THE SPEAKER

OBJECTIVES:

1) Know the definition of "decibel" as a measure of sound intensity or power level.
2) Know the relationship between voltage and power level measured in decibels.
3) Illustrate how the performance of an audio speaker is rated.
4) With the input voltage to a speaker held constant, measure the output voltage from a microphone at various frequencies. Plot the speaker response (in decibels) vs. frequency.

INTRODUCTION:

Because almost all uses of sound involve the human ear, a special scale, called the decibel (dB), is widely used to measure the sound intensity. The decibel scale roughly corresponds to the sensation that a human ear experiences when a sound strikes it.

The decibel scale is related to the physical sound intensity measured in watts/cm^2 by the following equation:

$$I = 10\ log\ \frac{P}{P_R} \qquad \text{defines I in units of decibels (dB)} \quad (1)$$

where, P is the sound intensity measured in watts/cm^2, P_R is a reference sound intensity (also in watts/cm^2), and *log* is the logarithm to the base 10. We will usually put the (dB) in such equations in parentheses to remind us that it is a unit, not a factor in the formula. From equation (1), it can be seen that the decibel scale is a measure of the relative intensity of two sound levels.

Example:

$$P = 10^{-2}\ W/cm^2 \qquad P_R = 10^{-6}\ W/cm^2$$

$$I = 10\ log\ \frac{10^{-2}}{10^{-6}} = 10 log 10^4 = 10 \times 4 = 40(dB)$$

The factor of "10" is in the decibel equation because the resulting decibel unit represents approximately the smallest increment in sound level that is noticeable to a human ear. Without the factor of 10, the intensity I would be in bel units, which are too large to be convenient.

Given a value for I, we can solve for the ratio P/P_R by using the fact that 10^x is the inverse of *log* x. From equation (1), if I=1 dB, we have $P/P_R=10^{0.1}=1.26$. Thus, a 26% change of power level (in watts/cm^2) is just barely detectable by a human ear.

The decibel scale is defined in terms of ratios, so one must choose a reference, P_R. No matter what P_R is chosen, that power level *by definition* represents 0 dB since:

$$\log\left(\frac{P_R}{P_R}\right) = 0$$

This does not cause serious ambiguity. Suppose we changed our mind about the reference in equation (1) and used Q_R instead. What happens?

$$I_{new} = 10\ log\ \frac{P}{Q_R} = 10\ log\left(\frac{P}{P_R}\times\frac{P_R}{Q_R}\right) = 10*\log\left(\frac{P}{P_R}\right) + 10*\log\left(\frac{P_R}{Q_R}\right) = I + \text{constant}$$

The constant has to do only with the ratio of the old and new reference levels. So changing reference values does not change the shape of the curve of I values (vs. frequency, for example), but merely shifts the origin.

For most of this experiment, we will use for the reference power the power at a specific frequency, 2000 Hz.

In work with sound levels and the human ear, the value 10^{-16} watts/cm^2 is normally used because it is about the weakest sound intensity detectable by a human ear. For a sound intensity of $P=P_R$, the decibel intensity is 0 dB, since

$$log\left(\frac{P_R}{P_R}\right) = 0$$

A very loud sound can cause pain to a human ear. The highest sound intensity that a human ear can tolerate without experiencing pain is about 10^{-4} watts/cm^2, which is

$$10 * log\ \frac{10^{-4}}{10^{-16}} = 10 * log\ 10^{12} = 10 \text{ x } 12 = 120 \text{ (dB)}$$

The ear is a remarkable sound detector. It can detect sound intensities over a range of 12 decades in decibels!

The decibel difference between two sound intensities P_1 and P_2 (in watts/cm^2) is given by:

$$\Delta I = I_2 - I_1 = 10 * log\left(\frac{P_2}{P_R}\right) - 10 * log\left(\frac{P_1}{P_R}\right)$$

Or:

$$\Delta I = 10 * log\left(\frac{P_2}{P_1}\right) \text{(dB)}$$

The following table gives some useful numbers:

power ratio P_2/P_1	decibel difference (dB)
1.26	1.00
2	3.01
10	10.00
20	13.01

100	20.00
1000	30.00

The sound level in W/cm^2 produced by an audio speaker is directly proportional to the electrical power in W provided as input to the speaker. Therefore, the input power to a speaker is also often measured in decibels. Since it is often easier to measure the voltage in an electrical circuit, it is desirable to know the relationship between the electrical power in decibels and the voltage ratio. For a resistive load, we have

$$P = \frac{V^2}{R}$$

Here P is the power in watts, V is the voltage in volts, and R is the resistance in ohms. If the equivalent resistance in the circuit is a constant, then the power ratio can be written as,

$$\frac{P_2}{P_1} = \frac{V_2^2}{V_1^2}$$

Thus, the power level difference in decibels can be written as,

$$\Delta I = 10\ log\left(\frac{P_2}{P_1}\right) = 10\ log\left(\frac{V_2^2}{V_1^2}\right) = 20\ log\left(\frac{V_2}{V_1}\right)\ \text{(dB)}$$

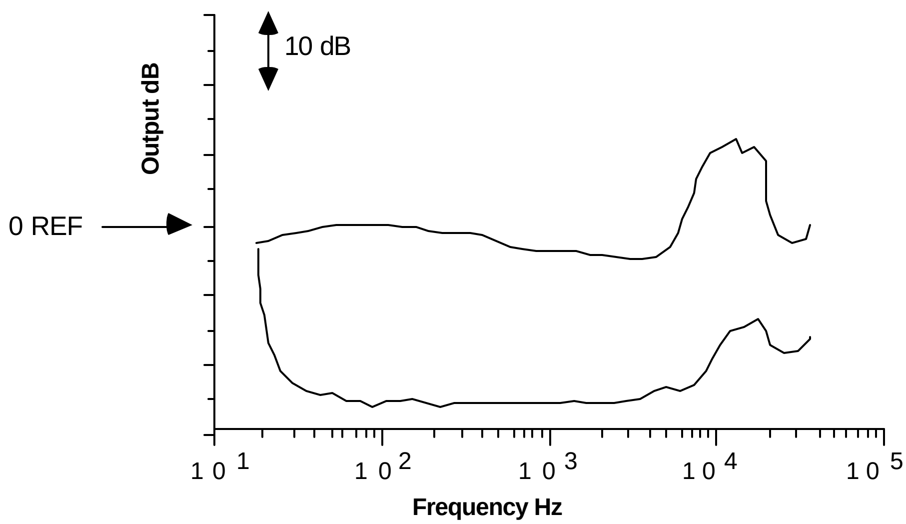
In audio circuits, the power ratio P_2/P_1 could represent either an electrical power ratio or a sound intensity ratio.

One of the applications of the decibel scale is in the specification of the frequency response of audio equipment (e.g., a speaker or a microphone). There are many measures of the quality of an audio system, one of them being the frequency response. To achieve true reproduction of music or voice, a good audio system should have uniform (constant) sound reproduction efficiency over frequency range from 20 Hz to 20000 Hz. This means, with the input intensity held constant, if one plots the output intensity as a function of frequency, the curve should be flat in this frequency range. Since we are not so concerned about the absolute efficiency here, one often plots the relative efficiency as a function of frequency. The relative efficiency I_S as a function of frequency is defined as

$$I_S(f) = 20\ log\left(\frac{V_{out}(f)}{V_{out}(f_{ref})}\right)\ \text{(dB)}$$

Here $V_{out}(f)$ is the output voltage at the frequency f, $V_{out}(f_{ref})$ is the output voltage at the reference frequency f_{ref}. Usually an intermediate frequency, such as 2000 Hz, is chosen as the reference frequency.

Good sound reproduction means that the power out of the speakers is directly proportional to the input power (from the recording), no matter what the frequency. For this to be true, the output for a fixed input power also must be constant at any frequency.



Frequency Response Curve of a Stereo Phonograph Pickup Cartridge
Figure 1

Figure 1 is a graph published in a "hi-fi" magazine indicating the frequency response curve of a particular stereo phonograph cartridge. The upper curve is the output of the channel being driven by the test record while the lower curve is the output of the channel not being driven. The ideal cartridge would have a flat response (at 0 dB) for the driven channel and no audible output from the other channel (-40 dB or less). The frequency scale is logarithmic so that the low frequencies are not too compressed. This graph shows that the output of this cartridge is relatively constant ("flat") within ± 2 dB from 20 to 8,000 Hz. However, the response is not constant from 8,000 to 20,000 Hz. The other channel only has significant output from 20 and 30 Hz, and above 8,000 Hz. In this lab, we will perform a similar test on a cheap speaker, which will have a response curve not nearly as flat as the graph shown here.

APPARATUS

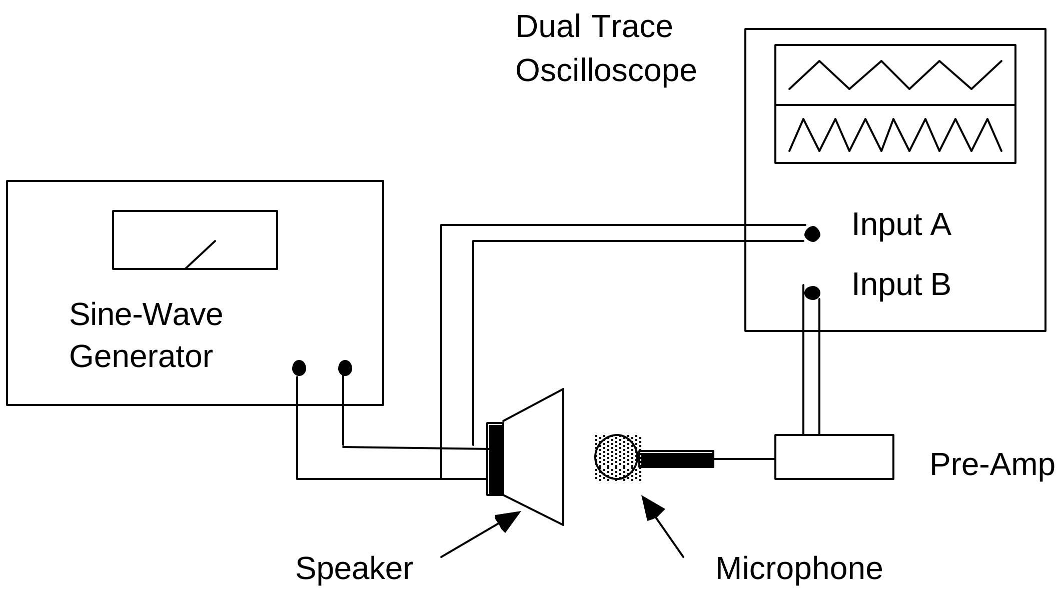


Figure 2

Shown in figure 2 is a schematic drawing of the apparatus you will use. The output of the sine-wave generator will be input to the speaker we wish to evaluate. The input signal for the speaker is monitored on the oscilloscope Channel A. The sound coming out of the speaker is picked up by a microphone and boosted by a pre-amplifier. The output signal is monitored on the oscilloscope Channel B.

In the experiment, you will set the sine-wave generator to various frequencies and measure the corresponding output voltages from the microphone. Then, you will convert the output voltages to sound level intensities in decibels. Finally, you will make a graph of sound level intensity vs. frequency, which will be the frequency response curve of the test speaker.

Partner _________________________ Name _________________________

_________________________ Section ________________________

To test that you understand the meaning of decibel differences, fill in the blank columns in the following tables (*before class, as part of your preparation for the lab*):

decibel difference (dB)	power ratio P_2/P_1
0	
1	
2	
3	
4	
10	
11	
12	
13	
40	

voltage ratio V2/V1	power decibel difference (dB)
1.26	
2	
10	
20	
100	

PROCEDURE

1. Set the signal generator at 2000 Hz.

2. Rotate the microphone out of the way and place the sound level meter in place of the microphone in front of the speaker.

3. Adjust the signal generator output so that the sound level meter reads **70 dB**. The signal generator output will be kept at this value throughout this experiment.

4. Measure V_{pp} (input) to the speaker from the oscilloscope (Channel A).

   V_{pp} (input) = ________________ volts

5. Move the microphone in front of the speaker. Measure the peak-to-peak voltage of the output signal from the microphone [V_{pp}(microphone)] from the oscilloscope (Channel B), and record it on the first line (frequency=2000 Hz) of the table (next page).

6. Qualitative Speaker Response:
   Speaker response is its loudness for a given input. Our ears can measure that, but rather roughly, since our ears are not equally sensitive at all frequencies. Vary the frequency from 200 Hz to 10 KHz and comment on which frequencies seem loudest. and which seem weakest?

7. Measure V_{pp}(microphone) for each frequency listed in the table.
   (For each frequency, you should check if V_{pp}(input) is the same as it was at 2000 Hz. If it is different, adjust signal generator output to the correct value.)

8. Calculate the voltage ratio, which is defined as voltage ratio of each frequency (**See page 3 about this equation!**)

   $$\text{Voltage ratio}(f) = \frac{V_{pp}(f)}{V_{pp}(\,2000\text{Hz})} \qquad \text{[Note: Voltage ratio (2000 Hz) = 1]}$$

   $V_{pp}(f)$ is the microphone peak-to-peak voltage at the frequency indicated.

9. Calculate I_T (total response), using $I_T = 20\ log$ (voltage ratio).

10. Calculate the actual speaker response (I_S) which is given by

    $$I_S = I_T - I_M$$

    Here I_M is the microphone response, which is a list of corrections.

11. Plot the voltage ratio vs frequency on semi-log graph paper with the frequency on the log scale. Draw a line at ratio = 1. This will be your reference line.

12. Plot I_S vs. frequency on a semi-logarithmic graph with the frequency on the log scale. This will give you a frequency response curve for the speaker.

13. Draw a line across the graph at 0 dB. This is your reference line.

Frequency (Hz)	Vpp (mV) (Microphone)	voltage ratio	I_T (dB)	I_M (dB)	I_S (dB)
2000 (Ref.)				0	
200				0	
250				0	
300				0	
350				0	
400				0	
500				0	
600				0	
700				0	
800				0	
1000				0	
1200				0	
1500				0	
1750				0	
4000				1	
6000				3	
8000				2	
10000				2	

QUESTIONS

You may find it useful in answering the questions that follow to look at both your ratio plot and your dB plot.

1. Describe the difference between your ratio plot and your dB plot.

2. Which frequencies have voltage ratios above ratio = 1?

3. Which frequencies have sound intensities above the 0dB line?

4. Are the frequencies in Questions 2 and 3 the same? Why or why not?

5. What does it indicate when your data points go above the 0 dB line?

What does it indicate when your data points go below the 0 dB line?

6. How would your plots have changed if you had used 500 Hz as the reference instead of 2000 Hz?

7. What does it mean if a speaker response curve is “flat” (all frequencies near the 0dB line)?

8. Is your speaker response curve “flat”?

9. In what frequency range is your speaker response curve relatively “flat”?

11. What does the "flat” portion of the curve indicate about the sound level intensity of the frequencies within that region?

12. Which frequency does the speaker produce most easily? (Easily produced sounds would have a large ratio of output/input.)

13. Which frequency does the speaker produce least easily?

14. Comment on whether the easiest and least easy frequencies correspond to those you identified by ear as the louder and weaker sounds.

15. Normally, an audio speaker is rated by the frequency range within which the speaker’s response is almost "flat”, and also by the intensity variation within this range. For example, if a speaker is rated as 40 - 20,000 Hz ± 3 dB, it means in the range of 40 to 20,000 Hz, the speaker’s response is “flat”, and the intensity variation within this range is no more than ±3 dB above and below the 0 dB line. Rate your speaker in a similar manner.