

A STUDY OF SOME ENGLISH VOWELS
FROM THE VIEW POINT OF
ACOUSTIC-ARTICULATORY PHONETICS

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1. The human voice, especially the speech, is so complex and so attractive that many a linguists have discussed this matter in various ways. Here, in this short essay, I will treat the human voice as a physical phenomena and anylyze it to understand its formation and then, by tracing back the process of analysis, I will explain the way of producing vowel-like sounds in terms of electrophonetics. This device of vowel synthesizer will surely help us much to study the human voice. We can hardly stop the function of any of the speech organs with ease, but we can do it only with the help of this device. Natural sound, i.e. a voice produced by one is, as it were, always a completed sound. But, here, in this study, we need an incomplete sound. I will discuss only a few of English vowels here; consonants and successive speech are very complex and difficult to examine and produce without the help of physical devices.

2. That the light of the sun projected on the wall through a prism is divided into seven colors is known to every one. Just like this phenomena, we can divide or analyze sounds we utter into some frequency ranges. The instrument used for

this analysis is called a sound spectrograph, which produces spectrograms. As I don't have a sound spectrograph at hand, I cannot but make use of ready-made data.

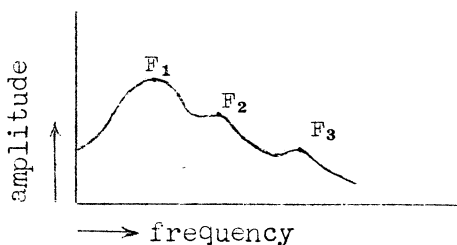
3. The figure below shows the relationship between frequency and amplitude of a certain vowel sound. In this figure, we can mark three peaks.

we call these points

Formants.

Formant frequency values

depend on the shape of



the vocal tract. When the soft palate is raised, shutting off the nasal cavities, the vocal tract is a tube about seven inches long from the glottis to the lips. For such a tube (with a uniform cross-sectional area along its whole length), the principal resonances are at 500 cps (cycles per second), 1500 cps, 2500 cps, 3500 cps and 4500 cps. In general, the cross-sectional area of the vocal tract varies considerably along its length. As a result, its formant frequencies will not be as regularly spaced as the resonant frequencies of a uniform tube; some of them will be higher in frequency and others lower. The lowest formant frequency is called the first formant; the one with the next highest frequency, the second formant, and so forth.

4. The following is a tabulation of the Average Formant Frequency Values. (a report from the Bell Telephone Laboratories)

The vowel sounds given in this tabulation were pronounced in single syllable words like heat, hit, head, hat, father, etc. and were analyzed at the B.T.L.

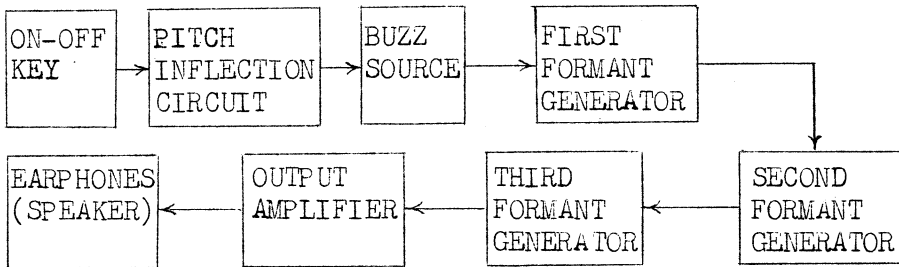
	/ee/	/i/	/e/	/ae/	/ah/	/aw/	/u/	/oo/	/A/	/er/
	1st Formant Frequency									
M:	270	390	530	660	730	570	440	300	640	490
F:	310	430	610	860	850	590	470	370	760	500
	2nd Formant Frequency									
M:	2290	1990	1840	1720	1090	840	1020	870	1190	1350
F:	2790	2480	2330	2050	1220	920	1160	950	1400	1640
	3rd Formant Frequency									
M:	3010	2550	2480	2410	2440	2410	2240	2240	2390	1690
F:	3310	3070	2990	2850	2810	2710	2610	2670	2780	1960

#(M: Male, F: Female)

Take a good look at the graph. We can see that the first two formant frequencies are important cues for identifying vowel sounds. But for good recognition, listeners use more information than just the first two formants; for instance, the higher formants, the identity of the speaker as a male, female, child or adult, and even subtle cues about the regional accent of the speaker that listeners can derive from pitch inflection and timing. For example, listeners can correctly identify

the vowel sounds "ah" (as in father) said by a child, and "aw" (as in call) said by an adult, even though the two sounds have very similar first and second formants.

5. The following is the Block diagram of the three-formant vowel synthesizer.

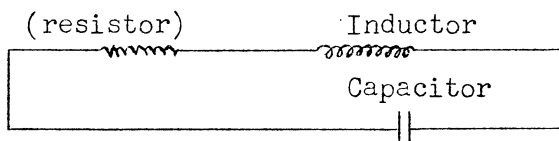


Buzz source gives the electrical vibration which is to simulate the air-vibration of the vocal cords. The pitch inflection circuit is to control the pitch of the sounds.

The most important thing is how to form the three formants by electronic circuit. The formants of the natural sounds are formed by the shape of the vocal tract as I have already stated in 3. Electric waves can, just like the sound waves in the vocal tract, be resonated with the help of a Capacitor and an Inductor. Just as a given spring-mass combination has a particular natural (or resonant) frequency determined by the size of its spring and mass, so the resonant frequency of an electrical inductance-capacitance (i.e. L-C) circuit is determined by the values of its inductor and capacitor. The natural frequency of electrical resonator is given by the equation

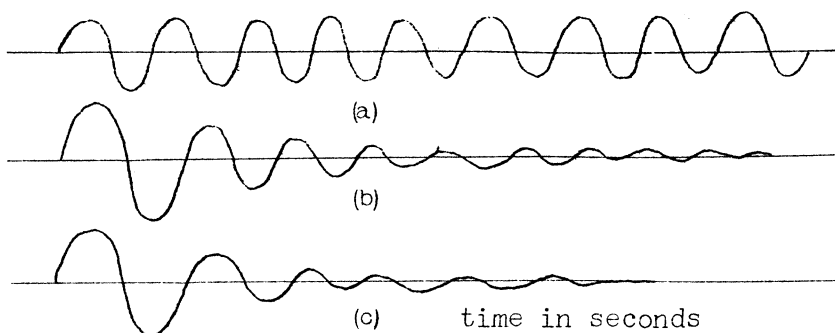
$$f = \frac{1}{2\pi\sqrt{LC}} \dots\dots(A) \quad \text{or} \quad C = \frac{1}{4\pi^2 Lf^2} \dots\dots(B)$$

where L and C are inductance (in henries) and capacitance (in farads), respectively.



An electrical resonator

A little resistance in a resonator is unavoidable. Because inductors and capacitors can store energy temporarily, but a resistor always dissipates it—converts it into heat. This, of course, has a damping effect on the circuit, and its oscillations decrease in amplitude. Like mechanical vibrations, practical L-C circuits always have some damping. Compare the wave shapes below.



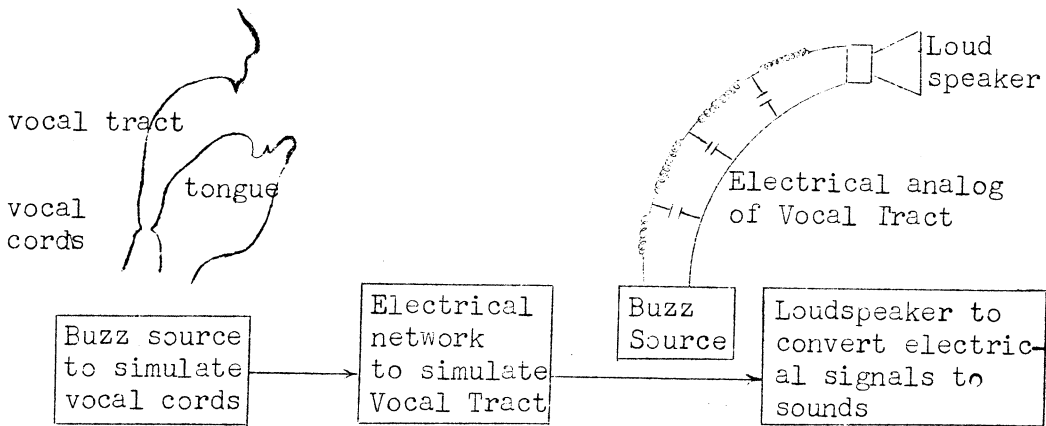
Displacements of the vibrating mass with and without damping: (a) no damping; (b) lightly damped; (c) more heavily damped.

6. ELECTRICAL, MECHANICAL AND ACOUSTIC ANALOGS

We have touched on the similarities between electrical and mechanical resonators. We should emphasize that this similarity is not merely a superficial resemblance, but a parallel in the basic laws that govern these different phenomena---a similarity that is apparent in the mathematical equations used to describe such systems. For example, the equations for describing the behavior of a capacitor are identical to those for describing the behavior of a spring; the equations that describe the response of an electrical resonator are identical to those that describe the response of a spring-mass system. The only difference is in the names of the variables. And the similarity does not stop with resonators. Indeed, the actions of a very large class of mechanical and acoustic systems can be duplicated by acoustic and mechanical systems. These duplicates or scale models are called analogs.

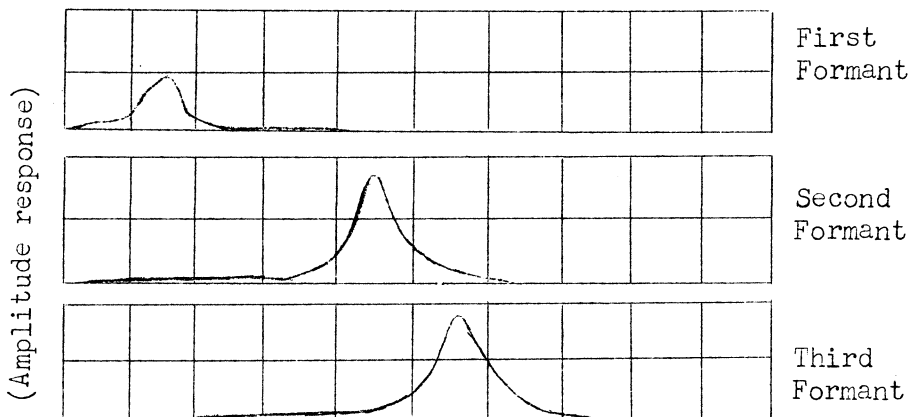
(1) VOCAL TRACT ANALOGS

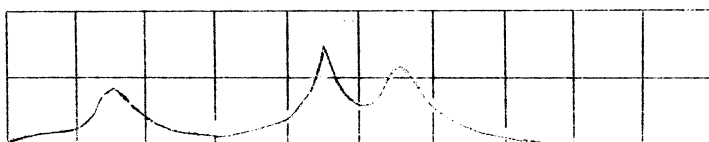
We can build an electrical analog of the vocal tract. Since the current-voltage behavior of an inductor is analogous to the inertia or mass behavior of air, and since the behavior of a capacitor is similar to the spring-like behavior of air, it is possible to build an electrical, artificial vocal tract. For example, we might use the array of capacitors and inductors shown in the figure below. (Also see the diagram shown in 5.)



(2) FORMANT RESONATOR ANALOG

One way of producing the spectral peaks needed to simulate the formants of natural speech is to use simple electrical resonators. This type of terminal analog is called a formant resonator analog. That is, one can use a simple resonance curve for each formant of the vocal tract and get the tract's complete response at any frequency by multiplying the values of the individual formant resonance curves at the same frequency. This principle is illustrated below.





Composite
Curve

(Frequency in cycles per second)

A composite resonance curve built up from three simple resonances. The value of the composite curve for any frequency is found by multiplying the values of the three simple curves.

7. As to the result of this vowel synthesizer and further research, I will report before long. I have just built up this device and am examining the vowel-like sounds produced by it. In the following research I will examine the structures of sounds to describe them in a certain way, and, if possible, I will advance to the study of speech analysis.

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