

Problem Set 4 Solutions

Problem 1

(i) For the syllable /ba/:

$$\text{change in amplitude of F4 due to F1 transition: } 40 \log \frac{600}{350} = 9.36 \text{ dB}$$

$$\text{change in amplitude of F4 due to F2 transition: } 40 \log \frac{1200}{1000} = 3.16 \text{ dB}$$

$$\text{total change in F4 amplitude from point A to B} = 9.36 + 3.15 = \boxed{12.52 \text{ dB}}$$

For the syllable /da/:

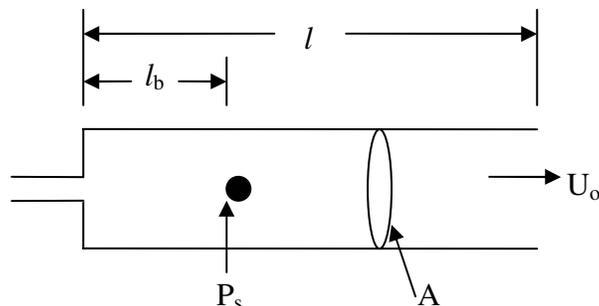
$$\text{change in amplitude of F4 due to F1 transition: } 40 \log \frac{600}{350} = 9.36 \text{ dB}$$

$$\text{change in amplitude of F4 due to F2 transition: } 40 \log \frac{1200}{1700} = -6.05 \text{ dB}$$

$$\text{total change in F4 amplitude from point A to B} = 9.36 - 6.05 = \boxed{3.31 \text{ dB}}$$

(ii) At point A of both syllables, the only difference between the two syllables is the frequency of the second formant. The difference in F2 causes the amplitudes of F4 to be different. The amplitude of F4 in /da/ is approximately $40 \log \frac{1700}{1000} = \boxed{9.22 \text{ dB}}$ higher than of /ba/.

Problem 2



(a) Assuming the tube is lossless, the transfer function $\frac{U_o}{P_s} = \frac{U_o}{U_1} \cdot \frac{U_1}{P_s}$

We first calculate $\frac{U_o}{U_1}$.

From 3.3.1 of the text, we have $U(x) = jP_m \frac{A}{\rho c} \cos kx$

$$\frac{U_o}{U_1} = \frac{U(x=0)}{U(x=-(l-l_b))} = \frac{jP_m \frac{A}{\rho c}}{jP_m \frac{A}{\rho c} \cos k(l-l_b)} = \frac{1}{\cos k(l-l_b)}$$

Now, to calculate $\frac{U_1}{P_s}$, in terms of circuit, U is analogous to current, and P is

analogous to voltage, so $\frac{U_1}{P_s}$ is analogous to $\frac{I}{V} = \frac{1}{Z}$, where Z is the total

impedance looking to the left and right of the pressure source. In this case, the impedance looking to the left from the pressure source is a closed tube with length of l_b , and the impedance looking to the right is an open tube with length of $l - l_b$

$$\begin{aligned} \frac{U_1}{P_s} &= \frac{1}{Z_l + Z_r} \\ &= \frac{1}{-j \frac{\rho c}{A} \cot(kl_b) + j \frac{\rho c}{A} \tan(k(l-l_b))} = j \frac{A}{\rho c} \frac{1}{\frac{\cos(kl_b)}{\sin(kl_b)} - \frac{\sin(k(l-l_b))}{\cos(k(l-l_b))}} \\ &= j \frac{A}{\rho c} \frac{1}{\frac{\cos(kl_b) \cos(k(l-l_b)) - \sin(kl_b) \sin(k(l-l_b))}{\sin(kl_b) \cos(k(l-l_b))}} \end{aligned}$$

using the trig. Property: $\cos(A+B) = \cos(A)\cos(B) - \sin(A)\sin(B)$

$$= j \frac{A}{\rho c} \frac{\sin(kl_b) \cos(k(l-l_b))}{\cos(k(l_b+l-l_b))} = j \frac{A}{\rho c} \frac{\sin(kl_b) \cos(k(l-l_b))}{\cos(kl)}$$

Finally, we get

$$\frac{U_o}{U_1} \cdot \frac{U_1}{P_s} = \frac{1}{\cos k(l-l_b)} * j \frac{A}{\rho c} \frac{\sin(kl_b) \cos(k(l-l_b))}{\cos(kl)}$$

$$\boxed{\frac{U_o}{P_s} = j \frac{A}{\rho c} \frac{\sin(kl_b)}{\cos(kl)}}$$

The poles of this expression are the natural frequencies of the entire tube, and the zeros are the frequencies at which the impedance looking to the left of the pressure source is infinite, which means there is no volume velocity through the tube.

(b) $l = 3\text{cm}$, $l_b = 2\text{cm}$.

$$\text{From } \frac{U_o}{P_s} = j \frac{A \sin(kl_b)}{\rho c \cos(kl)},$$

the lowest frequency pole is when $kl = \frac{2\pi f}{c} \cdot l = \frac{\pi}{2} \Rightarrow \boxed{f_p = \frac{c}{4l} = 2950 \text{ Hz}}$

the lowest frequency zero is when $kl_b = 0, \Rightarrow \boxed{f_z = 0 \text{ Hz}}$

Problem 3

- a) begins with alveolar voiced stop consonant \Rightarrow /d/
 vowel formants: 700 Hz, 1200 Hz, 2600 Hz \Rightarrow /Λ/
 ends with voiced velar stop (F2 & F3 close together) \Rightarrow /g/

\Rightarrow dug

- b) begins with voiceless fricative that has energy in high frequencies \Rightarrow /s/
 vowel formants: 600 Hz, 1800 Hz, 2600 Hz \Rightarrow /æ/
 ends with voiced velar stop (F2 & F3 close together) \Rightarrow /g/

\Rightarrow sag

- c) begins with voiceless fricative that has energy in high frequencies \Rightarrow /s/
 vowel formants: 600 Hz, 1700 Hz, 2500 Hz \Rightarrow /æ/
 ends with voiced alveolar stop (energy in high frequencies) \Rightarrow /d/

\Rightarrow sad

- d) begins with voiced labial stop (rising F2) \Rightarrow /b/
 vowel formants: 400 Hz, 2000 Hz, 2500 Hz \Rightarrow /I/
 ends with voiced velar stop (F2 and F3 close together) \Rightarrow /g/

\Rightarrow big

- e) begins with voiced alveolar stop (high F2) = /d/
vowel formants: 700 Hz, 1200 Hz, 2600 Hz => /ʌ/
ends with voiced labial stop => /b/
=> dub
- f) begins with voiced labial stop (F1 and F2 close together) => /b/
vowel formants: 700 Hz, 1200 Hz, 2500 Hz => /ʌ/
ends with voiced velar stop (F2 and F3 come together) => /g/
=> bug
- g) no evidence of consonant produced, starts with vowel.
vowel formants: 500 Hz, 2000 Hz, 2900 Hz => /ɛ/
ends with labial stop, F1 and F2 come together => /b/
=> ebb
- h) begins with voiced velar stop (energy around 1500 Hz) => /g/
vowel formants: 500 Hz, 1100 Hz, 2500 Hz => /ʊ/
ends with voiced alveolar stop (energy in high frequencies) => /d/
=> good
- i) begins with voiceless fricative that has energy in high frequencies => /s/
vowel formants: 300 Hz, 2200 Hz, 3000 Hz => /i/
voiced alveolar stop (energy in high frequencies) => /d/
=> seed

Problem 4

- a) To distinguish between “see” and “saw”, we know that /i/ is a front, high vowel, with a high F2 (2290-2790 Hz, Peterson & Barney) and a very low F1 (270-310 Hz, Peterson & Barney), while /ɔ/ is a non-low back vowel, with F2 range of 840-920 Hz (P&B), and F1 range of 570-590 Hz (P&B). If the two formants in the spectrogram are far apart, it must be “see”, otherwise, it is “saw”.

Similarly, to distinguish the three names:

/ɪ/ in Timmy, is a lax front high vowel, meaning F1 (270-310, P&B) and F2 (2290-2790, P&B) are far apart similar to /i/, and the duration of the vowel is short.

/ɔ/ in Tommy, like that in “saw”, has F1 near 580 Hz, and F2 ranging from 840-920Hz. The duration of the vowel would be longer than that in Timmy.

/æ/ in Tammy, is a low (high F1, 660-860 Hz, B&P) front (high F2, 1720-2050 Hz, B&P) vowel. It is also a tense vowel, so it would have a longer duration than that of Timmy.

Spectrogram 1: second vowel has F1 and F2 far apart => “see”
third vowel has F1 and F2 close together => “Tommy”

=> I see Tommy

Spectrogram 2: second vowel has F1 and F2 far apart => “see”
third vowel has F1 and F2 close together => “Tommy”

=> I see Tommy

Spectrogram 3: second vowel has F1 and F2 close together => “saw”
third vowel has F1 and F2 close together => “Tommy”

=> I saw Tommy

Spectrogram 4: second vowel has F1 and F2 far apart => “see”
third vowel’s F1 and F2 are far apart,
the duration is not short => “Tammy”

=> I see Tammy

Spectrogram 5: second vowel has F1 and F2 close together => “saw”
third vowel’s F1 and F2 are far apart,
the duration is short => “Timmy”

=> I saw Timmy

Spectrogram 6: second vowel has F1 and F2 far apart => “see”
third vowel’s F1 and F2 are far apart,
the duration is short => “Timmy”

=> I see Timmy

Spectrogram 7: second vowel has F1 and F2 close together => “saw”
third vowel’s F1 and F2 are far apart,
the duration is short => “Timmy”

=> I saw Timmy

Spectrogram 8: second vowel has F1 and F2 close together => “saw”
 third vowel’s F1 and F2 are far apart,
 the duration is not short => “Tammy”
 => I saw Tammy

- b) Female speakers have higher F0 (fundamental frequency), which means the glottal pulses (vertical lines in the spectrum) are closer together.

Female: 2, 3, 5, 6

Male: 1, 4, 7, 8

- c)

Spectrogram	Male F0
1	120 Hz
4	140 Hz
7	130 Hz
8	130 Hz
Average	130 Hz

Spectrogram	Female F0
2	200 Hz
3	210 Hz
5	200 Hz
6	210 Hz
Average	205 Hz

- d)

Female “see”	F2 (Hz)	F3 (Hz)
Spectrogram 2	2600	3100
Spectrogram 6	2600	3200
Average	2600	3150

Female “saw”	F2 (Hz)	F3 (Hz)
Spectrogram 3	1400	2900
Spectrogram 5	1500	2900
Average	1450	2900

Male “see”	F2 (Hz)	F3 (Hz)
Spectrogram 1	2400	3000
Spectrogram 4	2400	3100
Average	2400	3050

Male “saw”	F2 (Hz)	F3 (Hz)
Spectrogram 7	1200	2700
Spectrogram 8	1200	2800
Average	1200	2750

% increase from male to female:

% Difference	See F2	See F3	Saw F2	Saw F3
	8.3 %	3.28 %	20.83 %	5.45 %

The percentage difference between male and female is not uniform for the four pairs. This makes sense because the male vocal tract is not longer than the female's by the same ratio. While the male vocal tract length is approximately 20% longer than that of the female, the pharynx length is longer by 41%. The male's oral cavity length, in contrast, is only 4% longer than the females. Due to this non-constant ratio, various utterances' formants between males and females would not have the same % difference.