Sound Asleep

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Grade 7

Abstract

Identifying methods by which noise is removed from desirable sounds is important for human comfort. Research shows that sound propagates in waves with different frequencies, and that desirable sounds and noise have different frequencies. Also, sound waves can interfere with each other either constructively, causing the sound level, or amplitude, to increase, or destructively, resulting in overall amplitude reduction. Further, sound propagating through a tube can undergo reflections at its open ends and reflected sounds can interfere resulting in overall amplitude increase or reduction.

The objective of this experiment is to determine how a change in length of the tube affects the amplitude of sound propagating through it. The hypothesis is that sound amplitude will periodically increase and decrease as the length of the tube is reduced. Sound generated with an iPhone is propagated through an adjustable-length cardboard tube and the amplitude at the end of the tube is measured in decibels using another iPhone. The length of the tube is decreased while recording the lengths and amplitudes at which the amplitude minimums and maximums occur.

The results confirm the hypothesis. As the length of the tube is decreased, the amplitude oscillates between a maximum and a minimum. Also, the distance between successive extrema is constant for a given frequency. The results can be used to identify certain combinations of frequencies and tube lengths to attenuate undesired frequencies or amplify desired frequencies. Real world applications include reducing undesirable noise from car exhaust and noise cancellation in headphones.

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Question

What is the effect of the length of a hollow tube on the amplitude of sound propagating through it?

Research

Sound is a form of energy caused by vibrations that travel through a medium by changes in air pressure. Sound propagates as a sequence of alternating compressions, a high-pressure area, and rarefactions, a low-pressure area, moving through a medium such as air. A sound wave is created by a sound source, such as a vibrating membrane of a speaker, and propagates through a medium such as air as a longitudinal pressure wave. The distance between two consecutive compressions (or rarefactions) is defined as the wavelength λ of a sound wave. The amplitude of sound is the sound pressure level of a sound wave in a medium and is measured in decibels. It is computed using the logarithm of the ratio of the sound pressure to the ambient air pressure. The velocity of sound in air is measured as 330m/sec. The frequency *f* of a sound wave, measured in Hertz, is the number of sound waves that pass a given point in a second. The wavelength λ, frequency *f* and the velocity v of a sound wave are related by $v = f\lambda$. Human ear can hear sounds only in the range of 20Hz to 20KHz. The properties of a sound wave are illustrated in Figure 1.

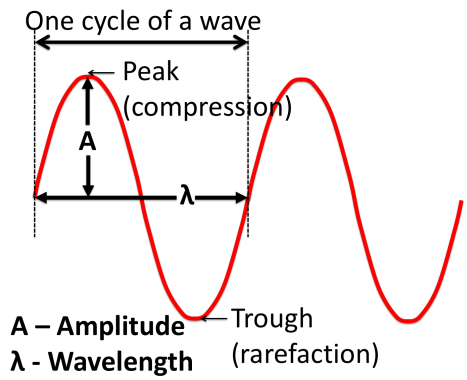

Figure 1. Properties of a sound wave.

Different sound waves can interfere with one another in two ways: constructive interference and destructive interference. Constructive interference occurs when the rarefactions and compressions of the two waves align to create a wave with a higher amplitude. Destructive interference occurs when the rarefaction of one wave overlaps with the compression of another. This causes the waves to cancel each other out, yielding sound with less or zero amplitude. This is illustrated in Figure 2.

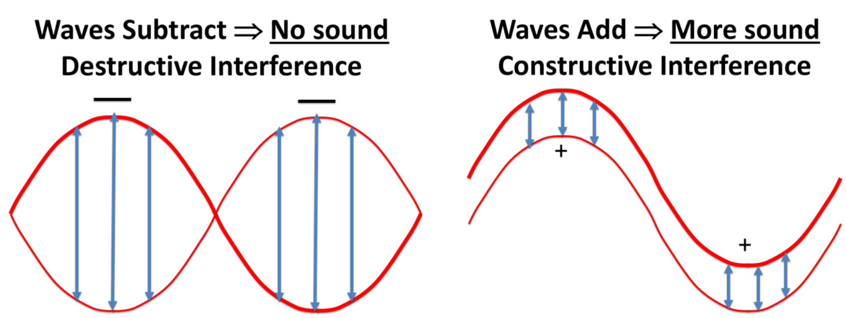

Figure 2. Sound destructive and constructive interference.

Sound waves traveling through a hollow tube are reflected at the ends of the tube. This reflection occurs whether the end of the tube is closed or open. In the case of an open tube, part of the sound wave reaching the open end is reflected back while the rest pass through. Sound wave reaching the open end of a tube is reflected back with an inversion in its pressure level, while a wave reaching a closed end of a tube is reflected back with the same pressure level. The reflected wave reaches the source end and is reflected back once more. If a new wave originating from the source reinforces this reflected wave, then the amplitude of the wave inside the tube increases and is referred to as a standing wave (though it is really not stationary). Similarly, a situation can occur when the new wave originating from the source interacts destructively with the reflected wave in the tube resulting in the sound amplitude decreasing. Whether the sound waves undergo increase or decrease in amplitude as a result of the superposition of the source and reflected waves depends on the frequency of the sound generated and on the length of the tube. For certain combinations of frequency of sound and length of the tube, maximum amplification can occur, for certain others the sound level can reach a minimum, and for other combinations, the sound level will lie in between these extremes. The sound reflections within an open tube are illustrated in Figure 3.

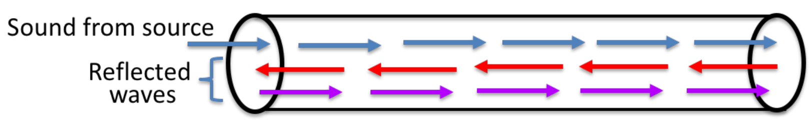

Figure 3. Sound reflections within an open tube.

The objective of this experiment is to determine the how a change in length of the tube affects the amplitude of the sound propagating through it. The results of this experiment can be used to identify certain (frequency, tube length) combinations for which the sound level is minimum so that if such frequencies are not desired then the tube levels can be set to reduce the amplitude of such frequencies. These results can be applied in the real world to eliminate static in recordings, muffle construction work, reduce undesirable noise from exhaust in cars, and create noise cancellation headphones.

After exploring various sound generators and sound amplitude measurement devices, it was decided to use to an iOS app called the Function Generator PRO for sound generation, and another iOS app called the Decibel X PRO to measure the sound level in decibels. After searching for a variable length tube, it was decided to use a set of telescoping cardboard tubes usually used for packing rolled maps and artwork. The telescoping tubes are such that one tube slides back and forth around the other, creating the ability to vary the tube length.

Hypothesis

If the length of the tube is gradually reduced, then the amplitude of the sound will change periodically.

Scientific principles and reasoning

The superposition of sound waves creates a resultant sound wave pattern. If the compressions of one coincide with the rarefactions of another with the same amplitude, then the amplitude of the resulting sound wave is zero. Sound wave from a source entering an open tube at one end interferes and interacts with multiple waves reflected from either ends of an open tube creating another sound wave pattern. As discussed in the research section, whether this results in overall amplification or a reduction in the sound level is decided by the relationship between the frequency of the sound and the length of the tube. If the frequency is kept constant and the tube length is varied, the expectation is that the sound level will vary.

Setup

The setup used for the experiment is shown in Figure 4 and the apps used for sound generation and amplitude measurement are shown in Figure 5.

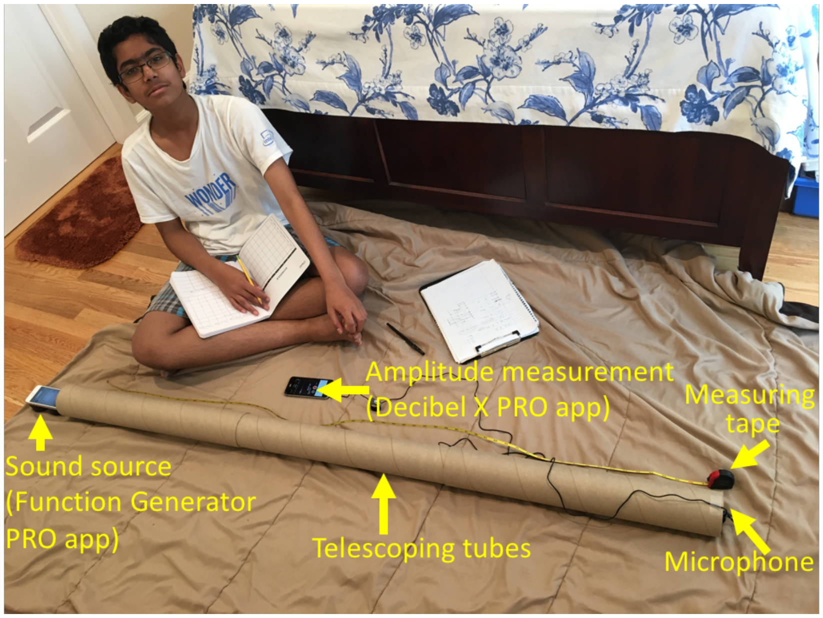

Figure 4. Experiment Setup.

Function generator PRO app Decibel X PRO app

Figure 5. Sound generation and amplitude measurement iOS apps.

Materials

The following materials were used for this experiment.

- A set of two telescoping hollow cardboard tubes whose overall length can be varied between 0.5 meter to 1 meter.
- An iPhone with the Function Generator PRO iOS app to generate sound with frequencies between 20Hz and 20,000 Hz.

- An iPhone with the Decibel X PRO iOS app to measure the sound level in decibels.
- A tape measure to measure the length of the tube at various points in the experiment.
- A lavalier microphone to capture sound and connect to the iPhone for decibel measurement with the Decibel X PRO app.
- A pencil and paper to record measurements.

Methods

The procedure followed to conduct the experiment is given below.

1. Setup the audio generator in the Function Generator PRO app at a frequency of 700Hz.
2. Extend the telescoping tubes to be 1 meter long.
3. Set the iPhone with the Function Generator PRO app at the entrance of the extended tubes at one end.
4. Connect the sound jack of the microphone to the headphone jack of the iPhone with the Decibel X PRO app.
5. Position the microphone at the entrance of the tube next to the source and measure the sound amplitude.
6. Connect the microphone to the end of tube opposite to the sound source and position it at the center of the tube.
7. Reduce the tube length slowly by collapsing the second tube inside the first and stop when the sound amplitude either reaches a maximum or a minimum.
8. Measure and record the length of the tube.
9. Record the sound amplitude at the output of the tube.
10. Remove the tube and record the sound amplitude at the same distance from the source.

11. Repeat steps 7 through 10 by decreasing the tube length until all maximums and minimums are recorded until the tubes combined reach their minimum length (which occurs when one tube completely slides into the other).
12. Repeat steps 5-11 for frequencies increasing from 700Hz in steps of 500Hz up to 2700Hz.
13. Each measurement is repeated 3 times for trials.

Variables and groups

Independent variable:

The independent variable is the length (cm) of the tube.

Experimental group: The groups of trials to be tested with the use of the tube for sound frequencies of 700Hz, 1200Hz, 1700Hz, 2200Hz, and 2700Hz.

Control group: The groups of trials to be tested without the use of the tube for sound frequencies of 700Hz, 1200Hz, 1700Hz, 2200Hz, and 2700Hz.

Dependent variable:

The amplitude of sound (dB) at the end of the tube.

Constants:

- Setting of experiment (room and surrounding objects)
- Ambient sound level (no sound) in the setting of the experiment
- Material used for the open tube (cardboard)
- Device (iOS Function Generator PRO app and iPhone) used to produce sound
- Device (iOS Decibel X PRO app and iPhone) used to measure amplitude of sound

Challenges overcome

One challenge was finding hollow tubes whose length are adjustable. After days of searching, telescoping cardboard tubes usually used for packaging maps and art materials were used for this experiment. Another challenge encountered was doing the experiment in a quiet environment. The experiment was performed in a quiet room with doors closed during an afternoon time period when the ambient noise was minimal.

Data

The data recorded during the experiment is given in Table 1 through Table 10, with each pair of tables corresponding to a specific source frequency. For example, Table 1 and Table 2 correspond to a source frequency of 700Hz.

Table 1 shows the data for the amplitude of sound of 700Hz at the source. Columns 2 through 4 represent data from 3 trials and the last column represents the average of the three trials. In this case, the average amplitude of the sound of frequency 700Hz at the source is 97.1dB.

Table 1: Amplitude of sound with a frequency of 700 Hz at the source

Setting for measurement	Trial 1	Trial 2	Trial3	Mean
	Amplitude (dB)	Amplitude (dB)	Amplitude (dB)	Amplitude (dB)
At source	97.1	97.0	97.2	97.10

Table 2 has the data for the experimental and control groups for source at 700Hz. The first column indicates if the data is recorded when the amplitude reaches a minimum or maximum setting at the end of the tube. In columns 2, 3, and 4, the length of tube at which the extremum occurs, the extremal amplitude of sound at the end of the tube, and the amplitude at the same location without the tube, respectively, are recorded, for the first trial. In the subsequent 2 sets of 3 columns each, the data corresponding to trials 2 and 3 are recorded. The final 3 columns give the average of all three trials. For example, the average length when the first minimum in amplitude is reached when the tube is shortened is given in the column 11 of the 1st data row as 104.56cm. The average of the minimum amplitude reached at the end of the tube in this case is given in column 12 as 94.4dB, and the amplitude at the same location without the tube is given in column 13 as 66.1dB.

Table 2: The behavior of sound with a frequency of 700 Hertz with and without the tubes

Amplitude setting for measurement	Trial 1			Trial 2			Trial 3			Mean		
	Length L1 of tube (cm)	Amplitude (dB)		Length L2 of tube (cm)	Amplitude (dB)		Length L3 of tube (cm)	Amplitude (dB)		Length L of tube (cm)	Amplitude (dB)	
		At length L1 with tube (expt.)	At length L1 without tube (control)		At length L2 with tube (expt.)	At length L2 without tube (control)		At length L3 with tube (expt.)	At length L3 without tube (control)		At length L with tube (expt.)	At length L without tube (control)
1st minimum	104.46	94.7	65.9	104.78	94.2	66.1	104.46	94.3	66.3	104.56	94.4	66.1
1st maximum	91.76	104.4	73.8	92.08	104.9	73.7	91.76	105.2	74.2	91.86	104.83	73.9
2nd minimum	81.28	94.7	77.8	81.60	94.9	77.7	80.96	94.6	77.5	81.28	94.73	77.67
2nd maximum	68.90	104.6	73.2	68.26	105.4	73.0	67.63	105.8	72.9	68.26	105.27	73.03

As for the 700Hz case, data recorded for the 1200Hz case is given in Table 3 and Table 4, for the 1700Hz case in Table 5 and Table 6, for the 2200Hz case in Table 7 and Table 8, and for the 2700Hz case in Table 9 and Table 10.

Table 3: Amplitude of sound with a frequency of 1200 Hz at the source

Setting for measurement	Trial 1	Trial 2	Trial3	Mean
	Amplitude (dB)	Amplitude (dB)	Amplitude (dB)	Amplitude (dB)
At source	94.1	94.0	94.1	94.07

Table 4: The behavior of sound with a frequency of 1200 Hertz with and without the tubes

Amplitude setting for measurement	Trial 1			Trial 2			Trial 3			Mean		
	Length L1 of tube (cm)	Amplitude (dB)		Length L2 of tube (cm)	Amplitude (dB)		Length L3 of tube (cm)	Amplitude (dB)		At length L of tube (cm)	Amplitude (dB)	
		At length L1 with tube (expt.)	At length L1 without tube (control)		At length L2 with tube (expt.)	At length L2 without tube (control)		At length L3 with tube (expt.)	At length L3 without tube (control)		At length L with tube (expt.)	At length L without tube (control)
1st minimum	102.24	94.6	67.5	102.55	94.5	68.3	102.24	94.5	67.6	102.34	94.53	67.8
1st maximum	95.25	101.3	68.5	95.57	101.4	68.4	95.25	101.2	68.1	95.36	101.3	68.33
2nd minimum	88.58	95.0	69.3	87.63	95.0	69.7	88.27	94.9	69.5	88.16	94.97	69.50
2nd maximum	80.33	101.0	62.5	80.65	101.1	62.8	80.96	100.8	63.2	80.65	100.97	62.83
3rd minimum	72.39	94.7	66.2	73.03	94.1	65.8	73.34	94.6	65.7	72.92	94.47	65.9
3rd maximum	67.31	100.5	64.5	66.99	100.8	64.3	66.99	100.9	64.5	67.10	100.73	64.43
4th minimum	58.74	94.4	71.1	59.12	94.3	71.2	58.74	94.4	71.1	58.86	94.37	71.13

Table 5: Amplitude of sound with a frequency of 1700 Hz at the source

Setting for measurement	Trial 1	Trial 2	Trial3	Mean
	Amplitude (dB)	Amplitude (dB)	Amplitude (dB)	Amplitude (dB)
At source	93.5	94.2	94.1	93.93

Table 6: The behavior of sound with a frequency of 1700 Hertz with and without the tubes

Amplitude setting for measurement	Trial 1			Trial 2			Trial 3			Mean		
	Length L1 of tube (cm)	Amplitude (dB)		Length L2 of tube (cm)	Amplitude (dB)		Length L3 of tube (cm)	Amplitude (dB)		Length L of tube (cm)	Amplitude (dB)	
		At length L1 with tube (expt.)	At length L1 without tube (control)		At length L2 with tube (expt.)	At length L2 without tube (control)		At length L3 with tube (expt.)	At length L3 without tube (control)		At length L with tube (expt.)	At length L without tube (control)
1st minimum	101.92	93.3	60.0	101.60	93.3	59.6	101.28	93.6	59.2	101.60	93.40	59.6
1st maximum	96.84	97.5	58.7	97.16	97.3	58.5	96.52	97.4	57.9	96.84	97.40	58.37
2nd minimum	92.08	93.3	66.7	91.76	93.5	66.3	92.08	93.6	66.5	91.97	93.47	66.50
2nd maximum	86.68	97.9	68.2	86.36	97.9	68.9	86.68	97.9	68.8	86.57	97.90	68.63
3rd minimum	81.28	94.0	68.5	80.96	94.2	68.2	81.60	93.9	69.2	81.28	94.03	68.63
3rd maximum	76.52	97.8	69.8	76.20	98.1	69.9	76.52	97.9	70.0	76.41	97.93	69.90
4th minimum	71.12	93.9	65.4	71.44	93.9	65.1	70.80	94.0	66.3	71.12	93.93	65.6

Table 7: Amplitude of sound with a frequency of 2200 Hz at the source

Setting for measurement	Trial 1	Trial 2	Trial3	Mean
	Amplitude (dB)	Amplitude (dB)	Amplitude (dB)	Amplitude (dB)
At source	96.8	96.8	96.9	96.83

Table 8: The behavior of sound with a frequency of 2200 Hertz with and without the tubes

Amplitude setting for measurement	Trial 1			Trial 2			Trial 3			Mean		
	Length L1 of tube (cm)	Amplitude (dB)		Length L2 of tube (cm)	Amplitude (dB)		Length L3 of tube (cm)	Amplitude (dB)		Length L of tube (cm)	Amplitude (dB)	
		At length L1 with tube (expt.)	At length L1 without tube (control)		At length L2 with tube (expt.)	At length L2 without tube (control)		At length L3 with tube (expt.)	At length L3 without tube (control)		At length L with tube (expt.)	At length L without tube (control)
1st maximum	105.41	100.2	67.6	105.09	100.2	67.5	105.09	100.1	67.4	105.20	100.17	67.50
1st minimum	101.92	97.6	69.2	101.60	97.7	69.5	101.60	97.7	69.6	101.71	97.67	69.43
2nd maximum	96.84	100.4	58.2	97.16	100.5	58.5	96.84	100.4	59.4	96.94	100.43	58.70
2nd minimum	93.35	97.8	66.3	92.71	97.9	66.5	93.03	97.9	65.5	93.03	97.87	66.10
3rd maximum	89.54	100.5	59.7	89.85	100.5	60.6	89.85	100.5	58.4	89.75	100.5	59.57
3rd minimum	85.73	98.1	70.3	85.41	98.0	70.4	85.09	98.0	70.3	85.41	98.03	70.33
4th maximum	81.60	100.5	71.4	81.92	100.3	71.5	81.60	100.4	71.6	81.70	100.4	71.50
4th minimum	78.11	97.8	66.8	77.79	97.8	66.5	77.47	97.9	66.4	77.79	97.83	66.57

Table 9: Amplitude of sound with a frequency of 2700 Hz at the source

Setting for measurement	Trial 1	Trial 2	Trial3	Mean
	Amplitude (dB)	Amplitude (dB)	Amplitude (dB)	Amplitude (dB)
At source	100.1	100.2	100.2	100.17

Table 10: The behavior of sound with a frequency of 2700 Hertz with and without the tubes

Amplitude setting for measurement	Trial 1			Trial 2			Trial 3			Mean		
	Length L1 of tube (cm)	Amplitude (dB)		Length L2 of tube (cm)	Amplitude (dB)		Length L3 of tube (cm)	Amplitude (dB)		Length L of tube (cm)	Amplitude (dB)	
		At length L1 with tube (expt.)	At length L1 without tube (control)		At length L2 with tube (expt.)	At length L2 without tube (control)		At length L3 with tube (expt.)	At length L3 without tube (control)		At length L with tube (expt.)	At length L without tube (control)
1st maximum	106.05	98.5	69.3	105.73	98.6	69.5	105.41	98.5	70.1	105.73	98.53	69.63
1st minimum	101.92	97.6	67.6	102.24	97.6	67.8	101.6	97.5	67.9	101.92	97.57	67.77
2nd maximum	98.74	98.7	72.5	99.06	98.8	72.1	98.43	98.7	72.5	98.74	98.73	72.37
2nd minimum	95.25	97.9	74.2	95.57	97.8	74.0	95.25	97.9	74.1	95.36	97.87	74.10
3rd maximum	92.08	98.6	71.9	92.39	98.9	72.0	92.08	98.8	71.6	92.18	98.77	71.83
3rd minimum	88.90	97.6	68.8	88.58	97.8	69.2	88.90	97.8	69.7	88.79	97.73	69.23
4th maximum	86.36	98.7	64.3	86.04	98.7	64.9	86.36	98.7	65.2	86.25	98.70	64.8
4th minimum	83.19	97.5	72.4	82.55	97.4	72.8	82.87	97.3	72.5	82.87	97.40	72.57

In Figures 6 through 10 below, the amplitude of sound with and without the tube is plotted against the distance from the source. Each figure shows the plot for a different frequency.

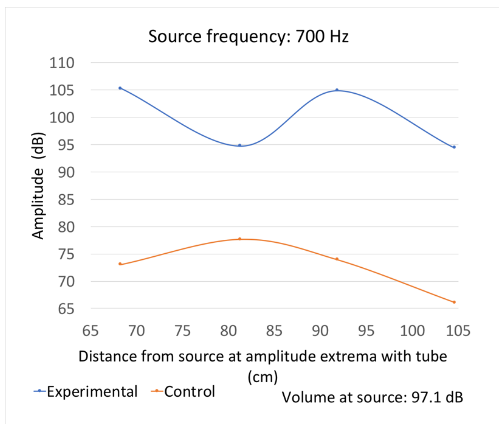

Figure 6: Amplitude at the end of tube for source frequency of 700Hz.

For example, Figure 6 shows the plot for 700Hz. The Y axis gives the amplitude of sound at the end of the tube while the X axis specifies the length of tube at which the measurement is performed. Note that the tube length is progressively decreased and a measurement is performed only when the sound amplitude either reaches a minimum or a maximum. The blue line shows the amplitude of sound at the end of the tube, and the orange line shows the amplitude of that sound at the same distance from the source but without the tube. The amplitude at the source, given at the bottom-right corner, is 97.1dB.

Similarly, Figures 7, 8, 9, and 10 show the plots corresponding to source frequencies of 1200Hz, 1700Hz, 2200Hz, and 2700Hz, respectively.

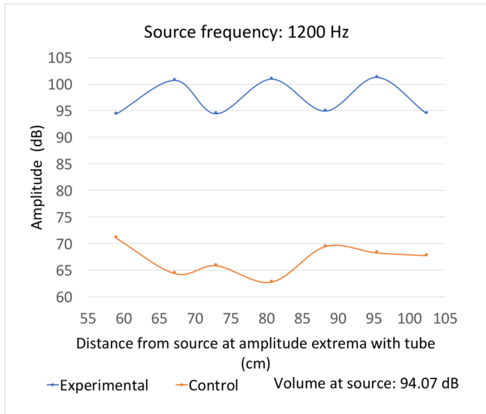

Figure 7: Amplitude at the end of tube for source frequency of 1200Hz.

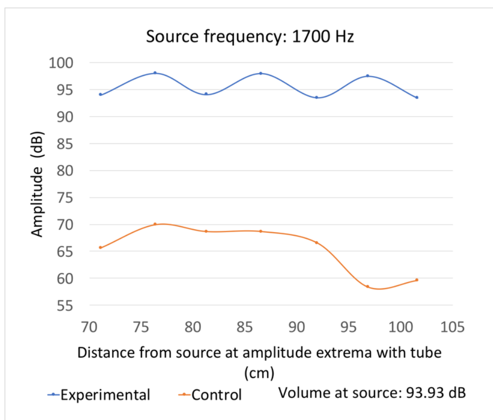

Figure 8: Amplitude at the end of tube for source frequency of 1700Hz.

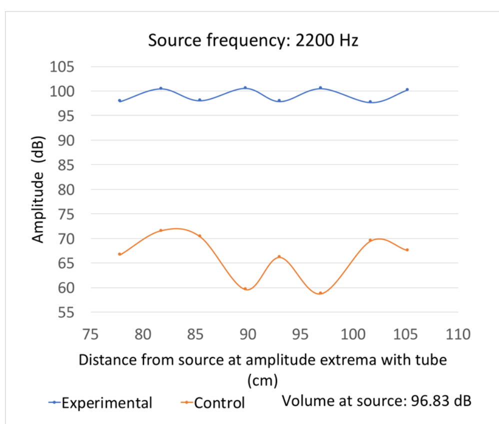

Figure 9: Amplitude at the end of tube for source frequency of 2200Hz.

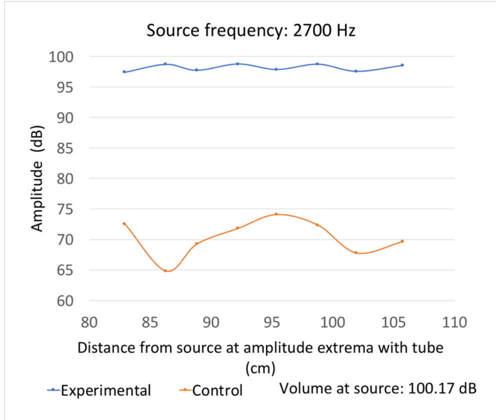

Figure 10: Amplitude at the end of tube for source frequency of 2700Hz.

Results

From Figure 6, corresponding to a source frequency of 700Hz, the following observations are made. First, it is seen that the amplitude of sound measured at the end of the tube, as shown by the blue line, oscillates as the tube length is changed. As the tube length is decreased, the sound amplitude increases and decreases and increases again, thus confirming the hypothesis. Second, the difference between the lengths of the tube at which consecutive extrema of amplitude occur is almost constant as the tube length decreases. Third, the amplitudes recorded with the presence of the tube (the amplitude shown by the blue line) are much higher than those without the tube (amplitudes shown by the orange line). Fourth, the amplitudes recorded without the tube at different distances from the source do not follow a specific pattern. Similar behavior is observed in Figures 7 through 10 for frequencies 1200Hz, 1700Hz, 2200Hz, and 2700Hz.

Now comparing plots across different frequencies, there are two observations that can be made. First, it is observed that the difference between tube lengths where consecutive minimums and maximums occur decreases as the frequency of sound increases. The average differences calculated from the eleventh columns in Tables 2, 4, 6, 8 and 10 are 12.1cm for 700Hz, 7.2cm for 1200hz, 5.1cm for 1700Hz, 3.9cm for 2200Hz, and 3.3cm for 2700Hz. Second, it is observed that the difference between consecutive minimums and maximums in amplitude decreases as the frequency increases. The average differences calculated from the twelfth columns in Tables 2, 4, 6, 8 and 10 are 10.4dB for 700Hz, 6.4dB for 1200Hz, 4.0dB for 1700Hz, 2.6dB for 2200Hz, and 1.0dB for 2700Hz.

Conclusions

The purpose of this experiment is to determine the effect of varying the length of a tube on the amplitude of the sound propagated through the tube. The hypothesis is that the sound amplitude will fluctuate periodically if the pipe length is gradually decreased. As see from Figures 1 through 5 and from the discussion in the results section, this is proven to be correct, as the amplitudes of all the frequencies oscillate periodically if the distance from the source decreases. In comparison to the data for the control group, the tube does create this periodic fluctuation in amplitude.

It is observed that the amplitudes of sound coming out of the tube are much higher than the amplitudes recorded for the control group without the tube. This is because of the fact the sound energy from the source is not focused through the tube but instead dispersed into the surrounding environment. Also, for the control group, the amplitude fluctuations do not seem to have a relationship to the distance from the source. This is probably due to reflections of sound off of other objects in the room.

The above observations indicate that the absence of a tube would be more effective in sound attenuation than propagating the sound through a tube. However, in many applications, where tubes are needed to transfer certain substances such as exhaust gas from an engine, the length of such a tube can be adjusted to reduce the amplitude of the accompanying undesirable sounds. Another application for the results of this experiment is the amplification of one frequency and the attenuation of another. For example, if there is background noise in an audio recording, then it may be desirable to propagate such sound through a tube and set the tube length in such a way that it attenuates the background noise while amplifying the main recording. The numerical values of the two frequencies can determine the length of a tube that can accomplish this goal.

Suggestions for improvement and further research

This experiment used a simple cylindrical open tube to explore sound amplification and attenuation. The investigations can be expanded to include different shapes of tubes, and also creating further reflections and attenuations by adding extra closed end tubes as mufflers. Also, the current experiment used only the reflections of the single source for attenuation. The experiment can be enhanced to use additional sound sources of specific frequencies to cancel undesirable frequencies from the main source.

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