ECE 537 **HW #2** **Fall 2007**

Univ. of Illinois **Due Fri., Sept. 14** **Prof. Allen**

Topics of this homework: Acoustics, Transmission line simulation, dB

This is a complex homework, that will take you significant time. *Note the estimated times following most of the problems.*

Estimated times are given for solving the problem, but not for writing up the solution, which in many case may take longer than solving the problem, depending on how you do your write-up. If you find that the actual time is much greater that my estimated time, tell me (send me email or bring it up in class).

Do the Matlab problem (# 6) last!

1. Speech:
   (a) How many people talking, at 20 dB-SPL measured at 1 m are required to light a 60 watt light bulb? (5 min)
   (b) How many people are required if the are speaking at 60 dB-SPL (1 meter)? (1 min)
   (c) What is a *phone*?
   (d) How long is the average phone [ms]?

2. Anatomy of the vocal system:
   (a) Hand-draw and label a picture of the Larynx. (10 min)
   (b) What is the purpose of the Larynx? (2 min)
   (c) How large is it? (2 min)
   (d) If the lungs were a cube, how long would the side of the cube be in inches? (3 min)
   (e) What are the following model parameters shown in Fig. 1.3 of the text, in MKS units?

$C_t = 0.06$	$C_d =$	$C_l =$	$[\mathrm{m}^5/\mathrm{Nt}]$	
$M_t = 0.04$	$M_d =$		$[\mathrm{kg}/\mathrm{m}^4]$	(10 min)
$R_t = 4$	$R_d =$		$[\mathrm{Nt\text{-}s}/\mathrm{m}^5]$	

   (f) Justify (derive/explain) the units of acoustic impedance for each of the elements in the previous question. For example, why does C_l have units of m^5/Nt? (5 min)
   (g) What is the definition of *Young's modulus*, including the MKS units?
   (h) Define the following: (1-2 mins each)
      i. Pharynx
      ii. Hyoid
      iii. Palate
      iv. Mandible
      v. velum
      vi. velar
      vii. Alveolar ridge (If necessary, look it up in the dictionary).
      viii. viscosity

3. Wave equations:

(a) Show that the function $f(x,t)$

$$f(x,t) \equiv e^{-3(t-x/c)} \sin\left(2 * pi * 100(\sqrt{c}t - x/\sqrt{c})\right) U(ct-x) \tag{1}$$

is a solution to the wave equation. $U(t)$ is the unit step function. (2 min)

(b) Explain where the formula $\gamma P_0 = \rho_0 c^2$ comes from? Namely, derive this formula. (5 mins)

(c) What year did D'Alembert derive his solution to the wave equation? (1 min)

(d) What is the form of D'Alembert's solution? (1 min)

(e) Webster Horn Equation:

i. Starting from the basic transmission line equations with an area function given by $A(x) = A_0 e^{2mx}$, derive the corresponding horn equation. I am not asking you to solve it, just write down the differential equation that describes wave propagation, when the area function is an exponential function. (7 min)

ii. What would you guess the form of the solution will be? (3 min max)

4. Reflectance:

(a) Find (derive) the formula for the load impedance at the end of a transmission line having characteristic impedance $z_0(x,s)$, in terms of the reflectance. Hint, I did this in class on 9/7/07. (5 min)

(b) Find the formula for the reflectance $R(s)$ in terms of the load impedance $Z_L(s)$ and the characteristic impedance z_0 if:[1]

i. $Z_L(x,s) = r$ [Nt-s/m^5] (3 min)

ii. $Z_L(x,s) = 1/sC$ [Nt-s/m^5] (3 min)

iii. $Z_L(x,s) = r||sM$ [Nt-s/m^5] (5 min)

iv. Two transmission lines are in cascade, one with area of 1 [cm^2] and a second one with area of 2 [cm^2], terminated with a resistor having a resistance of $r = \rho c/A$ where $A = 210^{-4}$ [m^2].

v. What is the inverse Laplace transform $h(t)$ of

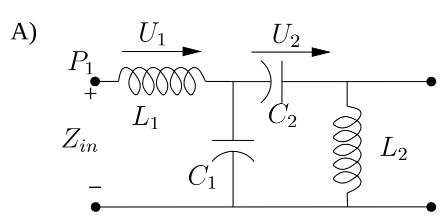
A. $H(s) = 1/(s+1)$? (1 min)

B. $H(s) = s/(s+1)$? (1 min)

5. In the figure below, two circuits are shown, (A) and (B). Analyize these circuits as follows:

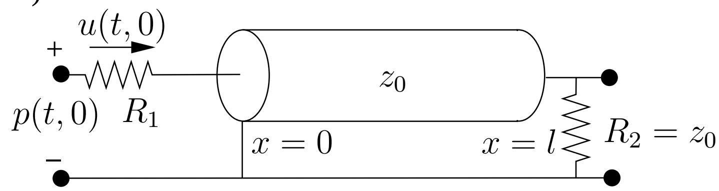
(a) Use a "traditional" analysis (define the impedances, and use formulas for series [$z = z_1 + z_2$] and parallel $z = \frac{z_1 z_2}{z_1+z_2}$ combinations), to obtain the input impedance $z_{in}(s)$, where s is the complex frequency ($s = \sigma + j\omega$), defined in the *Laplace Transform.* (Give me your best answer after 20 mins of work, not more. This time only includes analysis, not the write-up.)

(b) Use the ABCD (Transmission) matrix approach to find the input impedance of the same two circuits. (15 mins)



[1]Note that r, C and M represent an acoustic resistance, compliance and mass. Namely they are positive constants.

B)



6. Write a Matlab© program to simulate a tube. Write up a summary description of your solution, with labled figures, which includes a readable listing of the program. (2 hours) You can use MS word for you writeup, but I highly recommend LaTex when writing such a report, having equations and figures. There is some learning curve, but it pays off in the end, in my opinion.

   (a) Write a Matlab program along the lines of what I discussed in class (9/7/07) that simulates a impulse traveling along a transmission line with a sealed input end (glottis) ($Z_g = \infty$) and the output end (mouth) terminated in a resistor having a resistance of $Z_m = r_m = 2z_0$, where z_0 is the characteristic impedance of the tube.

       Use a sampling frequency of $F_s = 44,100$ [Hz], and make the tube 10 samples long and assume $c = 345$ [m/s]. (1-3 hr, depending on how well you know Matlab).

   (b) Find the mouth and glottus velocity impulse response, and its spectrum (FFT of the impulse response).

   (c) When you plot the impulse response use linear plots. When you plot the frequency response, use log-log coordinates (log-frequency, log amplitude). Only plot the positive frequencies from 100 to 10 [kHz]. Describe what you found. The writeup should also include an analysis of how you solve this problem, including the boundary conditions at the two ends of the tube, the length of the tube, etc. (30-60 min)