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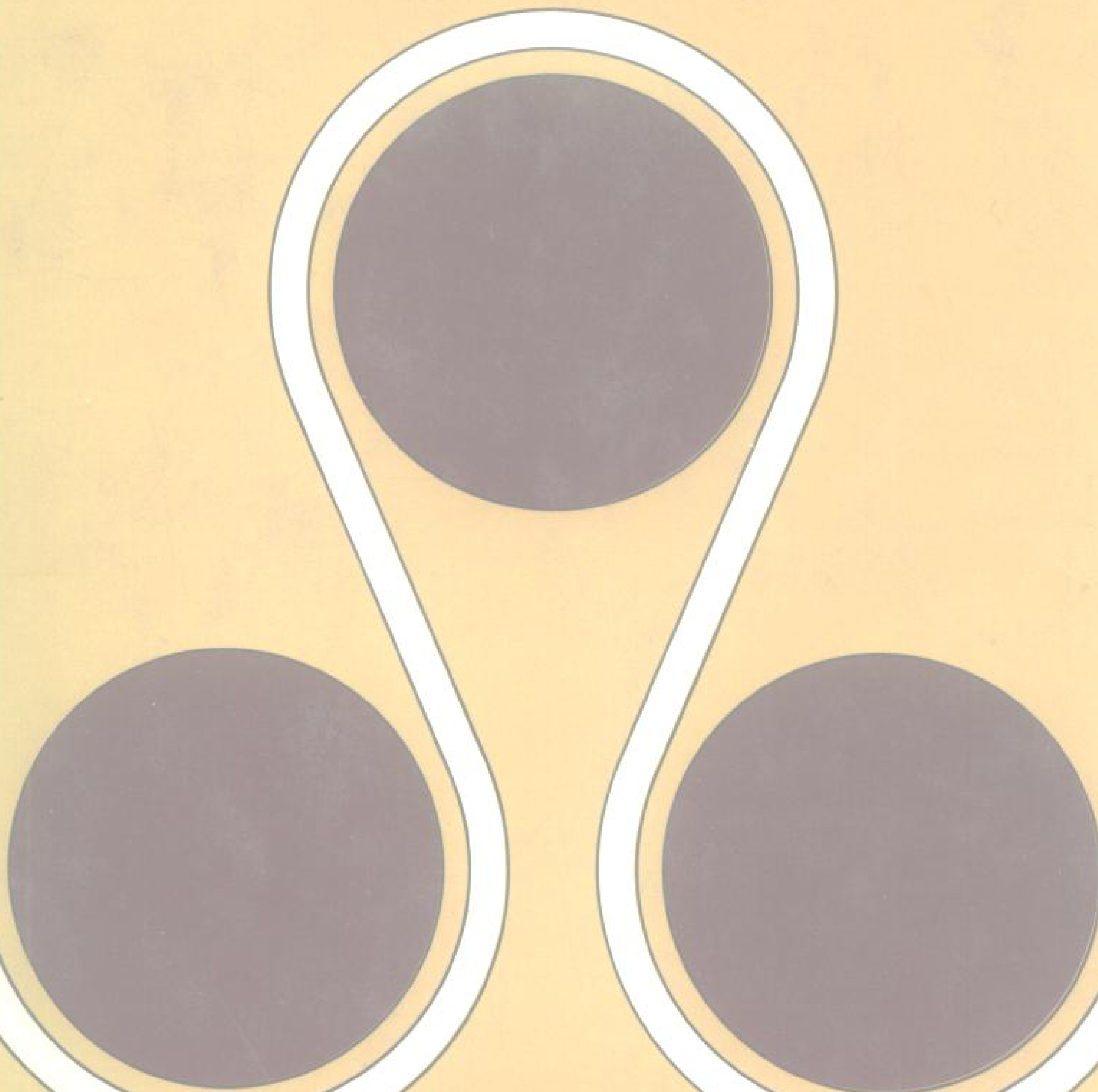
John Eargle



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Preface

Sound recording is a fast-paced industry. In 15 years its master recording requirements have progressed from simple three- and four-track capability to complex 16- and 24-track systems. During the same period the ancillary equipment and techniques used in recording have been broadened to include advanced digital techniques, both in signal processing and in console automation.

Fifteen years ago recording was chiefly concerned with documenting musical events, and the record was ideally a substitute for the event. During the mid-sixties, however, the phonograph record market changed dramatically; classical record sales in the U.S. slipped to about 5 percent of the total as the youth-oriented pop-rock market, spawned by the Beatles, gained the largest share. Most of this "new music" was born in the recording studio, and most of its sounds had their first existence over loudspeakers.

Many of the instruments of the new art depend heavily upon electronics and signal processing, and it is no longer easy to draw a distinct line between the tools of performance and those of recording. Even the roles of producer, musician, and engineer have intermingled; it is not uncommon for a musician to take on the duties of producer and engineer. In earlier days these roles were clear and distinct, but the new music has brought them together as a common creative endeavor.

Engineers used to work their way into the recording field by long years of apprenticeship. Today, many engineers come from a music-related background, and they are often required to advance in the recording art at a quick pace. Too often, there may be a good understanding of how the tools and techniques of recording are used, but only a meager understanding of how they work. It is the author's intent to relate cause and effect wherever possible so that young engineers can be given a firm basis on which to further their own education and growth in the recording arts.

Recording institutes and seminar programs have become popular in this country, and their aim is to give young engineers practical experience with the tools and techniques of recording along with a general broadening of their knowledge in the field. Typically, these schools present courses running anywhere from four to twelve weeks; some are affiliated with degree-granting institutions and allow credit for these courses. This book is designed as a supplement to the courses offered by these institutes and will be of value as a continuing reference work for their graduates.

As the seventies have progressed, a number of universities and colleges have set up degree programs in various phases of communications and electronic media. To the extent that these courses are involved with the tools and techniques of audio production work, this book will be of great benefit.

The book is broadly divided into two sections; the first consists of chapters of a tutorial nature, while the second discusses the devices and techniques used in recording. Chapter 1 covers those fundamentals of physical acoustics with which the recording engineer should be familiar. It calls for some mathematical background and will require careful study. Wherever possible, mathematical descriptions have been paralleled by graphical examples with their inevitable intuitive appeal. The engineer or technician, commensurate with his background, will appreciate both approaches, while the liberal arts student will probably opt for the latter. Chapter 2 covers the aspects of psychoacoustics which are important in recording and reproduction of sound. Chapters 3 and 4 cover the principles of stereophonic and quadraphonic recording, respectively.

The remaining chapters deal with microphones and their characteristics, monitor loudspeakers, audio control systems, magnetic recording, signal processing, and disc recording. Here, the emphasis is on how the devices work and how they have evolved. The discussions of microphones and signal processing deal as well with numerous recording applications.

Ultimately the United States will convert to the metric system. In the meantime most professional pursuits in this country continue to use a mixture of metric and English units. It is the author's feeling that a book which is devoted to practice should be written in terms most useful and applicable by the reader. Consequently, this book will retain those units which are a part of general practice. For example, architectural measurements are expressed in English units; electrical quantities, of course, are already compatible with the metric system. It may appear contradictory to some that the gross measurements of record groove geometry (groove width and pitch) are expressed in mils and lines per inch, respectively, while considerations of stylus velocity and acceleration are given in metric units. These are the standard terms used by the industry, and it is worth noting that engineers were measuring groove widths and pitch in the days of acoustical recording, while measurements of stylus velocity and acceleration are the products of a more advanced discipline.

The author is indebted to many manufacturers in all segments of the recording industry for their contributions to this book. Thanks are particularly due to the following companies for their permission to use illustrative material: Allison Research, Altec, Ampex, Automated Processes, Audio-Technica, Bruel & Kjaer, Electro-Voice, Gotham Audio, James B. Lansing Sound, Minnesota Mining & Manufacturing, Georg Neumann, Ortofon, Quad-Eight, Shure Brothers, Victor Company of Japan, Westlake Audio, and Westrex.

JOHN EARGLE

Contents

1

Physical Aspects of Sound

INTRODUCTION

The dedicated recording engineer ultimately becomes his own best teacher. As a young apprentice he learns from observing experienced engineers and by associating certain solutions with certain problems. But his real growth in the art comes when he begins to grasp the fundamentals of cause and effect, when he learns how to solve new problems through analysis of their elements. At the very foundation of this growth is a knowledge of basic principles of acoustics, sound generation, and sound propagation.

Though some mathematical background is essential for a thorough understanding of this chapter, the serious student of recording technology who has a limited mathematical background should not be frightened away. We have chosen to parallel mathematical explanations with graphical ones with the hope that pictures will suffice where numbers may not. Most of the concepts are intuitively obvious to anyone who has ever listened analytically and wondered why things sound the way they do. Accordingly, we suggest that the student who may find Chapter 1 difficult at first reread its sections slowly, making extra effort to associate its discussions with his own observations of sound behavior.

CONCEPT OF VIBRATION: PERIODIC MOTION

A *sine wave* is the simplest kind of vibration; it is that natural motion of a weight as it bobs up and down on a spring or of a pendulum swinging at a moderate displacement. Its characteristic motion is shown in Figure 1-1,a, a to-and-fro motion about a reference line. The motion can also be described as the projection of a point on a circle as that point moves about the circle with uniform velocity. One cycle of the wave constitutes rotation through the complete 360 degrees of the circle, and the time required for one cycle of the wave is called its *period* (T). A related term is *frequency*, the number of periods in a given interval of time. For example, if a sine wave has a period of one-fourth second (T = .25 sec), then its frequency is $1/T$, or 4 cycles per second (Hz). (The term *Hertz* (Hz) is now universally used in place of the older cycles per second.)

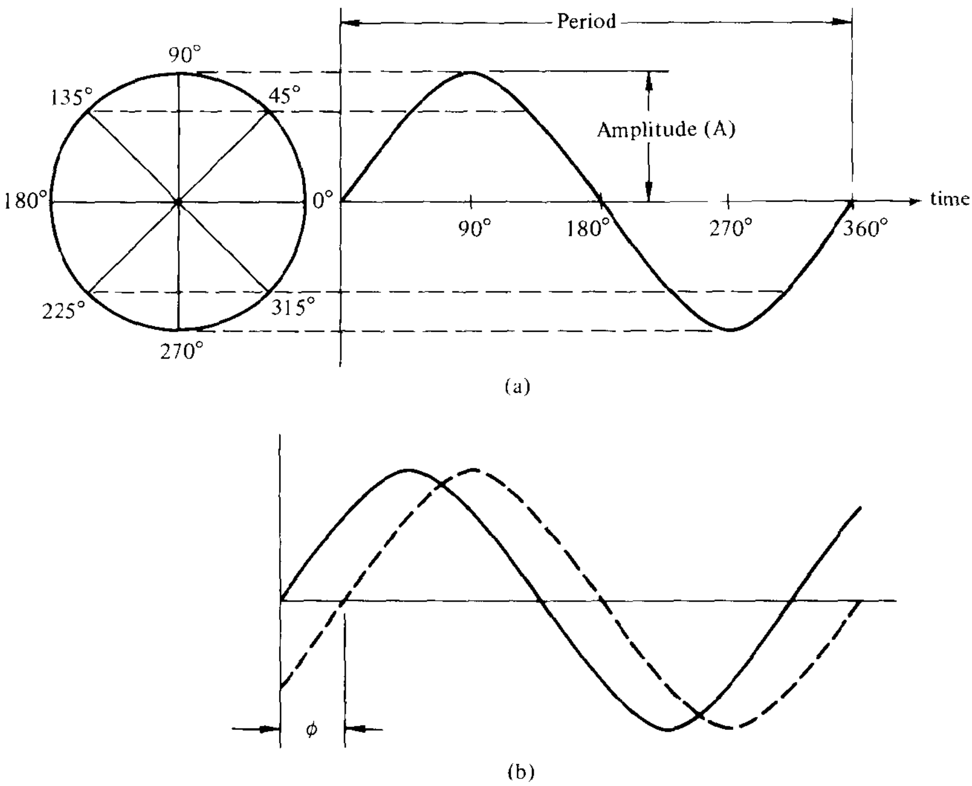

Figure 1-1. (a) Generation of a sine wave, showing amplitude and period. (b) Phase relationship between two sine waves of the same frequency.

EXAMPLE: Determine the frequency of a sine wave with a period of one-thousandth of a second.

$$\text{Frequency} = \frac{1}{T} = \frac{1}{.001} = 1000 \text{ Hz (or 1 kHz)}$$

(The term kHz, or kilohertz, means one thousand Hertz.)

Another characteristic of a sine wave is its *amplitude* (A), its displacement from the reference point. The displacement can be in distance, as in the case of a pendulum, or in a voltage or current if it is an electrical sine wave. The amplitude of a sound wave is customarily measured in pressure fluctuations above and below normal atmospheric pressure.

The concept of *phase* is important in describing sine waves. It refers to the relative displacement in time between sine waves of the same frequency. This is shown in Figure 1-1,b. Here, the dotted sine wave is displaced from the solid one by some distance ϕ, usually expressed in degrees, with one period of the wave representing 360 degrees.

As common as sine waves may be in electrical and mechanical engineering, they are rare in the world of sound for the reason that nearly all vibrating elements used in the generation of sound have a tendency to execute *complex* motions. If the motion is a sustained one, as in the case of a bowed string or a wind instrument, then the complex wave form can usually be expressed as an ensemble of sine waves, beginning with a *fundamental* wave and progressing upward through a set of harmonically related sine waves whose periods are related as 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, and so forth. This is shown in Figure 1-2, where four harmonically related waves are added together to produce a complex wave (Figure 1-2,c). The components of a complex wave are referred to as *harmonics*. At Figure 1-2,b and 1-2,d we have shown the frequency spectrum for each component as well as for the complex wave itself. By specifying the number of harmonics, their relative amplitudes, and phase relationships, we can generate practically any repetitive wave form.

APERIODIC MOTION: NOISE

Although we can describe as noise almost any unwanted sound, the term is usually reserved for wave forms of the kind shown in Figure 1-3,a. The wave has no period, and thus is called *aperiodic*. Just as a complex repetitive wave form can be shown to be made up of harmonically related sine waves, noise can be shown to be composed of a *continuous* band of an unbounded number of sine waves. If the array of frequencies present is as shown in Figure 1-3,b, the noise is re-

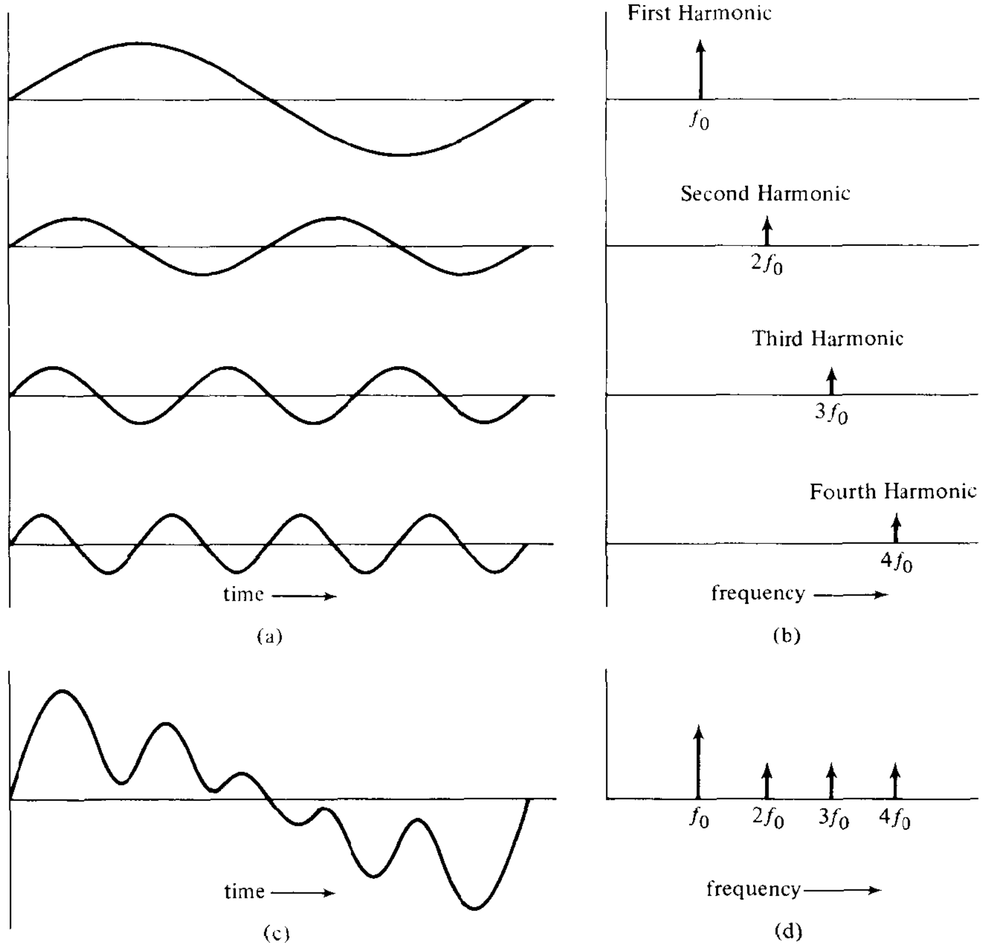

Figure 1-2. (a) Illustration of harmonically related sine waves. (b) Frequency spectra for sine waves shown in (a). (c) Generation of a complex wave by adding the sine wave components of (a). (d) Frequency spectrum for the complex wave shown in (c).

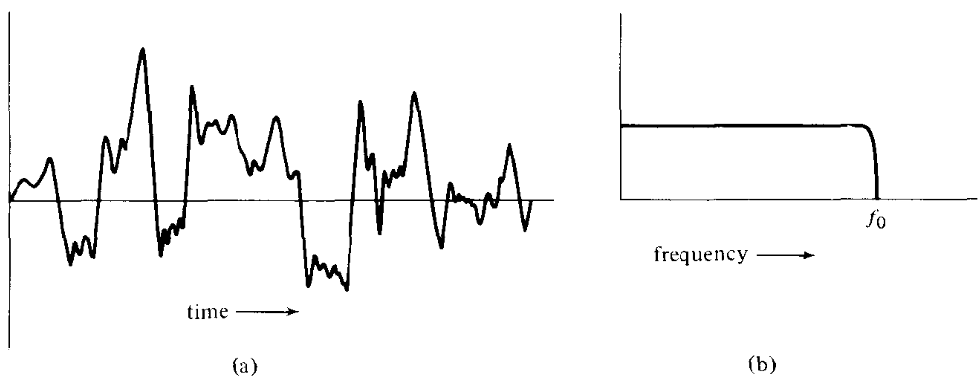

Figure 1-3. Wave form for a typical "white noise" signal (a) and its corresponding frequency spectrum (b).

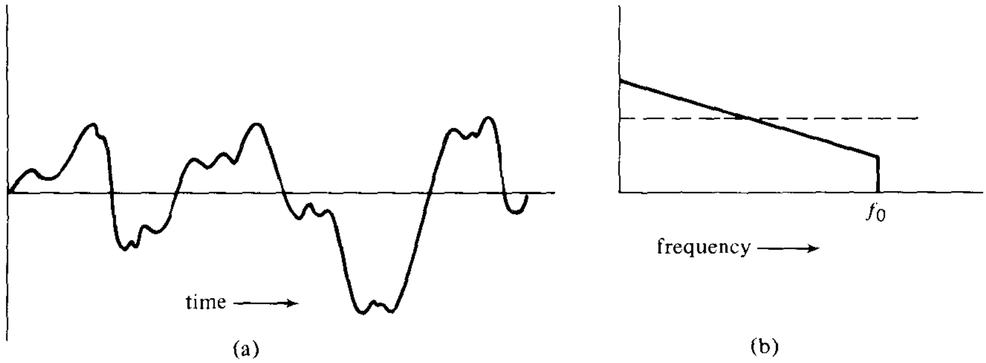

Figure 1-4. Wave form for a typical "pink noise" signal (a) and its corresponding frequency spectrum (b).

ferred to as "white noise" (similar to the interstation noise heard on FM sets). It is band-limited, containing frequency components up to some arbitrary f_0. The term white noise is by way of analogy with white light, which contains all components in the visible range equally. *Pink noise*, again by analogy with light, has less energy at higher frequencies; for each doubling of frequency, the energy present is halved. The waveform shown in Figure 1-4,a shows noticeably less high-frequency energy than the white noise waveform of Figure 1-3,a, and the corresponding frequency spectrum at Figure 1-3,b shows the characteristic roll-off at high frequencies.

White noise contains equal energy per cycle, or equal energy for each frequency present; pink noise contains equal energy per octave (or portion of an octave) and is useful, as we shall see in a later chapter, as a test signal for equalizing loudspeakers for desired response contours.

SOUND TRANSMISSION THROUGH AIR

If a vibrating object or surface is suitably large, then its vibrations impart energy to the air around it, and *sound* is produced. Generally, we can define sound as variations in pressure above and below the normal pressure of the atmosphere. The frequency range of *audible* sound is nominally 20 Hz to 20 kHz, and the velocity of sound through air is typically about 1130 feet per second. At elevated temperatures, the speed is greater, while at lower temperatures it is slower. Only in dealing with sound transmission over great distances out-of-doors will we ever be concerned with this velocity dependence on temperature. Figure 1-5 shows the range of frequencies produced by a variety of sound sources.

Let us assume a sound source of a frequency of 1130 Hz. At a velocity of 1130 feet per second, the period of the waveform begins anew every foot, and we now define wavelength as the distance between the beginning of successive

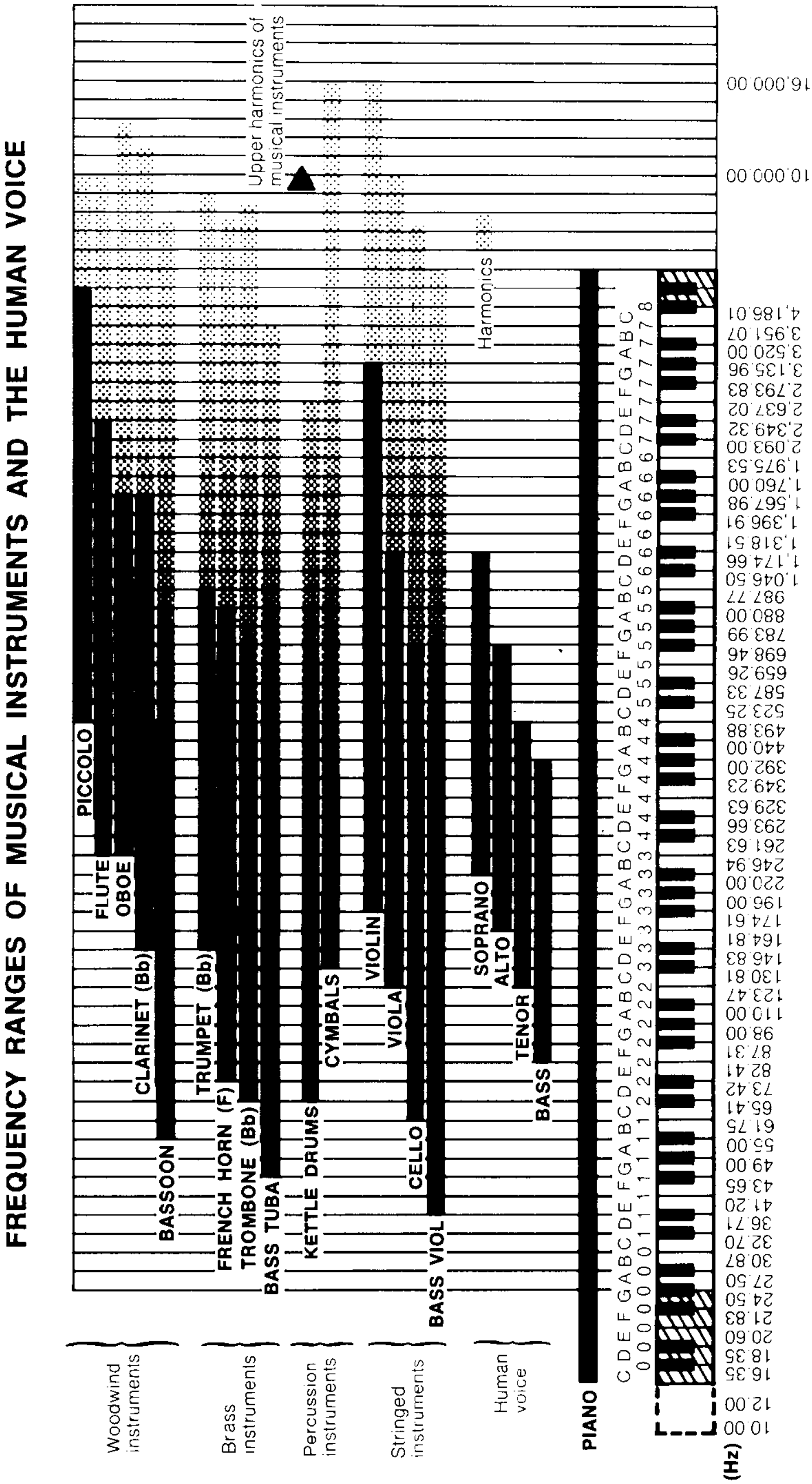

Figure 1-5. Range of frequencies for various sources of sound.

periods. In simple terms:

$$\text{Wavelength } (\lambda) = \frac{\text{speed of sound}}{\text{frequency}}$$

The Greek letter lambda, λ, is universally used to represent wavelength.

EXAMPLES: Determine the wavelength of a 10-kHz signal:

$$\lambda = \frac{1130}{10{,}000} = .113 \text{ feet, or about } 1\tfrac{1}{3}''$$

Determine the wavelength of a 50-Hz signal:

$$\lambda = \frac{1130}{50} = 22.6 \text{ feet}$$

Obviously, given any two of the three quantities, wave length (λ), frequency (f), or velocity (v), we can solve for the third:

$$\lambda = \frac{v}{f}, f = \frac{v}{\lambda}, \text{ and } \quad v = f\lambda$$

The precise nature of radiation of sound through air or any other medium is extremely complex, and any further discussion of it would surely call for more mathematics than we have in mind for this book. However, two important observations on sound radiation can be made:

Efficient low-frequency radiation requires large radiators. A string bass and a piccolo are both the right size for their respective jobs.

Directional radiation requires large radiators. Although a string bass can produce fairly low frequencies, it radiates them in many directions. By contrast, a large array of low-frequency loudspeakers used at a rock concert for "aiming" sound in a given direction might have dimensions approaching that of the radiated wavelength itself.

THE DECIBEL

Fundamentally, the *Bel* is defined as the common logarithm* of a power ratio:

$$\text{Bel} = \log \frac{P_1}{P_0}$$

Let us assign a value of 1 watt for P_0 and 2 watts for P_1. Then we have:

$$\text{Bel} = \log \frac{2}{1} = .3$$

*See Appendix I.

Thus, the *ratio* of 2 watts to 1 watt is said to be .3 bel. More conveniently, we use the unit *decibel* (dB), which is equal to one-tenth of a Bel. Our 2-to-1 watt power ratio is then 3 decibels. In fact, any 2-to-1 power ratio is a 3 dB ratio, 20-to-10 watts, 60-to-30, 6000-to-3000, and so forth. We can state a ratio either of two ways: 1 watt is 3 dB *less* than 2 watts, or 2 watts is 3 dB *greater* than 1 watt.

Extending the notion, we refer to a 4-to-1 power ratio as 6 dB; 1-to-2 represents 3 dB, and 2-to-4 another 3 dB, making a total of 6.

Let us express a 10-to-1 power ratio in dB:

$$\text{dB} = 10 \log \left(\frac{10 \text{ watts}}{1 \text{ watt}} \right) = 10 \times 1 = 10 \text{ dB}$$

Any 10-to-1 power ratio is a 10 dB ratio: 50-to-5, 1-to-0.1, and so forth. Figure 1-6 presents a useful nomograph for determining by inspection the value of power ratios in dB. Simply locate the two levels and read the number of dB between them.

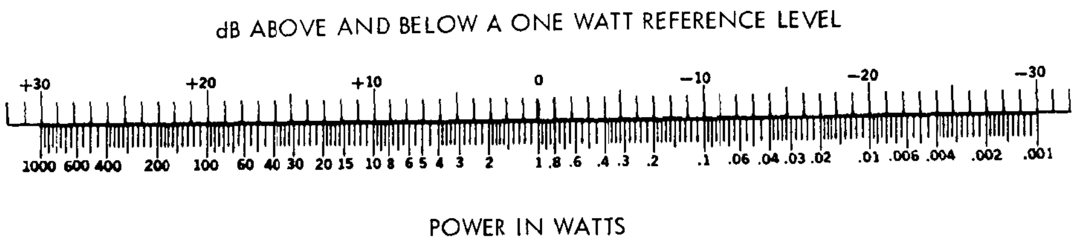

Figure 1-6. Nomograph for determining power ratios directly in dB.

EXAMPLE: Find the ratio in dB between 20 and 500 watts:
Above 20 watts read 13; above 500 watts read 27.

$$27 - 13 = 14 \text{ dB}$$

The chief value of decibel notation is that it allows us to deal with a large range of physical values with a relatively small range of numbers.

The watt is the unit of power, the rate at which work is done or energy expended. Electrically, power is the product of the voltage across a load and the current flowing through it:

$$\text{Power } (W) = \text{Voltage } (E) \times \text{Current } (I)$$

In Figure 1-7,a we show a 1-volt battery connected in series with a load resistance of 1 ohm. One volt across a resistance of 1 ohm results in a current of 1 ampere, and the resulting power is 1 watt. In Figure 1-7,b the voltage