INTRODUCTION TO ACOUSTIC PHONETICS 1

Hilary Term, week 5
15 February 2006

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1. What is acoustic phonetics and why should linguists study it?

1) Physical acoustic signal is the primary means through which messages are being transmitted from the speaker to the listener. We communicate using *sounds* - not movements of the tongue or other articulators.

2) Analysis of acoustic signal can provide insight into both the physiological phenomena underlying the production of speech and the perceptual mechanisms by which speech is perceived by listeners.

3) Meaningful differences between words are encoded as sound differences. Some natural classes (e.g. labials and velars; retroflex) make sense only in acoustic terms. Some aspects of speech (e.g. friction) can only be properly defined in acoustic terms.

4) Acoustic analyses have a wide range of applications, e.g. speech synthesis, automatic speech recognition, speaker identification, communication aids, clinical speech pathology and rehabilitation programmes, etc.

2. What is sound?

Sound is ***variation in air pressure detectable by the human ear***. It is a ***wave*** characterised by the transmission of energy in the form of compression (increased pressure) and rarefaction (decreased pressure) through the medium, a travelling pressure fluctuation.

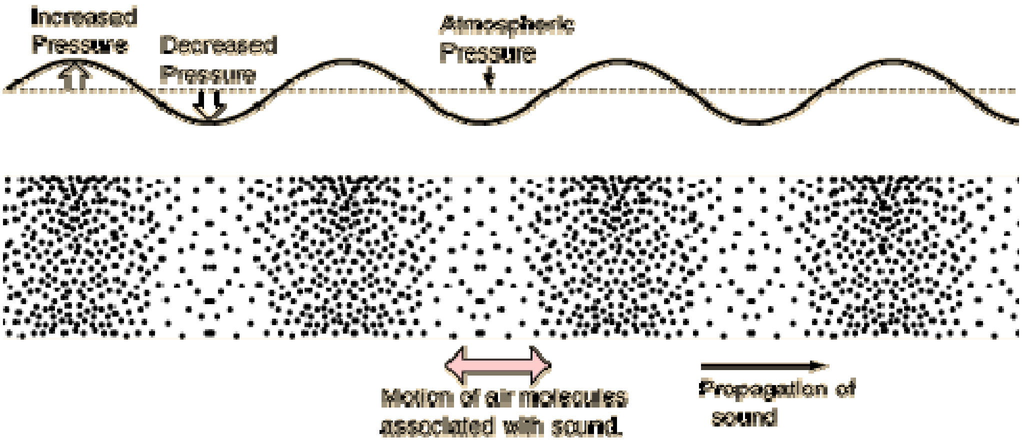

Fig. 1. Sound wave as variation in air pressure.

3. What type of a wave is a sound wave?

3.1. Mechanical waves vs. electromagnetic waves

Sound waves are *mechanical waves*, i.e. they rely on the movement of particles that make up the medium (air, water, etc) for their propagation. Unlike electromagnetic waves that constitute their own medium (e.g., photons in the case of light), sound waves depend on external physical media. If there is no medium of transmission, there will be no sound.

3.2. Transverse waves vs. longitudinal waves

All mechanical waves are further identified by the relationship between the motion of the disturbance and the motion of the particles of the medium.

Transverse waves are waves in which the direction of particle movement is at the right angle to the direction of the wave propagation (e.g. waves on the surface of water).

Longitudinal waves are waves in which particles moves back and forth along the line of the travelling wave. All sound waves are longitudinal waves.

4. What are basic properties of sound waves?

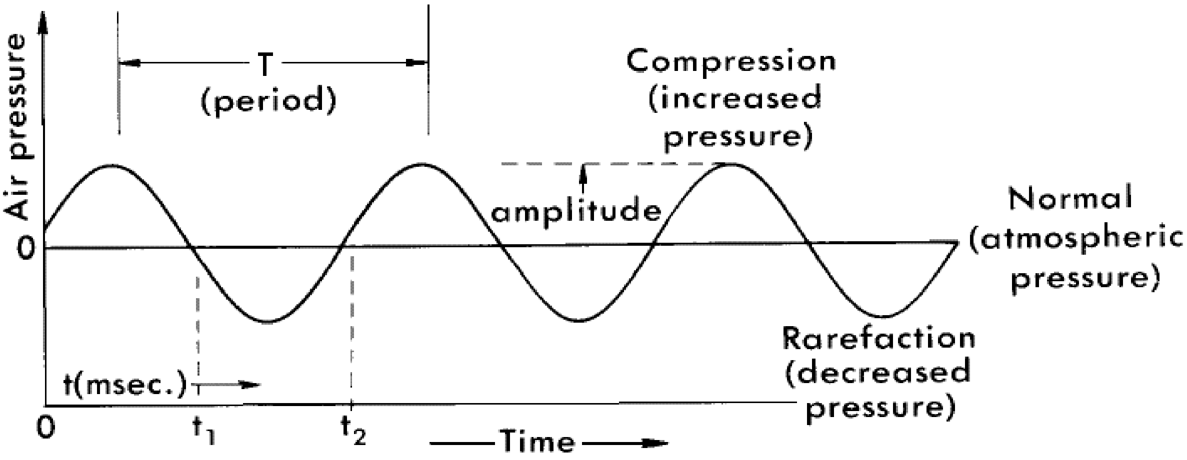

Fig. 2. Sinusoidal sound waveform and its properties

Period (T) is the amount of time needed to complete one cycle of movement. It is measured in seconds (s) and its fractions (millisecond, nanosecond, etc.).

Frequency (f) is the number of cycles completed in one second. It is measured in cycles per second, a unit of measurement known as *Hertz* (Hz). Human ear can pick up frequencies in the range between 20 and 20,000 Hz. The perceptual correlate of frequency is **pitch**.

Relation between frequency and period is

$f = 1/T$ e.g. a wave with a period of 1/100th of a second has a frequency of 1/0.01=100Hz

Amplitude (A) is the maximum displacement from the equilibrium position. In the case of sound waves, it is the extent of the maximum variation in air pressure from normal atmospheric pressure. Amplitude is related to **loudness**, when amplitude decreases the sound becomes less loud.

NB Frequency and amplitude are not connected. Two waves can have the same frequency but different amplitude and vice versa (see Fig. 3 and 4).

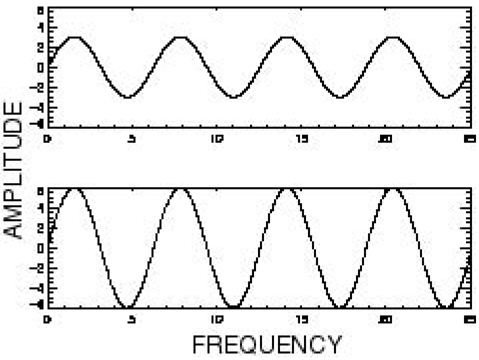

Fig. 3 Two waves of the same frequency but different amplitude

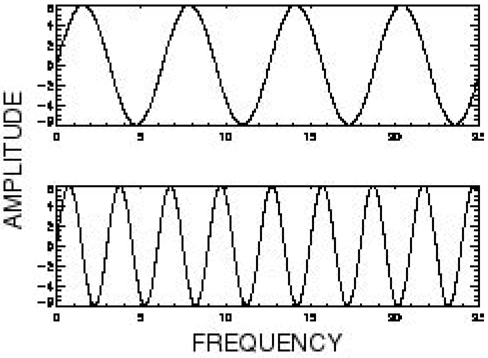

Fig. 4 Two waves of the same amplitude but different frequency

Standard **speed of sound** is ≈330 m/s, it is the velocity of the sound in the air (anything moving above this velocity is supersonic.). If the sound is transmitted through solids, liquids or gases other than air the speed of sound will vary depending on that medium.

Wavelength (λ) of a sound is the distance in space between the successive points of maximum condensation or rarefaction. It is measured in metres and its fractions.

Relation between frequency (f), wavelength (λ) and speed of sound (c) is as follows:

$\lambda = c/f$ e.g. a wave with a frequency of 100 Hz has a wavelength of 330/100=3.3m

5. What types of waveforms can we encounter?

There are three basic properties or dimensions by which sound waveforms can be classified: complexity, periodicity and duration.

5.1. Simple (sinusoidal) vs. complex waves

Simple waves are also called *sinusoidal/sine waves*; they result from *simple harmonic motion* (SHM) and are made up of a single frequency component. SHM is a regular motion, in which each cycle of the movement takes exactly the same time, e.g. vibration of a tuning fork. SHM can be represented as a uniform circular motion projected on a plane (hence the terms cycle, sine wave).

Addition of sine waves of the same frequency produces another sine wave of greater amplitude (imagine listening to the sound produced by two tuning forks of the same frequency – it will sound louder than just one fork).

Addition of sine waves of different frequencies results in a *complex wave*, therefore any complex wave always have more than one frequency component. It is possible to construct an infinite variety of complex waves by combining sine waves of difference amplitudes and frequencies (Fig. 5).

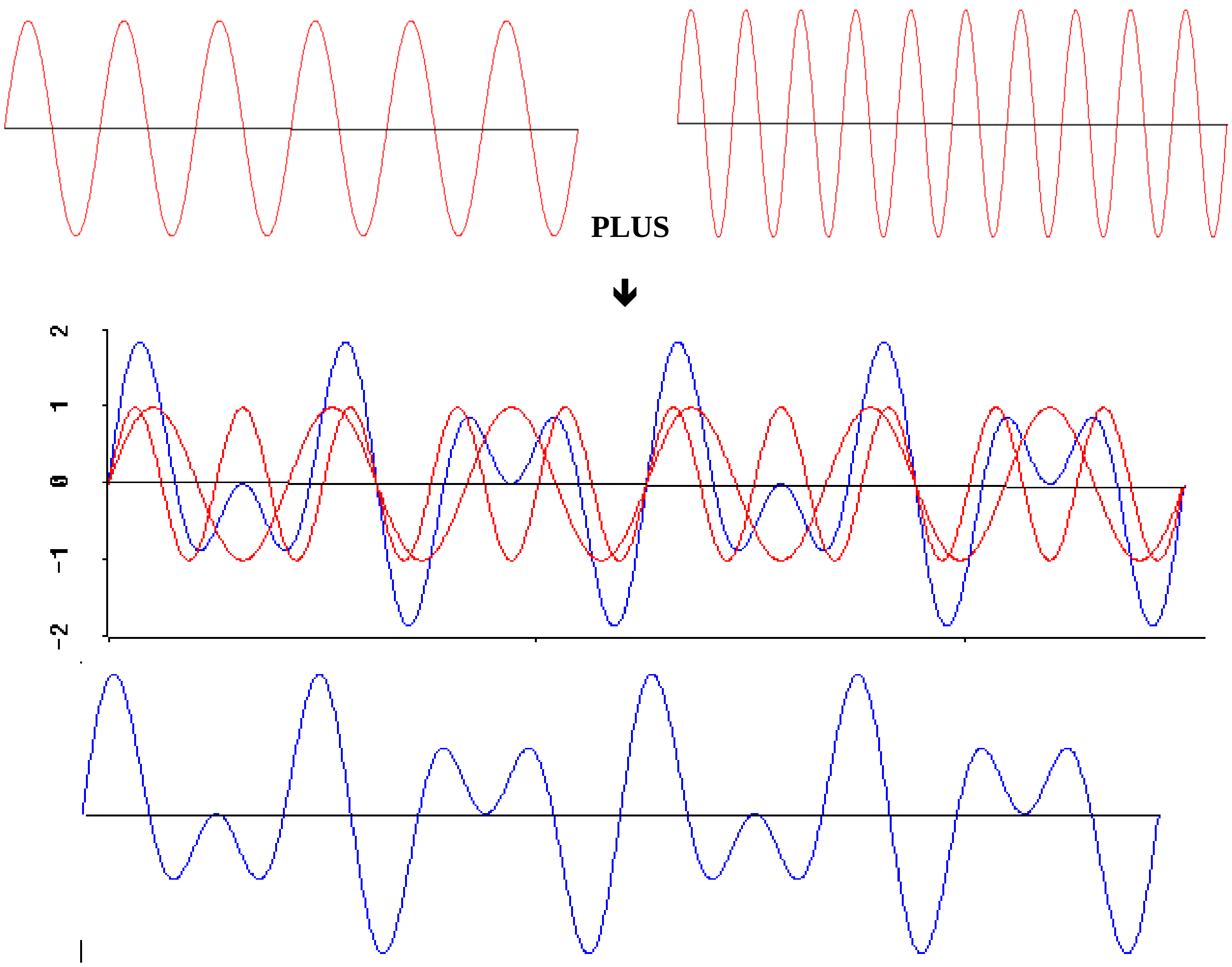

Fig. 6. Complex wave resulting from addition of two sine waves: 300 Hz (top left) and 500 Hz (top right)

All complex waves can be regarded as a sum of a (possibly infinite) number of sine waves (Fourier's theorem). *Fourier analysis* is a mathematical technique for decomposing a complex wave into its component sine waves. Result is the **spectrum** of sound. The horizontal axis of a spectrum corresponds to frequency and the vertical axis corresponds to amplitude of the individual components in the complex wave. Fig. 6 and 7 show spectra of a sine wave and a complex wave respectively.

Fourier's technique is very powerful. Sine waves are easy to deal with mathematically and the representation of complex functions as sine waves often makes analysis much less difficult.

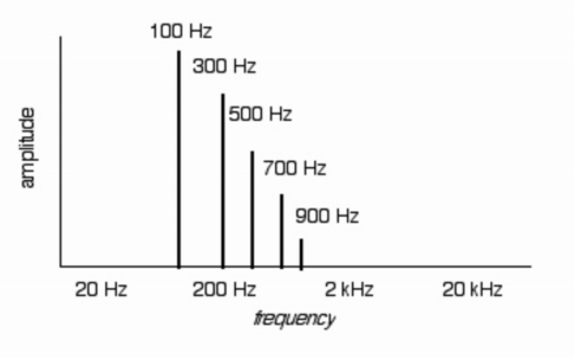

Fig. 6. Power spectrum of a sine wave

Fig. 7. Power spectrum of a complex wave

6.2. Periodic vs. aperiodic waves

Periodic waves have a pattern that repeats itself at regular intervals. Additionally, there are *quasi-periodic* waves that may be not quite regular or not wholly repeating. Vowel sounds are examples of quasi-periodic sound waves.

The frequency components of sine waves that make up a complex periodic wave are called **harmonics**. The lowest harmonic is **fundamental frequency** (f_0). All higher harmonics – also called **overtones** or **partials** – are integer multiples of the fundamental frequency (Fig. 8).

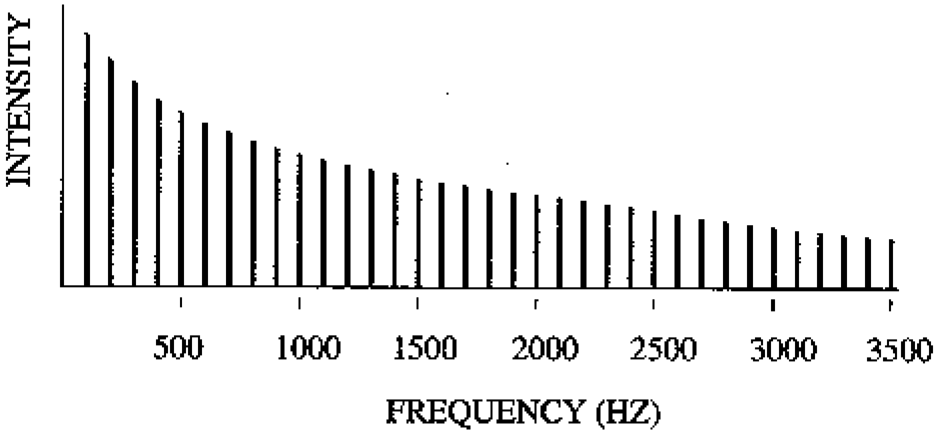

Fig. 8. Line spectrum of a complex periodic wave, showing regular relationship between fundamental frequency and higher harmonics

Aperiodic waves do not have a regular repeating pattern and are perceived as noises. They do not have a harmonic basis, i.e. the component frequencies, of which they are made up, are not related to each other (component frequencies are not integer multiples of fundamental frequency).

6.3. Continuous vs. transient waves

Aperiodic waves are further divided into two groups. The first compromises *continuous* waveforms that have random patterns. White noise is an ideal example of aperiodic noise characterised by absolutely random pressure fluctuations, other examples – hissing, flow of water, whisper.

Although continuous aperiodic waves do not have harmonic structure it is still possible to perform Fourier analysis on them. Aperiodic sounds are better represented by continuous rather than line spectra (Fig. 9).

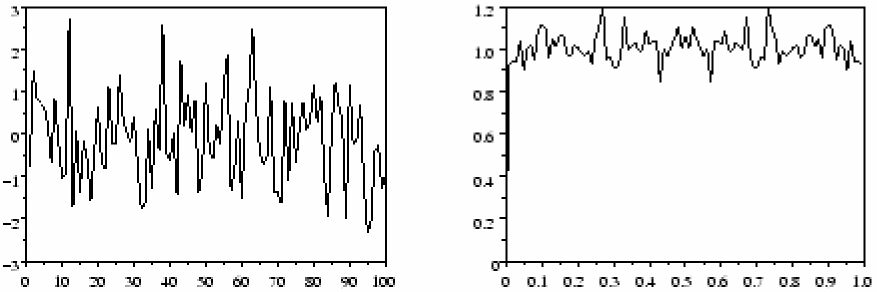

Fig. 9. A part of a waveform (left) and spectrum (right) of white noise

Transient sounds are characterized by a sudden pressure fluctuation that is not sustained or repeated over time. Examples of transient noises include hammer hitting the table, the slamming of a door, the popping of a balloon. Transient sounds can also be analysed into the spectral components using Fourier analysis. In ideal (theoretical) case the spectrum of a transient sound contains an infinite range of frequencies at approximately equal amplitude for an infinitely brief period of time.

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