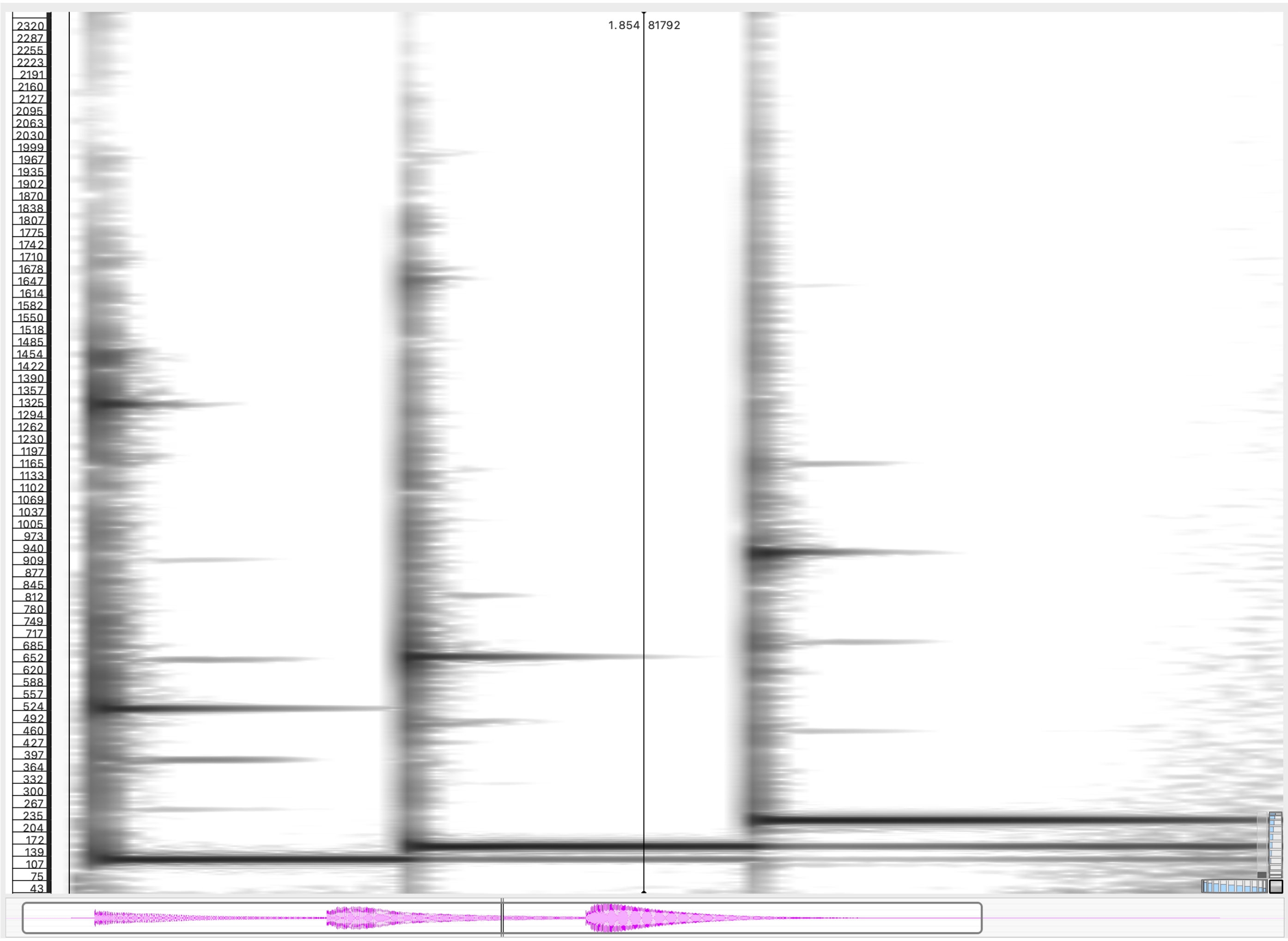
Answer at least two of the following questions. Please motivate all your answers, show all the steps and specify the sources. All the necessary theory is covered within the course material but you can also use external sources if you want to. Submit the answers in a pdf. A scanned handwritten paper is OK if it is clearly written. All work should be done individually and according to the code of honor as linked on the course web.

Q1 The figure below shows a spectrogram (and waveform) of a three-note monophonic melody played on an acoustic instrument and recorded in a room.

a) (20%) Could the resulting sound be considered harmonic or inharmonic, i.e. will you perceive a distinct pitch or not? Motivate your answer.

c) (20%) Make a clever guess and suggest which instrument it could be. Motivate your answer.

d) (10%) Expressed as MIDI pitch, what are the pitches played?



Q2 Clarinet Synthesis

A clarinetist would like to make an electronic copy of their clarinet. Since they know very little about the physics of the sound production, they are using a 'brute-force' method. Thus, they start to record steady tones for every possible pitch at several dynamic levels. The resulting audio files are allocated in a sampler so that the instrument could be played via MIDI commands from a keyboard. This is wavetable synthesis.

The clarinetist finds the result to be unsatisfactory. While the sound of individual notes sounds fine (they should since they are recordings of the real instrument), a simple melody sounds very static. In particular, the synthesis lacks a convincing change of dynamics during a sounding tone, and it is not possible to perform pitch glides.

a) (10%) Explain how one might implement a continuous change of dynamics using wavetable synthesis.

b) (10%) Explain why it is difficult to do a continuous change of pitch using this method.

c) (30%) Describe in detail an alternative synthesis method that could produce a convincing clarinet sound across the dynamic range and pitch range. Also note the limitations of your proposed method.

Q3 Ocarina design

The ocarina is a little wind instrument that can have many shapes. It resembles a recorder in that it has the same kind of sound generation mechanism, and different holes in the body that you cover with your fingers to play different pitches. In the recorder the pitches are determined by the air modes in a tube, thus, the acoustical length of the tube determines the possible pitches. Instead, in the ocarina, the pitches are determined by a Helmholtz vibration in the cavity. Therefore, neither the shape of the cavity nor the position of the holes are important for the resulting pitch – just that they are open or closed.

The concept of *end correction* refers to the fact that the air just outside an open pipe moves in phase with the air in the pipe close to the opening. The net effect is that a plug of air with a certain mass is added to the oscillating air column in the pipe and the effective acoustical length of the pipe is extended beyond the actual geometrical length. The magnitude of the end correction depends on the cross-sectional area and terminating conditions at the edges of the pipe/object. The end correction plays an important role for the Helmholtz resonator in the ocarina.

a) (20%) Compute the resonance frequency of an ocarina. Assume that the volume is $V = 9.4$ cm^3, the opening where the sound is generated has the radius $a =$ 3 mm (note that this is always open), and the thickness of the material $l = 3$ mm. Make the calculations at *three* levels of approximation: 1) ignoring end corrections, 2) including the end correction only at the outer end of aperture; 3) including the end correction at the outer and inner end of the aperture. Give the results in Hertz.

b) (20%) Now we are ready to add some holes. Let's go for the well-tempered scale (choose one here: https://en.xen.wiki/w/Well_temperament) and a fingering similar to a recorder (lifting one finger at a time for playing the scale). Calculate the radius of the first two holes for playing the first three notes of a major scale starting from the calculated fundamental in a). Always include the end corrections. Assume that the first note is when both holes are closed, the second when the first hole is open, and the third when both holes are open.

c) (10%) Discuss and motivate whether the output will have harmonic/nonharmonic/no upper partials in the resulting sound.

Q4 Piano tuning A pianist studied different tuning systems and thought that it would be interesting to see if it was possible to tune a piano to just intonation and get rid of the beatings that normally occurs in equal temperament. The pianist started by tuning the major third above A4 to a perfect interval with small integer ratios according to the harmonic series.

a) (10%) A normal tuner was used with indication of the note played and the deviation from equal temperament in cent. What should be displayed on the tuner for the right intonation of the note a major third above A4?

b) (20%) A different sound quality was obtained but to the disappointment the sound was not completely beat-free. Compute the *cent deviations* and the resulting *beating frequency* for the lowest partial pair that coincide in two ideal strings. Assume that the inharmonicity coefficient is $B = 6 \cdot 10^{-4}$.

c) (20%) Will there be any perceived roughness? Describe and discuss the most probable sources of roughness.

Q5 Deviation from theory During an acoustics lecture the professor demonstrated that if an organ flue pipe resonating with some fundamental frequency is closed with their palm (thus moving from an open-open pipe to an open-closed pipe), the fundamental drops an octave because the wavelength of the standing can only be a quarter the length of the pipe rather than half. Except that the actual pitch dropped less than an octave.

a) (10%) The measured fundamental frequency of the open-open flue pipe was 414 Hz, and that of the open-closed pipe was 215 Hz. Compute the wavelengths of these standing waves.

b) (10%) Compute the wavelength of the expected fundamental of the open-closed flue pipe, and the difference with the measured wavelength.

c) (30%) Attempt to explain this discrepancy.