9.35 Spring 2024

Problem Set 1: All About Sound Due: 2/26/2024 at 11:59pm

Please follow the instructions on the syllabus regarding problem set preparation.

The goals of this problem set are to:
a) gain experience generating sounds, for use in the upcoming Illusion Lab
b) think about the decibel scale
c) think about the compressive response of the cochlea

If you use Python to complete this problem set, make sure to import these libraries:

```
import matplotlib.pyplot as plt
import plotly.express as px
import numpy as np
import math
from scipy import signal
from IPython.display import Audio
```

1. Make a plot of the increase in level that would occur if the (rms) *amplitude* of a sound waveform were to increase by a factor r. By how much does the level increase in dB if the (rms) amplitude is doubled? Make a second plot showing the increase in level if the *power* of the waveform is increased by the same factor r? By how much does the level increase in dB if the power is doubled?

2. a) In Matlab, generate a 400 Hz pure tone, lasting 1 second in duration. Use a sampling rate of 20 kHz. Set the rms level to be equal to .05. Hint: first define a vector of time points, in units of seconds. In Matlab: t = [1:sr]/sr; where sr is the sampling rate. In Python: t = np.linspace(1,sr)/sr. Then use the time vector as part of the argument to the sin function you use to generate the pure tone.

b) Generate a complex tone with the first 10 harmonics of 400 Hz, again 1 second in duration. Set the amplitudes of each harmonic so that they decrease with increasing frequency, at a rate of 8 dB per octave. Then set the rms level of the whole waveform to .05. Plot the waveform of the tone. Then plot its power spectrum, with dB on the y-axis and Hz on the x-axis (you can use pwelch in Matlab, or signal.welch in Python, for this purpose, but make sure to specify the sampling rate so that you get the frequency labels to come out right; the other arguments do not matter as much, and you can use the defaults). Listen to the tone using the soundsc command in Matlab, or Audio in Python. Does it sound at all like a note on a musical instrument? ***MAKE SURE THE VOLUME SETTING ON YOUR COMPUTER IS SET TO A LOW LEVEL TO START WITH, TO AVOID DAMAGING YOUR EARS!***

c) Give the complex tone from (b) an exponentially decaying amplitude envelope (decaying 60 dB/second). Hint: define a vector containing the values of the exponential envelope, and then pointwise multiply with the complex tone waveform. Plot the waveform and power spectrum. Listen to the result. Does it sound more realistic than the tone of (b)? Why might this be?

d) Now give the complex tone from (b) an amplitude envelope that rises exponentially (one simple solution would be to time-reverse the envelope you generated for part c). Does this sound like a musical instrument?

3. Generate a one-second sample of Gaussian white noise, with a sampling rate of 20 kHz, and set the rms level to .05. Hint: successive samples of white noise are independent, such that a Gaussian white noise signal can be generated from independent draws from a Gaussian distribution. Use the butter function in Matlab, or the signal.butter function in Python, to make a low-pass filter with a cutoff of 600 Hz, a highpass filter with a cutoff of 1200 Hz, and a bandpass filter with cutoffs of 600 and 1200 Hz. The order of the filter should be 2. Make three additional noise samples by filtering the white noise with each of the filters, using filtfilt in Matlab, or signal.filtfilt in Python. Plot the power spectra of all four noises, with dB on the y-axis and Hz on the x-axis.

4. a) Make a graph plotting the amplitude of basilar membrane vibrations at the place with a characteristic frequency of 10 kHz as a function of the amplitude of a 10 kHz input tone. First plot both input and output in dB, and then on linear scales (i.e. make two different graphs). In both cases use the same axis scaling (e.g. have both the x and y axes span the same number of dB, and use a square axis ratio) Assume that the vibration amplitude is proportional to $A^{0.3}$, where A is the amplitude of the tone.
b) Now also plot the shape of the response functions for a dead cochlea in which the outer hair cells no longer function, such that the vibration amplitude is simply proportional to A (add these new response functions to the graphs from a). Hint: You may need to add some offsets to get the graphs to look like the ones we saw in lecture.

5. What is the topic or concept that has been most poorly explained in lecture so far (you can list more than one)?

Extra Credit. Suppose a single violinist on a stage produces a note with a uniform level of 60 dB SPL at the ears of a listener in the audience. Assuming that different violins produce sound waveforms that are uncorrelated, what is the sound level that would be produced by two such violinists? What is the sound level that would be produced by 96 violinists? Hint: perform your dB calculations in the power domain. Make a plot of the dB level vs. the number of violins.