Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science, and
The Harvard-MIT Division of Health Science and Technology

6.551J/HST.714J: Acoustics of Speech and Hearing

Take Home Quiz 2
Issued 1 PM on Wednesday 8-Dec-2004
Due back 1 PM Thursday 16-Dec-2004

Please enclose your completed exam in a sealed envelope with your and my name on it.

Also, please put your name on every page you hand in.

Each student is expected to work independently. Texts and libraries may be consulted but the course notes and homework solutions should be sufficient. Look over the exam by 1 PM Thursday 9-Dec-2004. You will only be able to ask questions about the exam during class on that day.

Student Name: ____

Problem 1. (20 points)

For the purposes of this problem, a system is linear if given any three inputs, *A, B*, and *C*, that produce outputs *X, Y,* and *Z* respectively,

1). For any real positive constant α, the input αA produces an output αX; i.e. $\frac{output}{input} = constant$;

2). The input $B + C$ produces the output $Y + Z$.

In this problem you are to consider whether the normal auditory system is linear as determined from perceptual experiments by giving examples of cases for which the system behaves linearly and examples for which the system does not.

Let the inputs correspond to stimuli, e.g., tone bursts of a given amplitude, frequency, and duration, or noise bursts of a given amplitude, spectral composition, and duration. Let the outputs correspond to just noticeably different tone bursts or noise bursts, or just detectable values of tonal amplitude in the presence of a tone masker or a noise masker, etc.

For example, let *A* be a 1000 Hz tone of 500 ms duration and intensity *I*, and let *X* be a 1000 Hz tone of 500 ms duration and an intensity $(I+\Delta I)$ that is just noticeably different from *A*. According to rule 1 above: if the system were linear, multiplying the intensity of the input by a constant e.g. $A' = \alpha I$ should result in a just noticeably different intensity $X' = \alpha(I+\Delta I)$. If you look at the results of Viemiester (1988) shown in Figure 9 of the notes on auditory sensitivity $(I + \Delta I)/I$ at the *jnd* can be considered constant (i.e. the response is linear by rule 1) for the range of inputs of $10 \leq I \leq 40$ dB SL, but not so outside this range.

- Specify two different stimulus configurations for which the auditory system is clearly perceptually *not* linear.

- Specify two different stimulus configurations for which the auditory system is (at least approximately) perceptually linear.

Provide a few sentences to explain and justify each of your answers. Your explanations should specify the stimuli *A, B, C, X, Y* or *Z* precisely and the range of stimulus values over which linearity holds or does not hold. You should cite the sources of data that support your reasoning.

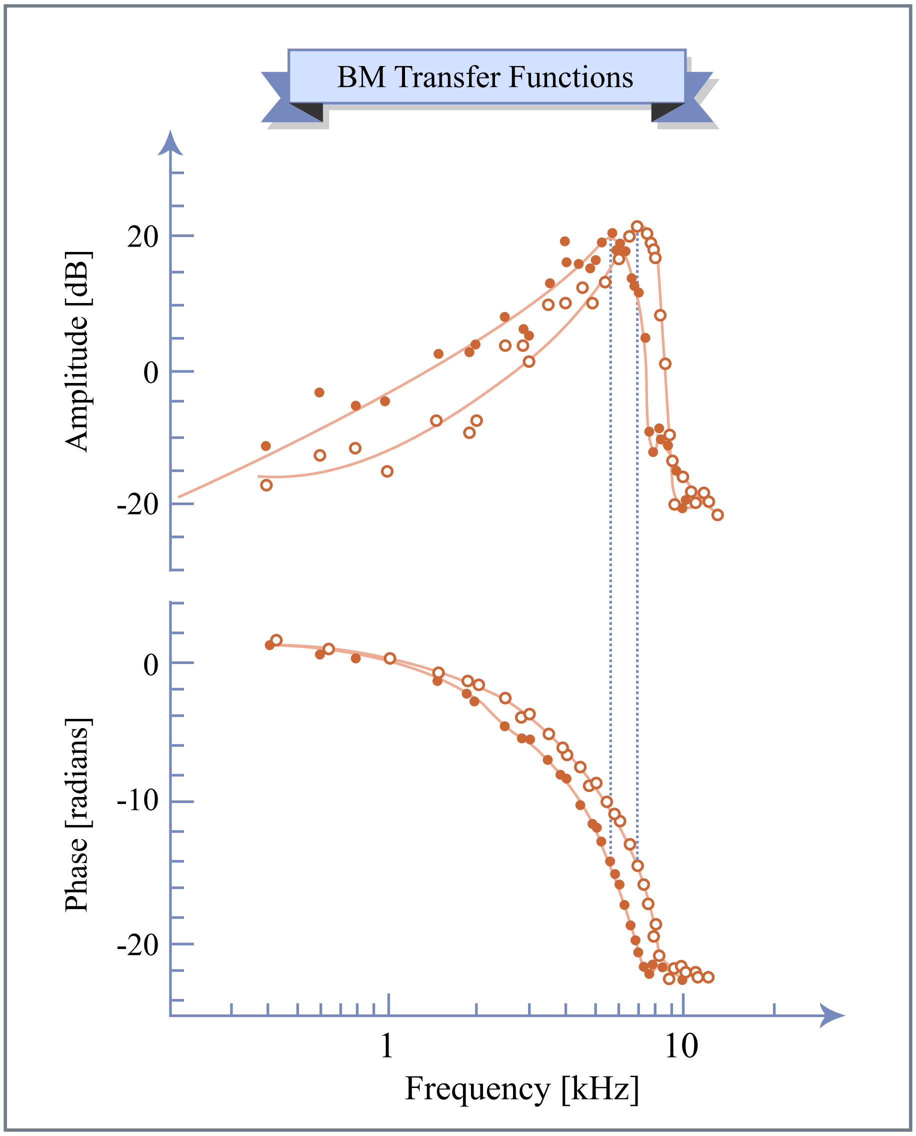
Problem 2. (20 points)

Are the following statements *True* or *False*: EXPLAIN YOUR REASONING!

1. The speed of sound in a fluid medium increases as the density of the fluid increases.
2. The characteristic impedance of a fluid medium is the square root of the product of the density and the *Bulk Modulus* of the medium.
3. People who have lost their tympanic membranes and ossicles have no hearing.
4. There are four ossicles in the human middle ear.
5. The ossicular lever ratio of the human makes the biggest contribution to middle-ear impedance transformation.
6. The pinna plays no role in sound localization in the median plane.
7. The *rms* intensity of the sum of two tones of identical frequency depends on the magnitudes and phases of the individual tones.
8. The *rms* intensity of the sum of two tones of different frequencies depends on the relative phases of the two tones.
9. The tonotopic arrangement of frequencies in the mammalian cochlea leads to the coding of high frequencies in the apex of the cochlea.
10. The frequency difference limen of the normal human listener is 10 Hz for frequencies between 0.1 and 10 kHz.

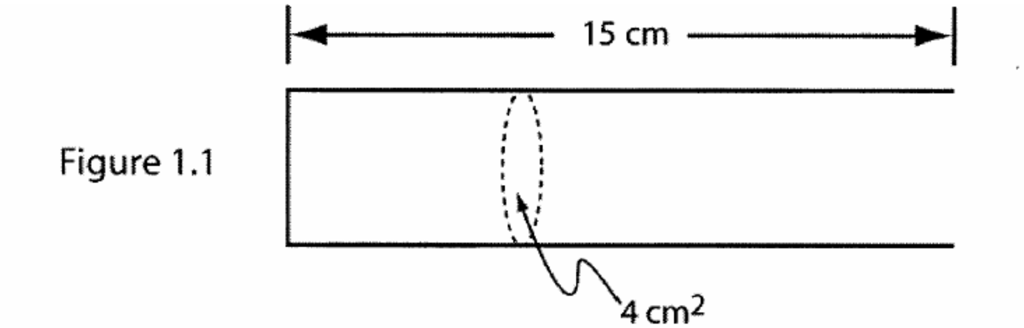
Problem 3. (20 points)
Figure 1 shows basilar-membrane mechanical transfer functions measured at two different cochlear locations in a squirrel monkey (Rhode 1972). According to Rhode, the two measurement locations are separated by approximately 1.5 mm along the basilar membrane.

1. Determine the cochlear position-frequency map assuming that the map is approximately exponential and that the squirrel monkey has a maximum frequency of 50 kHz.
2. Determine the CF group delay of the mechanical transfer function at the 7-kHz place. The group delay is defined as $-d\theta/d\omega$, where θ is the transfer function phase (in radians) and $\omega = 2\pi f$.
3. Use local scaling symmetry to estimate the wavelength of the traveling wave evoked by a 7 kHz pure tone at the 7-kHz place.
4. Use scaling to estimate values of the CF group delay and wavelength at the 14-kHz place. Explain your reasoning.



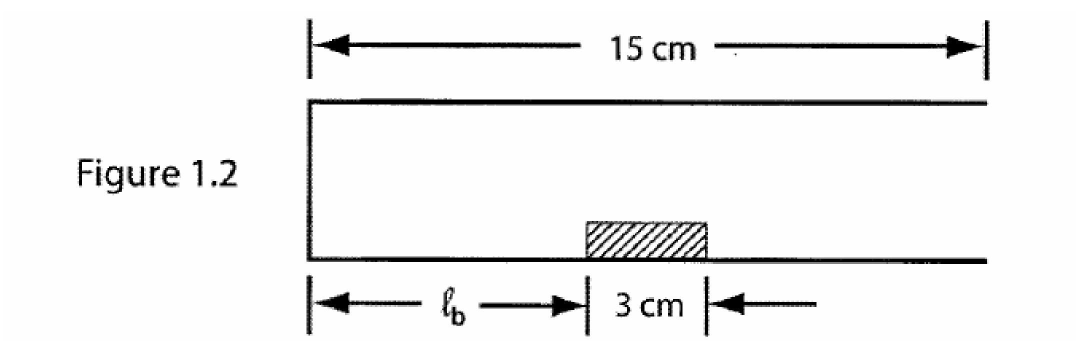
Adapted from Figure1: BM/stapes mechanical transfer functions in squirrel monkey (Rhode 1972).

Problem 4. (20 points)

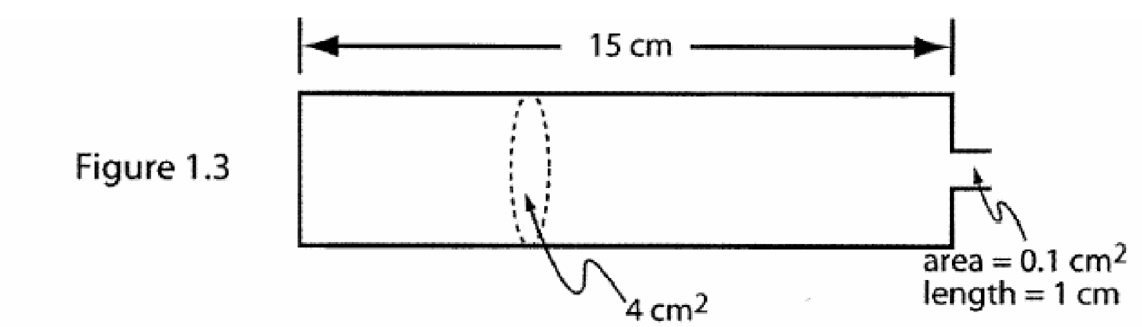


(a) A cylindrical hard wall tube of length l = 15 cm and cross-sectional area 4 cm^2 is closed at one end and open at the other, as shown in Figure 1.1. What are the first three natural frequencies F1, F2, and F3 of this tube? Assume that the sound pressure at the open end is zero.

(b) The configuration in Figure 1.1 is now modified by increasing slightly the cross-sectional area of a portion of the tube. The length of this portion is 3 cm, and the center of this perturbed section is distance l_b from the closed end, as shown in Figure 1.2. Find the value of l_b such that the lowest natural frequency F1 of the tube is increased relative to its value in (a) and the second natural frequency F2 remains unchanged.



(c) Return to the tube in Figure 1.1. This tube is now modified by adding a cylindrical plug at the right end, with a small hole, as shown in Figure 1.3. The length of the plug is 1 cm and the cross-sectional area of the hole is 0.1 cm^2. What the lowest natural frequency of this configuration? Make appropriate approximations.



Problem 5 (20 points)

The spectrogram of a sentence produced by a female speaker is shown in Figure 2.1 on the following page

(a) Somewhere in the sentence there is a one-syllable word containing an initial stop consonant, a front vowel, and a final nasal consonant. Identify the beginning and end of the region where this word occurs. You may either place legible marks on the figure or note the relevant time periods.

(b) Identify four regions in the sentence where a stop consonant is produced. For two of these consonants, state whether the place of articulation is labial, alveolar, or velar. You may either place legible marks on the figure or note the relevant time periods.

(c) The waveform of the sound over a 100-millisecond interval in the sentence is shown in Figure 2.2. Locate this region in the spectrogram. You may either place legible marks on the figure or note the relevant time periods.

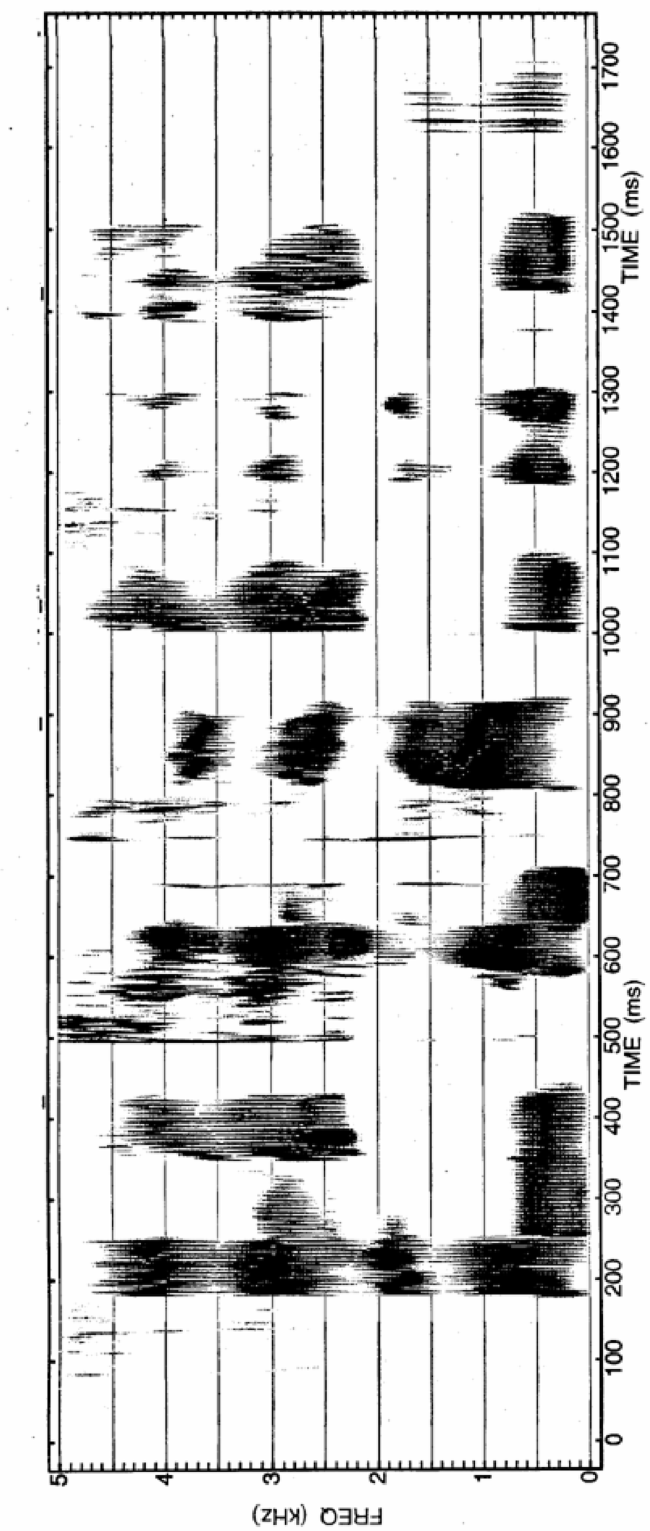


Figure 2.1

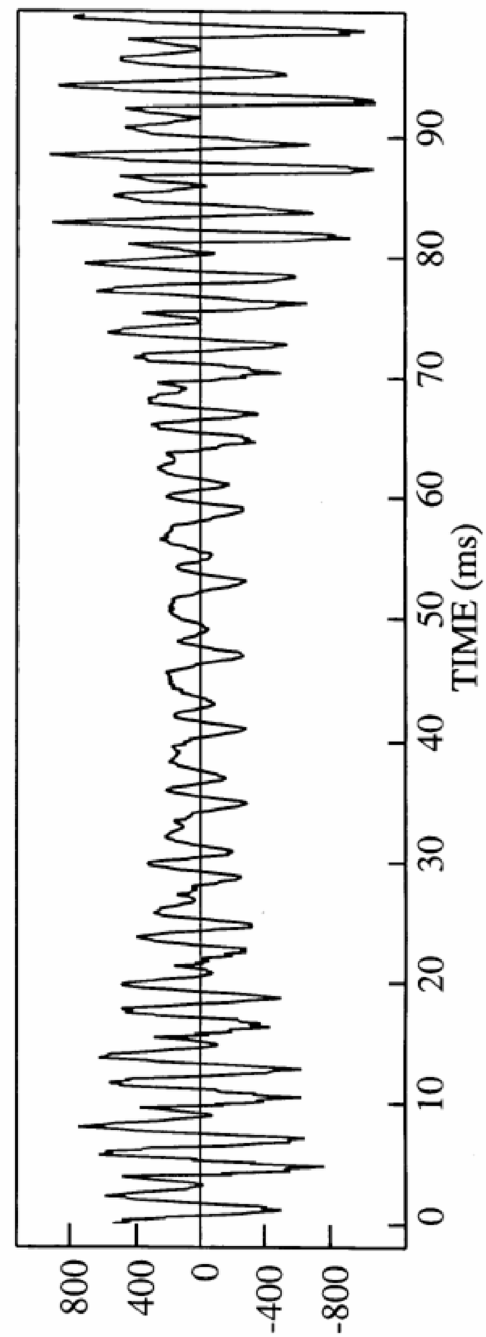


Figure 2.2