UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
Department of Electrical and Computer Engineering,
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ECE 598 The Speech Chain

Homework Set 9

Fall 2006

Issued: Monday, November 13, 2006 **Due:** Monday, November 27, 2006

Reading for problem set 9: Fletcher, "A Space-Time Pattern Theory of Hearing," JASA 1(3):311-343, 1930. Fletcher and Munson, "Loudness, Its Definition, Measurement and Calculation," JASA 5(2):81-108, 1933, Fig. 4.

Problem 9.1

This problem will examine, in some detail, Fletcher's theoretical explanations for loudness and masking of tones at different frequencies. This material is pretty abstract, so you will probably not have much physical intuition for it until after you have done the laboratory. The laboratory will let you listen to some noise-masked tones; doing so should help you to understand the point of this problem.

(a) Print out a copy of Fletcher's Fig. 10. Identify the curve that shows the stimulation level of the basilar membrane for the 75dB 2000Hz tone. By drawing lines on your printout, determine the stimulation levels $\alpha(x)$ separately for the values $x = 0, 1, 2, 3, \ldots, 15$mm (notice that the stimulation level drops to zero beyond 15mm).

(b) Use Fig. 14 to convert each of your stimulation levels, $\alpha(x)$, into an equivalent rate of nerve discharges per millimeter, $S(\alpha(x))$. The numbers on each of the curves tell you how much to scale the y-axis value, e.g., if you find the (x,y) pair (70dB,2.5) on the curve marked 10^3, then it means that a 70dB stimulus level α corresponds to a nerve firing rate of $S(\alpha) = 2.5 \times 10^3 = 2500$ spikes/mm/second.

(c) Add them up using the summation version of Eq. 22, below, in order to get the total number of spikes per second on the auditory nerve:

$$R = \sum_{x=0}^{31} nS(\alpha(x))$$

where $n = 1000$ is the approximate number of nerve fibers per millimeter. Compare your result to the number $R = 250,000$ given in Fletcher's table III.

(d) You have estimated that a 2000Hz tone at 75dB produces 250,000 spikes per second on the auditory nerve. Now use Fig. 15 to find out how loud a 1000Hz tone would have to be in order to produce the same number of spikes per second. The resulting level, in decibels, is called the "loudness level" of the 2000Hz tone.

(e) Notice that loudness level is a function of both the level (dB SPL) and frequency (in Hertz): a 2000Hz tone at 75 dB SPL is louder than a 1000Hz tone at 75dB SPL. Look at Fig. 4 from Fletcher & Munson (1933). Find the point on this graph that corresponds to a tone at 2000Hz, and at 75dB SPL. Confirm that the loudness level of such a tone is greater than 75dB.

(f) Model the effect of a 70dB white noise masker by drawing a horizontal line across Fletcher's Fig. 10 at a level of 70dB. Repeat part (a), but this time, instead of measuring the stimulus level with reference to a 0dB threshold, measure the stimulus level with reference to a 70dB threshold (the "masked threshold"). In other words, pretend that the ear has been listening to a 70dB white noise masker for some time, and then suddenly, a 75dB tone at 2000Hz is presented together with the masker—how much does the motion of the basilar membrane increase at each place?

(g) Repeat parts (b) and (c), in order to find out how much the spike rate on the auditory nerve *increases* when the 75dB tone is added to the pre-existing 70dB masker.

(h) Repeat part (d) in order to find out whether or not the *increase* in nerve firing rate is audible. If the *increase* in firing corresponds to a loudness level of more than 0dB, then the tone is audible; if not, the tone is masked. Is the tone audible, or masked?