University of California
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EE225D

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# Acoustic Tube Models

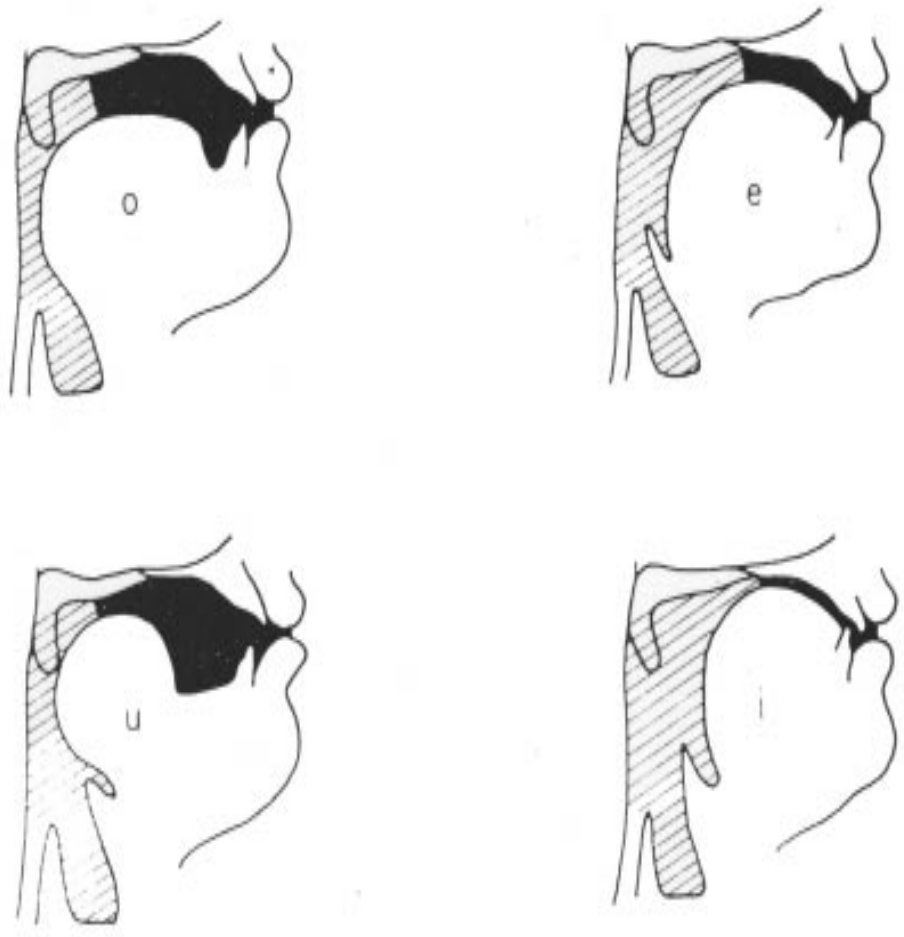
# Lecture 13

## Introduction :

Acoustic Tube Models of English Phonemes → 2 tube model.

## Assumptions :

- Lossless tubes
- Plane waves
- Rigid walls
- Friction
- Thermal effect




Vocal tract area for four vowel sounds

Vocal tract areas for four vowel sounds.

i - Tongue is High.

e - Tongue is a little Lower.

u - Tongue is very Low.

o - Togue is somewhat low.

1. Tube response vs. area function.
2. Discrete-time-space version.
3. Example - 2 tube representation of vowels.

**Problem for Today :**

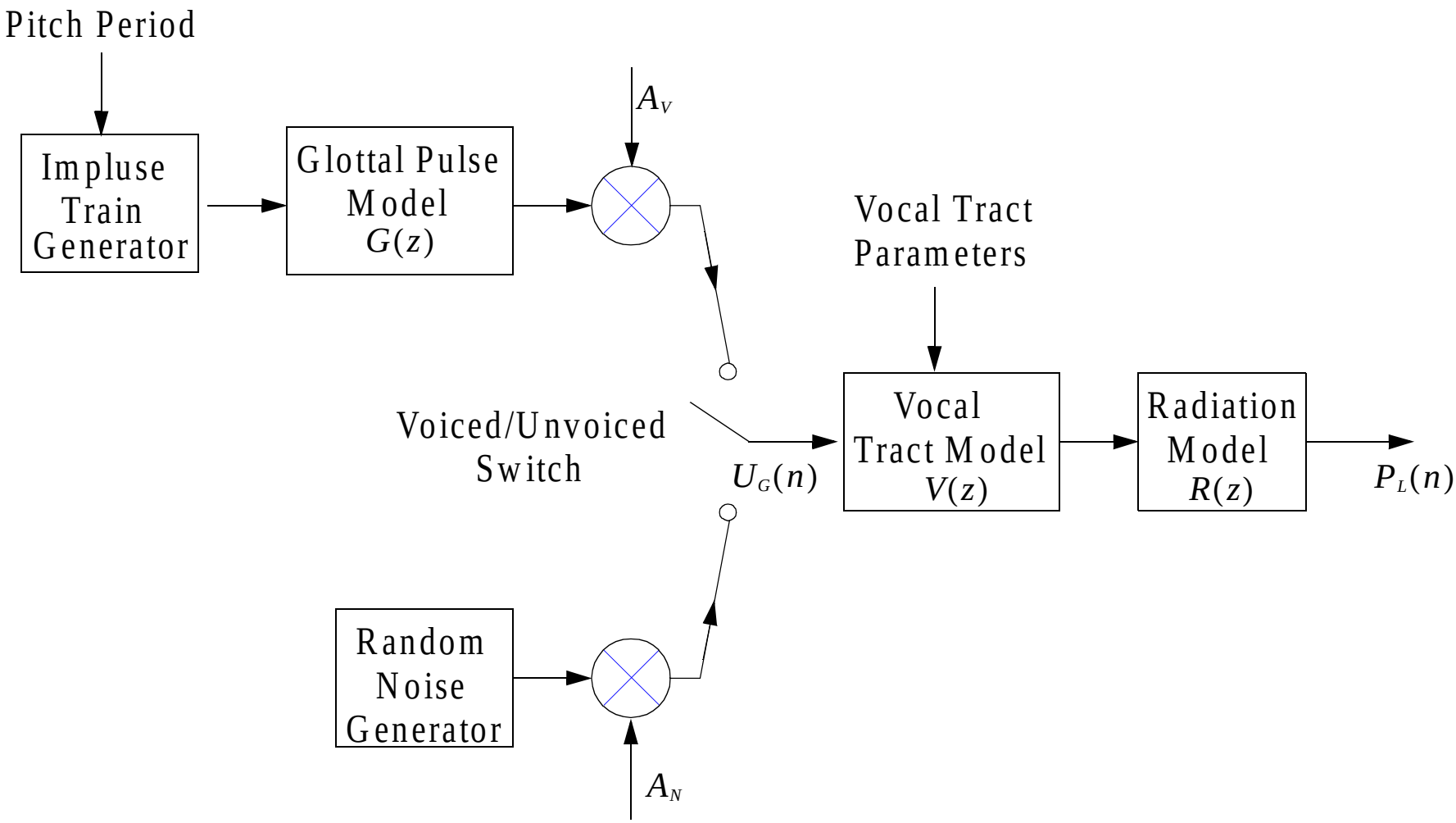
Develop a 2 tube model to derive a frequency response that approximates some vowels.

By solving a complicated wave equation, the frequency response can be found.

Look up equation in R & S.

$$-\frac{\partial p}{\partial x} = \rho \frac{\partial}{\partial t}(u/A)$$

$$-\frac{\partial u}{\partial t} = \frac{1}{\rho c^2}\frac{\partial}{\partial t}(pA) + \frac{\partial A}{\partial t}$$




Viewgraph 2 : General Discrete-Time Model for Speech Production.

Assumption in this Model :

Vocal Tract Model - Time varying

Radiation Model - May be time varying

Glottal Pulse Model - Usually considered independent of vocal tract model, but later we'll examine this wave closely

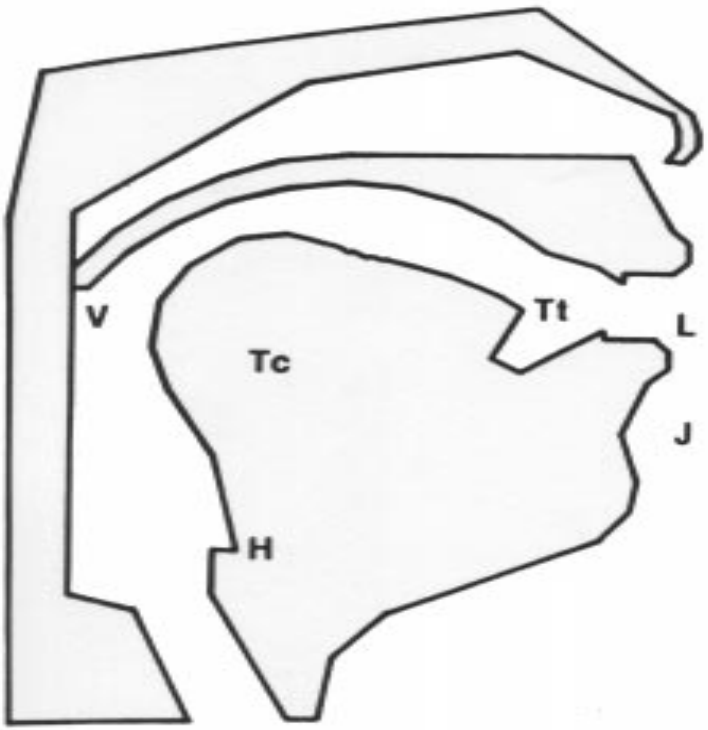
$$u(x,t) = u^{+}\left(t - \frac{x}{C}\right) - u^{-}\left(t + \frac{x}{C}\right)$$

$$p(x,t) = Z_o\left[u^{+}\left(t - \frac{x}{C}\right) + u^{-}\left(t + \frac{x}{C}\right)\right]$$

$p(l,t) = 0$ : open tube

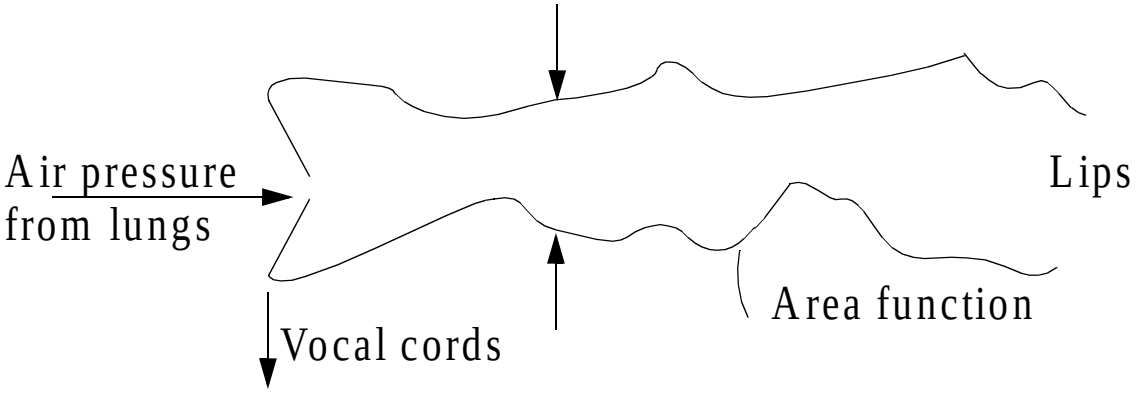
$$u^{+}\left(t - \frac{l}{C}\right) = -u^{-}\left(t + \frac{l}{C}\right)$$

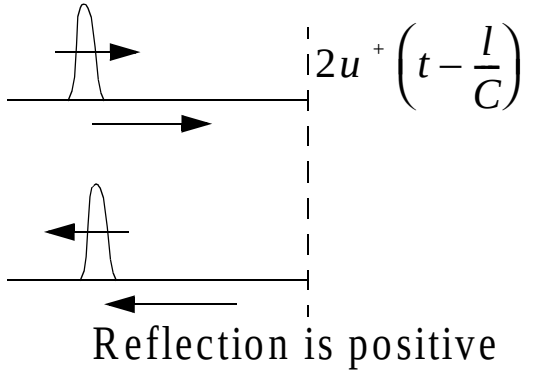
$$u(l,t) = 2u^{+}\left(t - \frac{l}{C}\right)$$




H = HYOID POSITION
J = ANGLE OF JAW OPENING
L = LIP PROTRUSION AND ELEVATION
Tc = TONGUE CENTER
Tt = POSITION OF TONGUE TIP
V = VELUM OPENING

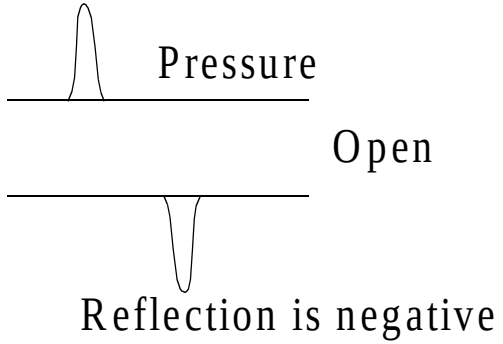
# Model of Vocal Tract




Closed Tube $u(l,t) = 0$

so $u^+\left(t-\frac{l}{C}\right) = -u^-\left(t+\frac{l}{C}\right)$




- Given Area Function we can compute Spectrum

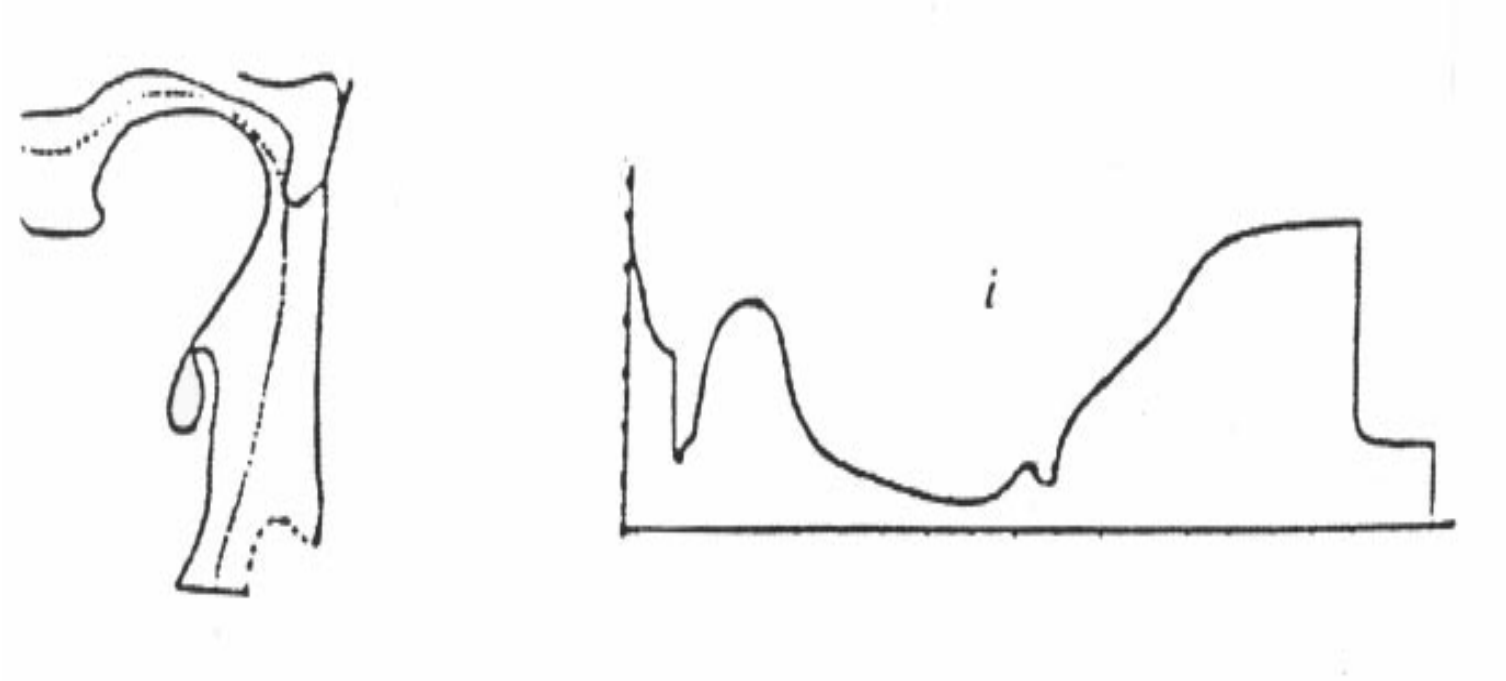



Figure 11.1: X-ray tracing and area function for phoneme /i/

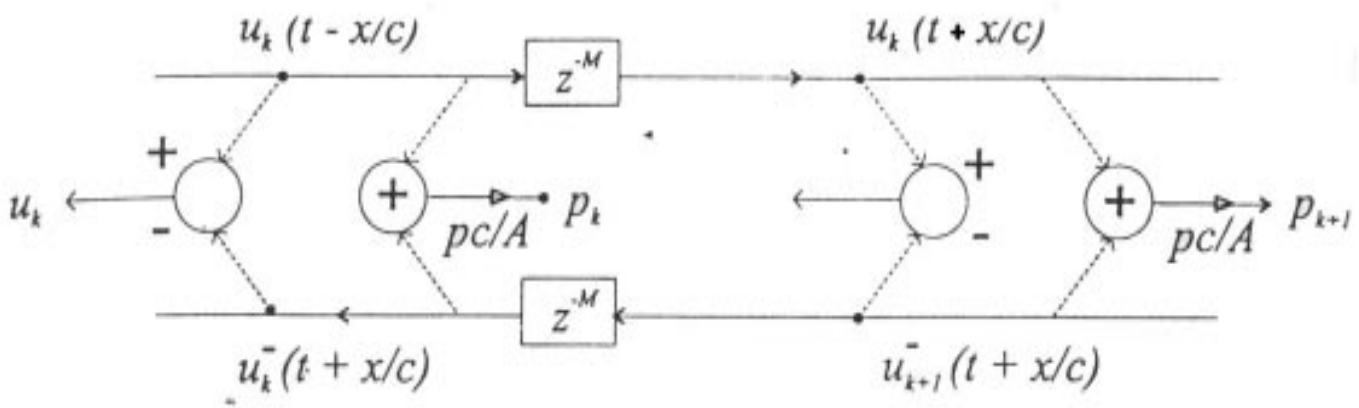



Figure 11.2: Single section of digital wave guide

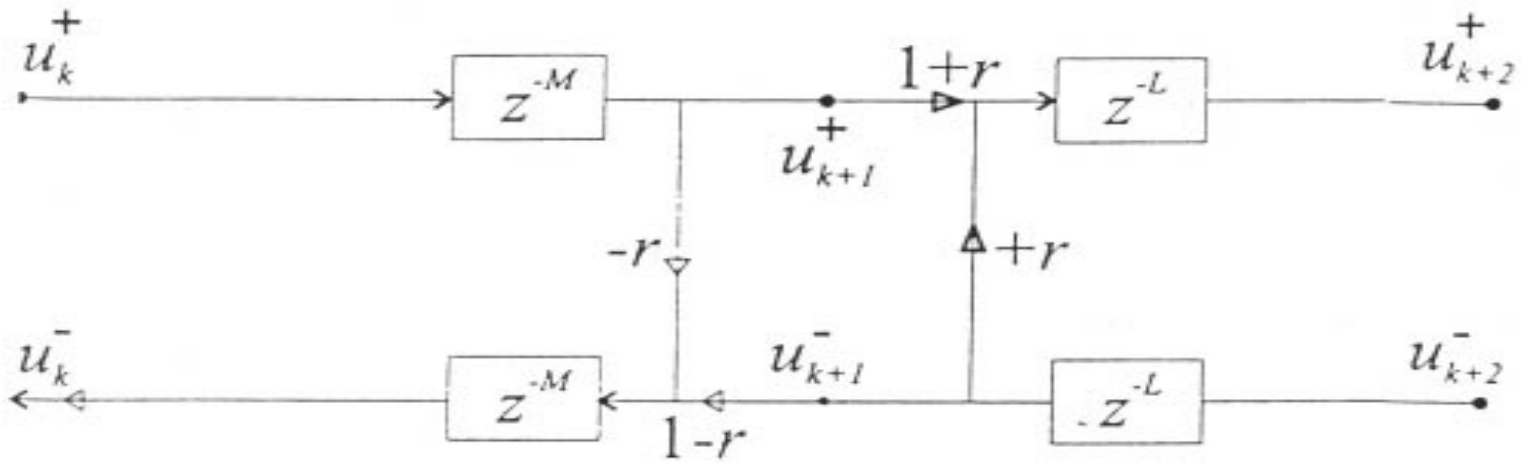



Figure 11.3: Two section digital wave guide

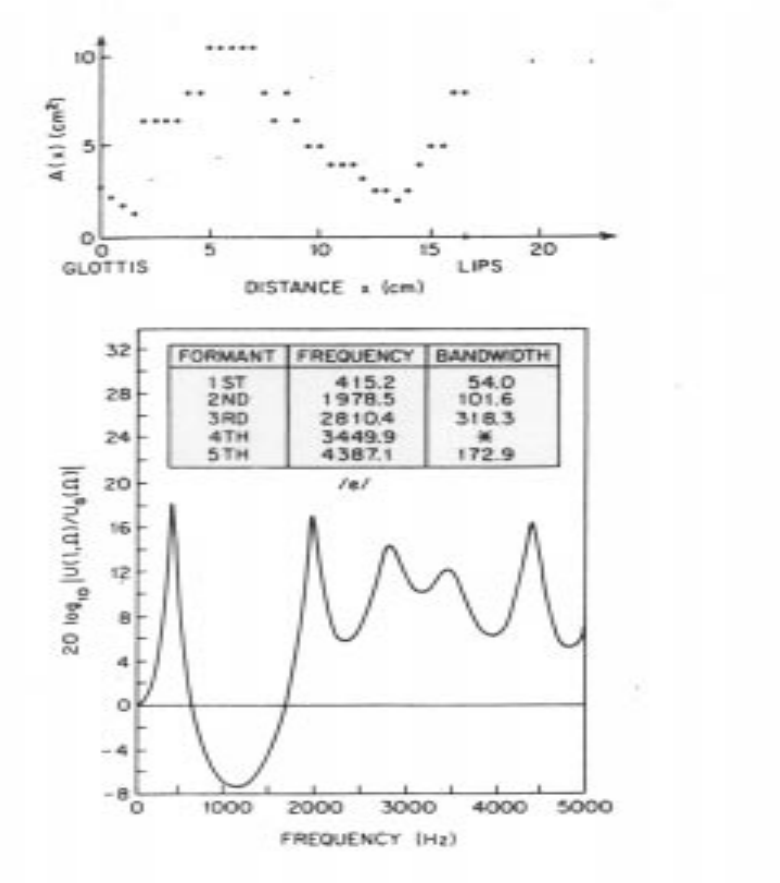



Figure 3.24 Area function and frequency response for the Russian vowel /*e*/

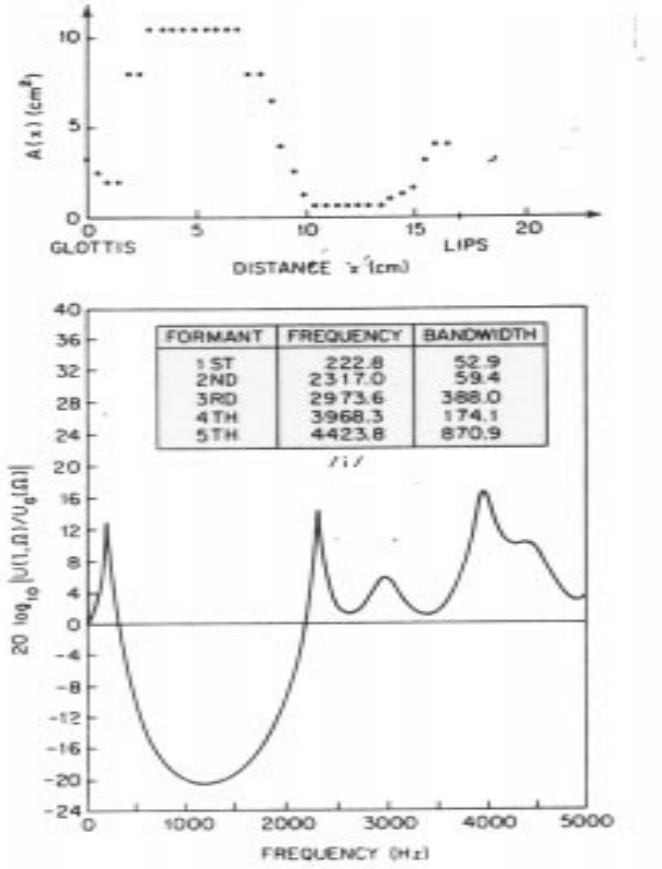
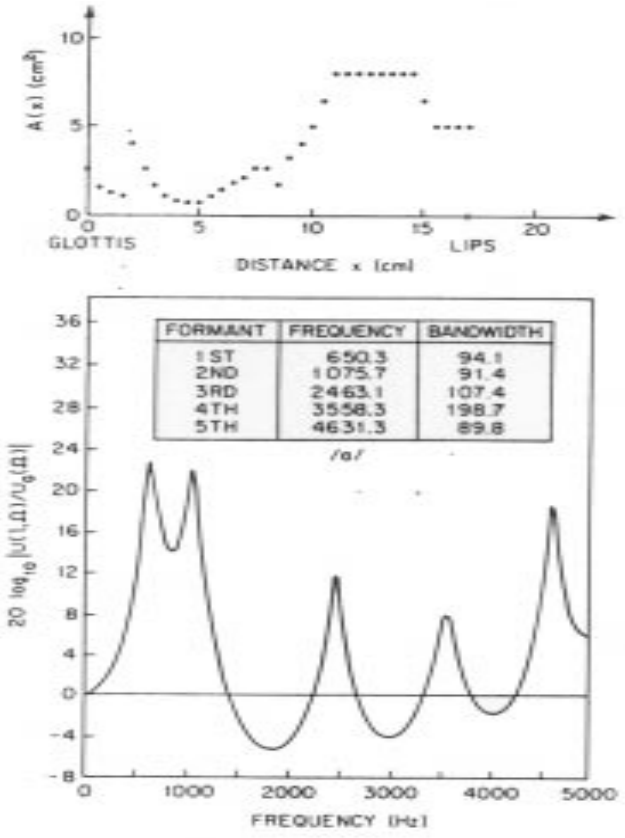
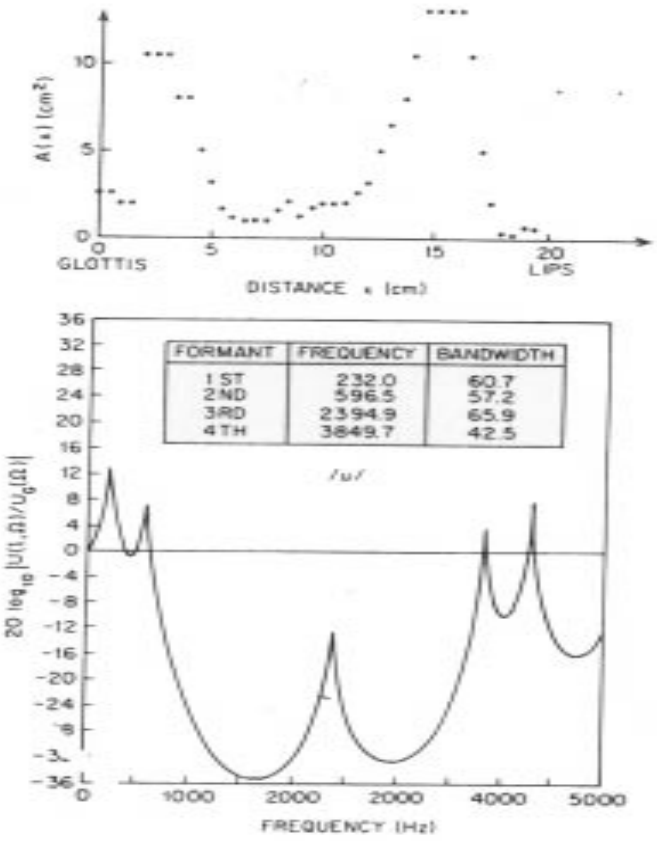


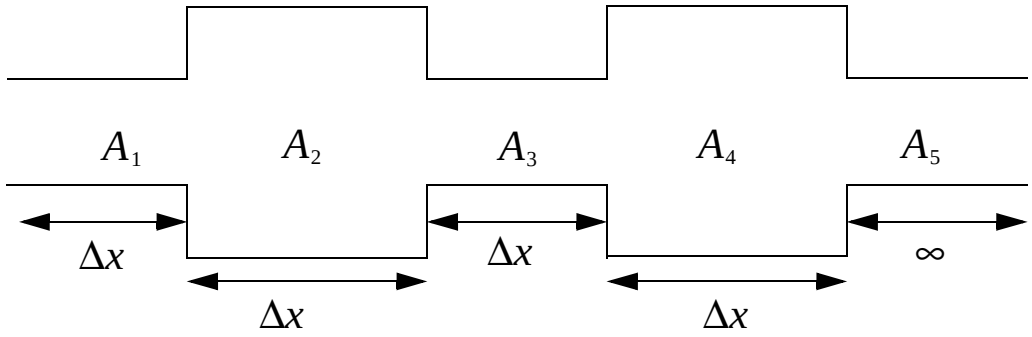

Figure 3.25 Area function and frequency response for the Russian vowel /*i*/


A(x) (cm²)
GLOTTIS
LIPS
DISTANCE x (cm)
FORMANT FREQUENCY BANDWIDTH
1 ST 650.3 94.1
2ND 1075.7 91.4
3RD 2463.1 107.4
4TH 3558.3 198.7
5TH 4631.3 89.8
/a/
20 log10 |U(1,Ω)/UG(Ω)|
FREQUENCY (Hz)

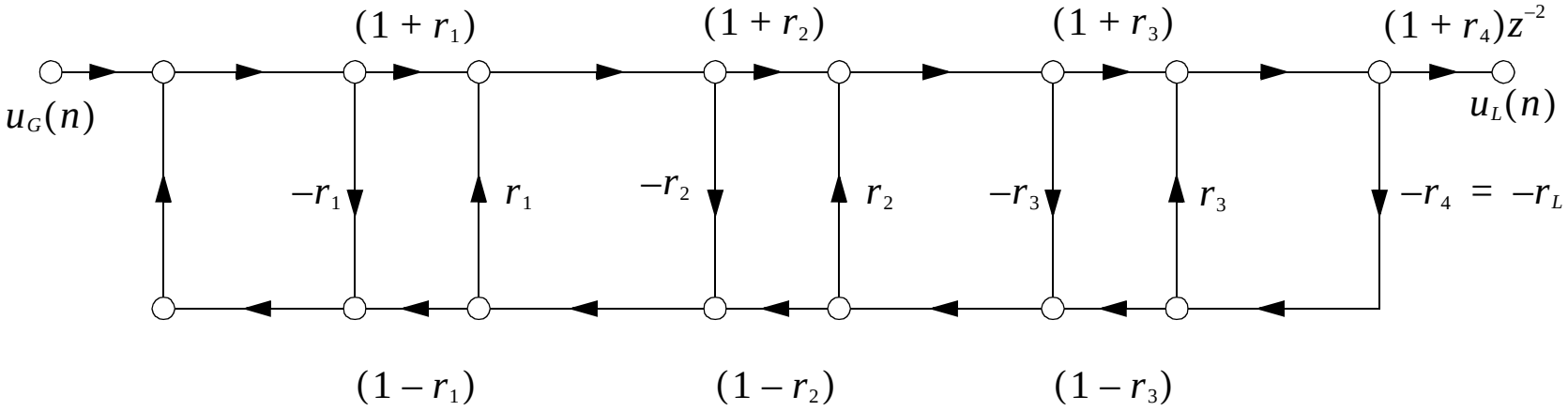

A(x) (cm²)
GLOTTIS
LIPS
DISTANCE x (cm)
FORMANT FREQUENCY BANDWIDTH
1 ST 232.0 60.7
2ND 596.5 57.2
3RD 2394.9 65.9
4TH 3849.7 42.5
/u/
20 log10 |U(1,Ω)/UG(Ω)|
FREQUENCY (Hz)

# More Complex Tube Structure

a)




b)



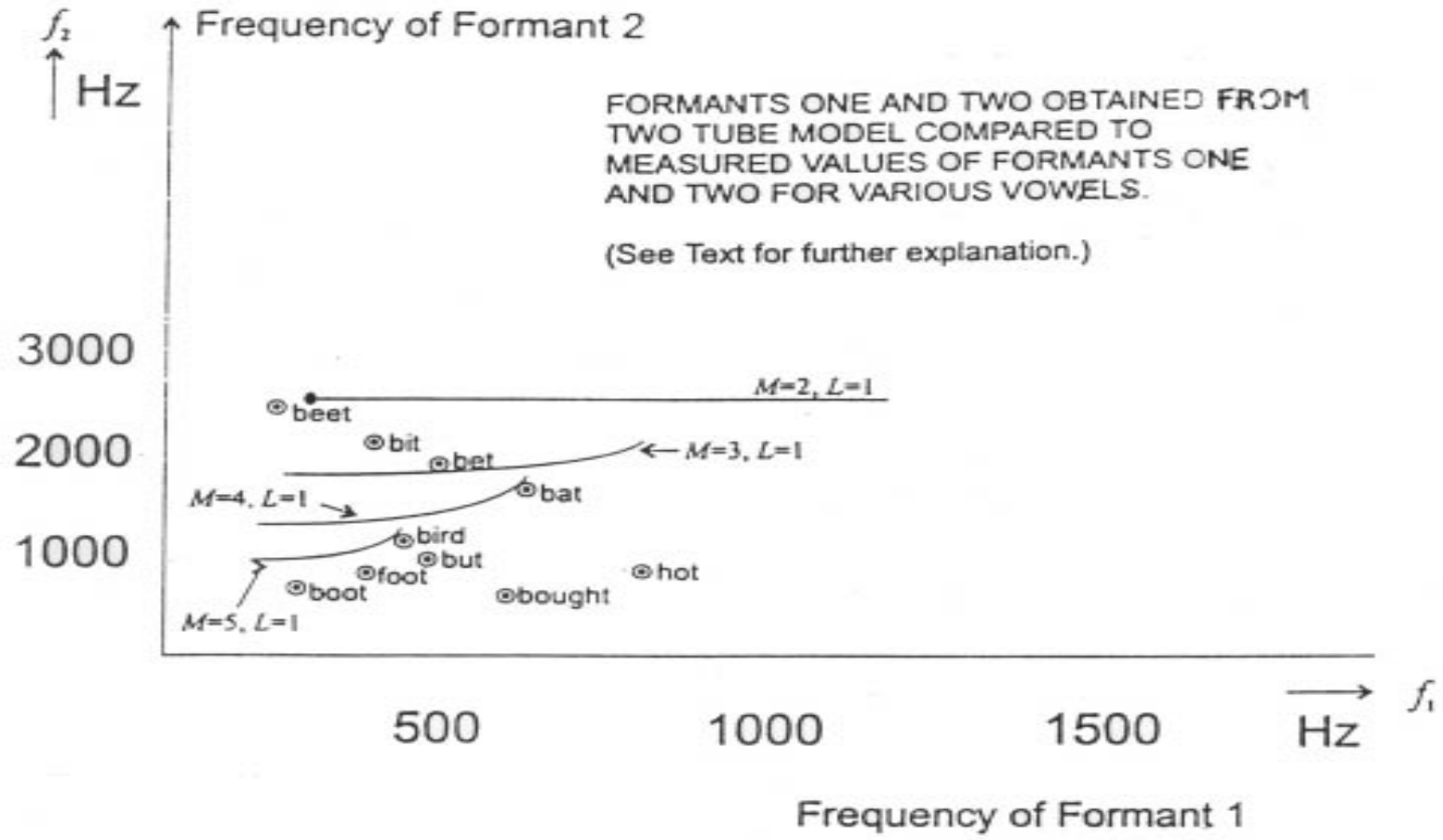



Figure 11.4 Formants 1 and 2 obtained from two tube model