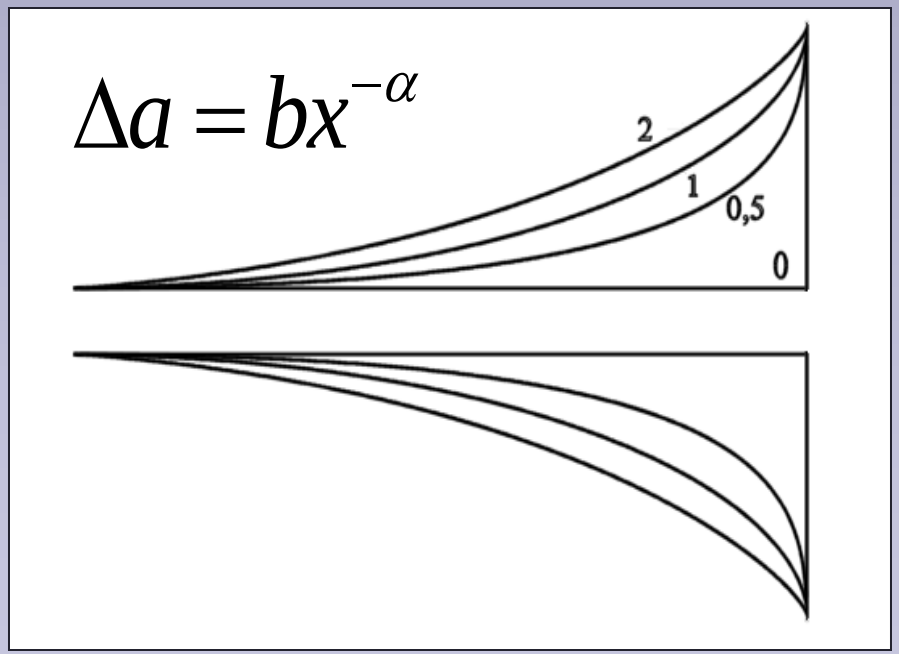
$$f = \frac{c}{4(L+\Delta l)}\left[(2n-1)+\beta\sqrt{\alpha(\alpha+1)}\right] \qquad (n = 0,1,2,3....)$$

α – enlargement coefficient,

x – distance from the beginning.

b – determines the radius of the instrument.

β – coefficient equal 0,6 for $\alpha < 0{,}8$ and 0,7 for $\alpha > 0{,}8$.

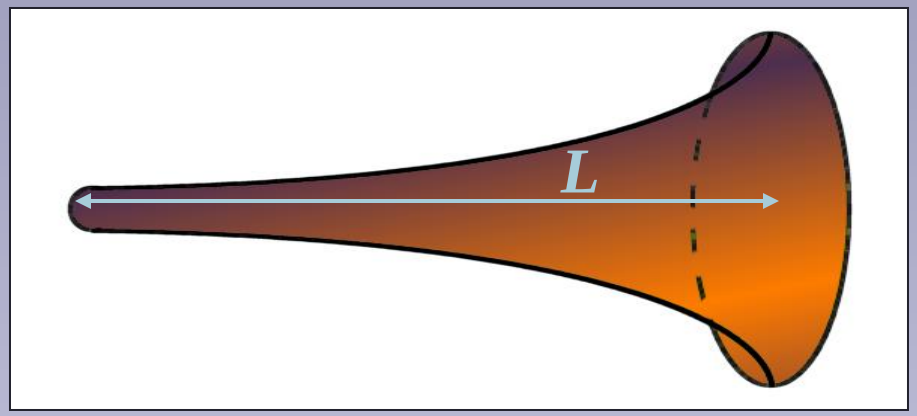


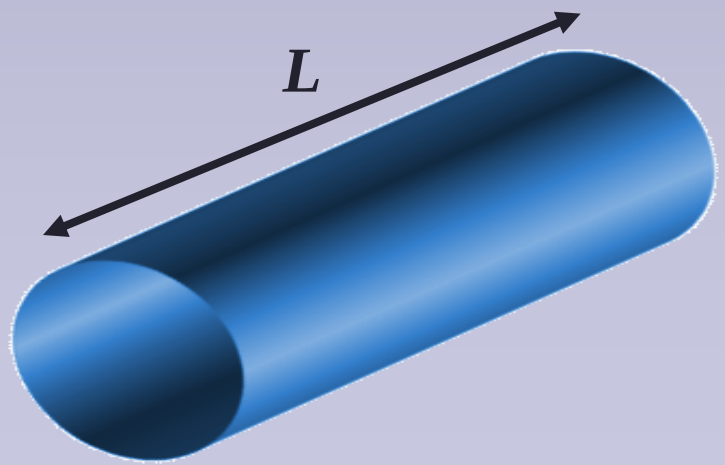
Didgeridoo vs Bessel's horn

$$f = \frac{c}{4(L+\Delta l)}\left[(2n-1)+\beta\sqrt{\alpha(\alpha+1)}\right] \qquad (n = 0,1,2,3....)$$

In case of typical widening Bessel's equation is much simpler:

$$for\ \alpha = 1: \qquad f \approx \frac{nc}{2(L+\Delta l)}$$





This theoretical model is working also for not widening didgeridoo:

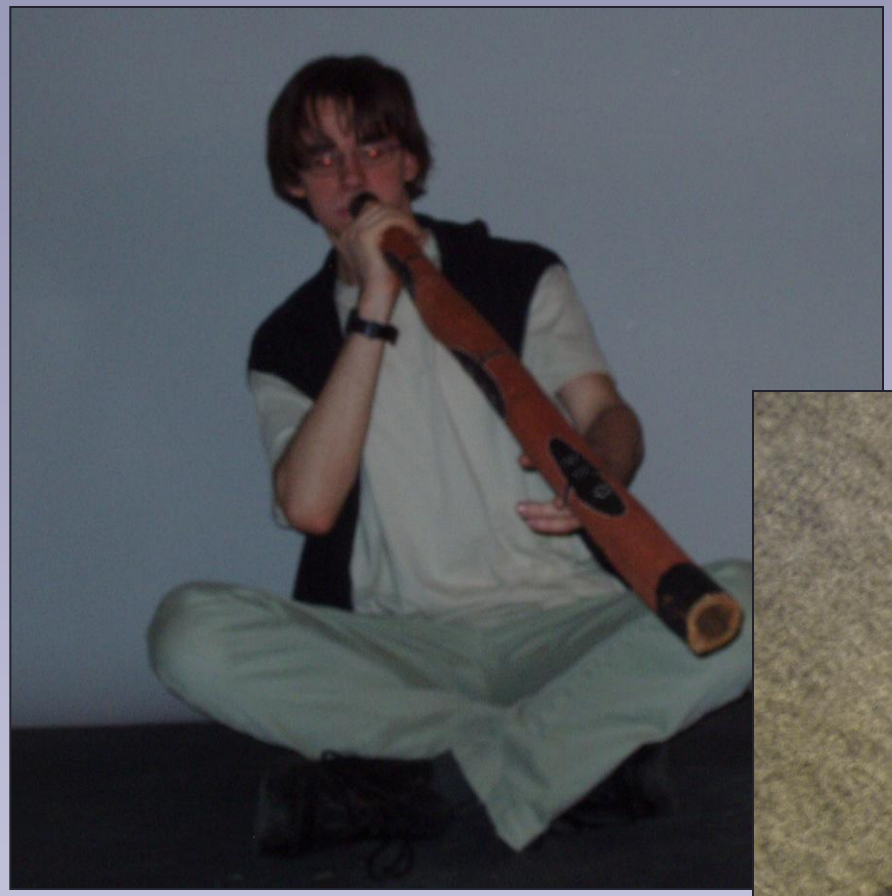
$$for\ \alpha = 0: \qquad f = \frac{(2n+1)c}{4(L+\Delta l)}$$

What is responsible for the sound of didjeridu?

sound waves amplified by the instrument

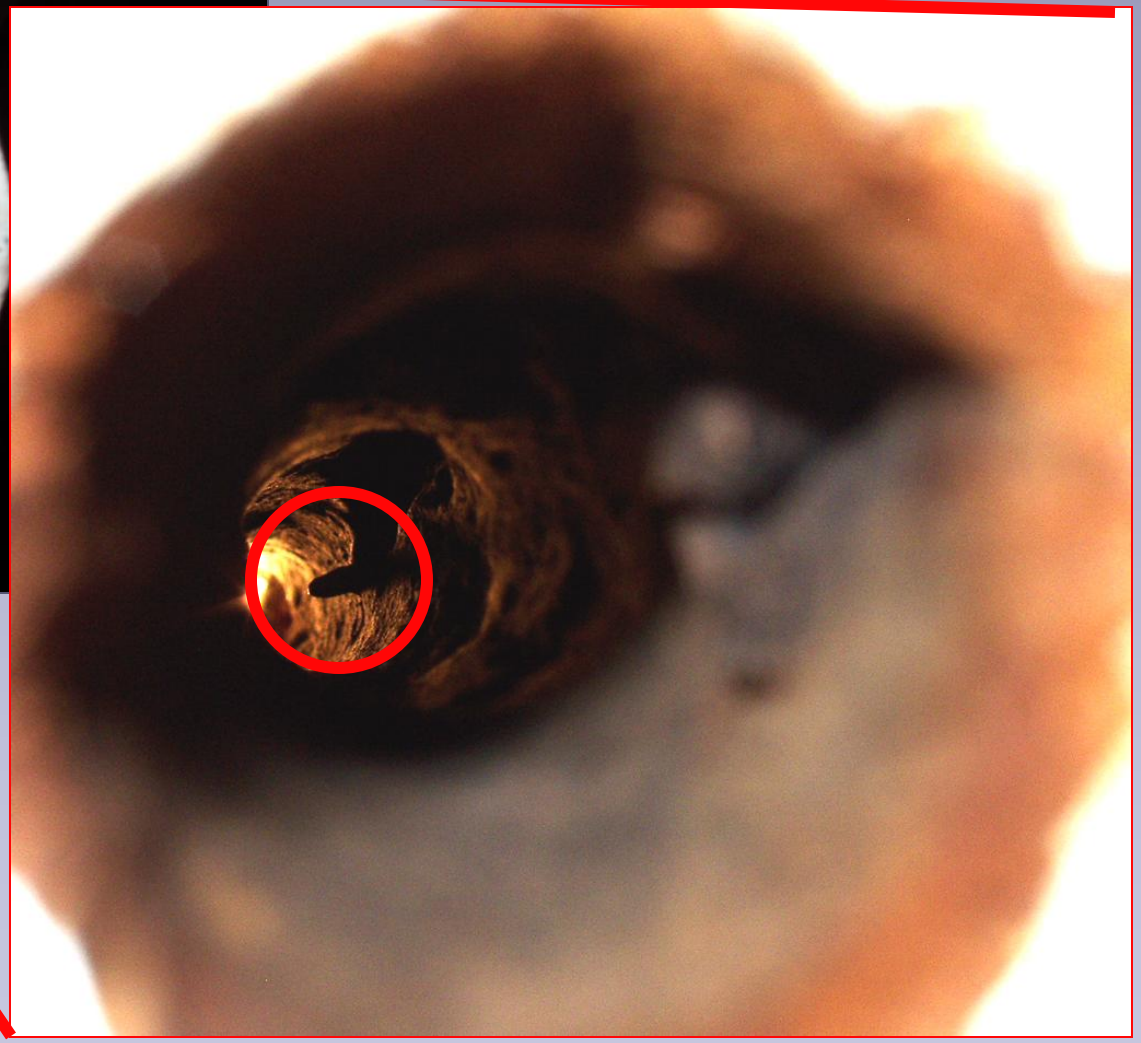
3rd case: rough interior

Didgeridoo - experiments



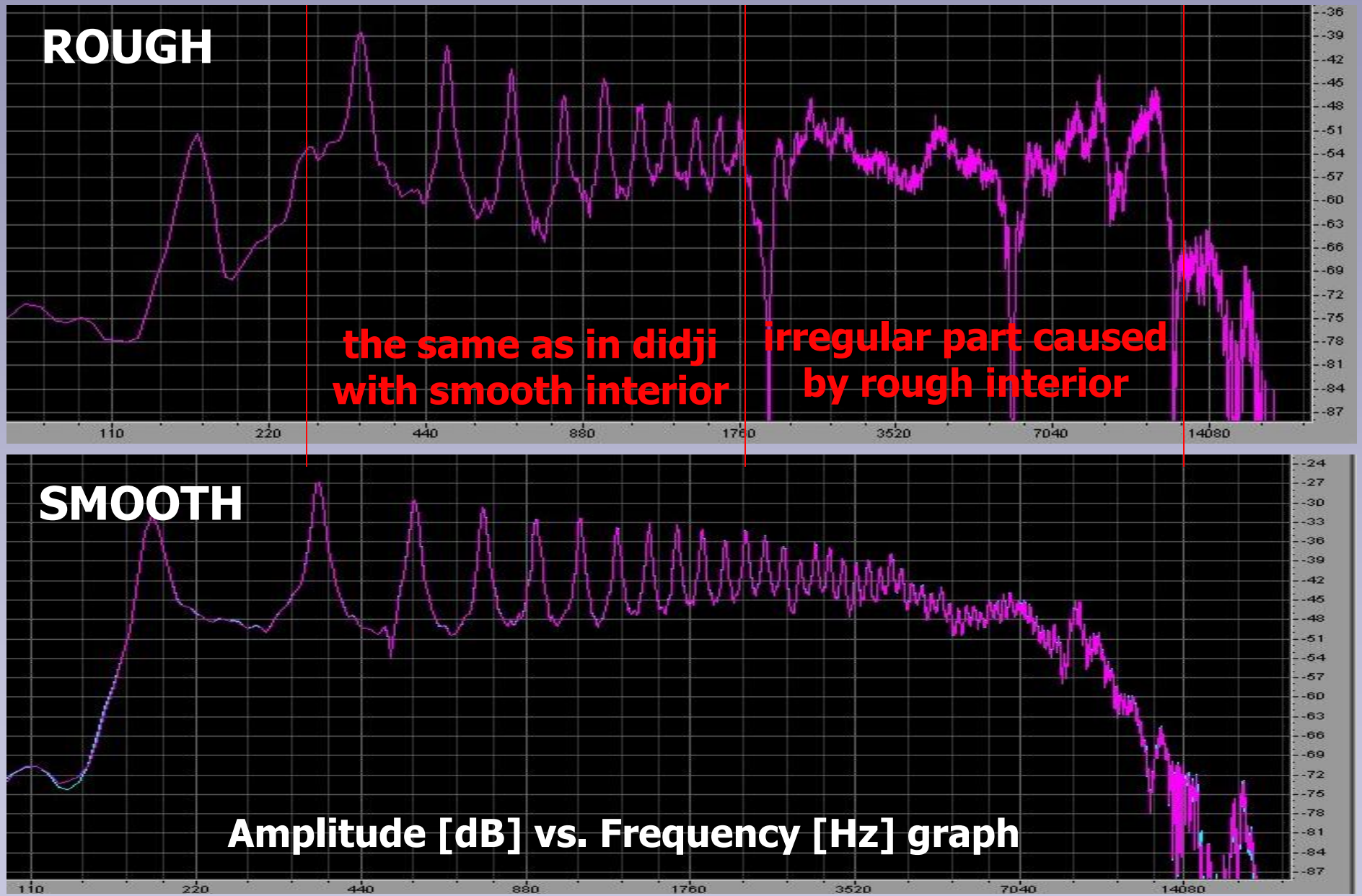
Museum of Asia and Pacific Ocean in Warsaw

Rough interior – Termites problem

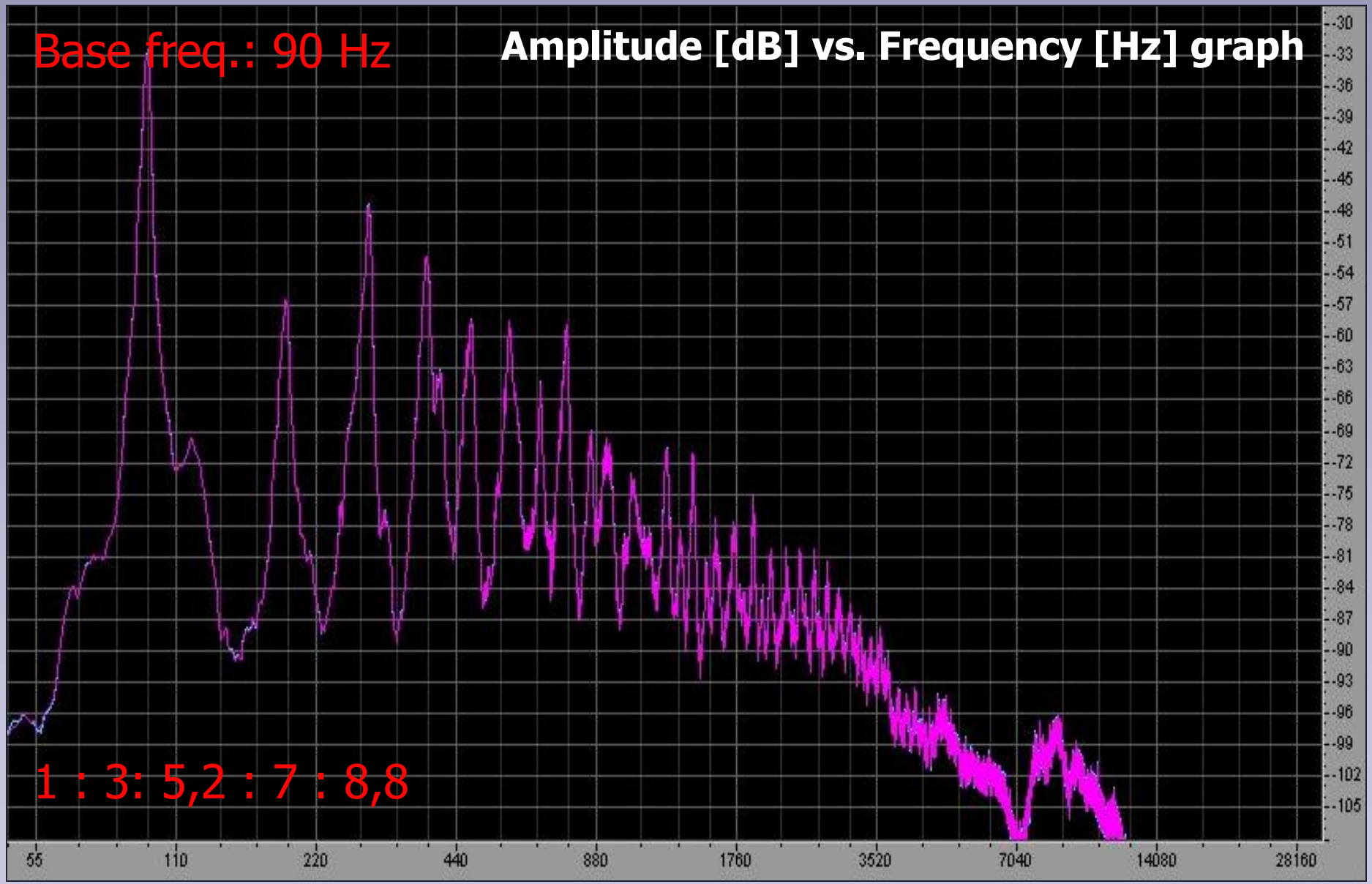


The chamfered interior is rough. There are even some 1,5 cm posts

Rough interior – Termites problem



Rough interior – Termites problem



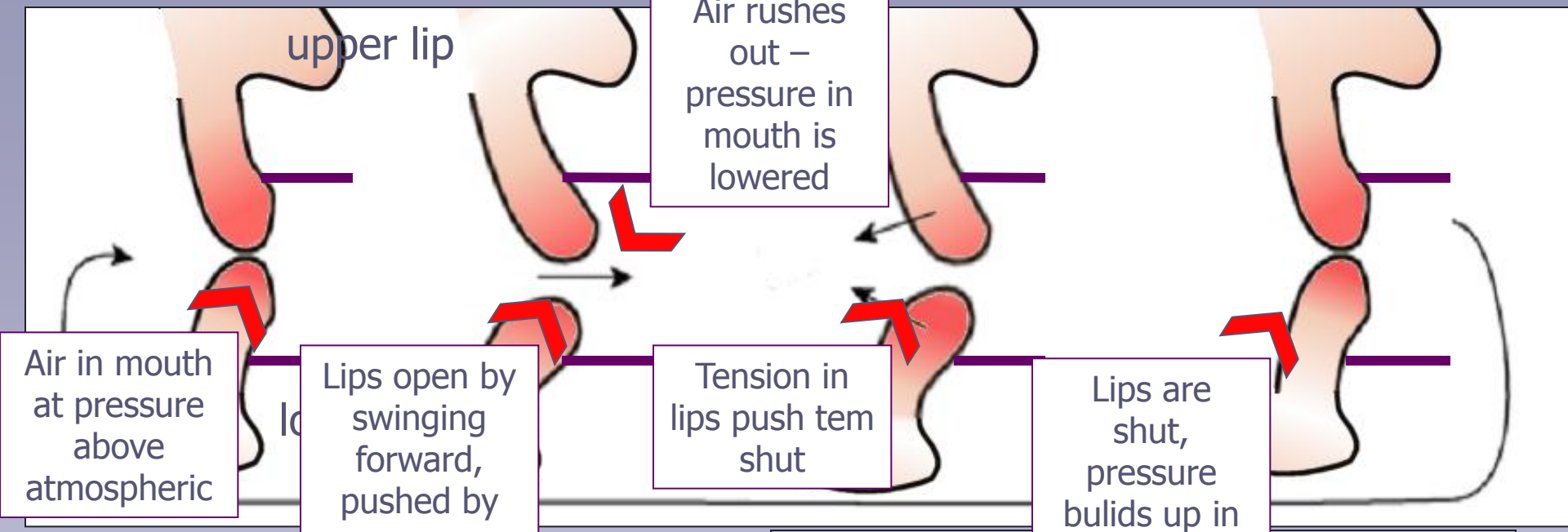
What is responsible for the sound of didjeridu?

motion of player's lips, tongue and cheeks – sounding mechanism

lip valve – vibration analysis

Changing the volume and shape of a resonant cavity (throat) by cheeks and tongue

Sounding mechanism



Because, the l rates at very nearly its resonance frequency the motion of the player's lips is nearly sinusoidal:

$$x = a_0 + a \cdot \sin 2\pi f$$

$$U = \gamma x (p_o - p)^2$$

a, a_0 – deter mplitude

p_0– steady blowing pressure

p– pressure inside the instrument

x – the lip opening.

f – frequency of the oscillations.

U – volume flow though the lip valve

Referring to: *The Didjeridu*, Neville Fletcher, Acoustics Australia, Vol 24

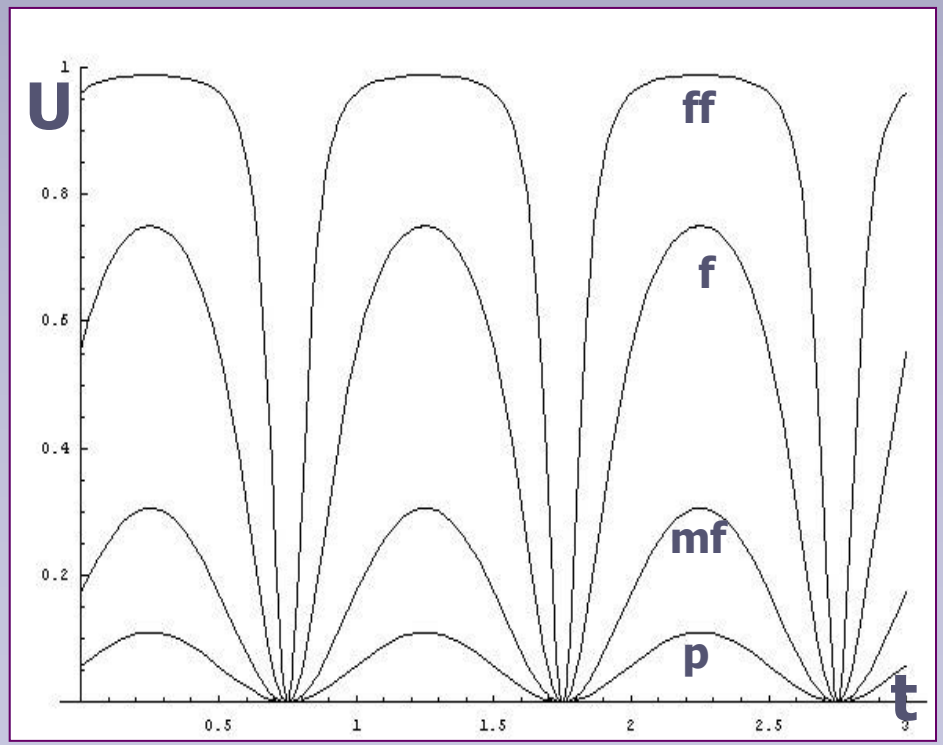
Sounding mechanism

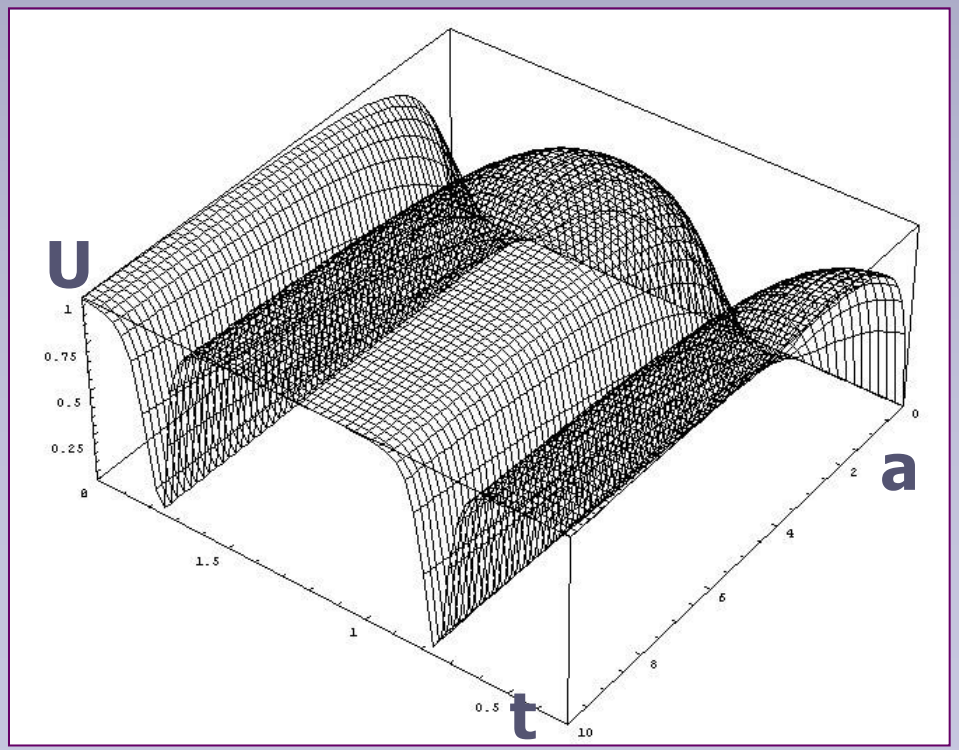
After solving these equations we obtain:

$$U \approx \frac{p_0}{R} - \frac{p_0^2}{R^3\left(a_0 + a \cdot \sin 2\pi f t\right)^2}$$

R - acoustic resistance of the instrument tube

The volume flow graphs vs. time for different amplitudes of lips vibration :



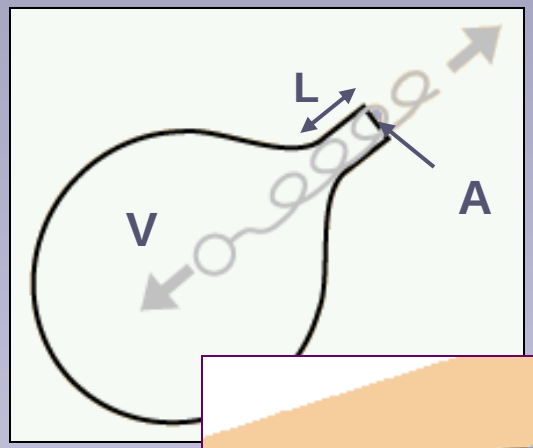


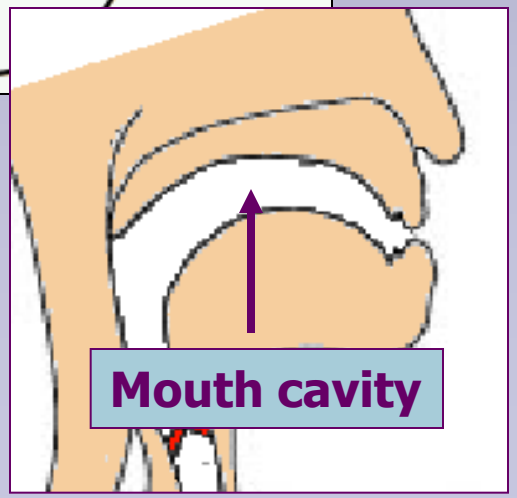
Sounding mechanism

MOUTH

blocked off by the closed lips

forms a Helmholtz resonator consisting of a closed volume vented by the lip opening





The resonance frequency of this resonator can be estimated by whistle frequency analysis (the whistle frequency is the resonance frequency of the Helmholtz resonator).

Achieved range – differs from about 500 Hz to about 3 kHz

(because of changing the mouth volume with the tongue and cheeks)

What is responsible for the sound of didgeridoo?

sound waves modified by the instrument

1st case: smooth interior, straight didj

2nd case: smooth interior, widened didj

3nd case: rough interior

sound waves created with player's vocal folds and throat

motion of player's lips, tongue and cheeks – sounding mechanism

lip valve – vibration analysis

Changing the volume and shape of a resonant cavity (throat) by cheeks and tongue

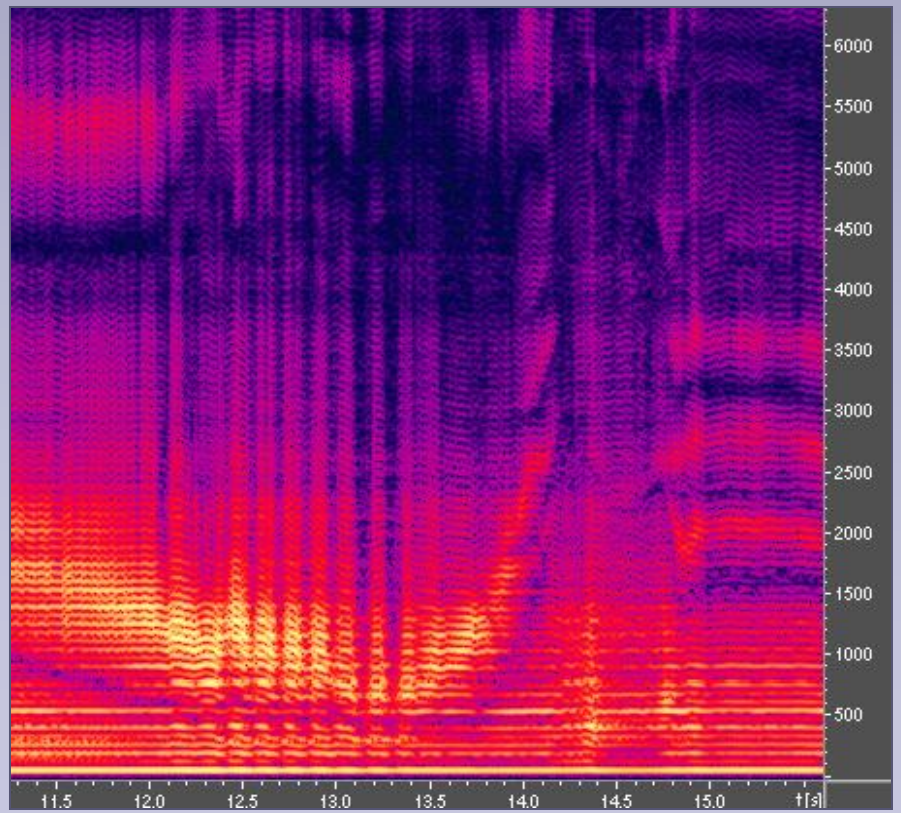
Overall explanation of frequency characteristic

Conclusions

- The best assumption is to treat Didgeridoo as a Bessel's horn type of resonator
- A big variety of sounds produced is caused by composition of resonating properties of didjeridu and mouth, cavity and vocal folds usage.

The didjeridu's sound is affected by:

- Length of the instrument;
- Thickness of the instrument;
- Its interior roughness;
- Shape;
- medium properties;



Literature

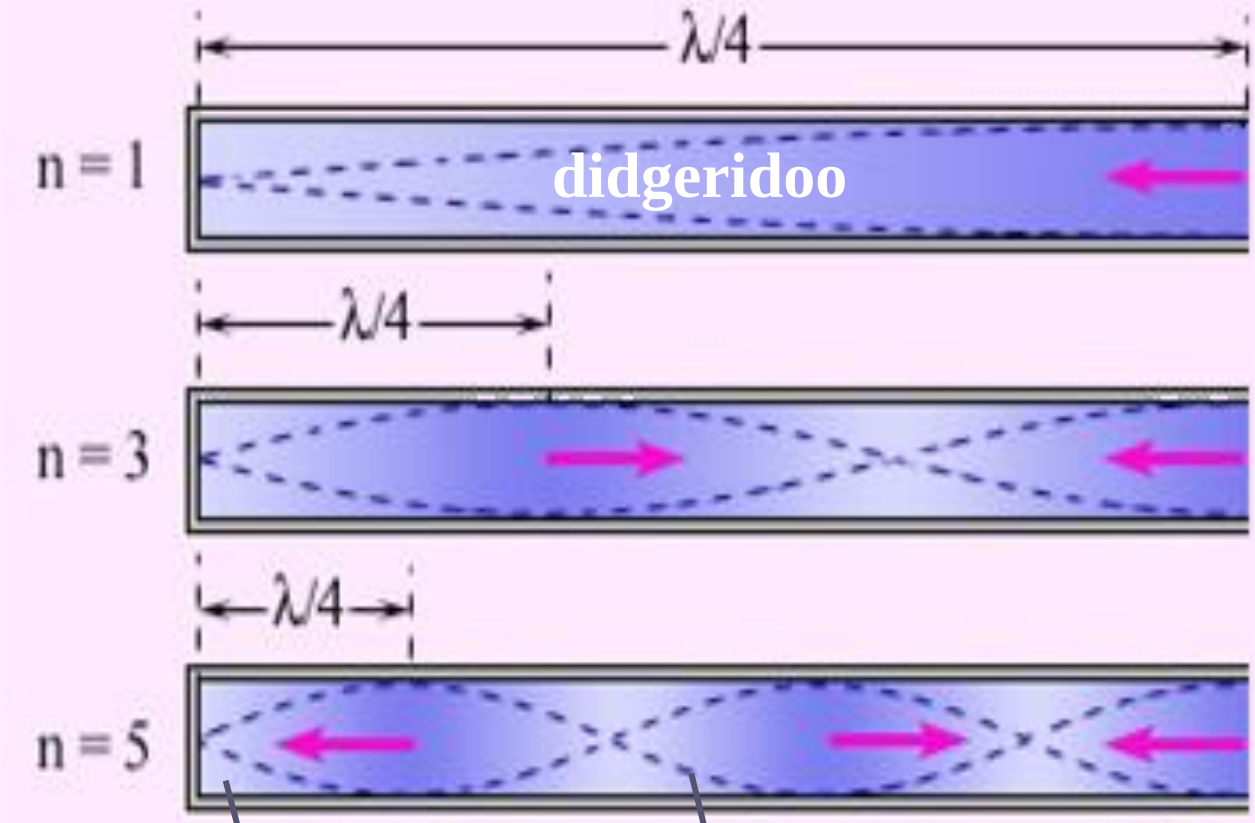
- *N.H. Fletcher, T.D. Rossing The Physics of musical instruments*
- *http://www.phys.unsw.edu.au/~jw/brassacoustics.html*
- *Neville Flecher, 'The dijeridu', Acoustic Australia nr.24 (1996)*
- *Cheryl Weynant, Ben Valentine The physics of the Didgeridoo (2003)*
- *http://www.didjshop.com/physicsDidj.html*

Used software

- *Cool Edit 2000*
- *Audio Analyzer 2000*
- *Realtime Analyzer Light 2.0.0.1*
- *Easy Video Capture*

‘Ligawka’ / ‘Trombita’ – Polish ‘didgeridoo’

Formation of sound in a didgeridoo



$$\lambda = 4L \qquad f_0 = \frac{v}{\lambda} = \frac{v}{4L}$$

$$\lambda = \frac{4}{3}L \qquad f = \frac{3v}{4L} = 3f_0$$

$$\lambda = \frac{4}{5}L \qquad f = \frac{5v}{4L} = 5f_0$$

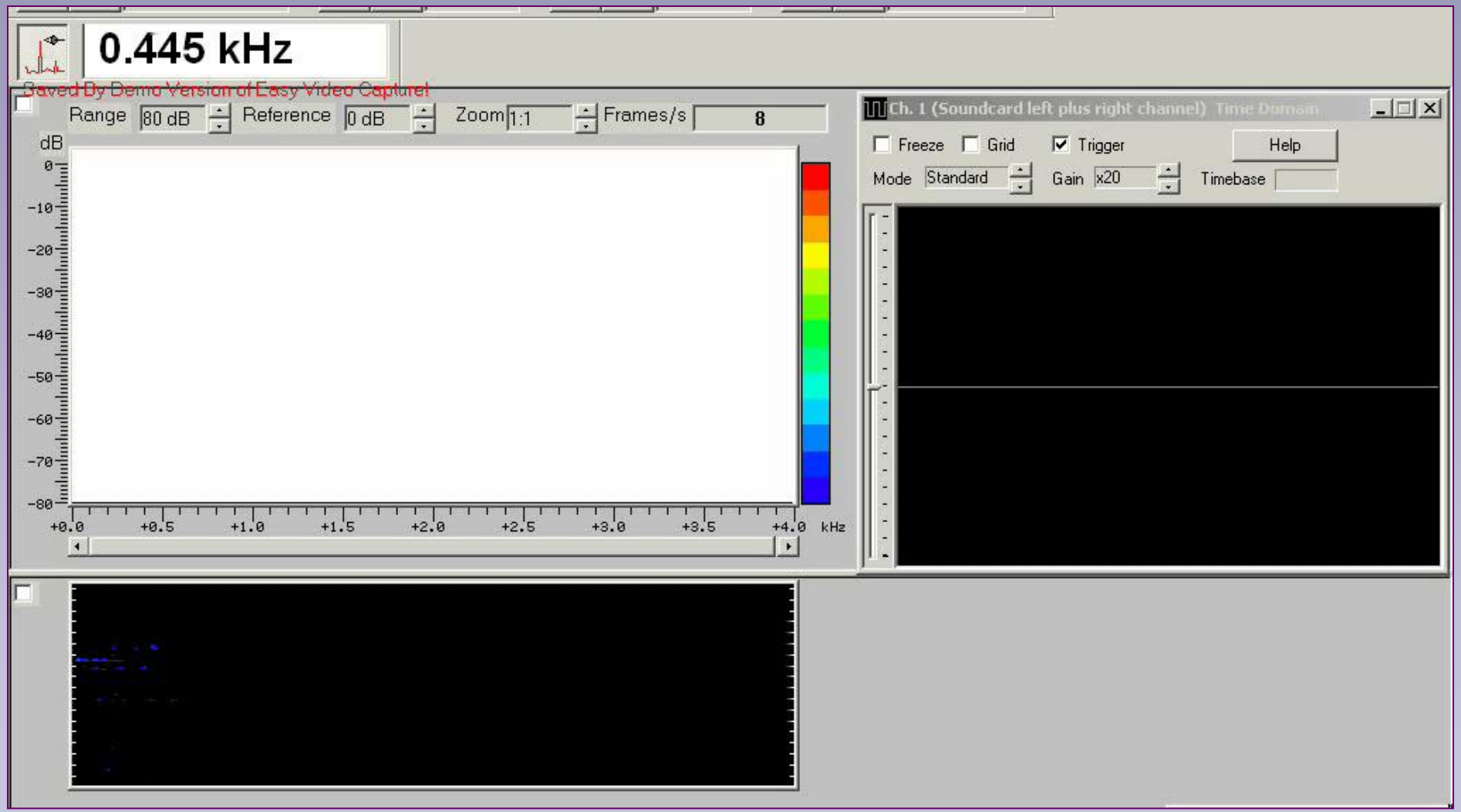
Antinode of pressure

Node of pressure

λ – wavelength,
f – resonance frequency
v – sound velocity

Overall explanation of frequency characteristic

Fundamental frequency:

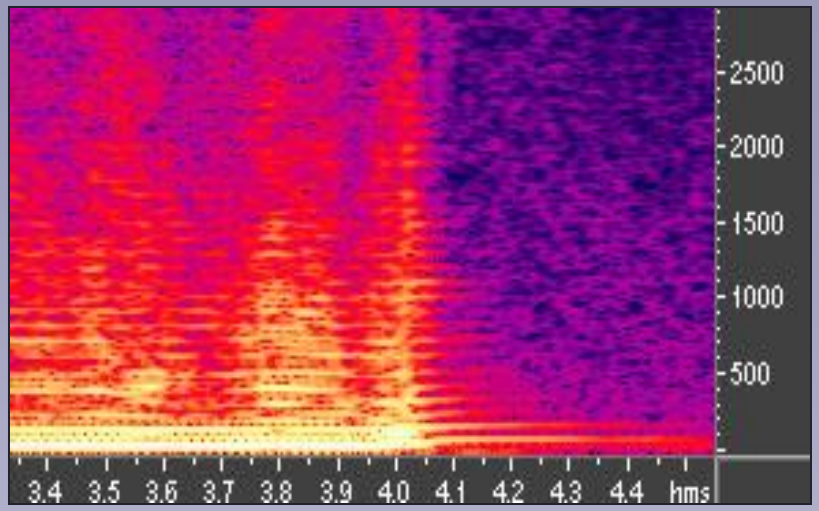


And now, the frequency analysis is understandable for us

PCV pipe – experimental results

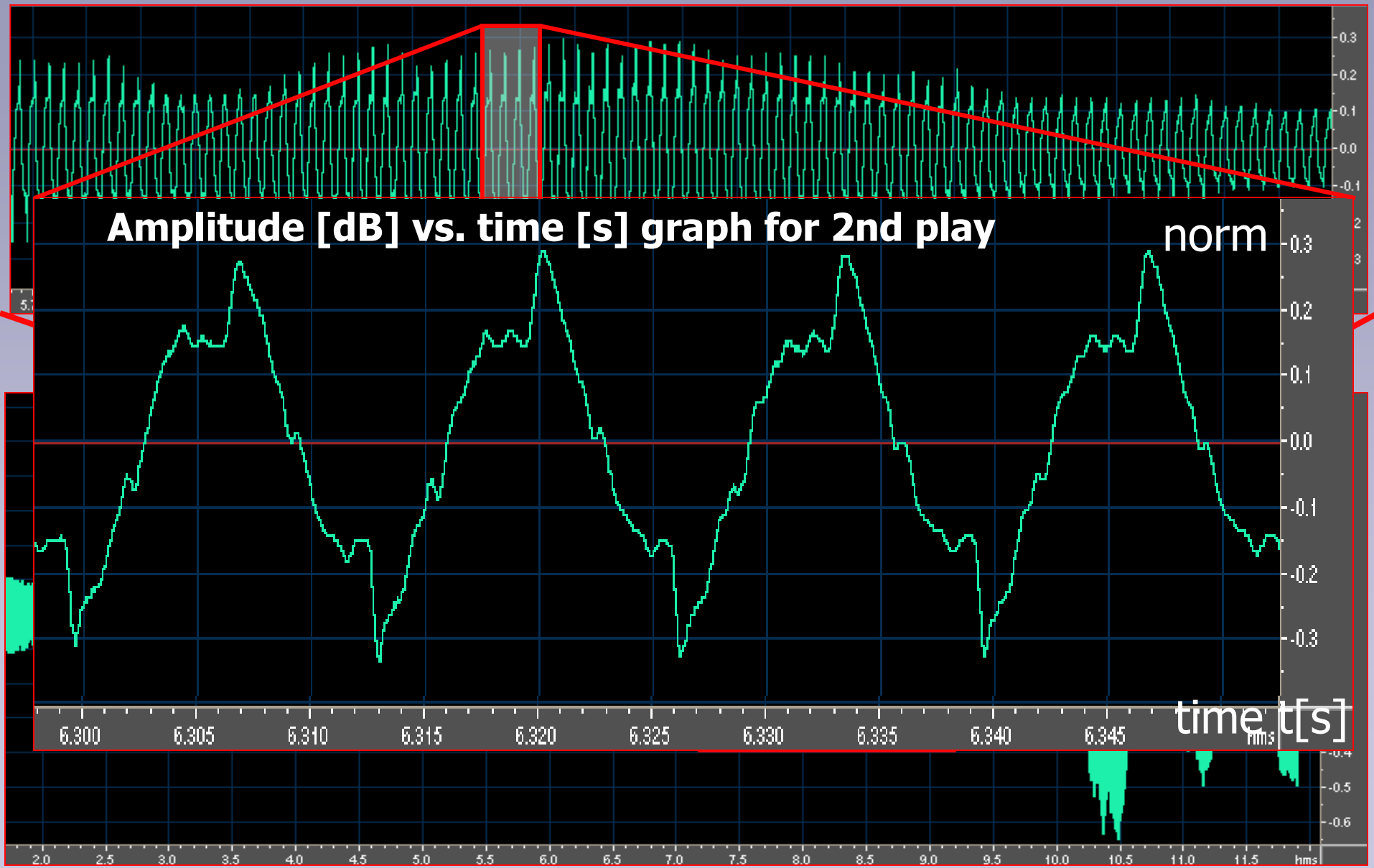
Theoretical values calculated from equation:

$$f_n = \frac{(2n+1)c}{4(L+\frac{8a}{3\pi})} \qquad (n = 0,1,2,3\ldots)$$

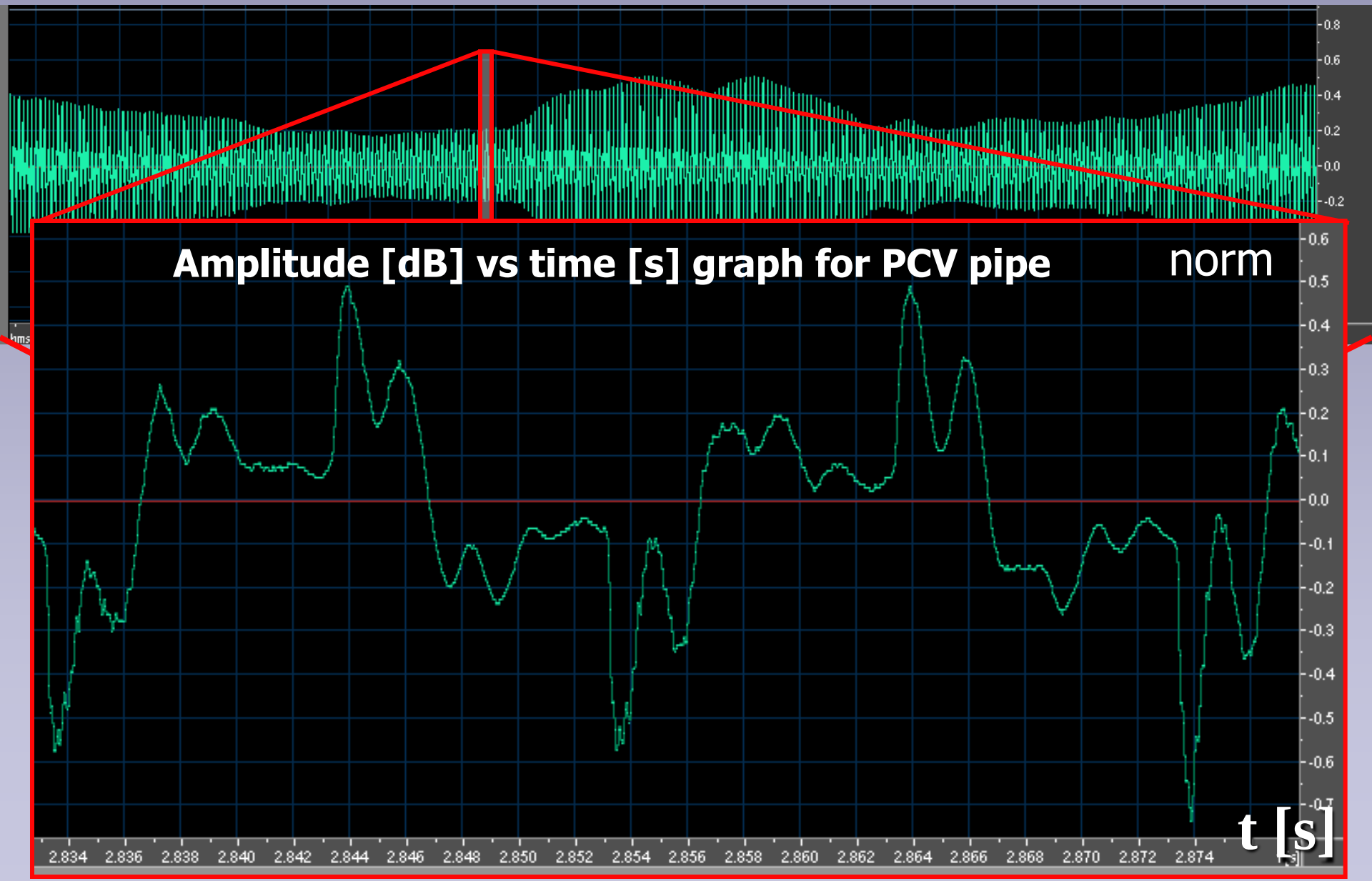


Harmonic components	Measured value of frequency		Theoretical value of frequency	
Base	54 Hz	1	49,9 Hz	1
1st harmonic	148 Hz	2.9	143,7 Hz	3
2nd harmonic	255 Hz	5.1	239,5 Hz	5
3rd harmonic	340 Hz	6.8	335,2 Hz	7
4th harmonic	435 Hz	8.7	431,2 Hz	9

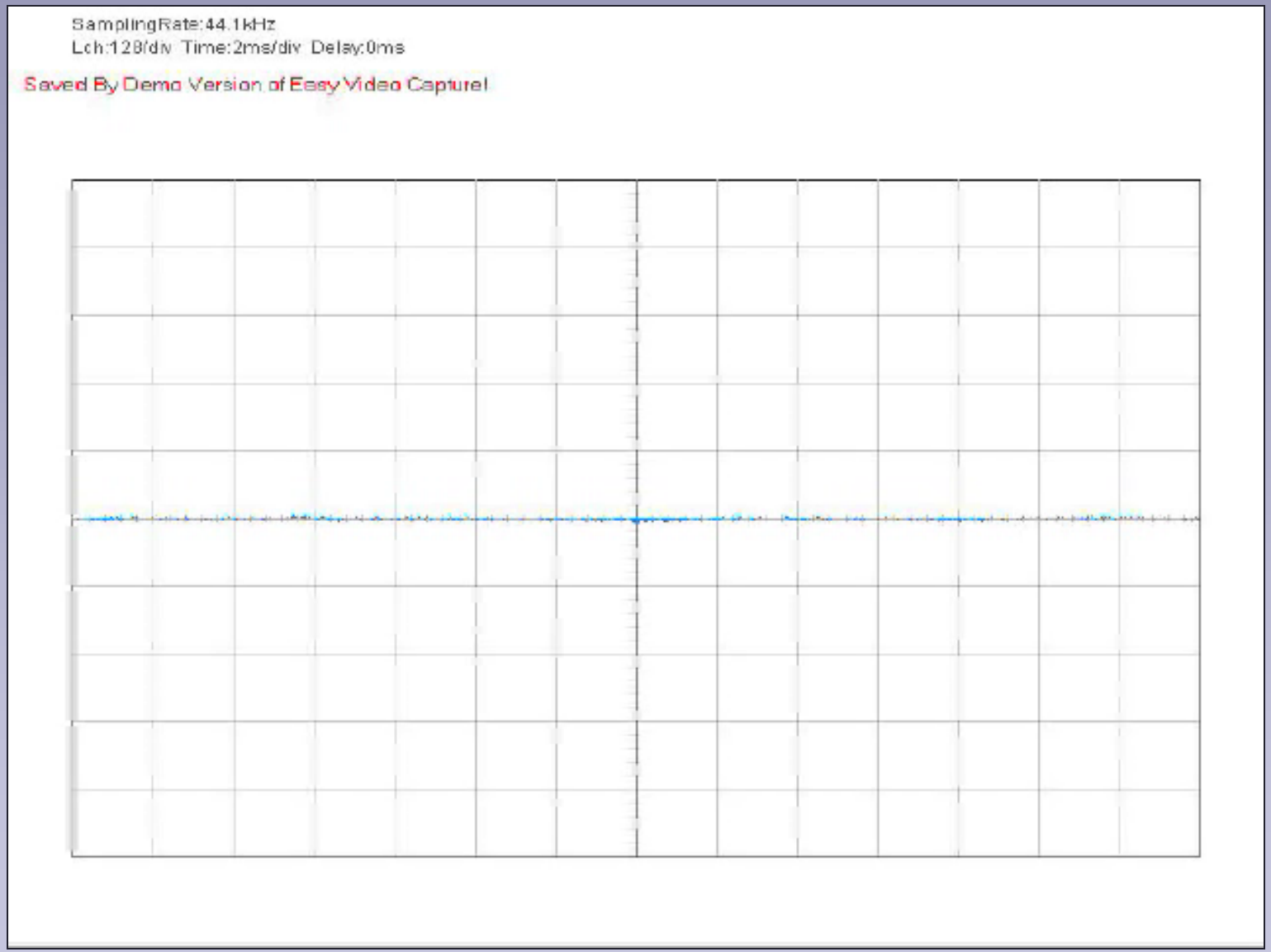
Waveform analysis



Waveform analysis



Waveform analysis



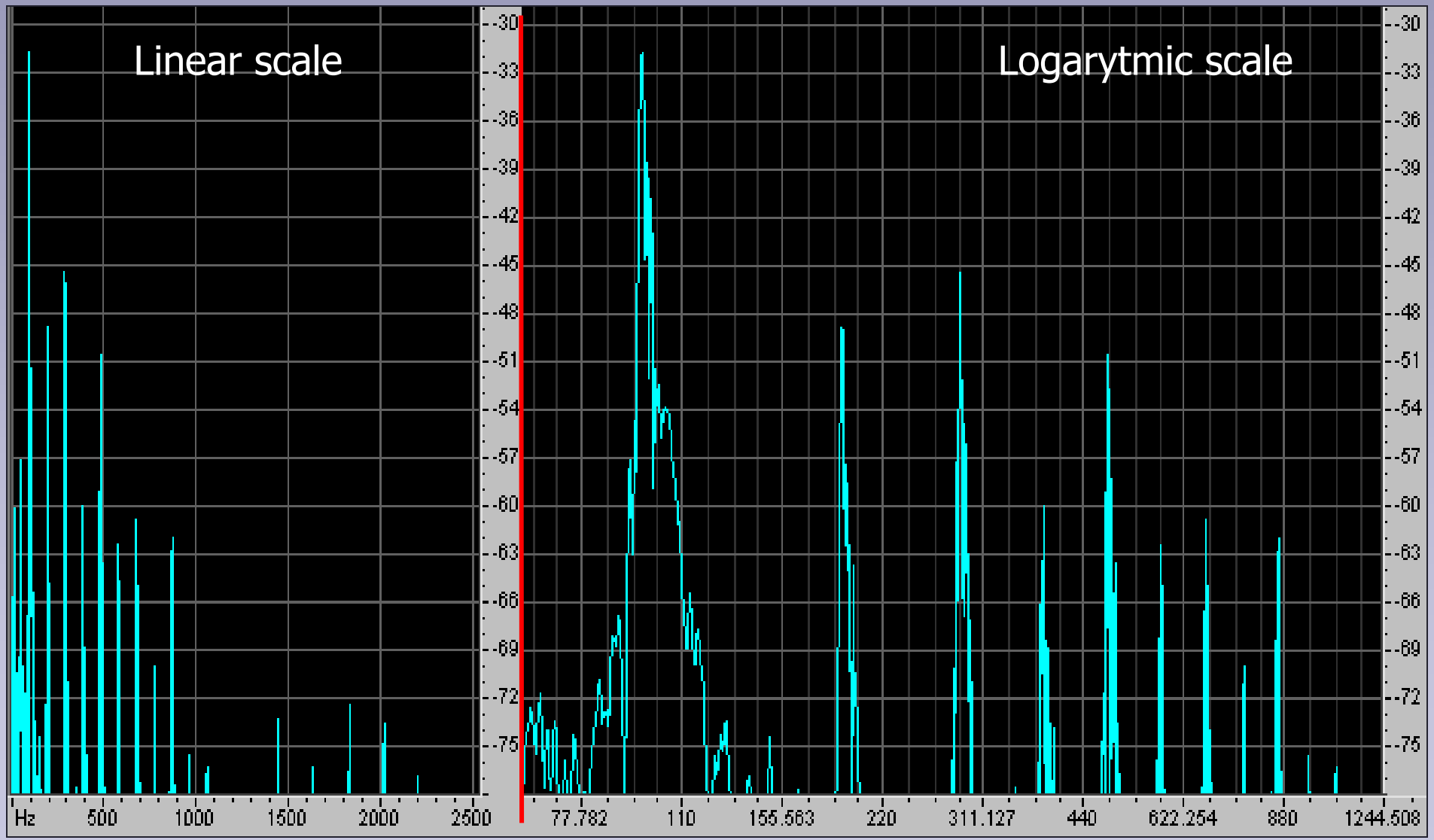
Amplitude [dB] vs time [s] graph for PCV pipe

Wavedorm analysis

Amplitude [dB] vs time [s] graph for PE pipe

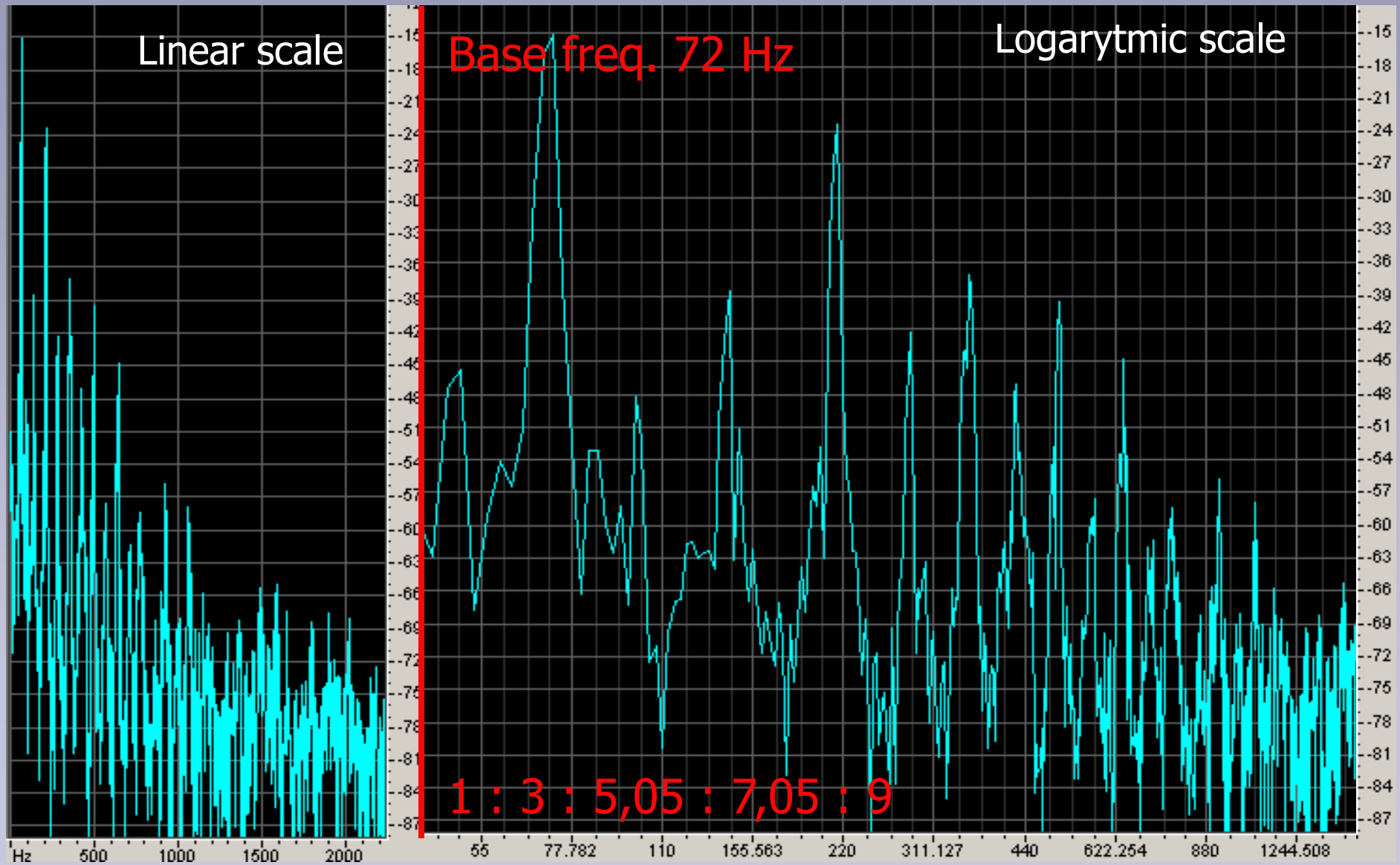
Frequency characteristic

Amplitude [dB] vs. Frequency [Hz] graph for PE pipe

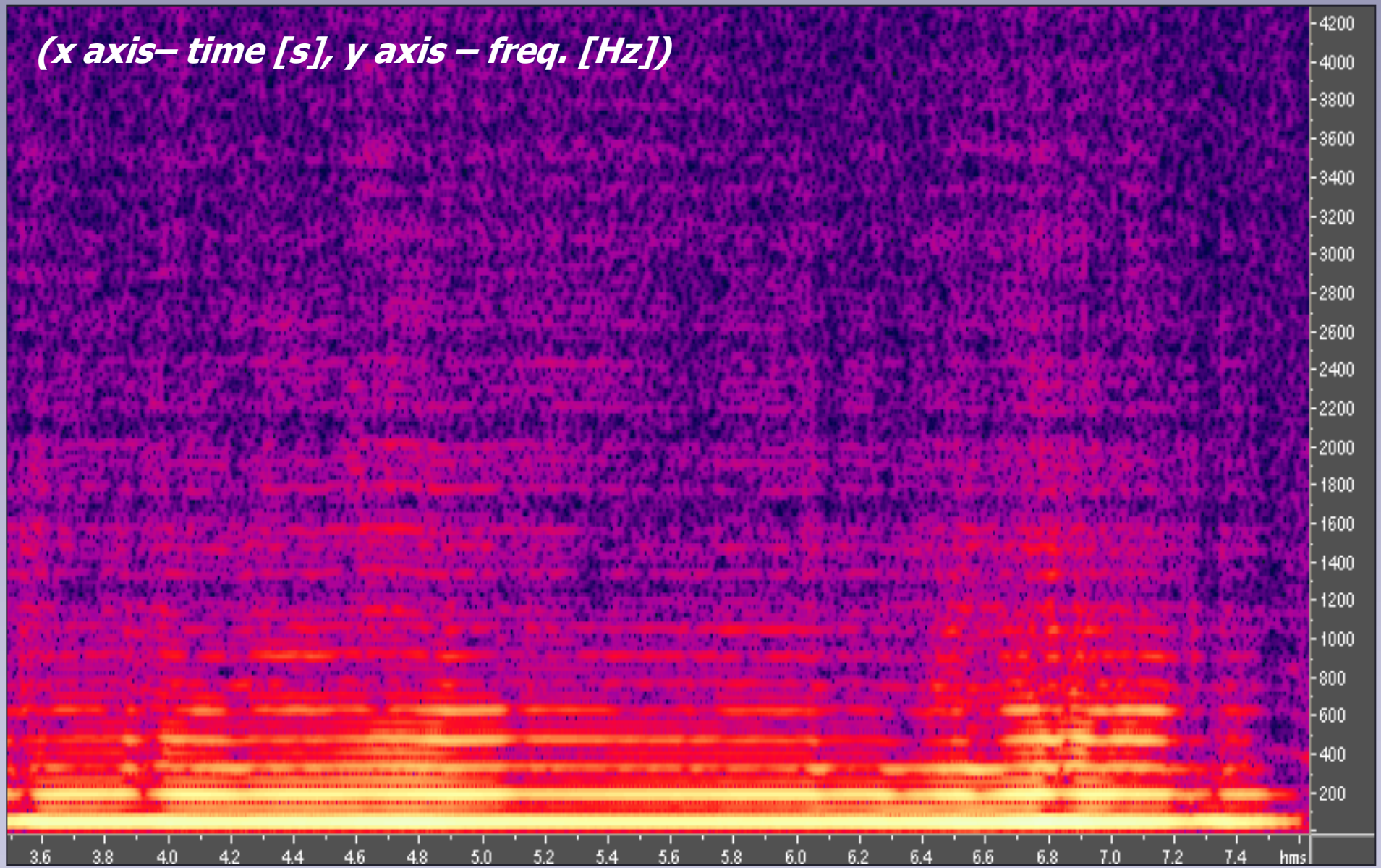


Frequency characteristic - 2

Amplitude [dB] vs. Frequency [Hz] graph for 2nd play



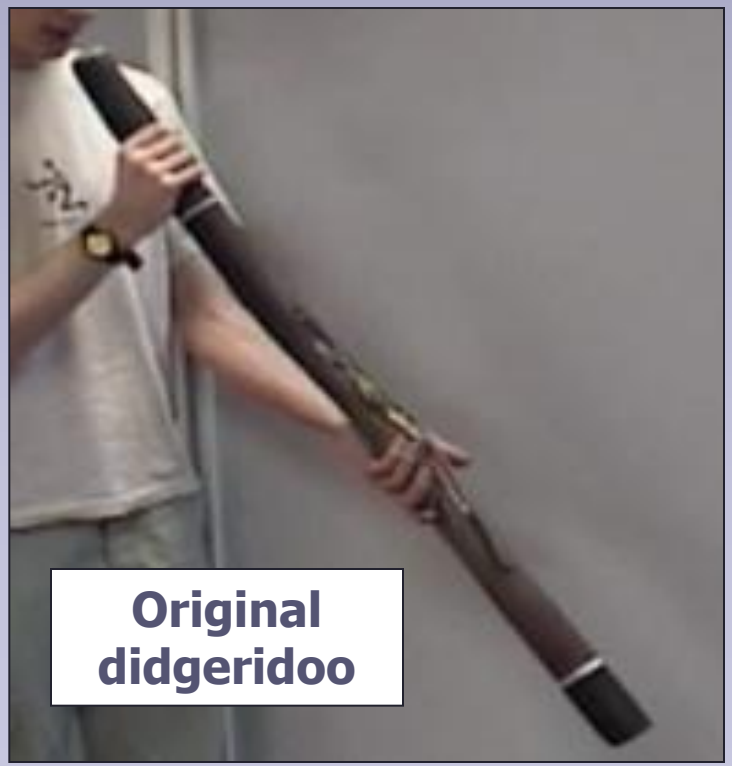
Spectral view of sound

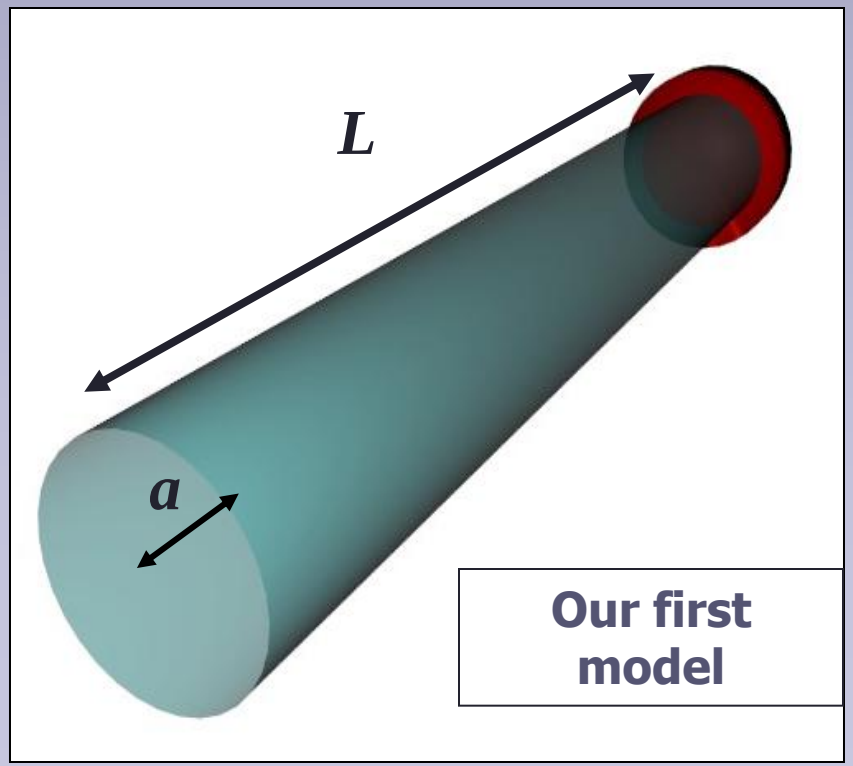


Teoretical model of didgeridoo

- To simplify the initial analyse of the problem let's consider a nonconical didgeridoo: a pipe of lenght l and radius r

- In that case we can describe formation of sounds in a pipe closed on one end





PE/PCV pipes vs real didgeridoo

PE/PCV pipe	Didgeridoo
little bit different timbre of produced sound (syntetic materials resonates slightly different than eucalyptus wood); smooth interior of the tube; no mouthpiece	instrument's interir is chamfered by white ants (must be considered separately); nonregular shape of the pipe (twisted, conical); beeswax mouthpiece 

PE/PCV pipes - experiments

← Short, curved PE pipe

L = 0,85m
d_{wew} = 3,2 cm
d_{zew} = 4 cm

Long, straight PCV pipe:

L = 1,7 m
d_{wew} = 4,4 cm
d_{zew} = 5 cm

Temperature influence on didgeridoo's sound

All our calculations contained the sound velocity in dry air of temp. 20 degrees. Let's see what will happen in other temperatures:

• The main influence on the sound velocity have the temperature, so we can neglect the humidity influence;

• for given temperature we can estimate sound velocity from equation:

$$c = 331.6 + 0.6 \times t$$

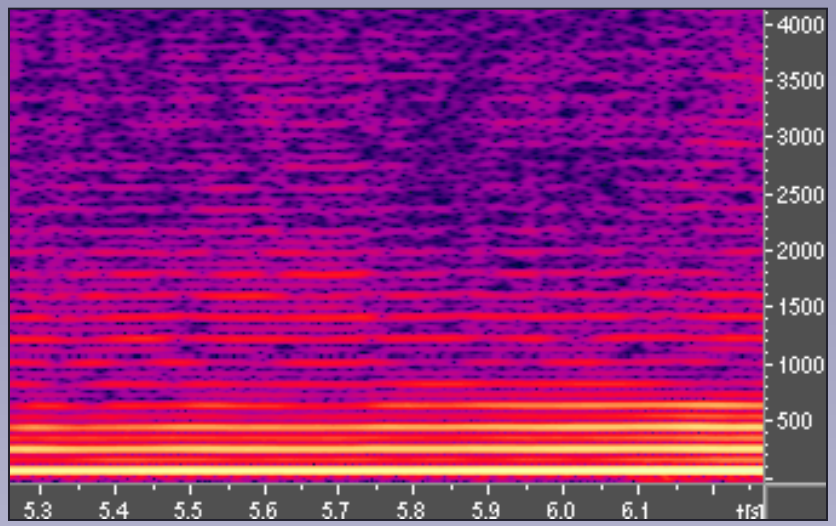
c = sound velocity [m/s]
t = temperature [°C]

That means, that in case of temperature difference 20 ° C frequency of the 1.3 m lenght instument increase about 3.4%, (quater of the musical key)

PE pipe – experiment results

Theoretical values calculated from equation:

$$f_n = \frac{(2n+1)c}{4(L+\frac{8a}{3\pi})} \qquad (n = 0,1,2,3\ldots)$$



Harmonic components	Measured value of frequency		Theoretical value of frequency	
Base	96 Hz	1	94,9 Hz	1
1st harmonic	287 Hz	3	284,7 Hz	3
2nd harmonic	477 Hz	4.95	474,5 Hz	5
3rd harmonic	670 Hz	7	664,3 Hz	7
4th harmonic	862 Hz	8.95	854,2 Hz	9

???Sounding mechanism

This expression cannot be taken too literally in the limit as a ® a0, but the shape of the flow waveform is essentially as shown in Fig. 3. Clearly such a waveform has many harmonics, and this accounts for the rich sound of the didjeridu, and of lip-excited instruments in general. The relative strengths of the upper harmonics are not well predicted by this simple flow waveform, however, for several reasons. The flow waveform gives a spectral envelope which is initially nearly constant and then declines at about 12 dB/octave. The assumption that *R* is constant, however, is not very good, and this resistance is less for the upper harmonics than for the resonant fundamental, except for accidental near-coincidences with higher horn resonances. Finally, the transfer function between flow spectrum and acoustic radiation rises at 6 dB/octave at low frequencies and is then flat above about 3 kHz for the didjeridu horn. Despite these reservations, however, this simple treatment does give a fair idea of spectral behaviour