L. Sound Systems

We address three more sound sources in this section. These are the record player, tape deck, and CD player. They represent three levels of improvement in sound reproduction. Faraday's Law and Ampère's Law will be important in our discussion of records and tape decks. We state applied versions of these laws in Table L-1. The two essential devices are the coil (electricity) and magnet (magnetism). Note again the interplay between electricity and magnetism. These are manifestations of the unified electromagnetic force of nature. Such unification makes possible the invention of diverse sound components.

Table L-1. Applied Versions of Two Basic Laws of Electricity and Magnetism.

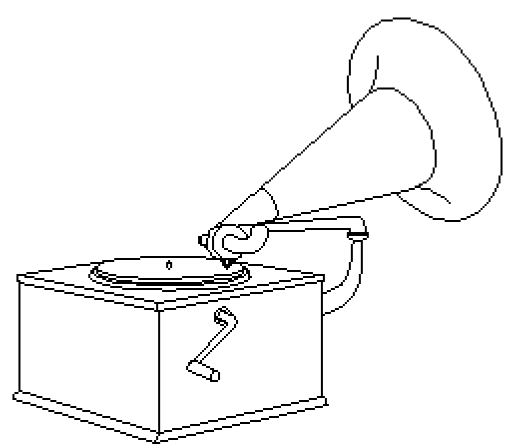
Law	Applied Version of Law
Ampère's Law	A changing electrical signal in a coil surrounding a magnet, causes relative motion between the coil and magnet.
Faraday's Law	Forced relative motion between a coil and inner magnet, generates a changing electrical signal in the coil.

Record Players

The record is our first practical method of storing sound. Sound vibrations are encoded as small hills and valleys on a disk. Thomas Edison invented the first model, a cylinder with grooves, in 1877. He coined the word *phonograph* at that time. However, the disk shape became the standard. The word *gramophone* was introduced in 1887 to distinguish the two. In America, the word phonograph is used to refer to both.

Fig. L-1 illustrates an old phonograph that is purely mechanical. You turn the crank and a needle vibrates to the bumps on the disk. The vibrations are amplified by the horn.

Fig. L-1. Old Mechanical Phonograph.



Early records had vertical hills and valleys. Later, one finds lateral cuts. We will illustrate the vertical cut and then move on to the two-channel stereophonic records.

The early records sounded poorly according to later standards because the hills and valleys in the grooves were cut using actual sound pressure itself. Starting around 1925, the cutting was done electrically. Cutting and playing back a record electrically brought about a significant increase in performance.

Engineers used the same electro-magnetic techniques we encountered with speakers (Ampère's Law) and microphones (Faraday's Law). Playing a record is the reverse of cutting a record. Fig. L-2 below illustrates the vertical or *hill-and-dale* cut. Here we keep the coil fixed and let a tiny magnet move. Remember that when there is a force between two bodies and one body is held fixed, the other moves. That's why we used the words "relative motion" for the description of the coil-magnet movements in our restated laws in Table L-1.

Fig. L-2a. Cutting a Monophonic Record (Ampère's Law).

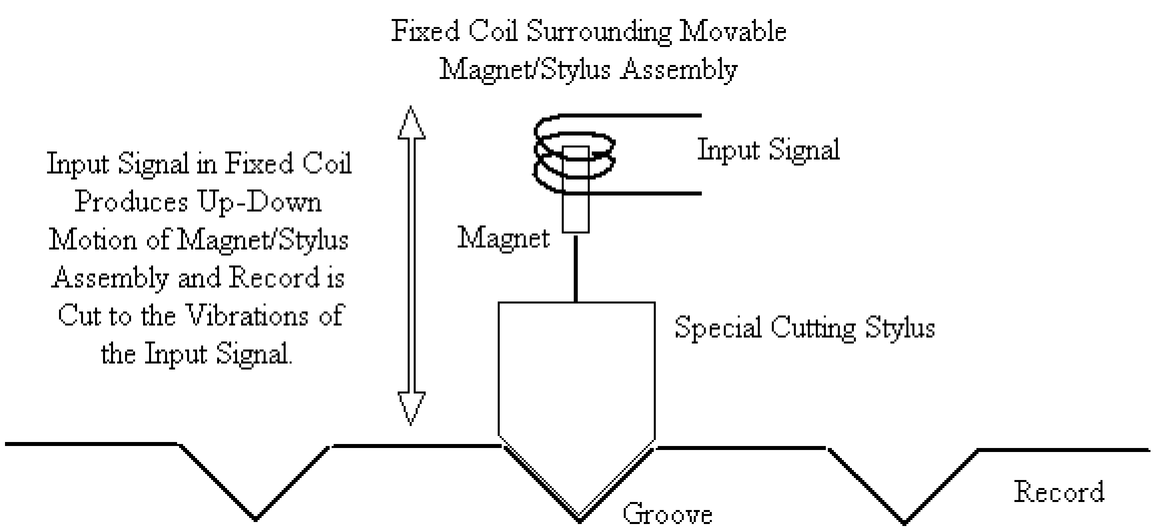
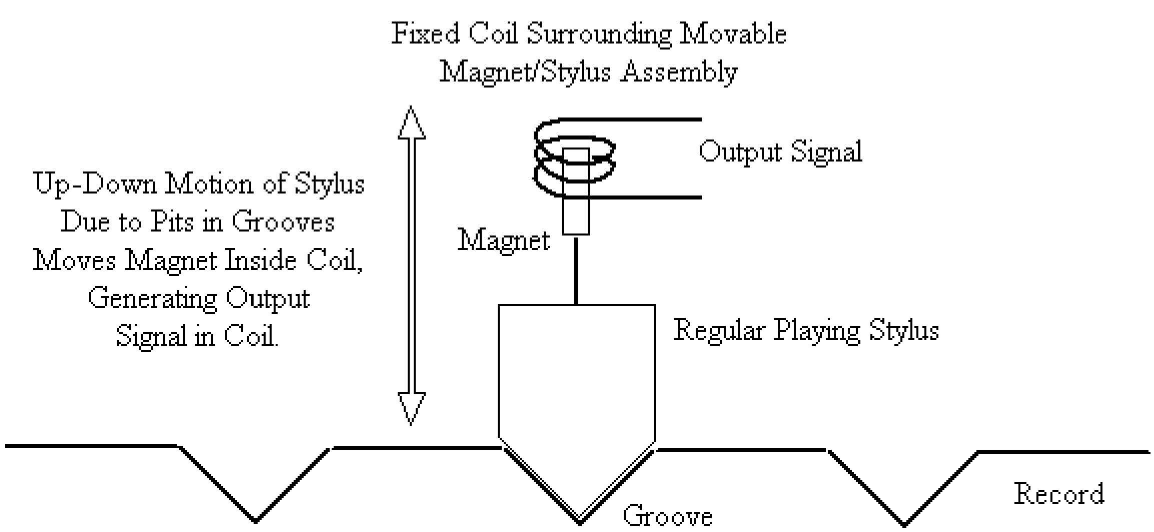


Fig. L-2b. Playing a Monophonic Record (Faraday's Law).



Monophonic or monaural records turned at various rates. The first popular standard records, made with a shellac compound, had a spin-rate of 78 rpm (rotations per minute). The later standards were the smaller 7"-diameter "45 (rpm)" with a large center hole, and the 12"-diameter long-playing (LP) records (33 1/3 rpm). Table L-2 lists data for these historical formats. The 45 became widespread for popular singles in the 1950s, while the LP was the standard for classical music.

Table. L-2. The Common Historical Record Formats.

Date	rpm	Type	Diameter	One Side	Material
< 1925	78	Mono	10"	5 min	Shellac
1948	33 1/3	Mono	12"	25 min	Vinyl
1949	45	Mono	7"	5 min	Vinyl
1958	33 1/3	Stereo	12"	25 min	Vinyl

The more expensive record players that appeared in the 1950s were able to run at three speeds: 78, 45, and 33 1/3. However, the 78s were phased out by this time. Then mono systems were outdated when stereo arrived in the late 1950s. The mono stylus assembly (cartridge) can only pick up one channel of information. Fig. L-3 illustrates the playback design of the stereo record. A stereo cartridge is needed to pick up two channels separately, the two series of undulations at 45° (see Fig. L-3). Stereo cartridges however can play a mono record. Why? The best stylus is a diamond needle, oval at the tip.

Fig. L-3. Playing a Stereophonic Record (Faraday's Law).

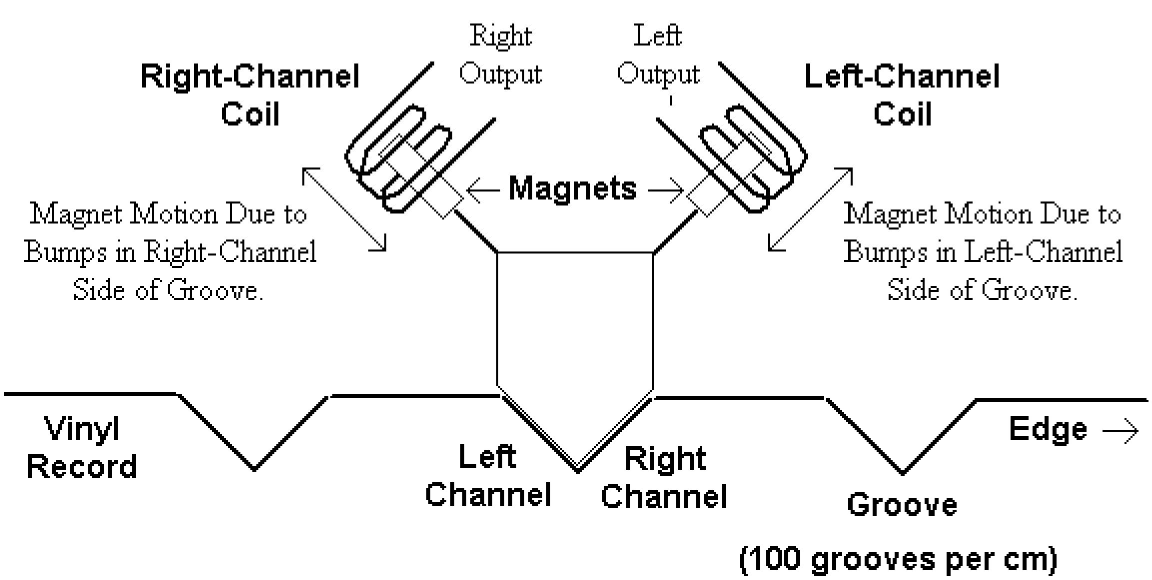


Fig. L-4 shows a side view of a turntable. It is important for the stylus not to press down on the record any more than is necessary. A fulcrum is used with a counterweight so that the heavy arm will not lean down very much on the record surface. The force of the stylus on the grooves is reduced to about 1 gram in this way. Physicists do not like to use the term "gram" for force or weight. Strictly speaking, gram is a unit of mass. Mass and weight are not the same. For example, your mass is constant, but your weight on the moon is 1/6 of your weight on Earth. However, by saying gram-weight, we are okay. One gram-weight is the weight of one gram of mass on Earth. At what gram-weight does the record player in Fig. L-4 track on the moon?

Fig. L-4. Use of Fulcrum and Counterweight to Reduce Tracking Force.

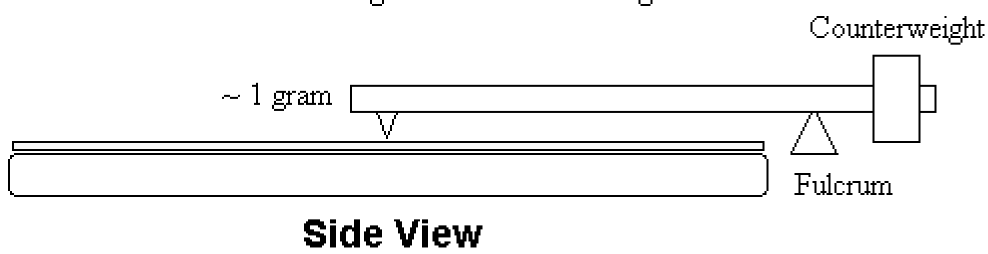
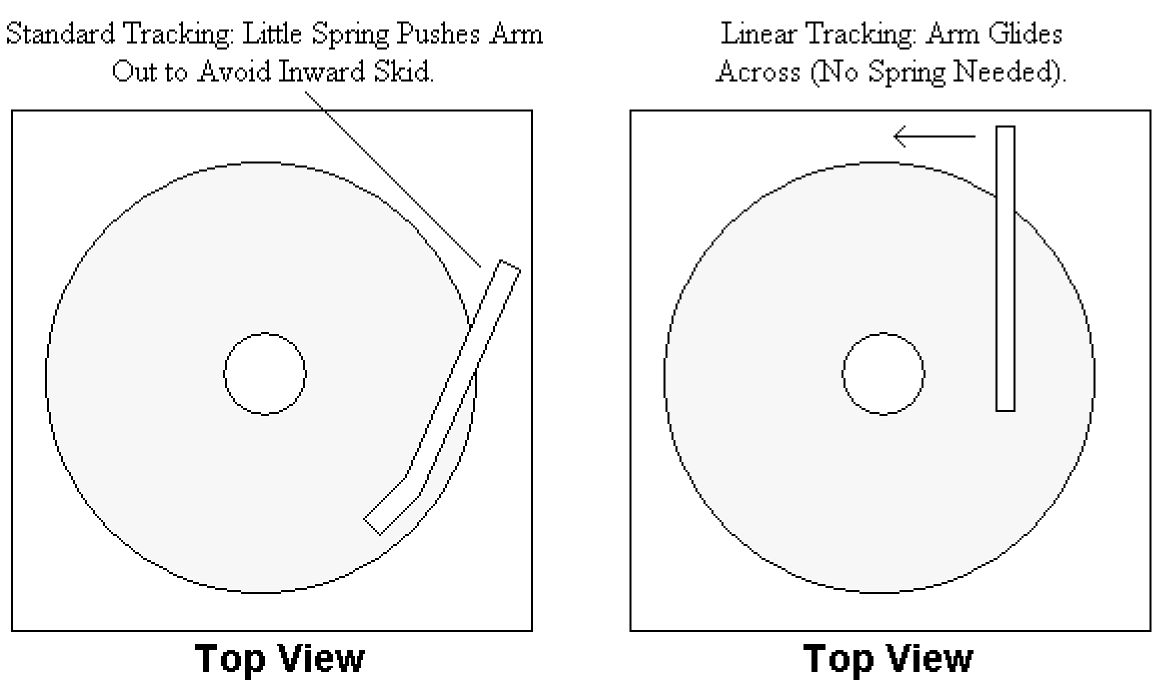


Fig. L-5 gives us a top view, illustrating two tracking methods. The record pulls the stylus end straight out in each case. This is fine for linear tracking, but causes the arm to "skate" inward toward the center in the usual arrangement. This "skating force" is balanced by a spring that supplies an outward force on the arm to compensate. This spring force is called the *antiskating force*.

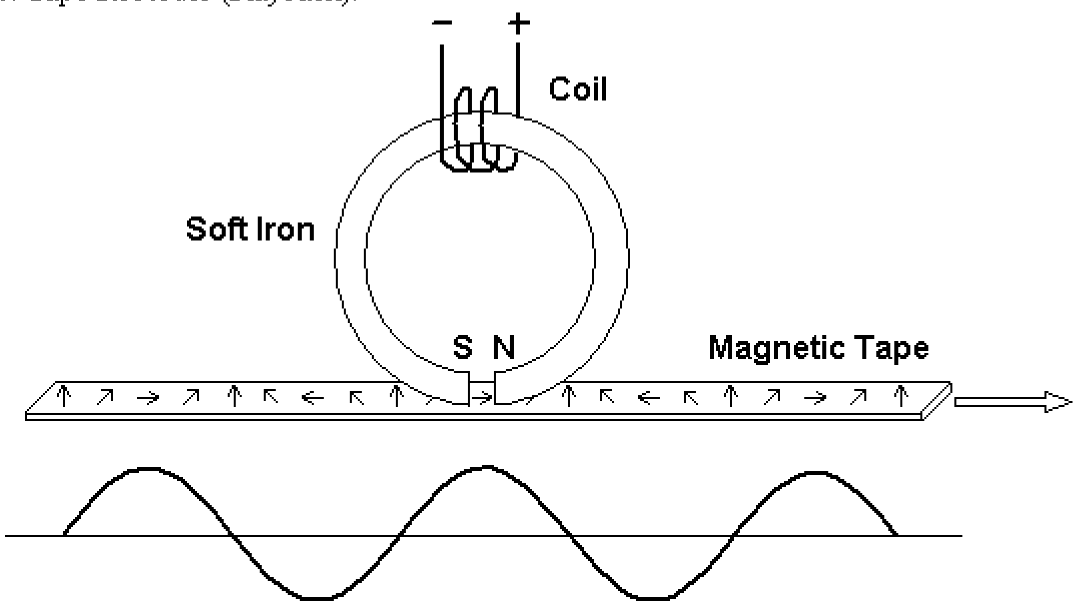
Fig. L-5. Arm Design for Tracking (Antiskating Force Needed in Standard Tracking).



Tape Recorders

Tape recorders became available in the mid 1950s due to the invention of plastic magnetic tape. The tape has tiny magnetic particles. These "baby magnets" are called *magnetic dipoles*. The magnetic coating that provides these are iron oxides or chromium oxides. We represent the magnetic dipoles as small arrows on the tape in Fig. L-6. Each arrow tip is a tiny north pole, while each tail is a south pole. The sizes are highly exaggerated in the figure.

Fig. L-6. Tape Recorder (Playback).



Sine wave encoded on above magnetic tape by orientation of magnetic dipoles (not to scale).

The dipoles in Fig. L-6 change direction in step with the sine wave illustrated. A maximum displacement (top of a crest) is represented by a dipole on the tape pointing to the right. Can you decode the other orientations? As the tape is moved across the playback head, the different magnetic orientations are picked up by the iron head. The iron is soft "magnetically," meaning that permanent magnetism will not occur.

The changing magnetic field is "sensed" by the surrounding coil at the other end. The changing magnetic fields induce electrical currents in the coil (Faraday's Law). The current changes in step with the magnetic field in the tape-head, which changes are in step with the changing orientations on the magnetic tape. To make a recording, the order is reversed. The coil in the record head (a 2nd head) receives electrical signals from a source. These cause magnetic changes in the core (Ampère's Law), which arrange the dipoles on the tape.

An erased tape is made by applying a high-frequency sine wave with the erase head (a 3rd head), so that the dipoles can't respond well. They become randomized. The early common tape recorders had two tape speeds: 3 3/4 inches per second (ips) and 7 1/2 ips (good for music). Cassettes use 1 7/8 ips, a speed unheard of for music in the 1950s. We will see why later.

CD Players

Compact disks (CDs) employ a new encoding technology, called digital technology. So far, we have encountered signals that vary continuously. This type of signal is called *analog*. Think of a meter with a dial, where the pointer can point to any value. On the other hand, *digital* signals are discrete. A piano is a digital system designed for your digits (fingers). You have 88 discrete choices of tones. A guitar or violin is an analog instrument because you can play between the regular tones by holding the string at any arbitrary point. The frets on a guitar assist you in using the guitar as a "digital" instrument.

Digital information consists of a series of numbers. Two digits, 0 and 1, are ideal for electronic processing and computers. Using two digits is called the binary system. Table L-3 gives the conversion from decimal to binary for the numbers from 0 to 15. Think of the odometer in your car. When you get to a mileage like 999, all the 9s turn to 0s the next mile and you get a fourth digit, starting at 1, i.e., 1000. With binary, you run out of digits quickly. After a binary 111, all the 1s turn to 0s and you get 1000. Look at the binary progression in Table L-3 as a changing odometer reading, where only two digits are available, 0s and 1s.

Another way to think of decimal numbers such as 3726 is to look at the position of the digits. The 3726 means 6 units plus 2 tens plus 7 hundreds plus 3 thousands. Reading right to left, you have units or 1s, 10s, 100s, 1000s, etc. You keep multiplying by 10 to get these numbers since there are 10 different symbols being used: 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. For binary, we multiply by 2 instead since we have only two different symbols at our disposal: 0 and 1. So instead of units, 10s, 100s, 1000s, etc. we have units, 2s, 4s, 8s, etc.

Table L-3. Binary Numbers.

Decimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

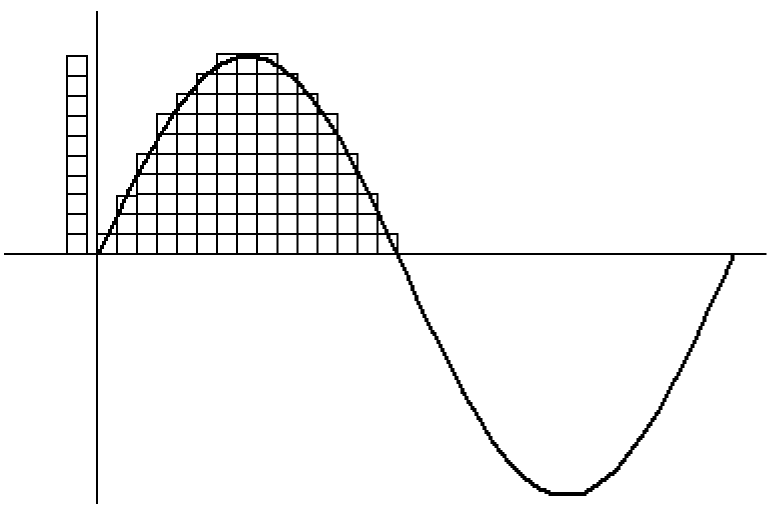
Therefore, the number 10 in binary indicates (reading from right to left) 0 units and 1 two, i.e., 2. Binary 11 indicates 1 unit plus 1 two or 3 in decimal. Similarly, 110 in binary implies 0 units plus 1 two plus 1 four, i.e., decimal 6. To avoid confusion with decimal numbers, a subscript 2 is used to indicate binary (base 2). We can write binary 110 as 110_2. As one last example, note that 1111_2 is equal to 1 unit + 1 two + 1 four + 1 eight, i.e., 15. Go through all the binary numbers in Table L-3, carefully checking each one in this way.

Now we are ready to digitize a wave. Fig. L-7 illustrates a sine wave. The sine wave varies smoothly. It is an analog signal. To digitize it we stack small boxes to approximate it. We count how many boxes we need for each small section of the wave. We list these results in the table under height. Then we convert to binary with the assistance of Table L-3.

The digitizing in Fig. L-7 is very crude. A real digital version would require boxes too small to count. The 0s and 1s for the coded information can be stored on a compact disk using a series of pits for the 1s. No pit can represent 0. These can be read by a laser. Compare a needle scraping in a groove (record) to a beam of light reflecting from pits in a groove of a compact disc (CD). The record wears out in a few years, but the CD is unaffected. The CD can last centuries!

Also, digital format can be read by computers. Computers can store music in digital form. They can also process the stored information, enhancing and modifying it. Records and tapes have limits to the range of loudness you can store. Hills and valleys can only get so high. Magnetic tape has saturation limits on how many dipoles can align together in a small region of tape. Digital methods are much superior.

Fig. L-7. Digitizing an Analog Signal.



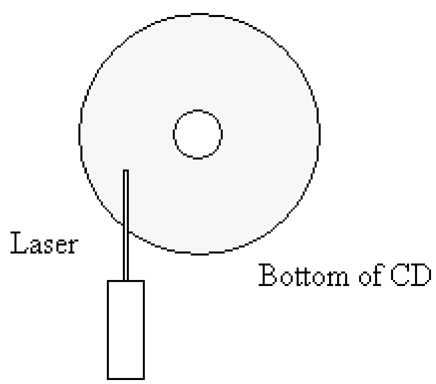
The actual boxes used are much smaller. The "horizontal box length" is taken to be about half the wavelegnth of a 20,000-Hz tone. The digital sampling rate is therefore about 40 kHz (actually 44.1 kHz).

Height	Binary
1	0001
3	0011
5	0101
7	0111
8	1000
9	1001
10	1010
10	1010
10	1010
9	1001
8	1000
7	0111
5	0101
3	0011
1	0001

Fig. L-8 depicts a compact disc. The laser shines light on the disc from below. The laser employs infrared light (IR). Infrared lies beyond the red end of the spectrum and is invisible. The IR light reflects from the pits on the CD. The reflected light is detected and analyzed. Data is read from the inside out as the CD varies its turning speed from 500 rpm to 200 rpm. The digital information is converted to an analog output signal which goes to the amplifier.

The first CDs became available commercially in 1983. The LP record, an important medium for stereo sound for 20 years (1960 to 1980), was in trouble. The phase-out period was underway.

Fig. L-8. Compact Disc.



The CD is about 5 inches in diameter. It can store 74 minutes of music. Many old recordings of famous musicians have been transferred to CDs. However, these were recorded with analog technology. These original works are often processed and remastered digitally. The original recording, intermediate processing and remastering stage, and the final format are summarized by three letters, each being either A (analog) or D (digital). A CD with the designation AAD means originally recorded with analog methods, processed and mastered as analog, then digitized for CD. The ADD indicates that the original analog recording has been digitally remastered before encoding on the CD. The combination DDD indicates a digital recording, digital processing, and final digital format. Of course, with a CD, the last letter is always D.

Let's return to the digitization of a sine wave. Refer again to Fig. L-7. The length of the rectangle is chosen so that two rectangles, side by side, extend to the wavelength of a 20,000-Hz tone. We say that we sample twice in the time-frame (period) of a 20,000-Hz tone. The s*ampling rate* is 40 kHz (actually 44.1 kHz). The height of the rectangle is chosen so that the distance from the trough to the crest of the "biggest wave" is given by the largest 16-digit binary number. This choice is called 16-bit sound. The largest 16-bit number is 1111 1111 1111 1111 which is 65,535. Since 0 is the first possible value, there are 65,536 numbers possible.

The amplitude is measured from equilibrium to crest, so the largest amplitude is one half this value, or 32,768. The loudness of a sound is given by the energy of the wave, which is related to the amplitude. The energy is essentially equal to the square of the amplitude. We state this without proof. It is saying that a water wave twice as tall has four times as much energy to hit you with. One 3 times as tall is 9 times more energetic. Therefore, the loudness range goes from 0 to 32,768 x 32,768. This is about 30,000 times 30,000 or 900,000,000, which rounds off to 1,000,000,000 (one billion). This is incredible dynamic range. Later we will learn that this corresponds to 90 decibels (90 dB).

--- End of Chapter L ---

