Методы и средства Цифровой Обработки Сигналов

Аудио системы

Круглов Евгений Владимирович, аспирант МИФИ
Решетов Владимир Николаевич, к.ф.-м. н. доцент МИФИ.

Москва 2008

Как мы слышим

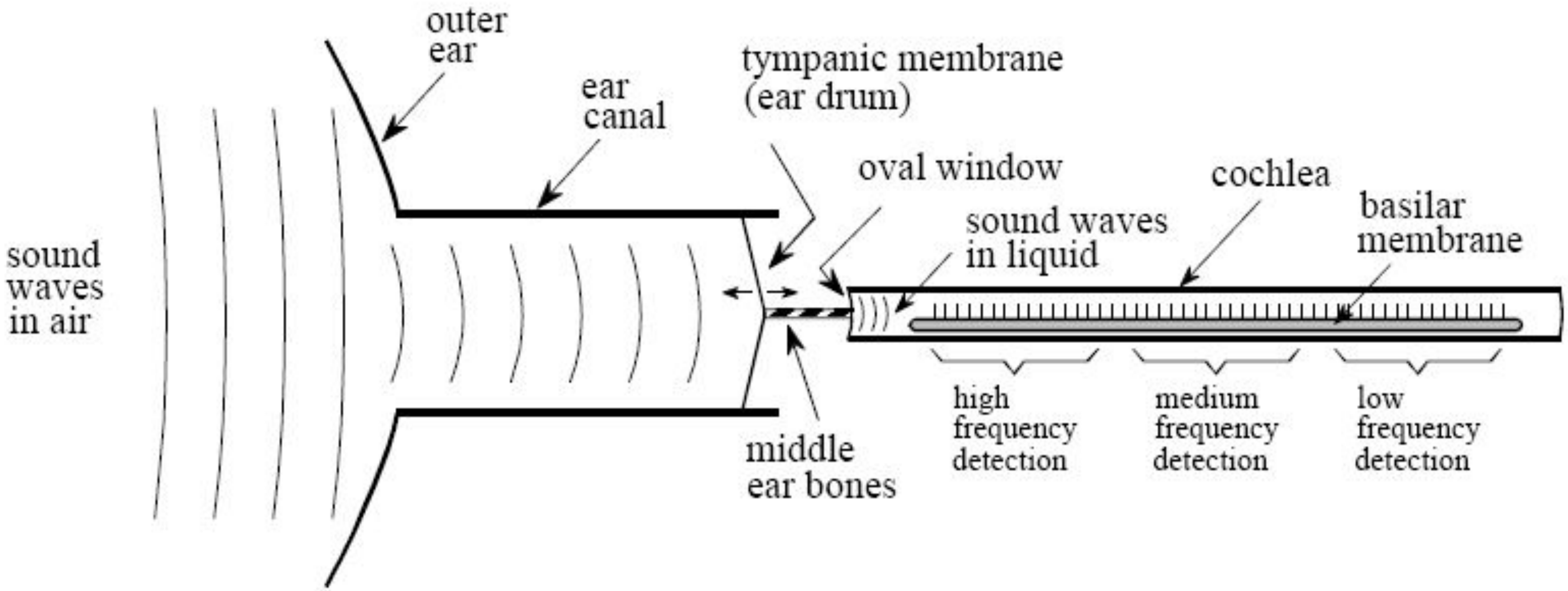


FIGURE 22-1
Functional diagram of the human ear. The outer ear collects sound waves from the environment and channels them to the tympanic membrane (ear drum), a thin sheet of tissue that vibrates in synchronization with the air waveform. The middle ear bones (hammer, anvil and stirrup) transmit these vibrations to the oval window, a flexible membrane in the fluid filled cochlea. Contained within the cochlea is the basilar membrane, the supporting structure for about 12,000 nerve cells that form the cochlear nerve. Due to the varying stiffness of the basilar membrane, each nerve cell only responses to a narrow range of audio frequencies, making the ear a frequency spectrum analyzer.

Уровни звукового давления

$$\text{dB} = 10 \log_{10} \frac{P_2}{P_1}$$

$$\text{dB} = 20 \log_{10} \frac{A_2}{A_1}$$

TABLE 22-1
Units of sound intensity. Sound intensity is expressed as power per unit area (such as watts/cm^2), or more commonly on a logarithmic scale called *decibels SPL*. As this table shows, human hearing is the most sensitive between 1 kHz and 4 kHz.

60dB	=	1000
40dB	=	100
20dB	=	10
0dB	=	1
-20dB	=	0.1
-40dB	=	0.01
-60dB	=	0.001

↑ Louder — Softer ↓

Watts/cm^2	Decibels SPL	Example sound
10^{-2}	140 dB	Pain
10^{-3}	130 dB	
10^{-4}	120 dB	Discomfort
10^{-5}	110 dB	Jack hammers and rock concerts
10^{-6}	100 dB	
10^{-7}	90 dB	OSHA limit for industrial noise
10^{-8}	80 dB	
10^{-9}	70 dB	
10^{-10}	60 dB	Normal conversation
10^{-11}	50 dB	
10^{-12}	40 dB	Weakest audible at 100 hertz
10^{-13}	30 dB	
10^{-14}	20 dB	Weakest audible at 10kHz
10^{-15}	10 dB	
10^{-16}	0 dB	Weakest audible at 3 kHz
10^{-17}	-10 dB	
10^{-18}	-20 dB	

Сумма и разность синусоид

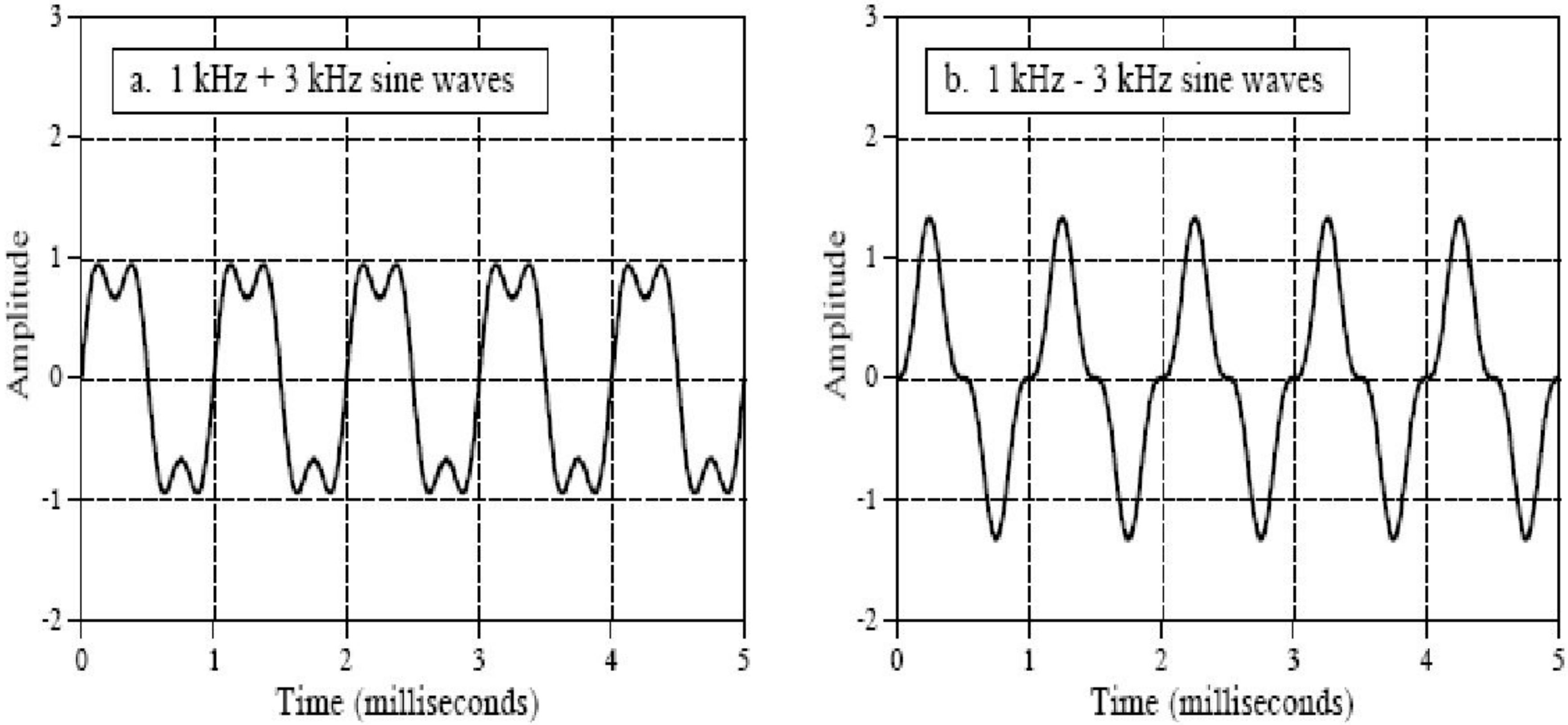


FIGURE 22-2
Phase detection of the human ear. The human ear is very insensitive to the relative phase of the component sinusoids. For example, these two waveforms would sound identical, because the *amplitudes* of their components are the same, even though their relative *phases* are different.

Скрипка

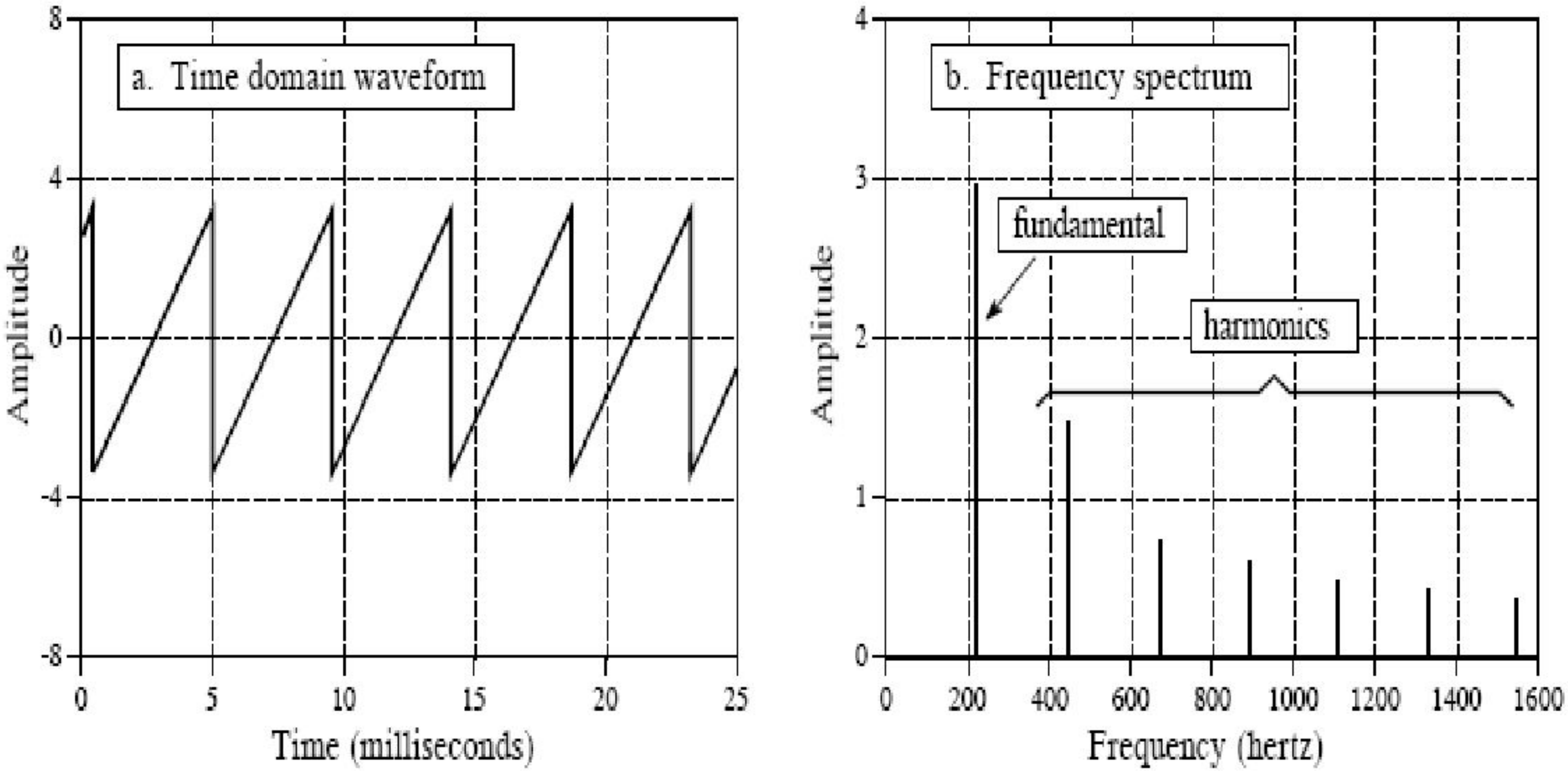


FIGURE 22-3
Violin waveform. A bowed violin produces a sawtooth waveform, as illustrated in (a). The sound *heard by the ear* is shown in (b), the fundamental frequency plus harmonics.

Музыкальные инструменты

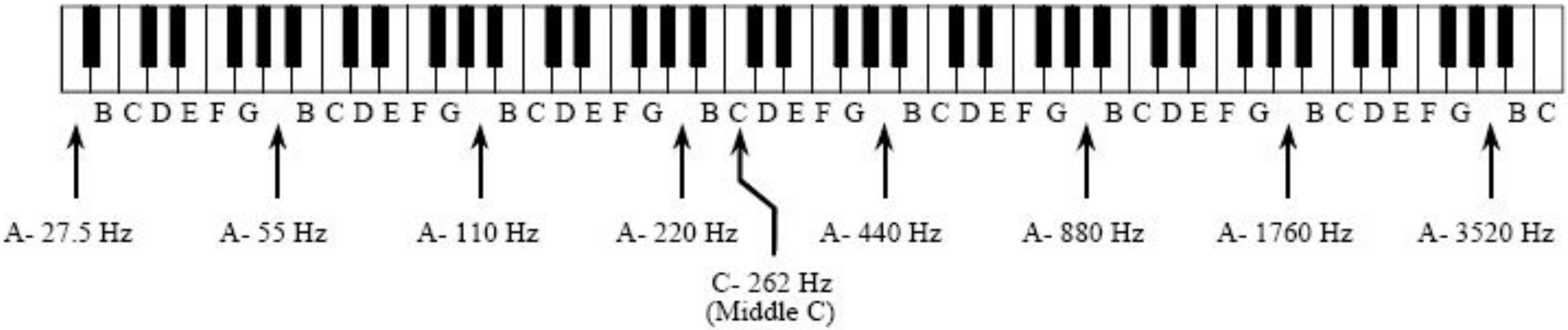


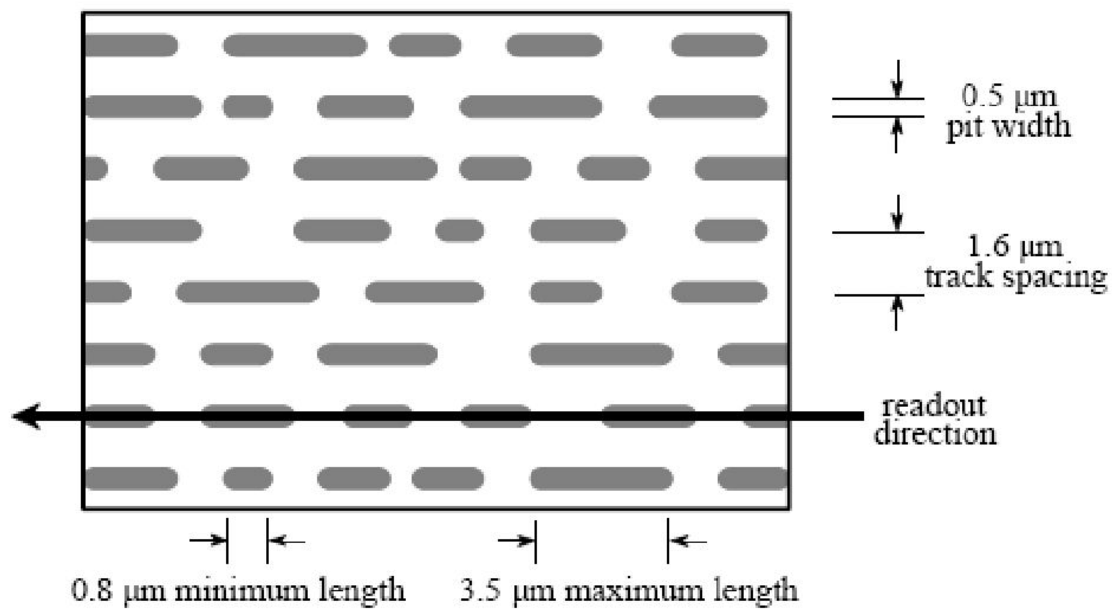
FIGURE 22-4
The Piano keyboard. The keyboard of the piano is a *logarithmic* frequency scale, with the fundamental frequency doubling after every seven white keys. These white keys are the notes: *A, B, C, D, E, F and G*.

Варианты оцифровки голоса

Sound Quality Required	Bandwidth	Sampling rate	Number of bits	Data rate (bits/sec)	Comments
High fidelity music (compact disc)	5 Hz to 20 kHz	44.1 kHz	16 bit	706k	Satisfies even the most picky audiophile. Better than human hearing.
Telephone quality speech	200 Hz to 3.2 kHz	8 kHz	12 bit	96k	Good speech quality, but very poor for music.
(with companding)	200 Hz to 3.2 kHz	8 kHz	8 bit	64k	Nonlinear ADC reduces the data rate by 50%. A very common technique.
Speech encoded by Linear Predictive Coding	200 Hz to 3.2 kHz	8 kHz	12 bit	4k	DSP speech compression technique. Very low data rates, poor voice quality.

Оптическая запись

FIGURE 22-5
Compact disc surface. Micron size pits are burned into the surface of the CD to represent ones and zeros. This results in a data density of 1 bit per μm^2, or one million bits per mm^2. The pit depth is 0.16 µm.



Блок схема проигрывателя

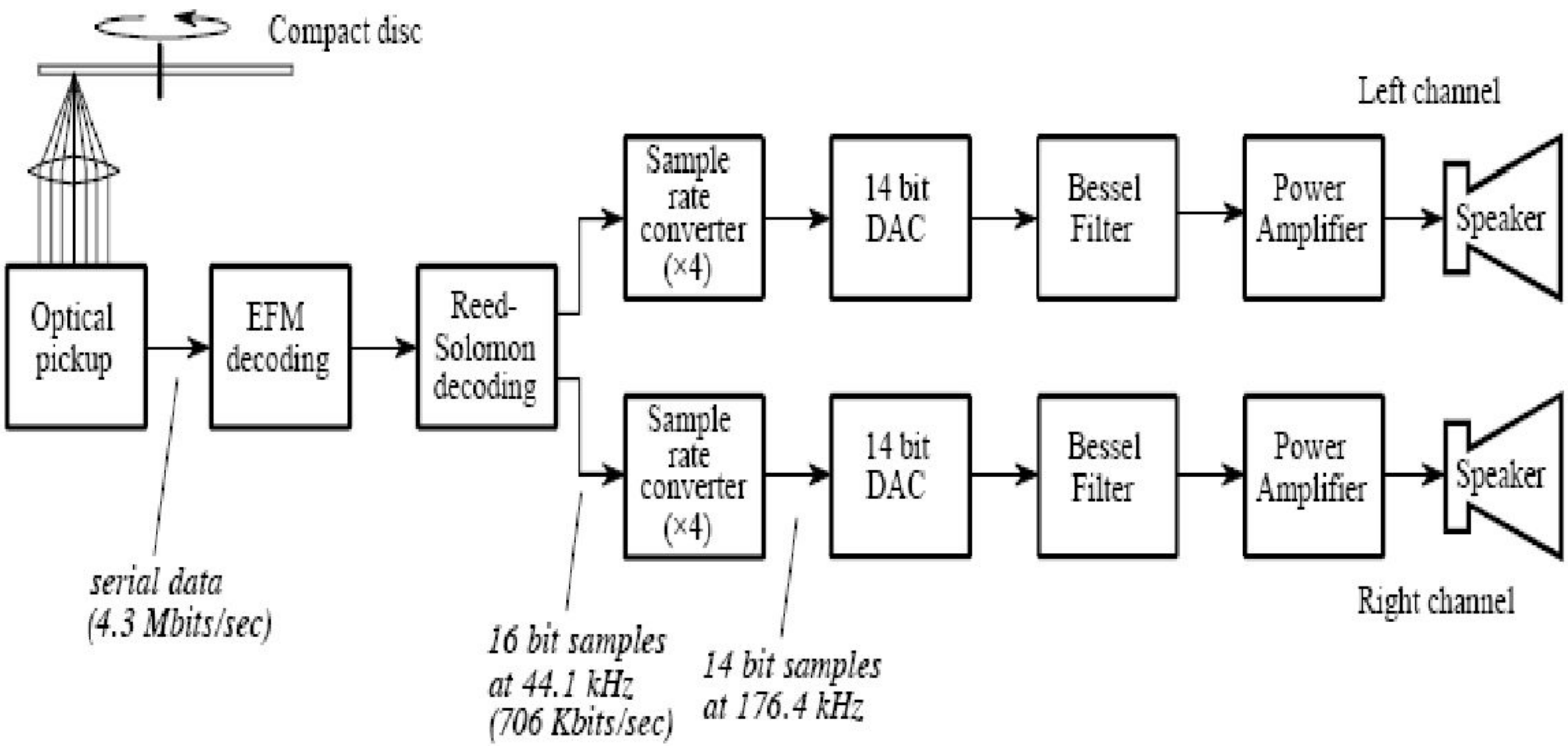


FIGURE 22-6
Compact disc playback block diagram. The digital information is retrieved from the disc with an optical sensor, corrected for EFM and Reed-Solomon encoding, and converted to stereo analog signals.

Так можно имитировать голос

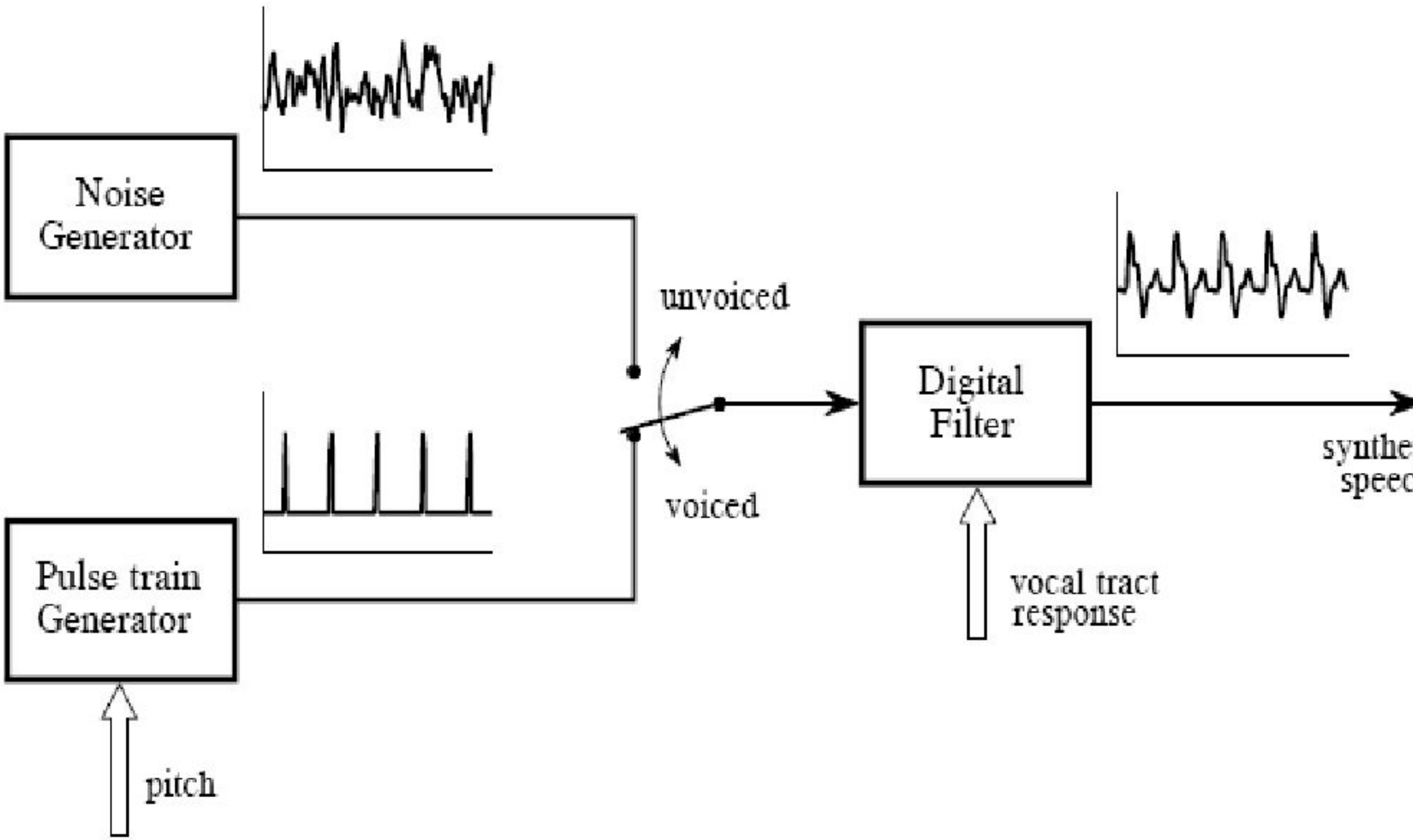


FIGURE 22-8
Human speech model. Over a short segment of time, about 2 to 40 milliseconds, speech can be modeled by three parameters: (1) the selection of either a periodic or a noise excitation, (2) the pitch of the periodic excitation, and (3) the coefficients of a recursive linear filter mimicking the vocal tract response.

Сонограмма

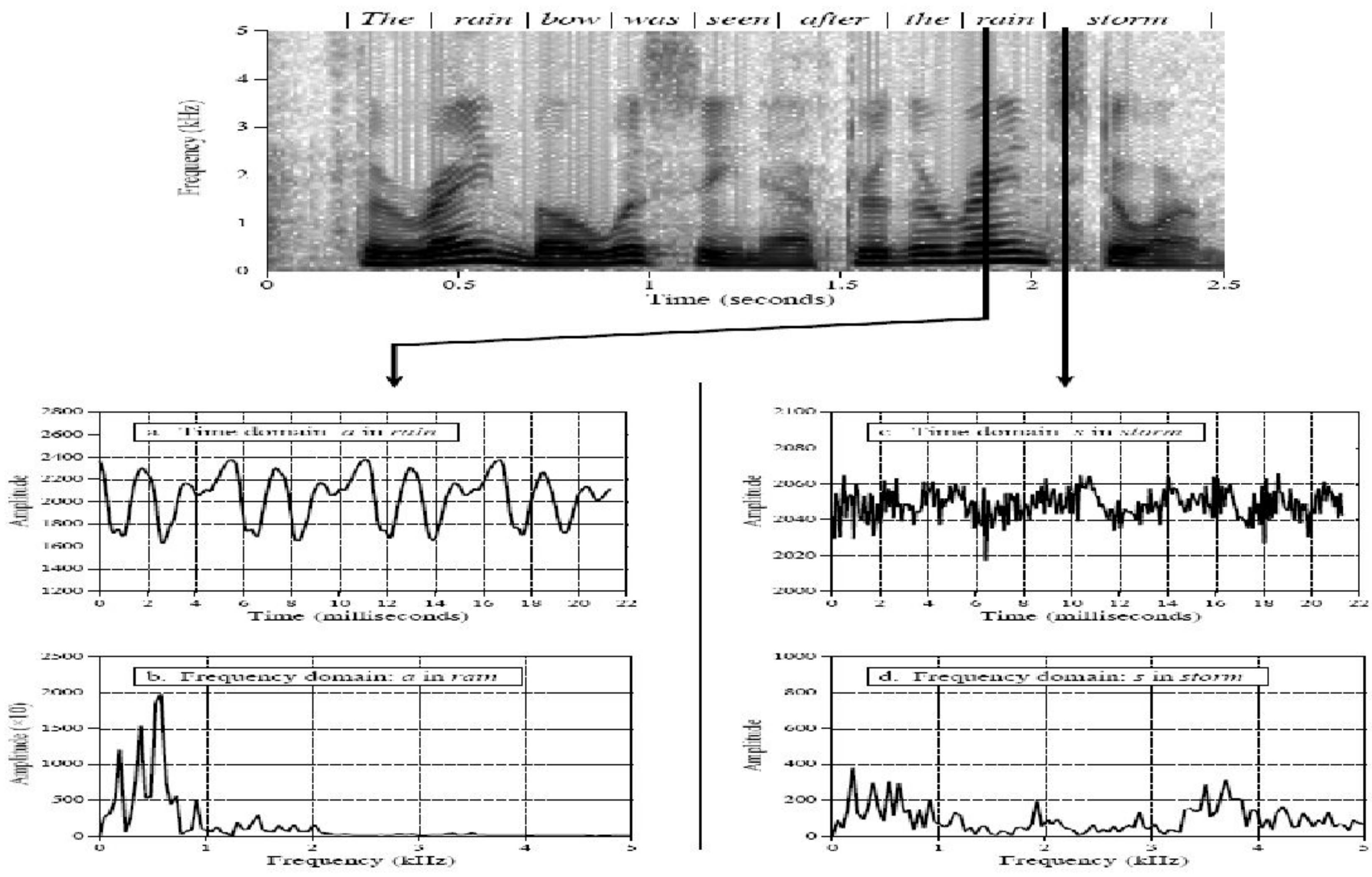


FIGURE 22-9
Voice spectrogram. The spectrogram of the phrase "*The rainbow was seen after the rain storm.*" Figures (a) and (b) shows the time and frequency signals for the voiced *a* in *rain*. Figures (c) and (d) show the time and frequency signals for the fricative *s* in *storm*.

Тон и его обертона

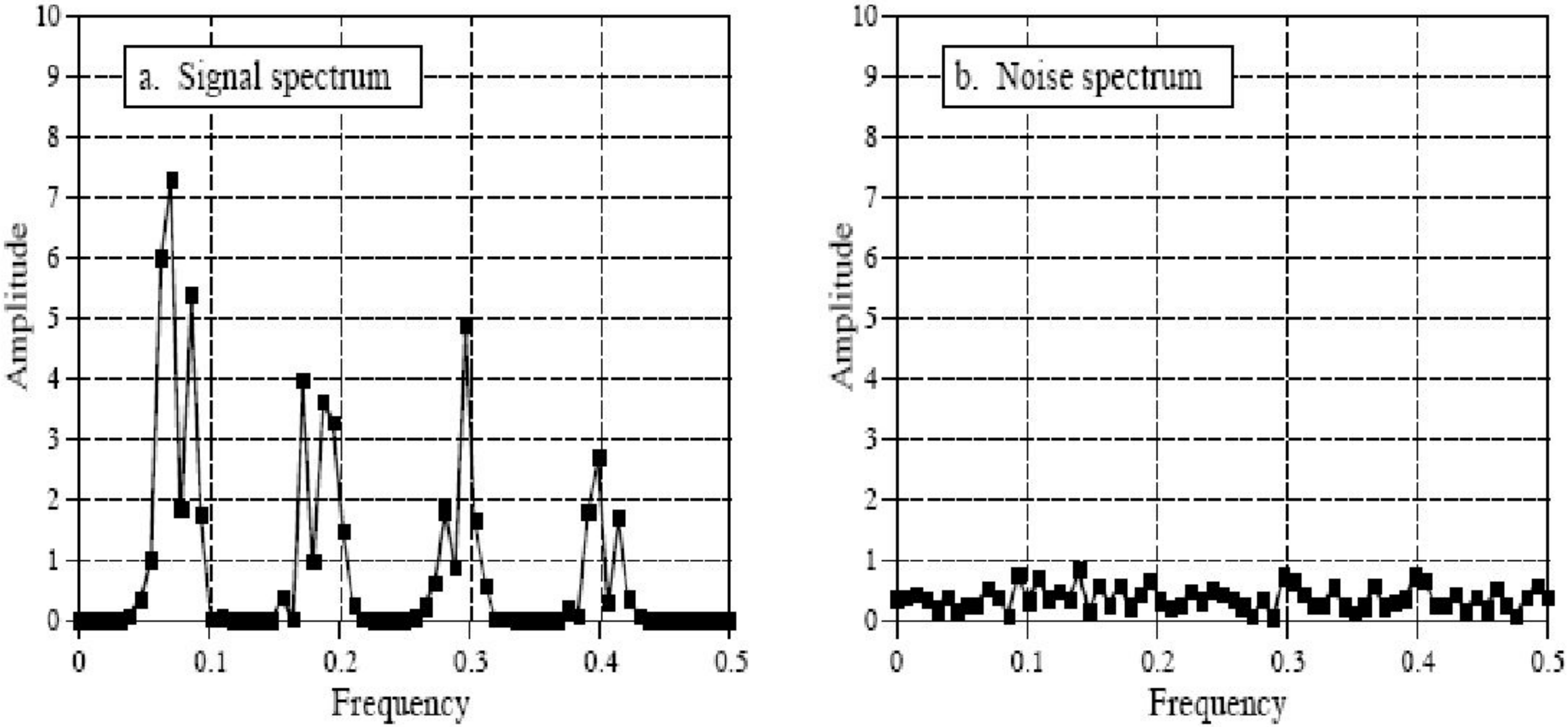


FIGURE 22-10
Spectra of speech and noise. While the frequency spectra of speech and noise generally overlap, there is some separation if the signal segment is made short enough. Figure (a) illustrates the spectrum of a 16 millisecond speech segment, showing that many frequencies carry little speech information, *in this particular segment*. Figure (b) illustrates the spectrum of a random noise source; all the components have a small amplitude. (These graphs are not of real signals, but illustrations to show the noise reduction technique).

Фраза

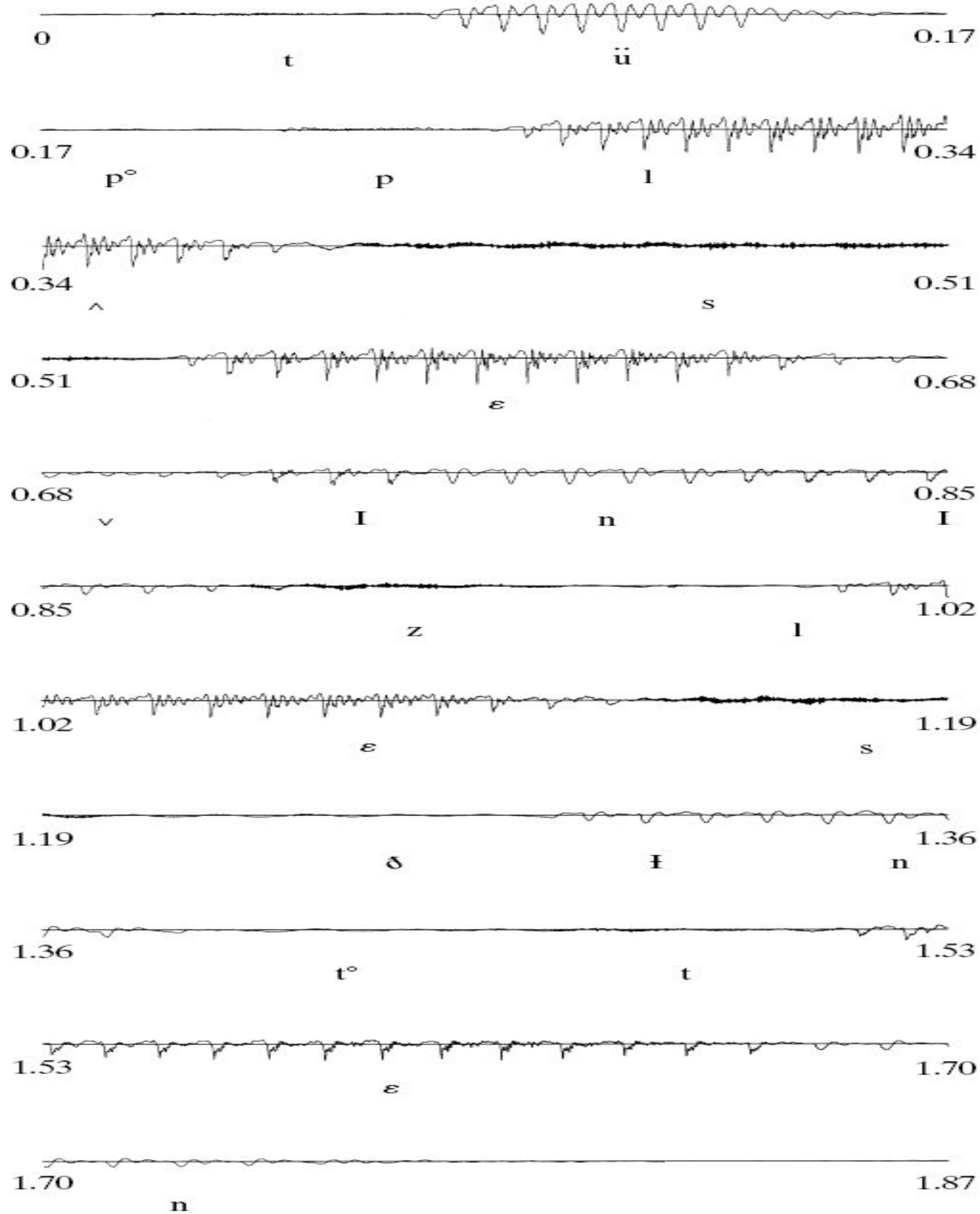


Figure 10.17 Waveform of the speech utterance "Two plus seven is less than ten." Each line is 0.17 s in duration. The time-aligned phonemic transcript is indicated below the waveform.

Сонограммы

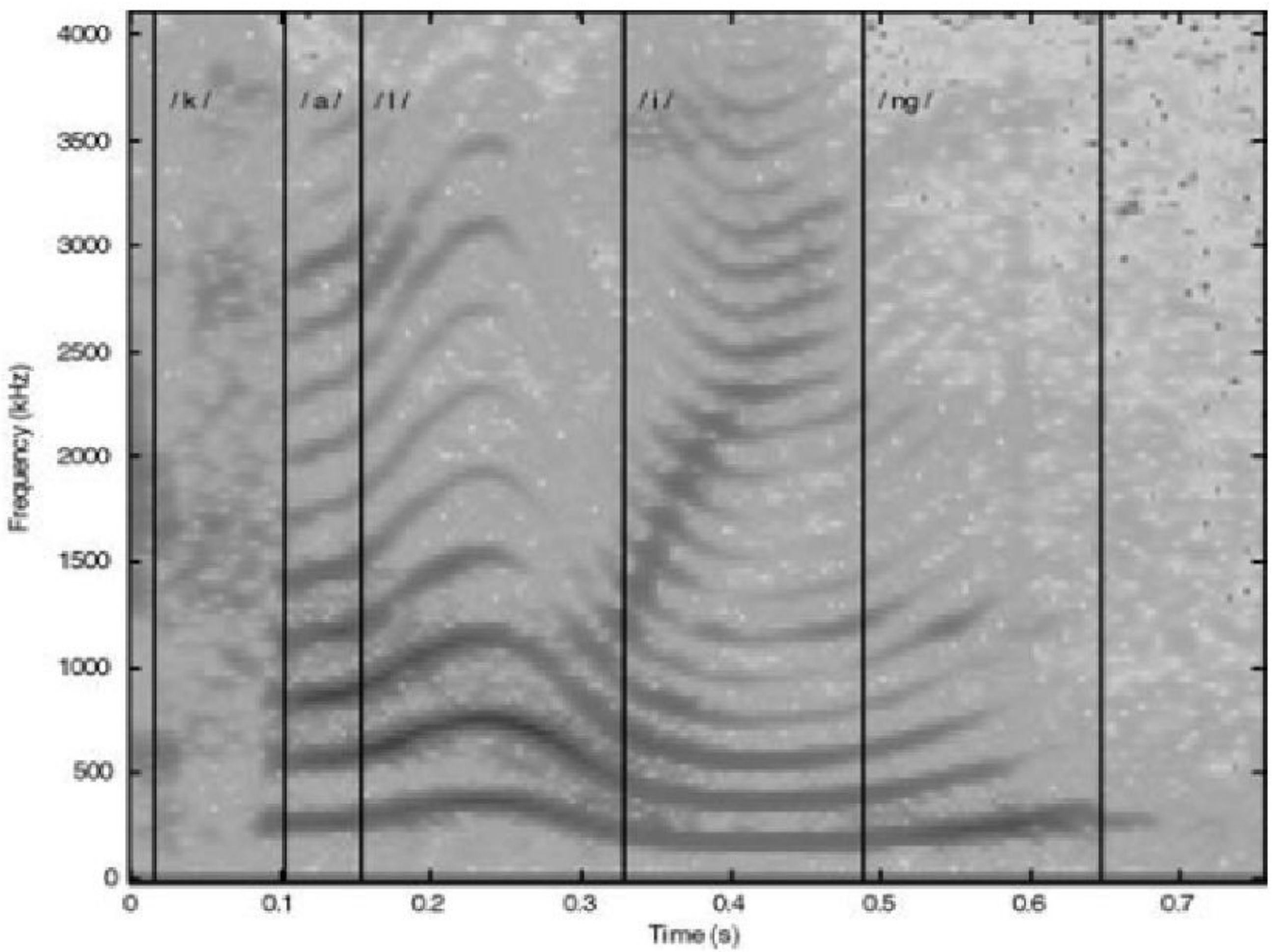


Fig. 9.29. Mixed-domain analysis of "calling" speech fragment. Using $N = 256$ point Hann windows for local frequency estimations centered $K = 32$ samples apart along the time axis produces the above time-frequency map. In many cases, voiced versus unvoiced speech segments can be found using the time-frequency map.

Сонограммы

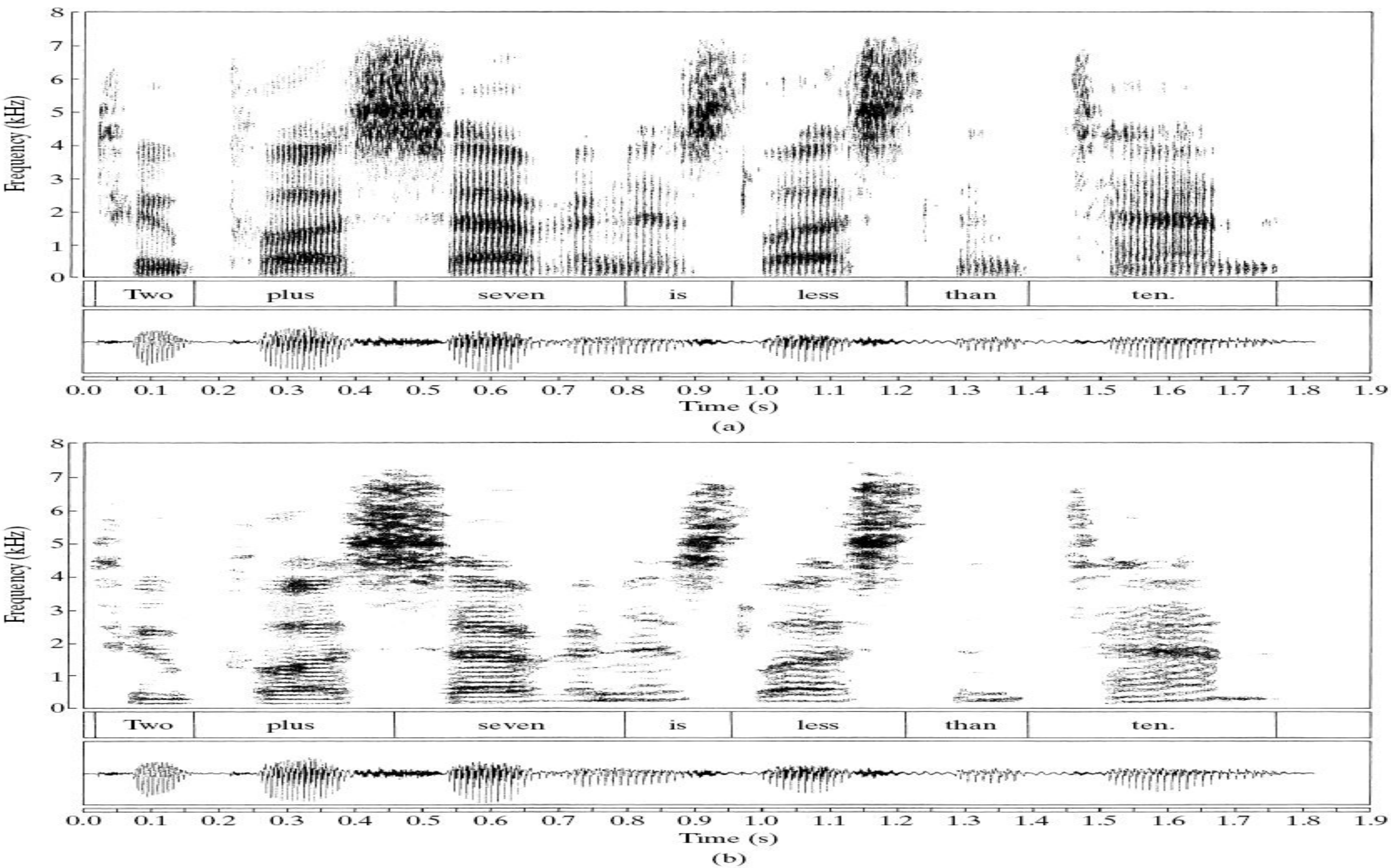


Figure 10.18 (a) Wideband spectrogram of waveform of Figure 10.17. (b) Narrowband spectrogram.