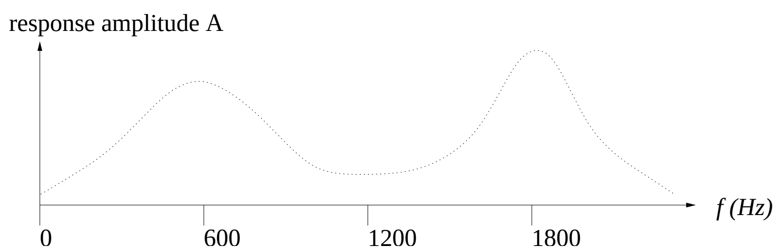
Math 5: Music and Sound. Homework 7

due Wed Nov 9 ... but best if do relevant questions after each lecture

For formant analyses you will want to use `praat` with suggested spectrogram settings 0-4000 Hz range, window length 0.05s, dynamic range 40 dB. You should also experiment with `Show formants`.

1. Short one connecting Q factor to resonance. Consider a bottle with a natural frequency of 200 Hz.
   (a) If the width of frequency response is found (*e.g.* by singing) to be half a semitone (50 cents), what is the Q factor, and thus the decay time of the mode? (This is typical for a Helmholtz resonator).
   (b) Compute the frequency response width of a wine glass vibration mode whose decay time is 1 sec, and whose natural frequency is the same as the bottle's. Why then is it much harder to excite a wine glass than a bottle by singing?
2. The frequency repsonse (steady-state amplitude A vs driving frequency f) of a pipe is shown below. Note that it has two peaks, each peak corresponding to a resonance of a single pipe mode (only the first two modes fall in the frequency range shown).



   (a) Estimate the length of the pipe. Is it open-open or closed-open?
   (b) Estimate the Q factors of the first and second resonant modes of the pipe.
   (c) Estimate the width *in semitones* (at the usual $1/\sqrt{2}$ max amplitude points) for the second resonance.
3. Download the file `noise_bottle.wav` which is recorded from a microphone being lowered into a bottle, while a stereo system emitted 'white noise' at all frequencies.
   (a) Looking at the spectrogram, describe the change in the frequency spectrum. Why does this happen? What phenomenon is responsible for the lowest-frequency strong peak that appears?
   (b) We defined the width Δf of a resonance peak as the size of the frequency interval where the response intensity is at least half its peak. What dB change does halving the intensity correspond to? (Review)
   (c) Use this to estimate the Q factor, and therefore the decay time τ, for this low frequency resonant mode. (Bring up a spectrum graph for the entire in-bottle part. Ignore the other nearby noisy peaks and use the width of the highest central one)
4. Consider a closed-open pipe of length 0.17 m, a model for the vocal tract. Assume initially the pipe has constant width and there's no end correction.
   (a) Compute the formant frequencies F1 and F2.

(b) If the mouth is now opened wider, what happens to F1? to F2?

(c) If the pharynx is constricted about 6cm up from the vocal cords, what happens to F1 (note it's nearer an antinode)? to F2?

5. Download the file `ee_aa_both.wav`, which I made with my own vocal instrument.

   (a) Measure the pitch (fundamental frequency), and also frequencies of formants F1 and F2 for the two spoken vowels.

   (b) For the same vowels whispered, is there a perceived pitch? Are there formants? If so do they have similar frequencies to the sung case? (give only brief discussion)

6. Record your own voice speaking three vowels 'ee', 'aa', and 'oo'[1]

   (a) Print out a spectrogram of your recording, label F1 and F2 for each vowel, and list their frequencies.

   (b) Now draw a new pair of axes: horizontally F1 (on a range 0-1000 Hz), vertically F2 (a range 0-3000 Hz), and plot the points giving the first two formants of each vowel (each vowel gives one point).

   (c) Apply `Convert - Change gender...`, choosing `Formant shift ratio` to be 1.3 if you're male or 0.7 if you're female . . . or subvert the concept of gender entirely and become a chipmunk. Examine the new spectrogram: Did the pitch change? What happened to the formants?

   If you produce something entertaining, upload it.

7. Read some of Prof Theodore Levin's article on *Tuvan throat singing* on the website Resources page.

   (a) How far up the harmonic series (approximately what n) do you need to go so that adjacent harmonics are separated by a whole tone? By a semitone? (Since melodies usually involve scales in which whole tone intervals appear, this tells you typical Tuvan harmonic numbers.)

   (b) A Tuvan singer wants to tune a formant to resonate at the 12th harmonic, but to give less than 1/2 that intensity for both neighboring 11th and 13th harmonics. What Q factor do they need to produce for this formant? (Assume their vocal cords produce equal intensities for all harmonics).

   (c) Draw a spectrum that could be observed if a Tuvan singer sings a fundamental of 100 Hz while tuning a formant as in part b).

8. A room has dimensions $4 \times 6 \times 10$ m^3. Compute the reverberation time T_{60} in the following situations:

   (a) The room is perfectly reflective (impossible in reality) but has windows open totalling area 5 m^2.

   (b) The room is everywhere lined with wood (use the absorbtion coefficients on p.222 at 1000 Hz) and the windows are closed (treat them the same as wood).

   (c) The room is lined with wood everywhere except 5 m^2 of windows are opened.

[1] Hold each for at least a second, and if you want, rather than changing suddenly, slide between them to watch formants change gradually. You will want to put the mic close to your mouth but not get crackle or noise from air blowing on it; experiment until you get a clean signal.