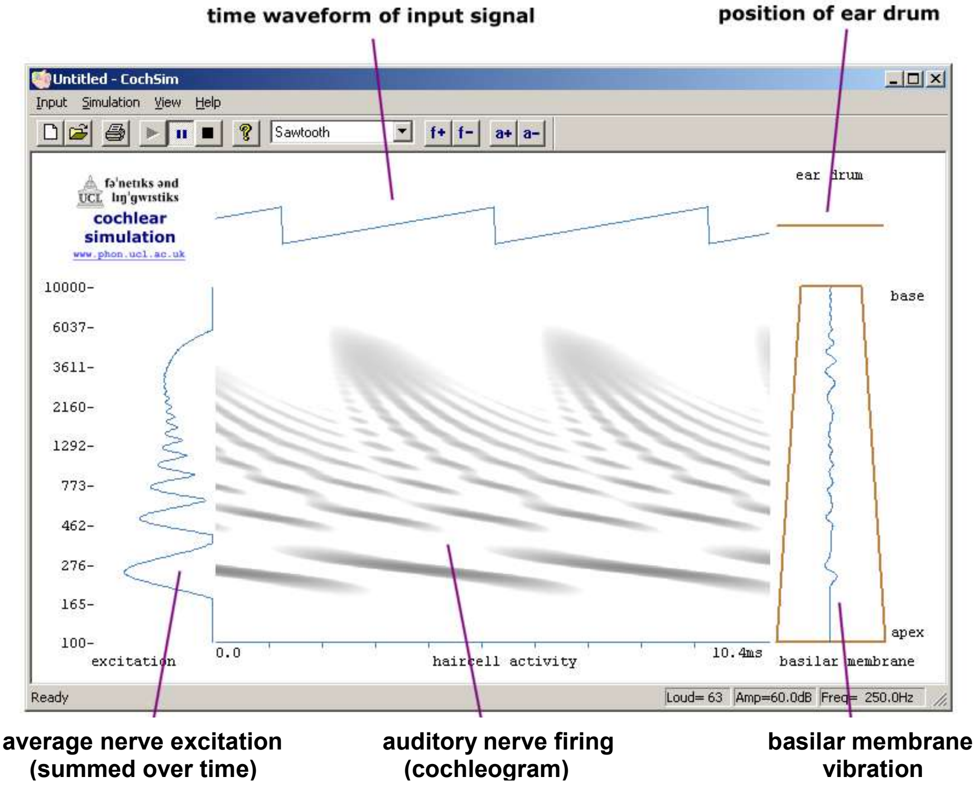
Signals, systems, acoustics and the ear
Lab week 5: Cochlear Simulation

In this laboratory we look at how a ‘model cochlea’ reacts to a range of simple and complex stimuli and hence try to gain a better understanding of cochlear place and time coding. Although simplified, the simulation exhibits many aspects of the behaviour of a real cochlea. It is available free at **http://tinyurl.com/6mbvrz**

The simulation has four panels:



(i) At top, a display of the sound waveform entering the cochlea (instantaneous amplitude vs. time).

(ii) At right, a representation of the motion of the eardrum (top) and of the travelling wave on the basilar membrane (below).

(iii) In the centre, a spectrograph-like representation of the auditory nerve activity arising from basilar membrane vibration known as a cochleogram (time on the x-axis). You can think of this as the summed firing of all the auditory nerve fibres coming from inner hair cells within a small region of the basilar membrane (some hundreds of fibres, as each hair cell can have 10-30 afferent fibres synapsed to it). Ignore the label ‘haircell activity’.

(iv) At left, a representation of the average (over time) of the firing rate in the auditory nerve as a function of cochlear position - the *excitation pattern*.

Panels ii) to iv) each make use of a vertical scale that shows frequency mapped out along the length of the basilar membrane. This axis represents a linear scale for position along the basilar membrane, which corresponds roughly to a logarithmic frequency scale.

Objectives

By the end of the laboratory session you should:

- understand what is meant by place and temporal coding of the frequency of pure tones
- understand how the fundamental frequency of a complex tone is encoded in place and time

Observations

1. Coding of the frequency of a sinewave

Select ***sinewave*** as the input signal from the white rectangular box on the menu. Explore the main controls of the program. Notice how you can change the frequency of the sinewave using the ***f+*** and ***f-*** buttons, and change the amplitude with the ***a+*** and ***a-*** buttons. The values you set appear bottom right of the display window. The amplitudes you set are scaled fairly arbitrarily so are not on the SPL or HL scales. The display runs much slower than real-time, and whenever you make a change, it takes a short while to stabilise. You can start the display running with the play button (right-pointing triangle, usually green) and also pause it (button just to the right of ***play***), or stop it (next button along). It is often useful to pause the simulation once the pattern has stabilised so you can study its properties more readily.

A. Set the amplitude to about 50 dB. As you change the frequency of the sinewave, how is 'place' coding represented in the different panels?

i. in the basilar membrane motion

ii. in the nerve firing pattern shown in the centre

iii. in the average nerve firing pattern shown at left

B. Temporal codes in nerve firing

i. Set the sinewave frequency to about 400 Hz. Pause the display once stable. How does the timing of the nerve firing shown in the main panel relate to the waveform of the sound at top? Note that if you want to consider activity from only a small group of auditory nerve fibres tuned to a particular frequency region, you must look at only a narrow horizontal band in the cochleogram.

ii. Why is the activity in the cochleogram shown as diagonal, rather than straight vertical, lines? Note: Hard question!

iii. Why is the periodicity of firing in all the stimulated nerve fibres identical?

iv. Increase the frequency to about 4000 Hz. What has changed in the temporal pattern of the nerve firing? Why?

2. Coding of complex periodic waves

Display a periodic complex tone using the ***sawtooth*** signal. You can change the fundamental frequency (the repetition frequency) of the complex tone as before. Set the fundamental frequency to around 200 Hz and the amplitude to about 60 dB.

A. Coding of harmonic components

i. How are the harmonics of the complex tone represented in the excitation pattern? Can you explain why the peaks in the excitation pattern are not equally spread along the basilar membrane?

ii. The acoustic signal contains a large number of harmonics. How many harmonics are evident in the excitation pattern? Why are the higher harmonics not evident?

B. Coding of fundamental frequency

i. How could the fundamental frequency be determined from the excitation pattern using place coding?

ii. How could the fundamental frequency be determined from the temporal coding of nerve firing?

3. Representation of resolved and unresolved spectral components

Select ***Two Sinewaves*** as the input signal with an amplitude about 50 dB. The first sinewave is fixed at 3925Hz but you can adjust the frequency of the other. Set that frequency to about 400 Hz.

The degree of interaction in the cochlea between these two components can be assessed by the excitation pattern at left. Here you can see two separate peaks, so the components are said to be ***resolved***, which means they are represented separately on the basilar membrane/in the auditory nerve.

A. Why is the temporal patterning of the two sinewaves different? You have answered this already!

B. Adjust the frequency of the lower sinewave to about 2.5 kHz. Are the sinewaves still resolved?

C. Adjust the frequency of the variable sinewave to 4 kHz (75Hz different from the other sinewave). Are the sinewaves still resolved? How can you tell?

D. What you see in the waveform and cochleogram with regards to overall changes in amplitude are known as beats. Why do beats happen?

E. Adjust the frequency of the variable sinewave upwards until you can no longer see any beats. What difference do you see in the excitation pattern from when the components were unresolved?

F. Try to come up with a hypothesis about what spacings between the frequencies of sinewaves will lead to beats in the inner ear, and what spacings will not.