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 1

Issued 2:30 PM on Thursday 21-Oct-2004
Due back 1 PM Thursday 28-Oct-2004

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 Tuesday 26-Oct. You will only be able to ask questions about the exam during class on that day.

Student Name:____

Problem 1:
Figures 1.1a & b show two steady state sinusoidal responses.

Figure 1.1a

$$a(t) = A\sin\left(2\pi\frac{1}{T}(t-\alpha)\right)$$

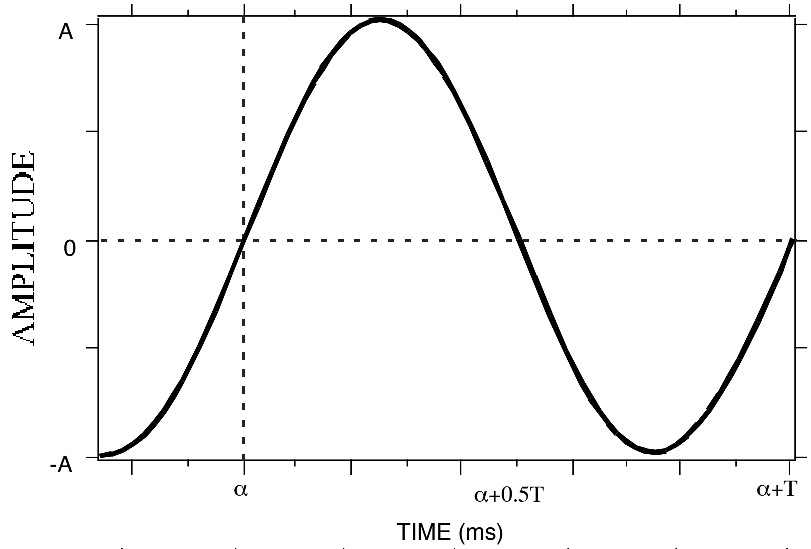
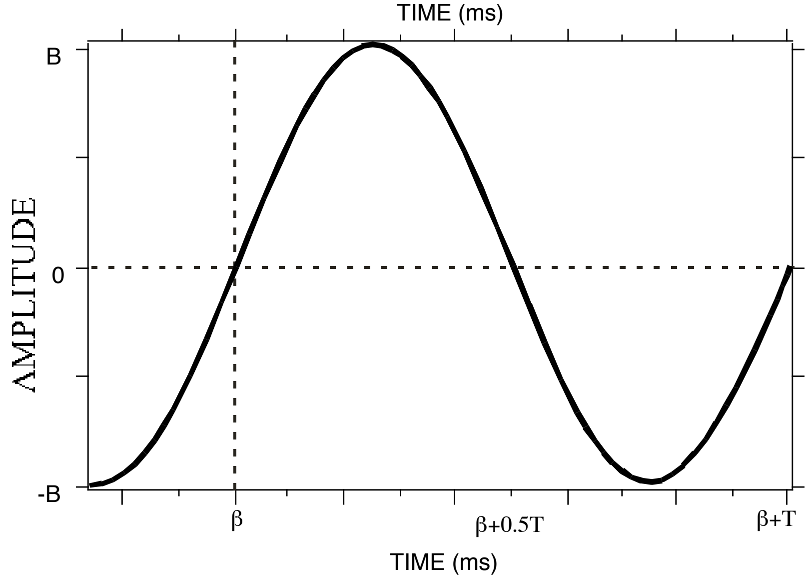


Figure 1.1b

$$b(t) = B\sin\left(2\pi\frac{1}{T}(t-\beta)\right)$$



a) Assume *a(t)* defines the sound pressure and *b(t)* defines the particle velocity of a forward propagating plane wave in an air-filled space at standard temperature and pressure.
   i. If $T = 1$ ms, what is the frequency of the wave?
   ii. What is the wavelength?
   iii. If $A = 1$ pascal, what is B (include units)?
   iv. If $A = 1$ pascal, what is the sound pressure in dB SPL?
   v. If $A = 1$ pascal, what is the average sound intensity in watts/m^2?
   vi. If $A = 1$ pascal, what is the average sound intensity in dB SPL?
   vii. How are α and β related? (Hint: if the phase of *a(t)* – phase of *b(t)* $=\pi/2$; then $\beta = \alpha + T/4$.)

b). Assume that Figures 1.1a and 1.1b describe two sound pressure *p(t,a)*= *a(t)* and *p(t,b)*= *b(t)* at different distances r_A & r_B from a simple source where: $A = 1$ pascal, $T = 1$ msec and $r_A = 3$ meter.

i. If $B = 10$ pascals, what is r_B?

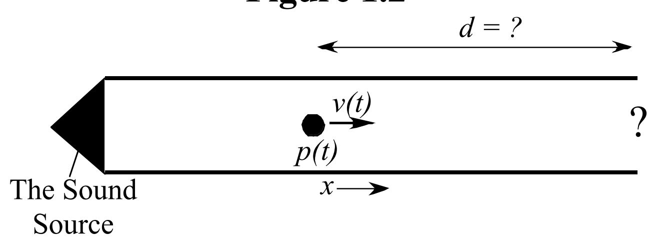
ii. How much time would it take a front at position *b* to propagate to *a*?

iii. If β= 0 ms, what is α?

iv. What is the specific acoustic impedance of the spherical wave front at r_B?

v. What is the specific acoustic impedance of the spherical wave front at r_A?

Figure 1.2



c). Assume that Figures 1.1a and 1.1b describe the sound pressure *p(t)*= *a(t)* and particle velocity *v(t)*=*b(t)* at a location inside a long air-filled cylindrical duct, where the radius *r* of the duct is less than 0.1 λ. The sound source is to the left, while to the right: *d*, the distance between the measurement point and the termination, and the status of the termination of the tube varies. The system is in the steady state.

i. Assume *d* is infinite.
   a. Describe the spatial variation in *<u>P</u>(x)* and *<u>V</u>(x)* in terms of complex exponentials that vary in *x*.
   b. If *A*=1 pascal, what is *B*?
   c. What is the relative phase angle between *<u>P</u>(x)* and *<u>V</u>(x)*, i.e. compare α and β.
   d. What lumped acoustic element best describes tube

ii. Assume the tube is terminated by a rigid wall and that $d < 0.1\ \lambda$.
   a. Given *A*=1 pascal, describe *B* in terms of *A, d, r* (the radius of the duct) and *f* (the frequency of the stimulus tone).
   b. What is the relative phase angle between *<u>P</u>(x)* and *<u>V</u>(x)*, i.e. compare α and β.

iii. Assume the tube is open at the termination and that $d < 0.1\ \lambda$.
   c. Given *B*=1 mm/s, describe *A* in terms of *B, d, r* (the radius of the duct) and *f* (the frequency of the stimulus tone).
   d. What is the relative phase angle between *<u>P</u>(x)* and *<u>V</u>(x)*, i.e. compare α and β.

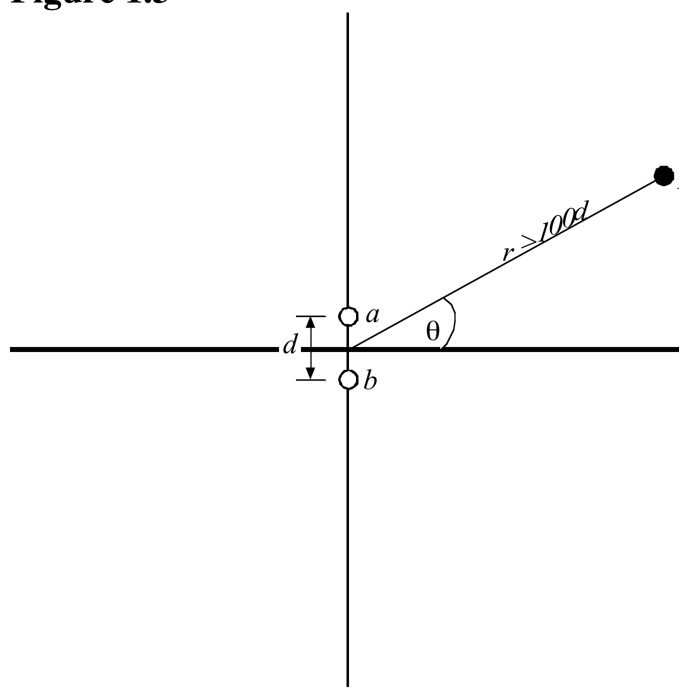
d). Assume that Figures 1.1a and 1.1b describe the sound pressure $p(t,a)= a(t)$ and $p(t,b)= b(t)$ at locations inside the long air-filled cylindrical duct of Figure 1.2, where position b is to the left position a. Also, $T = 1$ msec.

i. Assume d is infinite, and the separation of positions a and b is 10 cm.
   a. If A=1 pascal, what is B?
   b. What is the relative phase of $a(t)$ and $b(t)$?

ii. Assume d =0, the tube is terminated by a rigid cap perpendicular to the long axis of the tube, and the separation of positions a and b is 10 cm (i.e., position b is 10 cm to the left of the rigid cap).
   c. If A=1 pascal, what is B?
   d. What is the relative phase of $a(t)$ and $b(t)$?

e). Given two simple sources, source a and source b, whose arrangement in space is defined in Figure 1.3. Assume that Figures 1.1a and 1.1b describe the sound pressures produced at point p in space by source a ($p_A(t)= a(t)$) and source b ($p_B(t)= b(t)$), where the two sources have identical strengths and are in phase with each other.

Figure 1.3



i. Assume $d =\lambda/2$ and $\theta = 0$ degrees:
   i. If A=1 pascal, what is B?
   ii. What is the relative phase of $a(t)$ and $b(t)$?
   iii. If $c(t) = C \sin\left(2\pi \frac{1}{T}(t - \chi)\right)$ describes the sum of the two pressures. What is C and χ?

ii. Assume $d =\lambda/2$ and $\theta = 90$ degrees:
   i. If A=1 pascal, what is B?
   ii. What is the relative phase of $a(t)$ and $b(t)$?
   iii. If $c(t) = C \sin\left(2\pi \frac{1}{T}(t - \chi)\right)$ describes the sum of the two pressures at point p, what are C and χ?

iii. Use your answers to parts i. and ii. above as a basis of a short discussion of the directional output of the two sources when $d =\lambda/2$.

iv. BONUS POINTS: Use your understanding of acoustic reciprocity to suggest how you might use two non-directional microphones to make estimates of the location of a source in space.

Problem 2

A.

1) Stimulus X consists of the sum of two sinusoids $s_1(t)$ and $s_2(t)$.

$$
\begin{aligned}
x(t) &= s_1(t) + s_2(t) \\
s_1(t) &= \sqrt{2}\, S_1 \cos(2\pi f_1 t) \\
s_2(t) &= \sqrt{2}\, S_2 \cos(2\pi f_2 t):
\end{aligned}
$$

Given the choice of the following percepts:

(a) silence,

(b) a single tone (specify its frequency),

(c) a complex tone consisting of harmonics of a fundamental frequency,

(d) more than one tone (not harmonically related),

(e) a tone with loudness fluctuations,

describe what will be heard by a listener with normal hearing for each of the stimuli in Table 1. Provide a brief explanation for each answer.

part	S_1 dB SPL	f_1 Hz.	S_2 dB SPL	f_2 Hz.
a	20	100	20	400
b	80	400	40	500
c	30	200	80	400
d	40	400	80	410
e	50	400	70	410
f	70	400	50	410

Table 1: Stimulus parameters for Problem 2A.

B.

A trained listener with normal hearing is presented with tonal stimuli monaurally over headphones and is asked to make a series of two-alternative forced choice judgments about them.

The subject hears two stimuli A and B and is asked to determine if the two are the same or different. The makeup of A and B varies between measurements, but the subject always has to respond with either "same" or "different".

Each row of the following table describes stimulus A and stimulus B for the different measurement conditions. Each stimulus is 1 second in duration. For each measurement condition predict whether the subject's response was "same" or "different" and explain your reasoning.

Condition	Stimulus A	Stimulus B
1.	1000 Hz @ 15 dB SPL	1005 Hz @ 15 dB SPL
2.	1000 Hz @ 90 dB SPL	1005 Hz @ 90 dB SPL
3.	5000 Hz @ 90 dB SPL	5005 Hz @ 90 dB SPL
4.	1000 Hz @ 90 dB SPL	1000 Hz @ 90 dB SPL plus 500 Hz @ 50 dB SPL

Table 2: Stimulus parameters for Problem 2B.

Problem 3.

Depending on the characteristics of the sound source and listening conditions, a sound may be:

1) easy to localize to a unique angular (azimuth, elevation) position in space,
2) appear to arise from two (or more) distinct angular (azimuth, elevation) positions,
3) externalized but hard to localize,
4) not be externalized,
5) not be audible.

A blindfolded listener is seated with his/ her (immobile) head at the origin of an anechoic space. A 100 ms sound stimulus is presented from a simple source located in front of the listener at a radius r from the center of the head. The listener has no a priori knowledge of the location of the source.

For each of the 7 conditions below (a through g) select one of the five (1-5) statements above to describe the localizability of each condition. Also, if its definable, specify the location in terms of □ and □ to which the listener localizes the sound. Finally provide a few sentences to justify your answers.

a) The source (at r = 1.0 m, □= □/6 and □= 0) produces a 500 Hz sinewave with a pressure of 20 dB SPL at the origin (in the absence of the head).

b) The sound in (a) is moved to r = 1000 m.

c) As in (a) but the source produces a 5000 Hz sinewave.

d) As in (a), but □= 0 and □ = □/ 6. The source produces a flat spectrum noise (of bandwidth of 20 to 20,000 Hz) with an rms pressure of 50 dB SPL at the origin in the absence of the head.

e) As in (d), but the source produces an 8000 Hz sinewave.

f) As in (e), but the entrance to the left ear canal of the listener is blocked with clay.

g) As in (f), but the source produces a 200 Hz sinewave.

Problem 4.

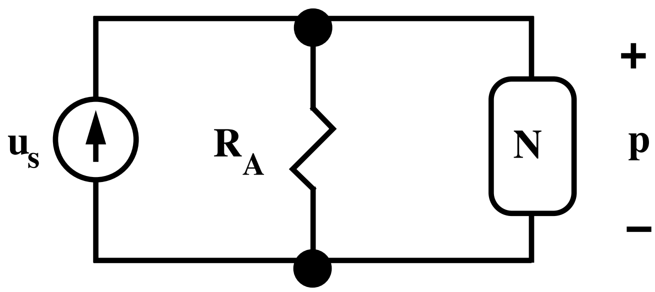


Figure 4: An acoustic circuit consisting of a volume velocity source, an acoustic resistance, and an unknown element N (acoustic mass or acoustic compliance).

The acoustic circuit of Fig. 4 consists of a volume velocity source, an acoustic resistance, and an unknown element N (acoustic mass or acoustic compliance). It is known that the acoustic resistance $R_A = 100$ acoustic ohms. When the volume velocity source is

$$u_S(t) = \sqrt{2}U_S \cos(2\pi f t)$$

where U_S is independent of f, the pressure across the unknown element is

$$p_S(t) = \sqrt{2}P \cos(2\pi f t + \phi)$$

where the dependence of P on f is given in Figure 5.

1. When $u_S(t) = U_S e^{st}$, $u(t) = P e^{st}$. Determine the system function $H(s) = P/U_S$ assuming that
   (a) Element N is an acoustic compliance.
   (b) Element N is an acoustic mass.
2. Determine the value of U_S, including units.
3. Determine whether the unknown element is an acoustic mass or an acoustic compliance.
4. Determine the value of the unknown element, including units.
5. Plot a graph of the dependence of ϕ on f on the axes provided in Fig. 5.

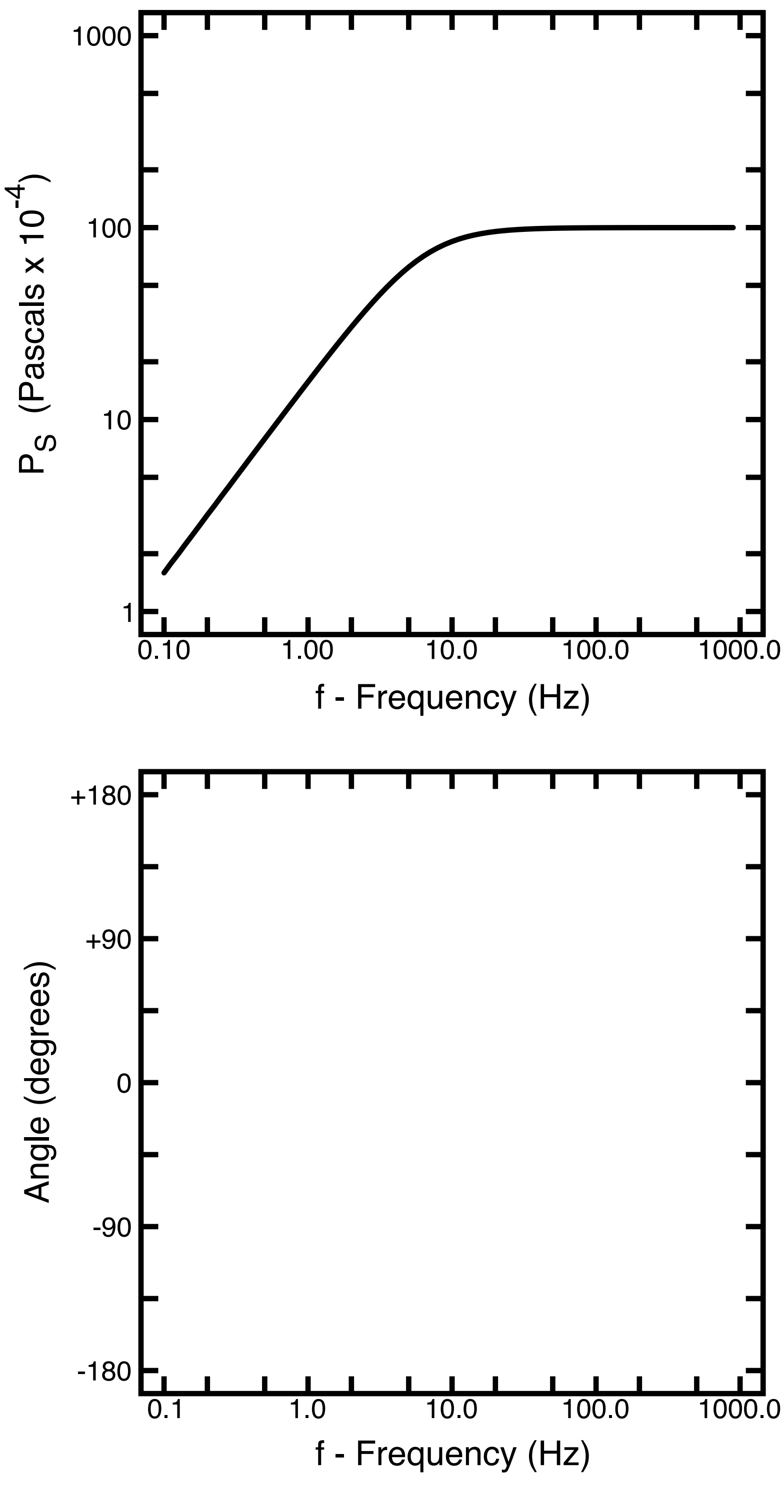


Figure 5: Graphs for Problem 4.