LING 576 Acoustic Phonetics
Spring 2009
Rod Casali
Topic number 4: Acoustic Categorization and Analysis of Sounds
1-20-09

Reading:
Borden, Gloria J., Katherine S. Harris & Lawrence J. Raphael. 1994. Speech science primer: Physiology, acoustics, and perception of speech. Baltimore: Williams & Wilkins. Read pp. 32-35.
Denes, P.B. & Pinson, E.N. 1993. The speech chain. 2nd edition. New York: W.H. Freeman. Read pp. 30-37.

1. Waveforms

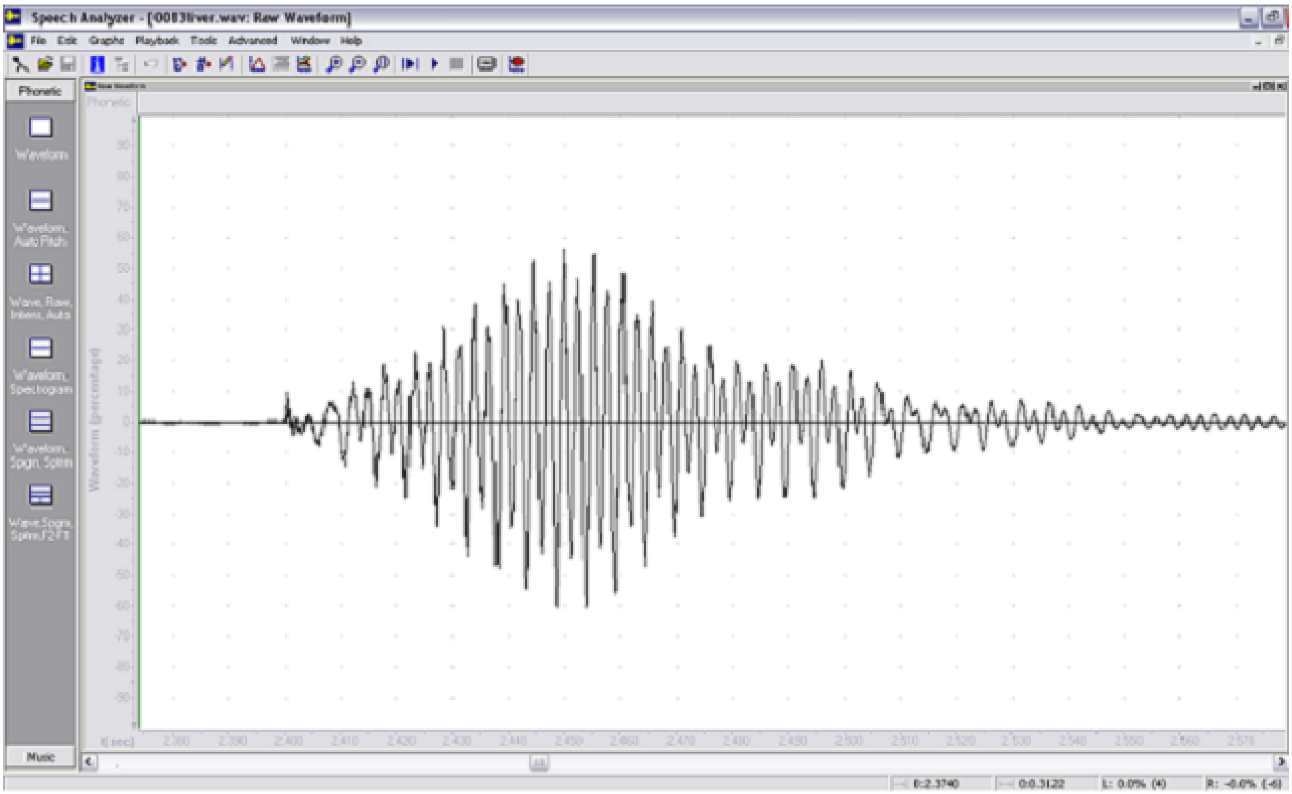
One of the most common and useful types of acoustic graphs is the *waveform* display.

A waveform is a two-dimensional display that shows fluctuations in pressure over time.

Typically, time is plotted on the horizontal axis and pressure amplitude on the vertical axis.

Some examples:

- Waveform of the vowel [e] from the Tafi word [ki-te] 'liver' as pronounced by an adult male speaker



- A music example from Ladefoged (1996:25)

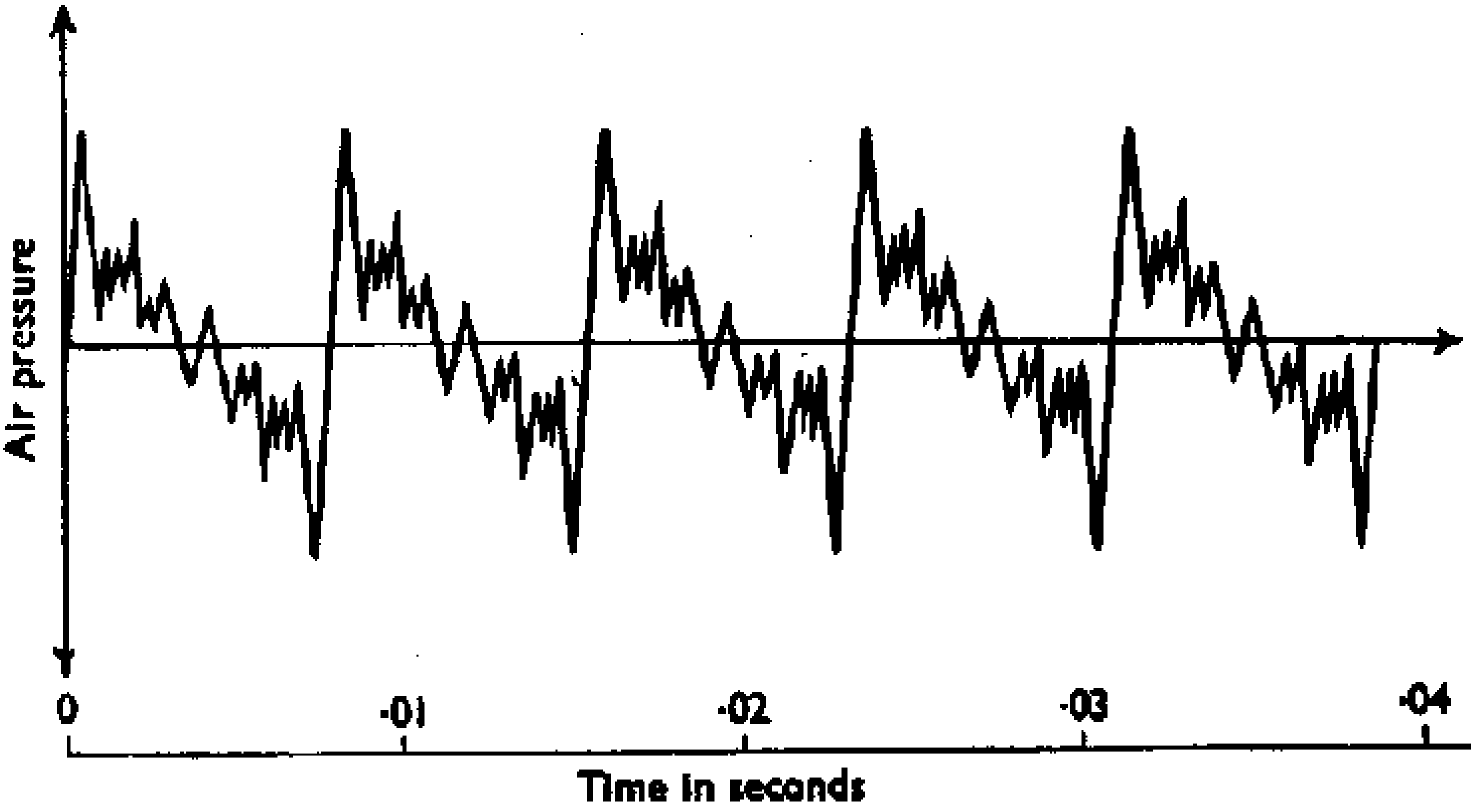


Fig. 3.1. The waveform of the C below middle C on a piano.

2. Periodic and aperiodic sounds

All sounds that occur in nature can be classified as either *periodic* or *aperiodic*.

- Periodic sounds have show a *regular pattern* of amplitude variation that *repeats* at some consistent time interval.

The length of time it takes for the pattern to repeat (= one cycle) is the waveform's *period.*

The number of times the basic pattern repeats per second is the waveform's *fundamental frequency*.

The fundamental frequency is often symbolized F_0. It is equal to the inverse of the period (1/T, where T is the period).

Example: What are the period and fundamental frequency of the [e] waveform shown above? (This is more easily measured using the original wave file in Speech Analyzer.)

- Aperiodic sounds do not have an identifiable variation pattern that repeats at regular intervals.

3. Aperiodic sounds

Aperiodic sounds can be either *transient* or sustained.

- A transient sound is one that lasts for a short interval, with a rapidly decaying amplitude.

Non-speech examples:

Speech examples:

- A sustained or non-transient aperiodic sound is one that persists with relatively constant average amplitude over some interval of time.

Non-speech examples:

Speech examples:

4. Periodic sounds

The simplest form of a periodic sound wave is a *sine* or *sinusoidal* wave.

Such a wave has a maximally simple pattern with only one frequency of vibration, the fundamental frequency.

An example (from Ladefoged 1996:12):

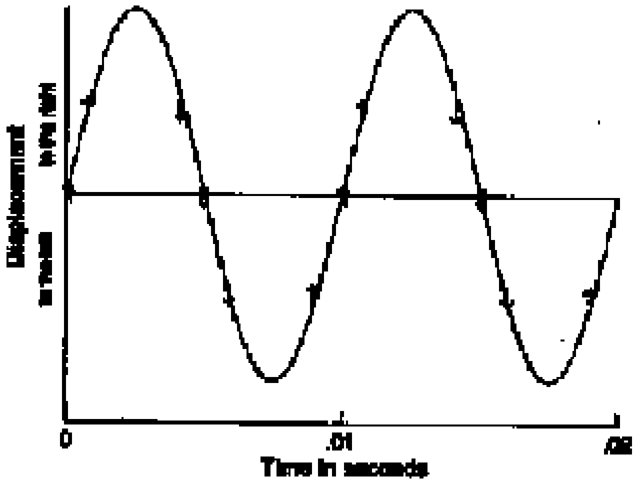


Fig. 1.6. The movement of an air particle during the sounding of a tuning fork.

Very few real sound sources produce sinusoidal waves. One that does is a tuning fork.

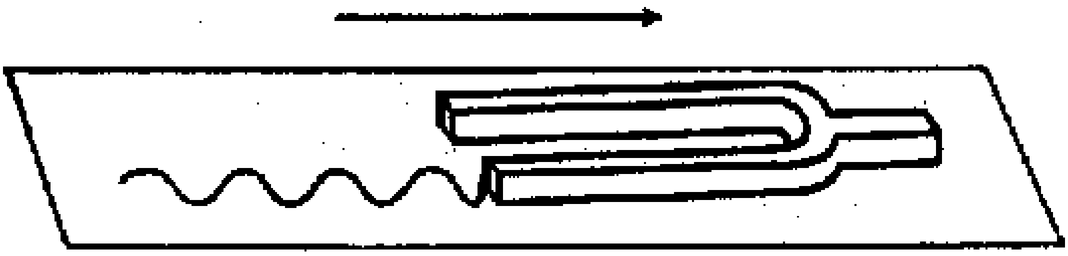


Fig. 1.5. A tuning fork being moved over a sheet of paper showing the vibrations of one of the prongs (much exaggerated).

-- From Ladefoged (1996:11)

Most real periodic sound sources produce waves that are more complex than simple sound waves, because they have more than one frequency of vibration.

Most real objects can vibrate at more than one frequency.

String example (Ladefoged 1996:26)

Fig. 3.2. Solid line: one position of a vibrating string. Dashed line: another position, giving an impression of vibration of parts of the string. Taken as a whole, the string may be said to vibrate in many ways at the same time.

Where a periodic sound wave contains multiple frequencies, the *lowest* frequency is called the fundamental frequency (F_0).

Real periodic sound sources generally have vibration patterns at the fundamental frequency and at higher frequencies that are *integral multiples* of the fundamental frequency.

Example: A sound source with an F0 of 100 Hz has additional frequency components (harmonics) at 200 Hz, 300 Hz, 400 Hz, and so on. In this case the 200 Hz component is called the *second harmonic*, the 300 Hz component the *third harmonic*, etc.

Note: In the terminology we will use in this class, the "first harmonic" is the same as the fundamental frequency.

This kind of sound wave pattern, with vibrations at a fundamental frequency and harmonic frequencies that are integral multiples of the fundamental, is typical of musical instruments.

It is also typical of sound waves produced by regular vibration of the human vocal folds.

5. Modes of vibration of a string

Possible modes of vibration of a string fixed at both ends (Fry 1979:45):

Modes of vibration

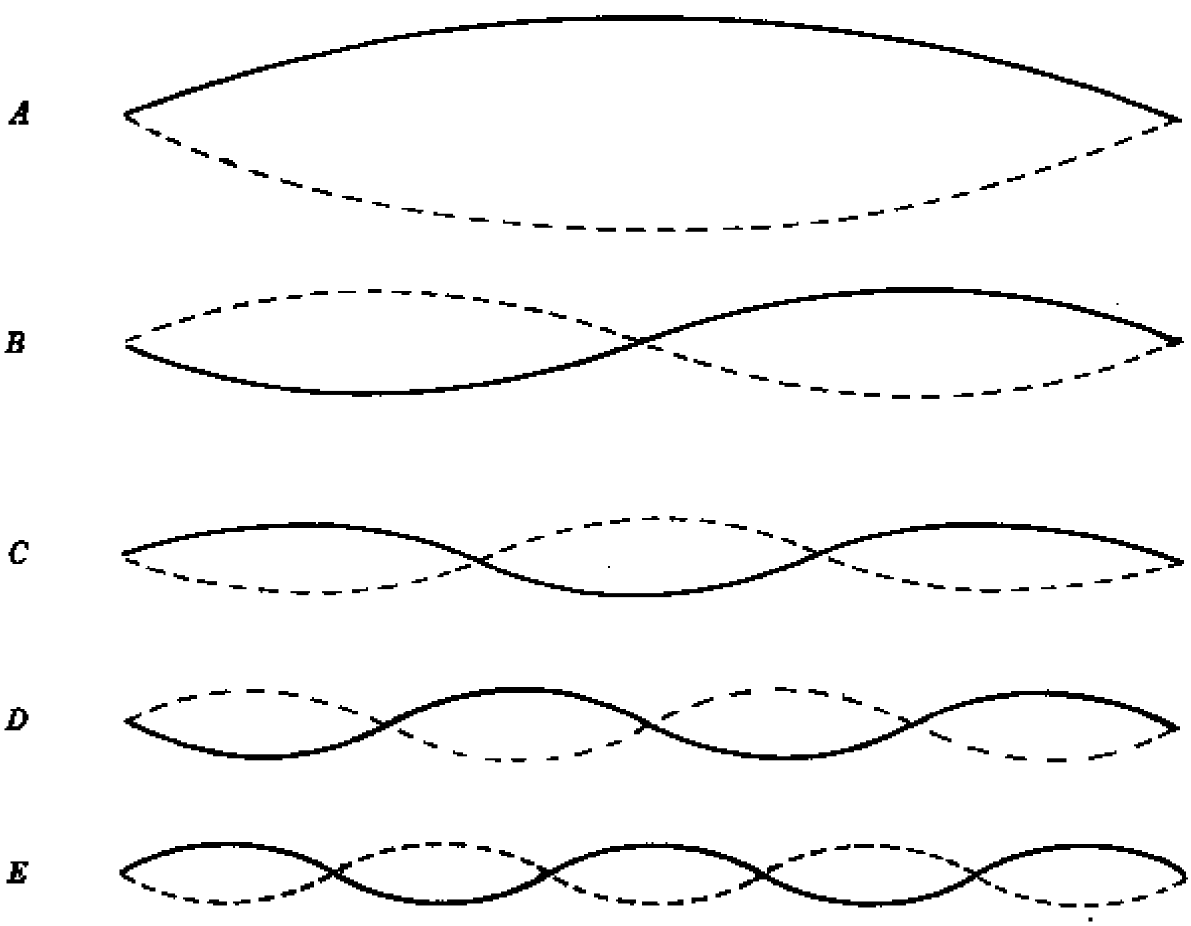


Fig. 21. Different modes of vibration in a string.

Note in this diagram that for each mode of vibration there are some points that remain fixed throughout the vibration cycle. These points at which no vibration occurs are known as *nodes*.

In contrast, point at which maximum changes in amplitude occurs are called *antinodes.*

(For animated displays of modes of string vibration, see http://www.physicsclassroom.com/mmedia/waves/wavesTOC.html; look under "1st harmonic" through "5th harmonic.")

The net acoustic sound wave produced by a vibrating string is equivalent to the sum of the individual sound waves associated with the individual modes of vibration (harmonics).

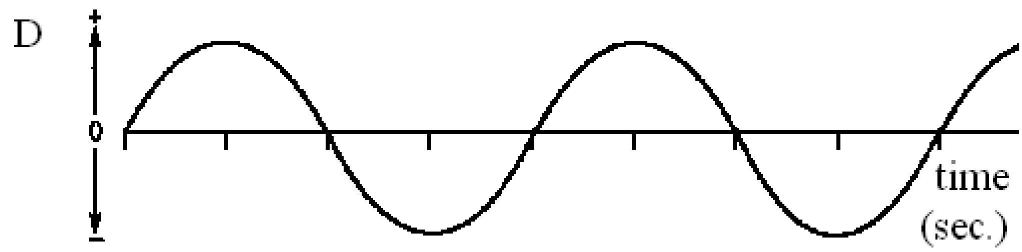
However, not all the harmonics will be of equal strength; some may be weak or absent.

It is also possible to force a string to vibrate in such a way that some harmonics are absent. (How?)

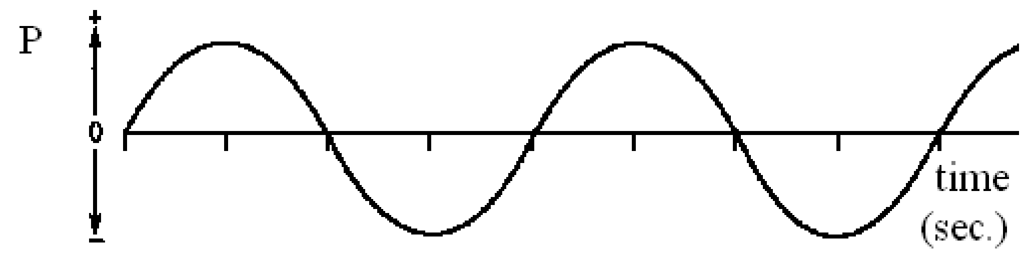
The vocal folds can also be made to vibrate in different ways, affecting the relative amplitudes of some of the harmonics. (Some of these differences are linguistically significant, e.g., the contrast between breathy and creaky voice.)

6. Acoustic waveforms for individual harmonics
Each individual mode of vibration (harmonic) of a string can be described by a sine wave.

The sine wave is a graph of the displacement (D) of a moving point on the string about the neutral position.



Because the motion pattern of the string is transferred to the surrounding air molecules, the same sine wave that describes the motion of the string also describes the air pressure (P) fluctuations resulting from the string's vibrations:



This kind of display is called an *acoustic waveform.*

We can plot the acoustic waveform corresponding to each harmonic precisely if know the frequency of vibration of the first harmonic (= fundamental frequency).

The fundamental frequency of the string depends on the length of the string, it's tension, and it's linear density (mass per unit length). (These same factors affect the fundamental frequency of vocal fold vibration.)

See the in-class exercise *Modes of vibration of a string, harmonics, spectra*.

7. Wave addition
Sound waves can be added together by summing the amplitudes of the individual waves at every point.

An example (from Denes & Pinson 1993:33):

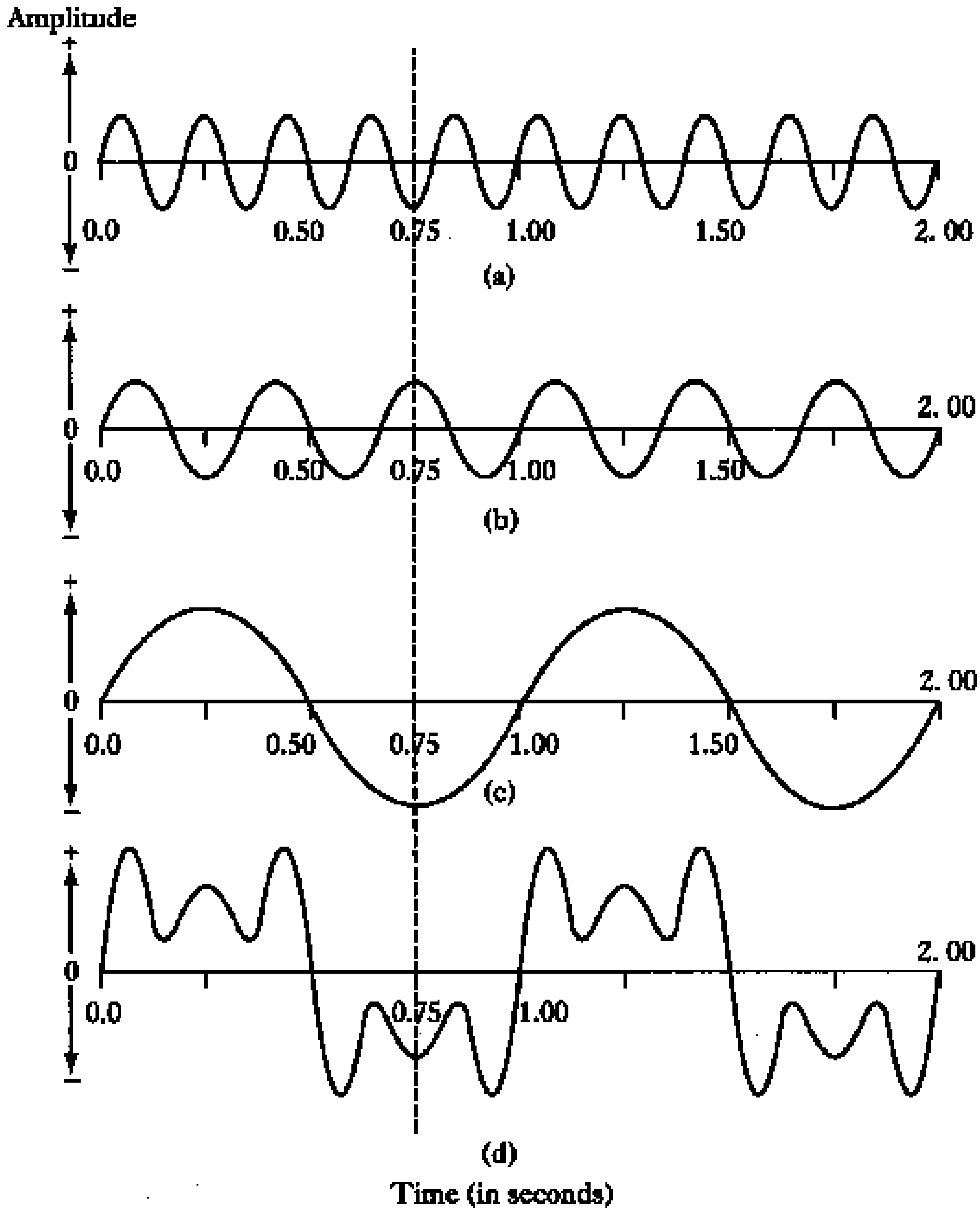


FIGURE 3.12 Building up a complex wave: (a), (b) and (c) are sinusoidal components of different frequencies. Portion (a) has five times and portion (b) three times the frequency of portion (c). The vertical dashed line shows the same instant of time in (a) through (d) and indicates how the components in (a) through (c) combine to give the complex waveform in (d).

For all relevant purposes, a complex wave behaves exactly as the sum of its individual component waves.

This is very important for acoustic speech analysis, which proceeds in practice by analyzing a complex sound wave into simpler component parts.

8. Spectral analysis of waves

Any complex periodic sound wave produced by a single source can be analyzed as equivalent to the sum of a series of individual sine waves that:

- Have frequencies that are integral multiples of the fundamental frequency.

That is, each of these individual component waves is a harmonic.

- Have different amplitudes (which may, in some cases, be zero).

The perceived quality of the overall sound wave depends only on the frequencies and amplitudes of the component waves (harmonics).

These component frequencies and amplitudes comprise the *spectrum* of a sound.

Sound spectra are commonly represented in displays like the ones shown below (from Fry 1979:59).

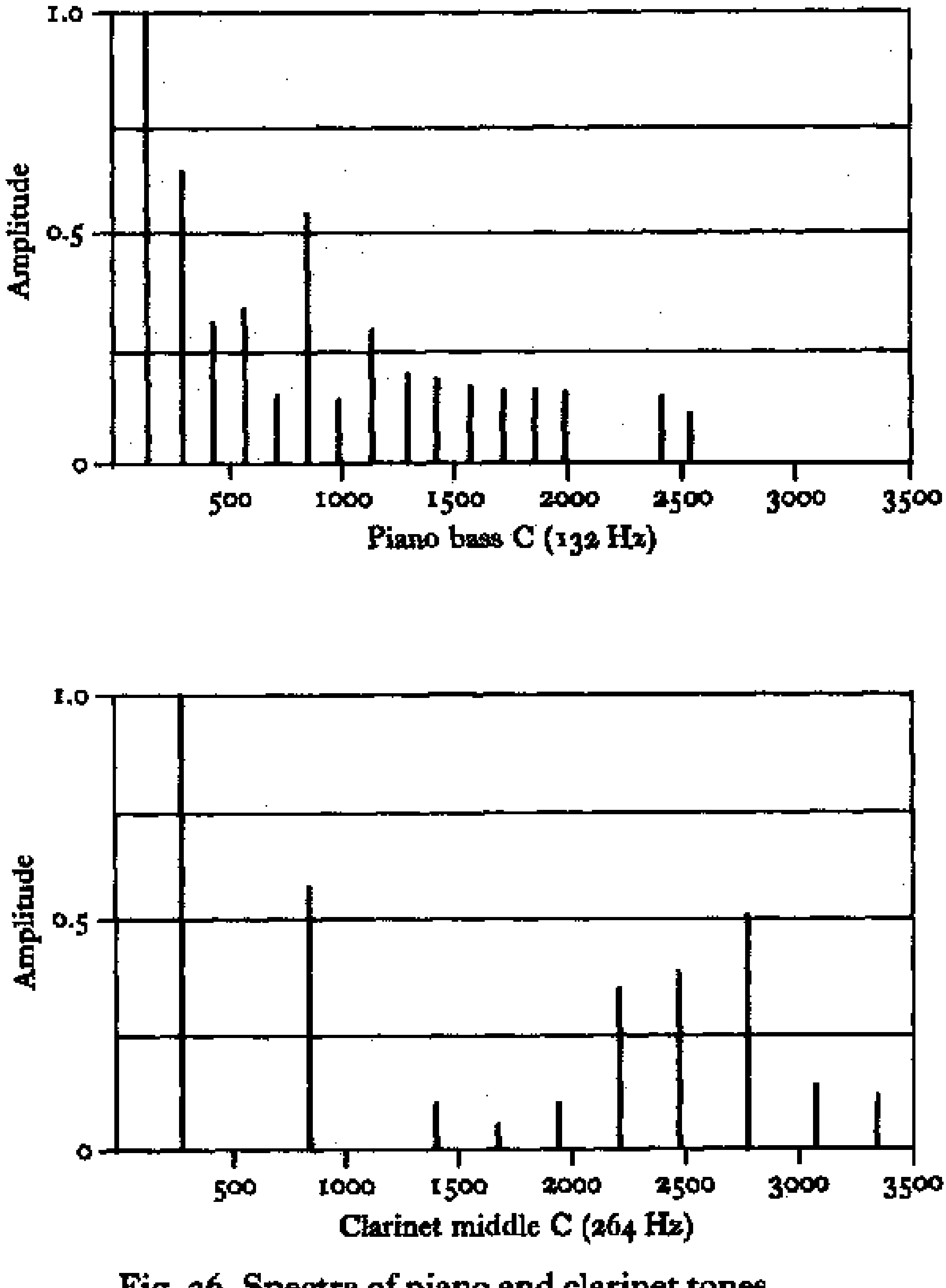


Fig. 26. Spectra of piano and clarinet tones.

Note that in both diagrams some harmonics have zero amplitude. (Which ones?)

The mathematical techniques for discovering the harmonic components (spectrum) of a complex wave were developed by the French mathematician J.B. Fourier in the 19th century.

References

Denes, P.B. & Pinson, E.N. 1993. The speech chain. 2nd edition. New York: W.H. Freeman.

Fry, D.B. 1979. The physics of speech. Cambridge: Cambridge University Press.

Ladefoged, Peter. 1996. Elements of Acoustic Phonetics. Chicago: University of Chicago Press. Second Edition.