Acoustic Resonator

Purpose:

The properties of waves inside cavities play an important role in modern physics. Waves are reflected from the walls of the cavity and if they do not have an appropriate wavelength (frequency), then they interfere destructively with each other. This concept should already be familiar to you since you have encountered it in treating the diffraction of waves passing through two slits. It is thus apparent that there will be certain frequencies at which the waves interfere constructively and these frequencies are denoted as the resonance frequencies of the cavity. You have already encountered this concept before when you considered the modes of vibration of a vibrating string. Resonances in a three-dimensional structure such as the rectangular acoustic resonator in this experiment are rather more complicated, but the basic principle is the same.

In this experiment you study some of the properties of a cavity in which sound waves are propagating. Because of the resonant character of the system, it is known as an acoustic resonator. Many of the features you study are applicable to any system for which wave propagation and trapped resonances are appropriate concepts. In particular you will measure the properties of the resonator near its resonance frequencies, you will study the geometry of the standing waves in the resonator, and you will observe how the resonance frequency is changed by introducing an obstacle into the resonator

It is very important to be able to determine what happens to a resonant system when it is disturbed a little. You will find, as you progress in physics, that many phenomena are explained by considering small perturbations to resonant systems. An example in atomic physics is the splitting of lines in the hydrogen spectrum which occurs when the emitting atom is embedded in a magnetic field (the Zeeman effect). In this case it is the electrons which may be considered as the system of resonating waves.

Apparatus:

The resonator is the large box standing by the bench. The lid is removable and has an electrostatic microphone embedded in it.

PLEASE DO NOT DROP OBJECTS INTO THE RESONATOR WHEN YOU REMOVE THE LID, OTHERWISE YOU WILL DAMAGE THE LOUDSPEAKER WHICH IS AT THE BOTTOM OF THE BOX. PLEASE BE CAREFUL THAT YOU DO NOT DAMAGE THE ELECTRONIC COMPONENTS ON THE LID WHEN YOU REMOVE IT.

These electronic components supply the microphone with power, amplify its output signal, and filter it to get rid of noises caused by building vibration. There is also a transformer to match the 50 ohm output impedance of the signal generator to the 8 ohm input impedance of the loud speaker which is at the bottom of the resonator.

On two of the four acoustics set-ups, a signal generator, frequency counter and dual trace oscilloscope are provided. The signal generator provides the signal to drive the loudspeaker, You should use the dual trace oscilloscope to monitor the input to the loud speaker and the output from the microphone.

On the other two set-ups, you or your partner must supply a notebook computer with an audio output and a microphone input. A software program for Windows called TrueRTA can be used to measure the response in place of the oscilloscope. You can download this program for free from http://www.trueaudio.com. You also need a signal generator. True RTA does provide one, but only in 1 Hz increments, and you will need to make measurements spaced more closely than this.

There is a dedicated signal generator you can get at: http://www.dr-jordan-design.de/Downloads.htm (SigGenfreeware) that can generate the sine wave signal you need.

You are also provided with a solid sphere and a slotted sphere that can be used as perturbations to cause small shifts (<5 Hz) in the resonance frequency of a particular acoustic mode.

Prelab Questions:

1. A good first guess at the resonance frequencies of many systems is to reduce the problem to a one dimensional one that you are familiar with (eg. a vibrating guitar string). The resonance frequencies of this simplest problem are given by $f_n = nv_s/(2X)$, where n is an integer, v_s is the velocity of propagation of the relevant waves, and X is the length of the resonator. For the acoustic resonator, use the height of the resonator and the speed of sound in air to make a first guess at the resonance frequencies.
2. The three dimensional resonator is more complicated than this 1-dimensional estimate. The solution to finding the modes involves solving the wave equations, constrained by the boundaries of the box, a type of problem that you will encounter **many** times in the next few years. Do some research into the solution for the resonant frequencies in a rectangular resonator (or solve the problem yourself if you dare). You'll find numerous acoustics texts in the library or you might even find useful information on the World Wide Web (try searching for "rectangular acoustic resonators"). Calculate the resonant frequencies for a few of the lowest frequency modes expected for the acoustic resonator in the laboratory.

Procedure

Resonant Response

Connect the components and, with the resonator closed, measure the output, $V(f)$, from the microphone as a function of frequency, f, for an input to the speaker of constant amplitude, A. If you are using your own computer and trueRTA, you may have to adjust the settings of the capture source for your sound card, in order to display the input from the microphone jack.

Do a quick survey of the resonance frequencies and compare with the calculations from your pre-lab questions. Some resonances are so strong that you will hear the increased response, while others are weaker and only apparent in the microphone signal. You should find a strong acoustic mode which has a resonant frequency near 430 Hz. Plot the response curve, $V(f)$ versus f: Cover a range of frequencies sufficient to characterize the position, width, and detailed shape of the resonance. where f_r is the frequency at peak output. Use gnuplot (or whatever other software you like that can do a **weighted** least squares fit) to fit this curve to the Lorentzian form:

$$V(f) = \frac{\Delta V_0}{[\Delta^2 + (f - f_r)^2]^{1/2}}$$

You may find that you need to add a constant term to get a good fit – why? What do you think determines the width Δ? Is this mode one of the ones that you predicted in the pre-lab questions?.

Perturbation by Sphere

Pass the rod through the lid of the resonator so that the solid sphere can be moved along the axis inside the resonator.

NOTE HOW FAR THE FLASK CAN BE LOWERED INTO THE RESONATOR BEFORE IT IS RAMMED THROUGH THE SPEAKER. DO NOT RAM IT THROUGH THE SPEAKER.

Start with the flask close to the lid and measure the resonance frequency. I suggest you do this by measuring the $V(f)$ at a few frequencies close to resonance, but above and below the actual resonance frequency. Suppose that when the flask is x cm below the lower face of the lid, the resonance frequency is $f(x)$, then $f(x)$ will be given by the expression:

$$f(x) = (f_1 + f_2)/2$$

where

$$V(f_1) = V(f_2)$$

and

$$f_1 > f(x) > f_2$$

It is best if $V(f_1) = V(f_2) \sim V(f_r))/2$. Why?

In other words: quickly tune the frequency source near the resonance, and note the approximate maximum received signal, then tune to either side of the resonance till the amplitude is at a convenient round number (but as identical as you can make it on both sides) where $V(f_1)=V(f_2) \sim V(f_r))/2$. This procedure is quite rapid and will give you a more accurate value for $f(x)$ than you would get by trying to locate the value of f which actually maximizes $V(f)$.

Move the flask down and repeat measurements of $f(x)$; do this at regular intervals until the flask has been lowered by a total distance of about 80 cm.

Plot a graph of $\Delta f = (f(x) - f_r)$ versus x, where f_r is the resonance frequency for the empty resonator. What you will find is that Δf varies periodically with x. Discuss why this is so. What is the relationship between the period in Δf and the wavelength of the resonant frequency?

Perturbation by a Slotted Sphere

Mount the slotted sphere inside the resonator by means of the brass rod which you insert through the upper hole in one of the vertical sides of the resonator. It should be possible for you to vary the angle between the discs and the vertical axis of the resonator. Use a sheet of polar graph paper and attach it to the side of the resonator so that you can measure the angle (θ) between the cardboard discs and the resonator axis. Measure the shift in resonance frequency (Δf) as a function of θ. What you should find is that when the slots are perpendicular to the resonator axis, the slotted sphere behaves like a solid sphere, but when the slots are parallel to the axis, the slotted sphere causes a very small shift in resonance frequency. Discuss why.

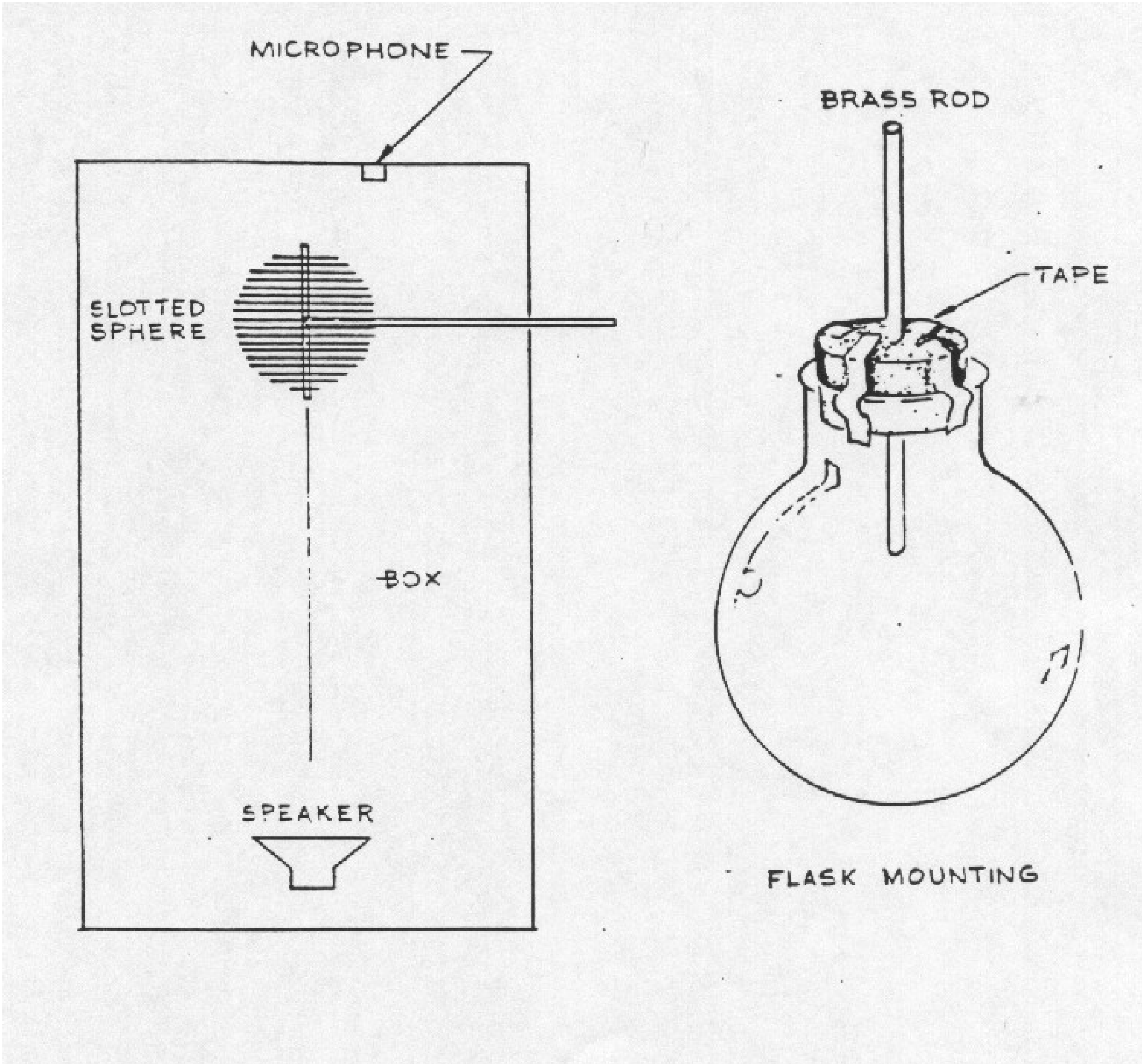

Fig. 1: Acoustic Resonator Setup

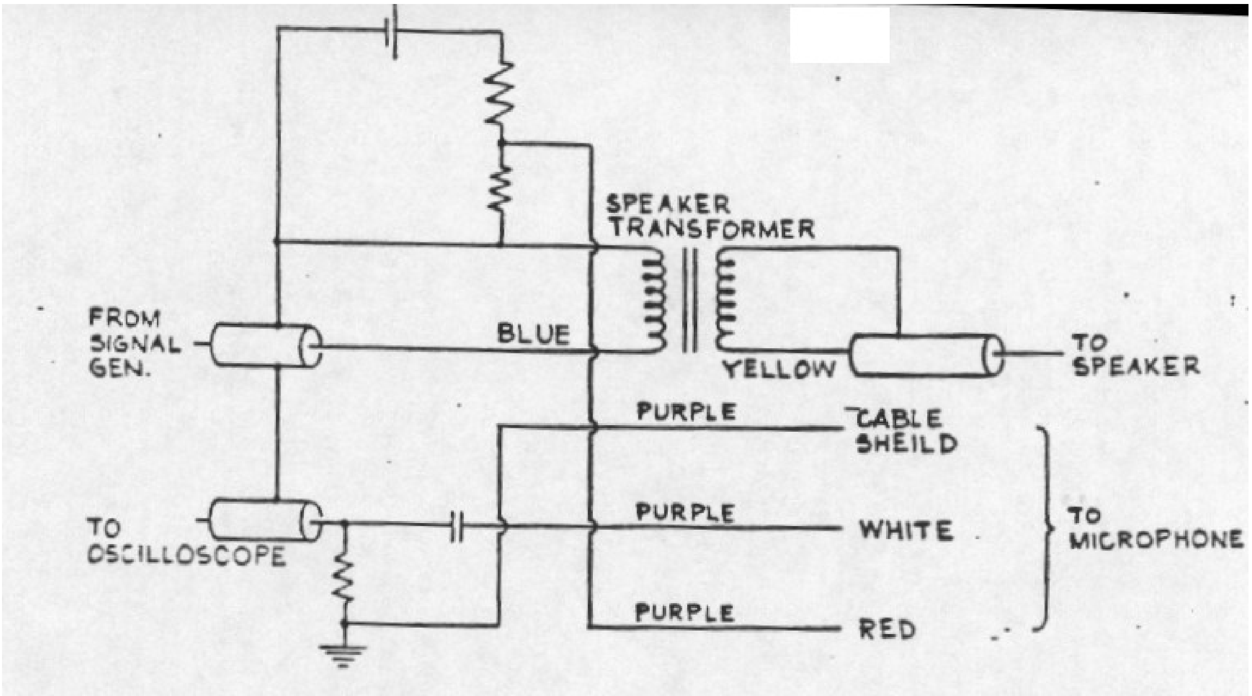

Fig. 2b: Resonator Lid Electronics