

Lab 5: Resonant Pipes & Harmonic Series

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1 Introduction

We are going to study different resonant systems and try to model them as either **open** or **closed** resonant pipes. Of course, real systems are not quite so simple, so we will be studying how closely such a real system matches the theoretical ideal.

2 Experiment

2.1 Practice

You will be given a resonant pipe. Spend a few minutes experimenting with it to discover how to efficiently generate as many resonant frequencies as possible. *Take your time!* This is not easy and it will take a little practice. Ask other groups for help if you are having trouble.

When you have mastered your instrument and are ready for performance, proceed to a tuner to measure the frequencies of these resonances. You should be able to generate at least 3 resonances.

2.2 Performance

(A sample data table is provided below.)

Measure the frequencies of as many resonances as possible. Have one person play the instrument and center the tone without looking at the meter, and have a second person take a reading. Be sure to stay on the resonance and not change the pitch by changing your mouth shape. You will know you are on the resonance when you feel a significant vibration on your face. This effect goes away quickly as you move off resonance.

Fill in the notes in a table starting from the highest resonance you can play and working down.

Most of you will be using musical chromatic tuners to determine your frequencies. The tuner will tell you the note (e.g. $F^\#$), and the cents above or below this note (e.g. +40). Record the notes as follows: ($F_5^\# + 40$), ***You must figure out the octave by comparing the sound you hear to a keyboard.*** There will be a keyboard available to assist you.

2.3 Frequencies

Once you have determined the note and octave (e.g. $F_5^\# + 40$), use the table at the end of this lab to compute your frequency (three digits of precision should be plenty). Then compute the difference between the two frequencies. (*Note: If you made an error, or are missing a resonance, it will show up at this point in the differences. If you find an anomaly, go back to your experimental setup and check for mistakes in your data.*)

2.4 Fundamental Frequency

You may or may not have measured the fundamental (lowest) frequency. Assuming you did not, you can estimate what it should be by stepping down the frequency.

- First, compute the average difference between the different resonances.
- Then use this average difference to step down from your lowest frequency until you reach a frequency that is about zero.
- The fundamental frequency is the frequency before the one that is approximately zero.

In the example table, I measured down to the 700 Hz resonance. Using the average difference of 200 Hz, I was able to determine the fundamental frequency was 100 Hz. I indicate that the values below 700 Hz are theoretical predictions (not measurements) using the last column.

2.5 Length of Instrument

Measure the length of your instrument in meters. Compute the expected fundamental if this were an open pipe and the fundamental for a closed pipe (*hint: Look back at the prelab*). How does this compare with what you found in your measurements? *Be sure to use the real value value for the speed of sound, not my fake 400 m/s.*

As always, the speed of sound is given by,

$$v = 332 \left(\frac{\text{m}}{\text{s}} \right) + 0.6 \left(\frac{\text{m}}{\text{s}^\circ\text{C}} \right) T$$

2.6 Repeat

Repeat the above steps so that you perform this experiment for three different resonant pipes.

3 Questions

- How closely did your real instruments match the theoretical models?
- Do the resonant notes from your instrument appear to be multiples of the fundamental frequency (e.g. $1f_0, 2f_0, 3f_0, 4f_0, 5f_0, \dots$) or only the odd multiples (e.g. $1f_0, 3f_0, 5f_0, 7f_0, \dots$)?
- Does your instrument appear to be harmonic or odd-harmonic?
- What elements would make the real instruments differ from the models?
- Identify at least two sources of statistical error and state how you would correct for them.
- Identify at least two sources of systematic error and state how you would correct for them.
- As always, do not forget to write an Abstract and Conclusion in your lab notebook.
- Can you make any other general conclusions or observations?

4 Example Data with Calculation

4.1 Data

Note	Frequency	Difference	Measured?
$F_6^\# + 20$	1500	n/a	yes
$E_6 - 20$	1300	200	yes
$C_6^\# - 10$	1100	200	yes
$A_5 + 40$	900	200	yes
	500	200	no
	300	200	no
	$100 = f_0$	200	no

4.2 Calculations

$$f_{\text{closed}} = \frac{v_{\text{sound}}}{4L} = 100 \text{ Hz}$$

$$f_{\text{open}} = \frac{v_{\text{sound}}}{2L} = 200 \text{ Hz}$$

A	440	-50	-40	-30	-20	-10	0	10	20	30	40	50
6	C	1016.7	1022.6	1028.5	1034.5	1040.5	1046.5	1052.6	1058.7	1064.8	1071.0	1077.2
6	C#	1077.2	1083.4	1089.7	1096.0	1102.3	1108.7	1115.2	1121.6	1128.1	1134.6	1141.2
6	D	1141.2	1147.8	1154.5	1161.2	1167.9	1174.7	1181.5	1188.3	1195.2	1202.1	1209.1
6	D#	1209.1	1216.1	1223.1	1230.2	1237.3	1244.5	1251.7	1259.0	1266.3	1273.6	1281.0
6	E	1281.0	1288.4	1295.9	1303.4	1310.9	1318.5	1326.1	1333.8	1341.6	1349.3	1357.1
6	F	1357.1	1365.0	1372.9	1380.9	1388.9	1396.9	1405.0	1413.1	1421.3	1429.6	1437.8
6	F#	1437.8	1446.2	1454.6	1463.0	1471.5	1480.0	1488.6	1497.2	1505.8	1514.6	1523.3
6	G	1523.3	1532.2	1541.0	1550.0	1559.0	1568.0	1577.1	1586.2	1595.4	1604.6	1613.9
6	G#	1613.9	1623.3	1632.7	1642.1	1651.7	1661.2	1670.8	1680.5	1690.3	1700.0	1709.9
6	A	1709.9	1719.8	1729.8	1739.8	1749.9	1760.0	1770.2	1780.5	1790.8	1801.1	1811.6
6	A#	1811.6	1822.1	1832.6	1843.2	1853.9	1864.7	1875.5	1886.3	1897.2	1908.2	1919.3
6	B	1919.3	1930.4	1941.6	1952.8	1964.2	1975.5	1987.0	1998.5	2010.1	2021.7	2033.4
7	C	2033.4	2045.2	2057.0	2069.0	2080.9	2093.0	2105.1	2117.3	2129.6	2141.9	2154.3
7	C#	2154.3	2166.8	2179.4	2192.0	2204.7	2217.5	2230.3	2243.2	2256.2	2269.3	2282.4
7	D	2282.4	2295.7	2309.0	2322.3	2335.8	2349.3	2362.9	2376.6	2390.4	2404.2	2418.2
7	D#	2418.2	2432.2	2446.3	2460.4	2474.7	2489.0	2503.4	2517.9	2532.5	2547.2	2561.9
7	E	2561.9	2576.8	2591.7	2606.7	2621.8	2637.0	2652.3	2667.7	2683.1	2698.7	2714.3
7	F	2714.3	2730.0	2745.8	2761.7	2777.7	2793.8	2810.0	2826.3	2842.7	2859.1	2875.7
7	F#	2875.7	2892.3	2909.1	2926.0	2942.9	2960.0	2977.1	2994.3	3011.7	3029.1	3046.7
7	G	3046.7	3064.3	3082.1	3099.9	3117.9	3136.0	3154.1	3172.4	3190.8	3209.3	3227.9
7	G#	3227.9	3246.6	3265.4	3284.3	3303.3	3322.4	3341.7	3361.0	3380.5	3400.1	3419.8
7	A	3419.8	3439.6	3459.5	3479.6	3499.7	3520.0	3540.4	3560.9	3581.5	3602.3	3623.1
7	A#	3623.1	3644.1	3665.2	3686.5	3707.8	3729.3	3750.9	3772.6	3794.5	3816.5	3838.6
7	B	3838.6	3860.8	3883.2	3905.7	3928.3	3951.1	3974.0	3997.0	4020.1	4043.4	4066.8
8	C	4066.8	4090.4	4114.1	4137.9	4161.9	4186.0	4210.3	4234.6	4259.2	4283.9	4308.7
8	C#	4308.7	4333.6	4358.7	4384.0	4409.4	4434.9	4460.6	4486.5	4512.4	4538.6	4564.9
8	D	4564.9	4591.3	4617.9	4644.7	4671.6	4698.6	4725.9	4753.2	4780.8	4808.5	4836.3
8	D#	4836.3	4864.3	4892.5	4920.9	4949.4	4978.0	5006.9	5035.9	5065.0	5094.4	5123.9
8	E	5123.9	5153.6	5183.4	5213.5	5243.7	5274.0	5304.6	5335.3	5366.2	5397.3	5428.6
8	F	5428.6	5460.0	5491.7	5523.5	5555.5	5587.7	5620.0	5652.6	5685.3	5718.3	5751.4
8	F#	5751.4	5784.7	5818.2	5851.9	5885.8	5919.9	5954.2	5988.7	6023.4	6058.3	6093.4
8	G	6093.4	6128.7	6164.2	6199.9	6235.8	6271.9	6308.3	6344.8	6381.6	6418.5	6455.7
8	G#	6455.7	6493.1	6530.7	6568.6	6606.6	6644.9	6683.4	6722.1	6761.0	6800.2	6839.6
8	A	6839.6	6879.2	6919.1	6959.1	6999.5	7040.0	7080.8	7121.8	7163.1	7204.6	7246.3
8	A#	7246.3	7288.3	7330.5	7373.0	7415.7	7458.6	7501.8	7545.3	7589.0	7633.0	7677.2
8	B	7677.2	7721.6	7766.4	7811.4	7856.6	7902.1	7947.9	7994.0	8040.3	8086.8	8133.7
9	C	8133.7	8180.8	8228.2	8275.9	8323.8	8372.0	8420.5	8469.3	8518.4	8567.7	8617.3
9	C#	8617.3	8667.3	8717.5	8768.0	8818.8	8869.8	8921.2	8972.9	9024.9	9077.2	9129.8
9	D	9129.8	9182.6	9235.8	9289.3	9343.1	9397.3	9451.7	9506.5	9561.5	9616.9	9672.6
9	D#	9672.6	9728.7	9785.0	9841.7	9898.7	9956.1	10013.7	10071.7	10130.1	10188.8	10247.8
9	E	10248	10307	10367	10427	10487	10548	10609	10671	10732	10795	10857
9	F	10857	10920	10983	11047	11111	11175	11240	11305	11371	11437	11503
9	F#	11503	11569	11636	11704	11772	11840	11908	11977	12047	12117	12187
9	G	12187	12257	12328	12400	12472	12544	12617	12690	12763	12837	12911
9	G#	12911	12986	13061	13137	13213	13290	13367	13444	13522	13600	13679
9	A	13679	13758	13838	13918	13999	14080	14162	14244	14326	14409	14493
9	A#	14493	14577	14661	14746	14831	14917	15004	15091	15178	15266	15354
9	B	15354	15443	15533	15623	15713	15804	15896	15988	16081	16174	16267
10	C	16267	16362	16456	16552	16648	16744	16841	16939	17037	17135	17235