How CD and DVD Players Work

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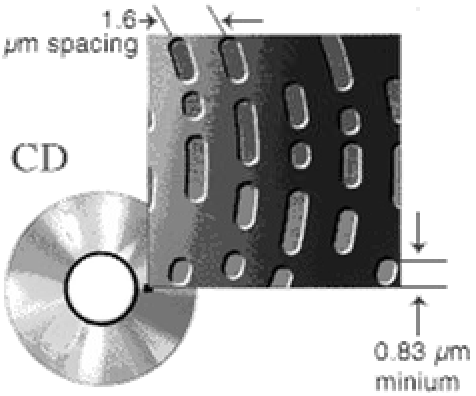
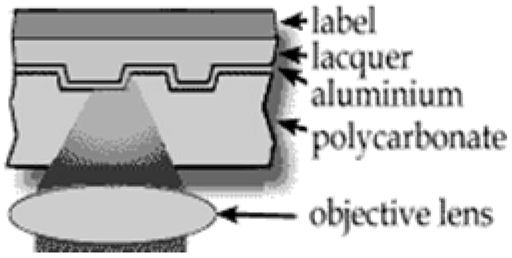


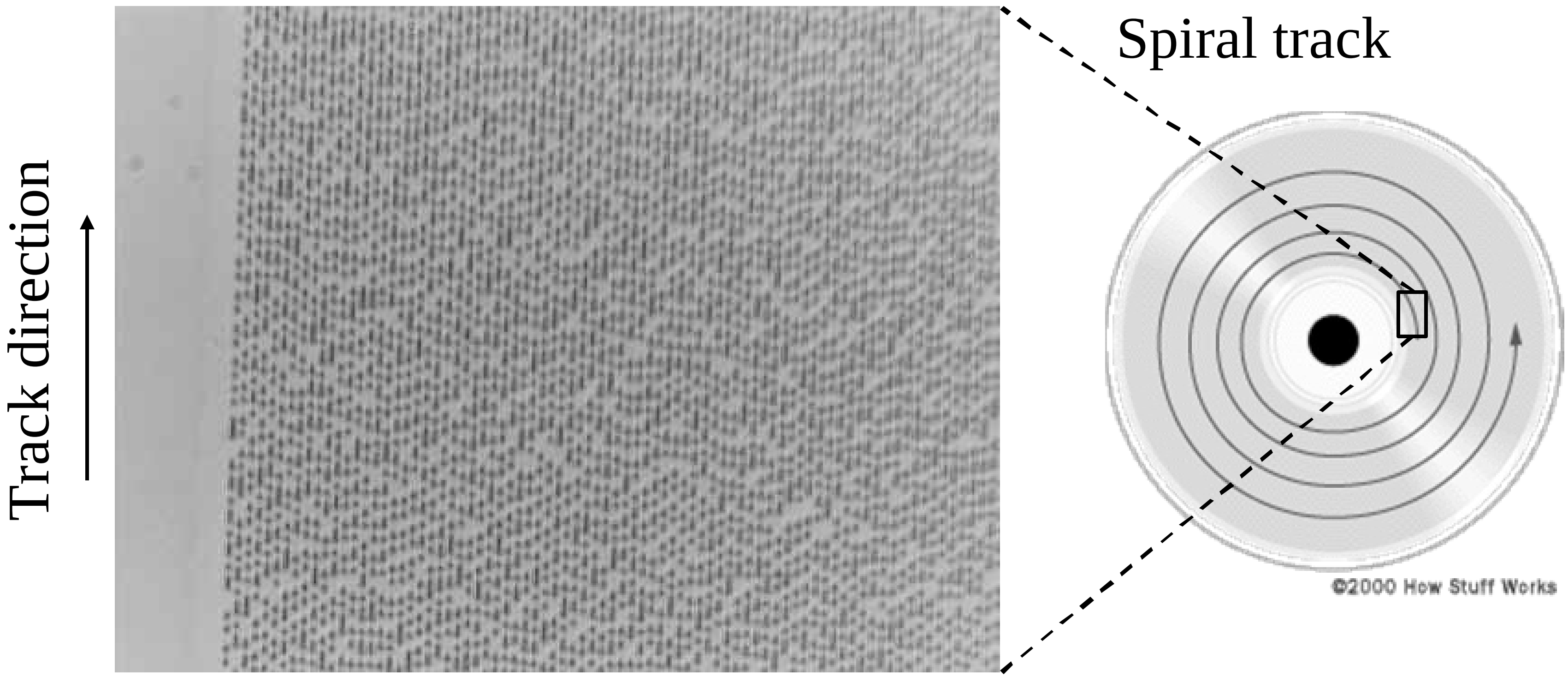


January 22, 2003

A Little History

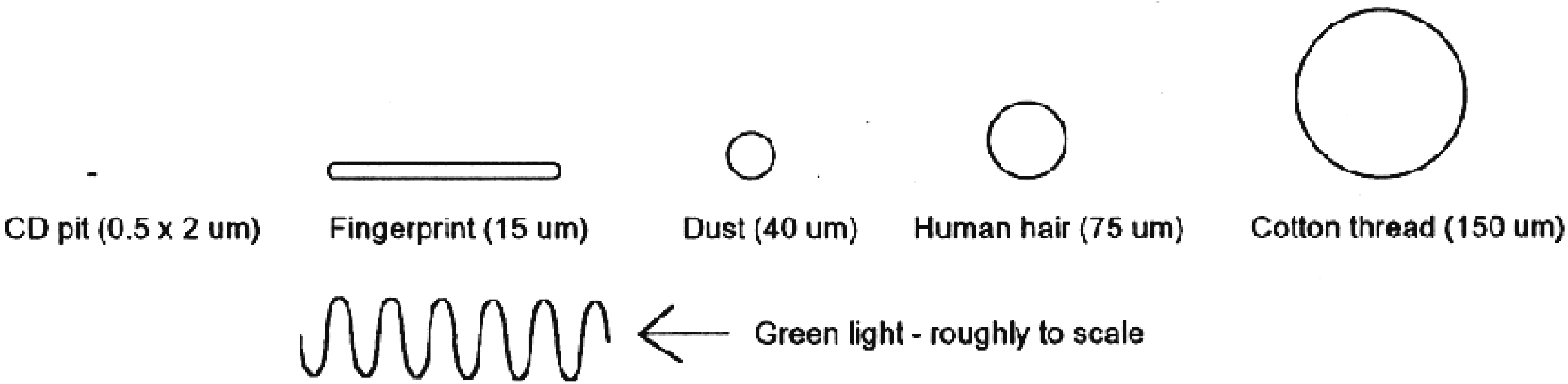
The history of the compact disk (CD) started in the 1970's with the videodisk in the form of Video Long Play (VLP) read-only systems. The videodisk did not become a commercial success, even after write-once optical disks of different formats and sizes were introduced. These were analog systems. In 1982 the CD-DA (compact disk-digital audio) was introduced to the market jointly by Phillips and Sony. It stored a high-quality stereo audio signal in a digital format. These systems became a huge success. In 1985, the technology was extended to computer storage, again in a collaboration between Phillips and Sony. This was called a CD-ROM (compact disk-read only memory). Early in 1995, two major groups were competing to develop the next generation of high-density compact disks. Under the partnership of Philips and Sony, there began the development of one such format. Concurrently, a group led by Toshiba and Time Warner was working on another format. In September of 1995 the two camps agreed to develop a single standard for a high-density compact disk. The first DVD-video players were sold in Tokyo in November'96, followed by their US introduction in August'97.

CD Under a Microscope



Low-magnification (´32) image of a CD showing an edge of the data zone.

How Small are the Pits on a CD?



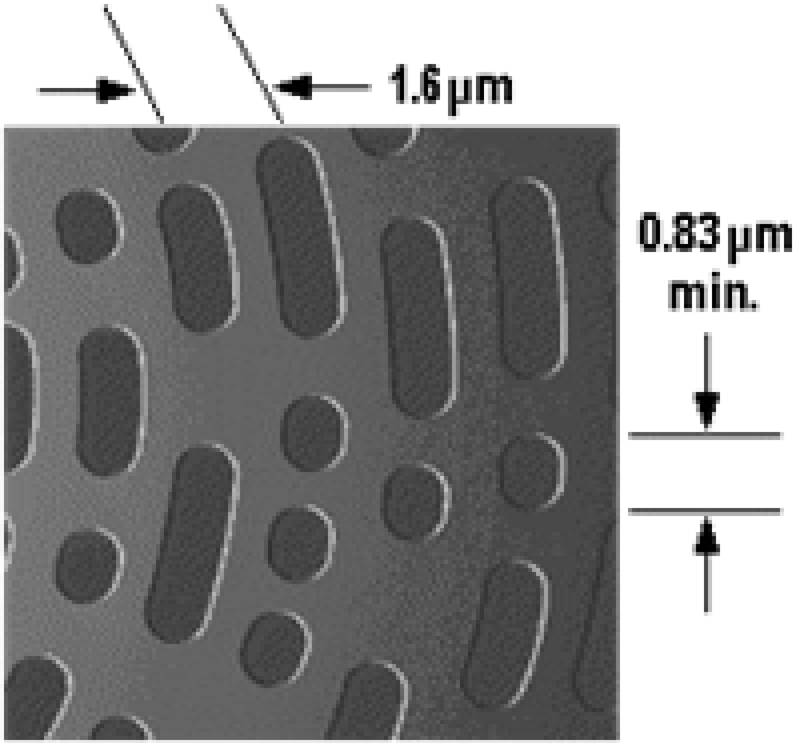
Track Density and Data Density

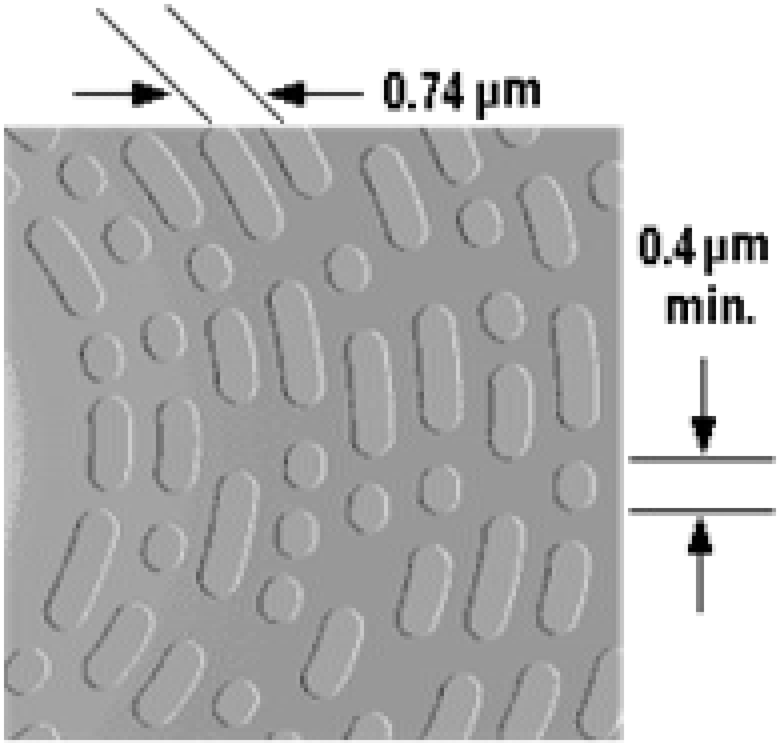
The CD is 12 cm in diameter, 1.2 mm thick, has a center hole 1.5 cm in diameter, and spins at a *constant linear velocity* (CLV) or *constant angular velocity* (CAV).

There is only one track on the optical disk and all data are stored in a spiral of about 2 billion small pits on the surface. There are about 30,000 windings on a CD - all part of the same track. This translates into about 16,000 tracks per inch and an areal density of 1 Mb/mm^2.

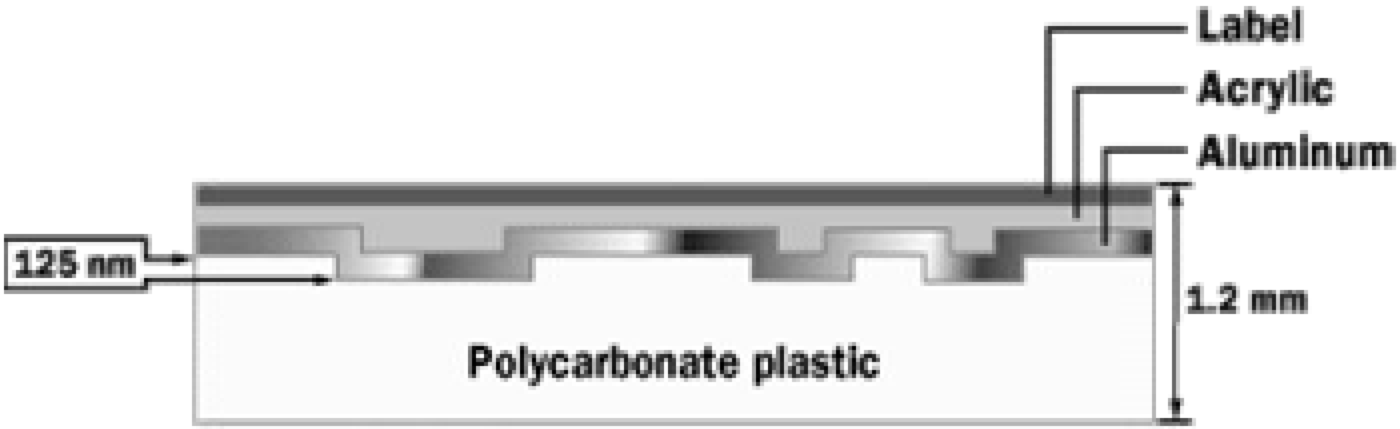
The total length of the track on a CD is almost 3 miles.

CD Versus DVD





CD in Cross-section

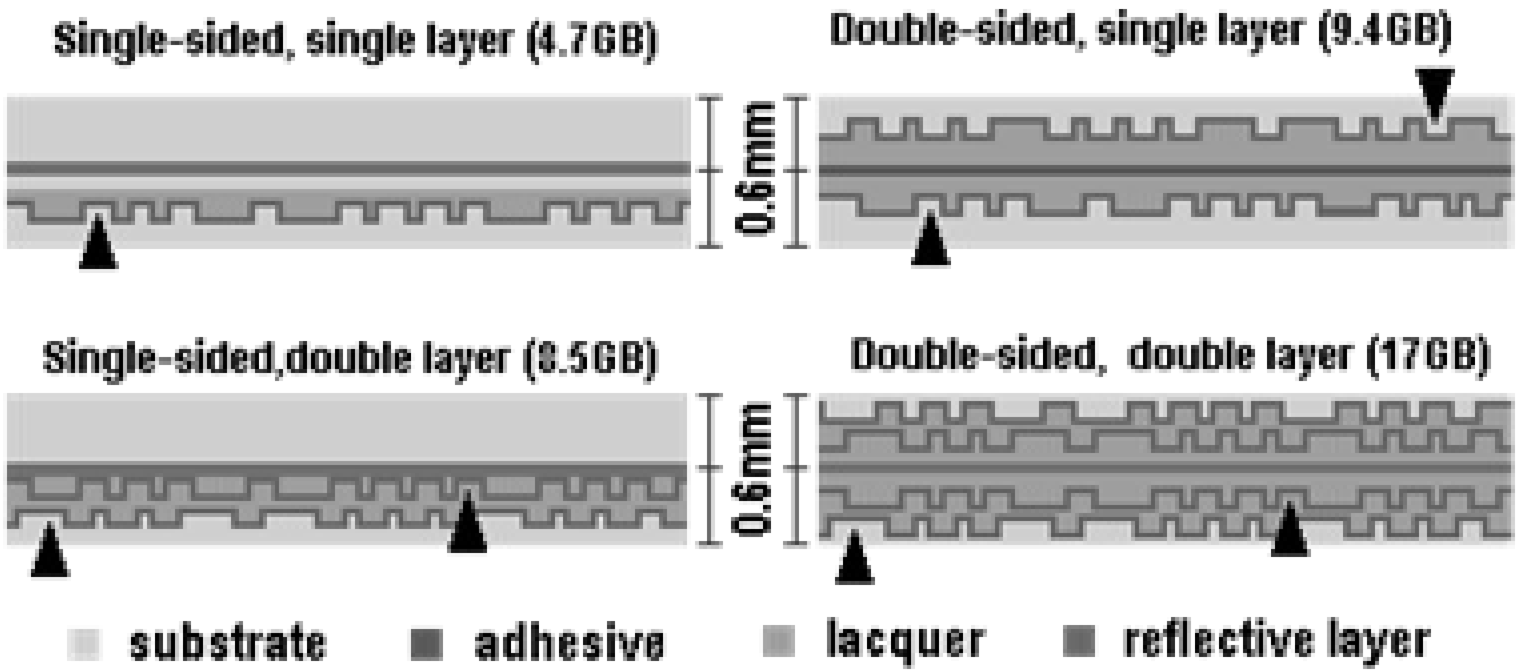


A CD can store up to 74 minutes of music, so the total amount of digital data that must be stored on a CD is:

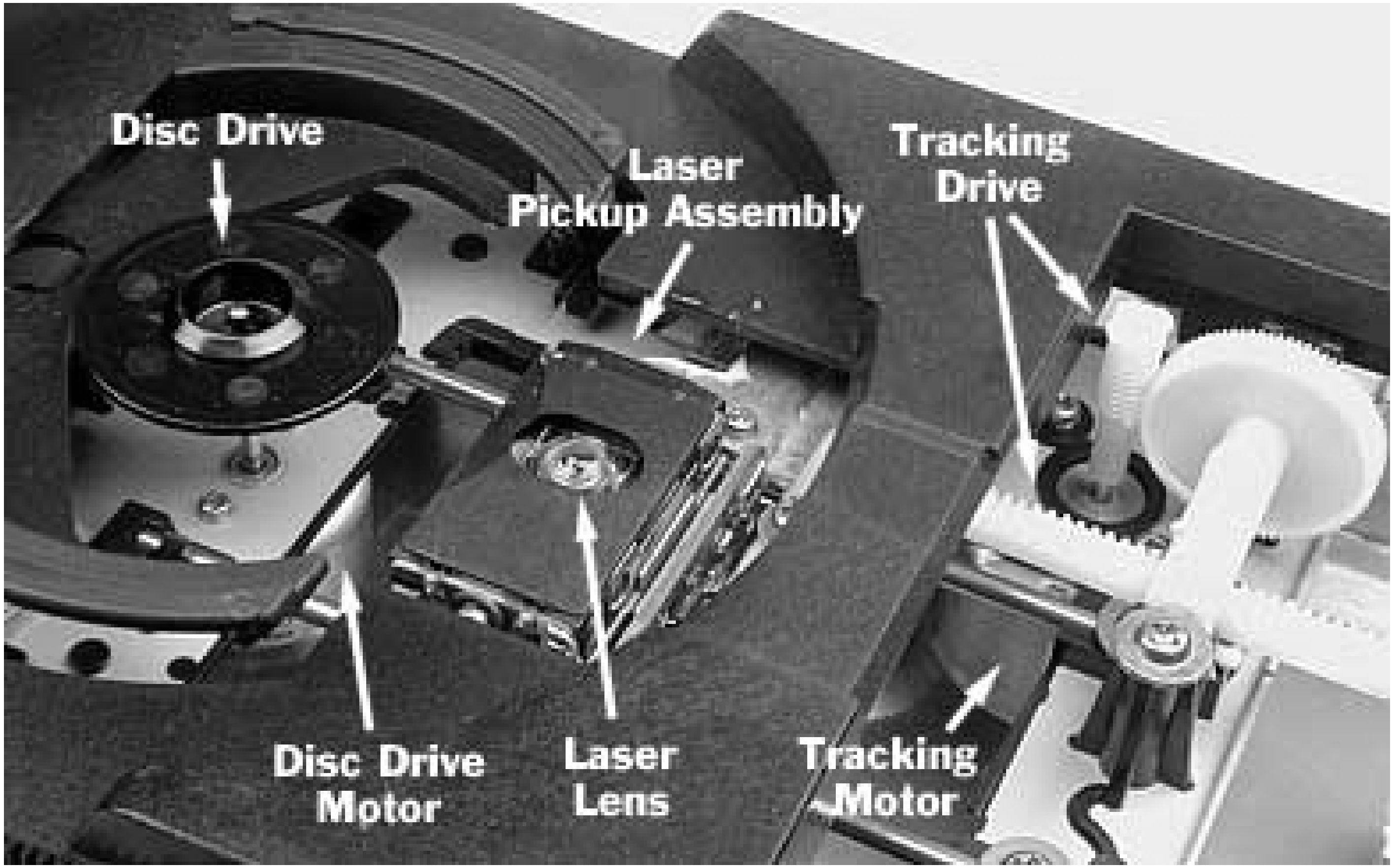
2 channels ´ 44,100 samples/channel/second ´ 2 bytes/sample ´ 74 minutes ´ 60 seconds/minute = 783,216,000 bytes

To fit more than 783 megabytes onto a disk only 12 cm in diameter requires that the individual bits be very small.

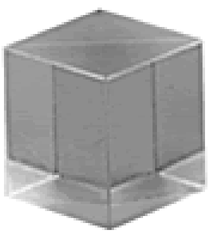
Different Types of DVD

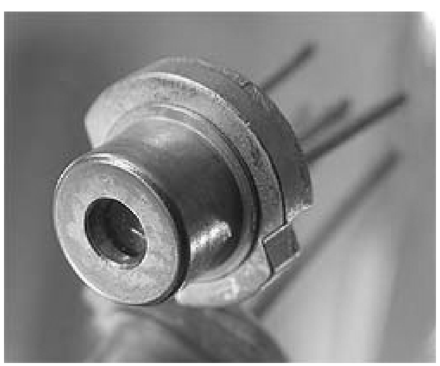


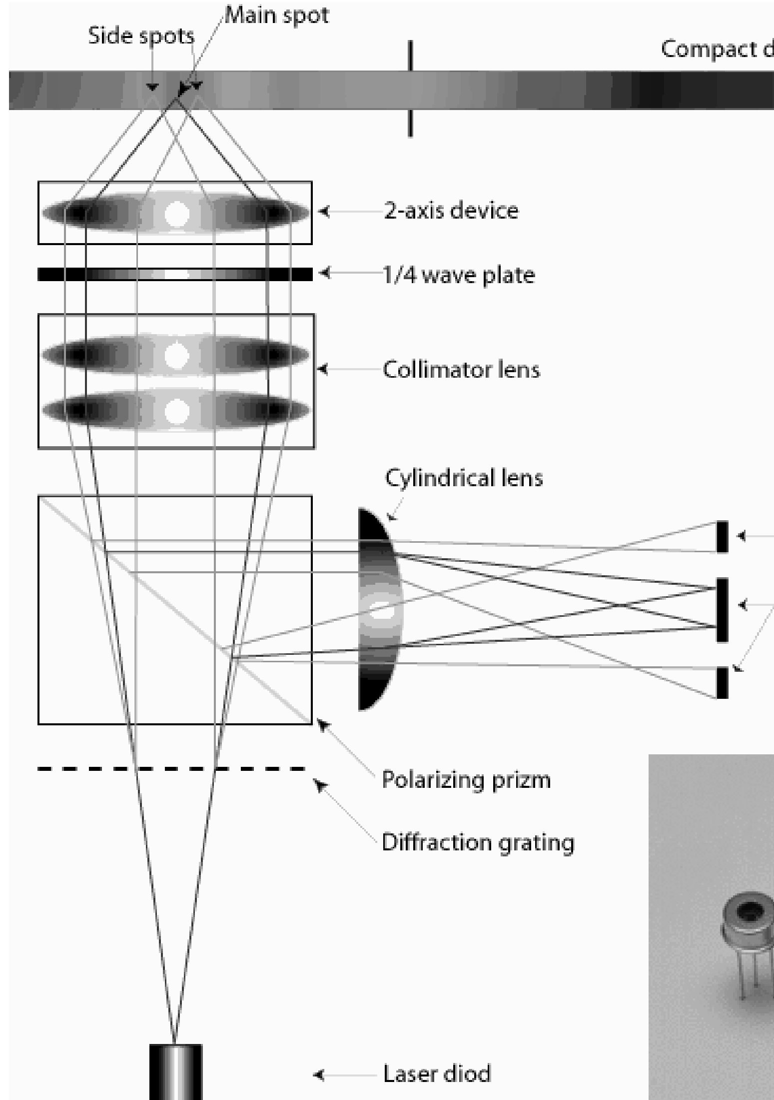
Inside a CD Player

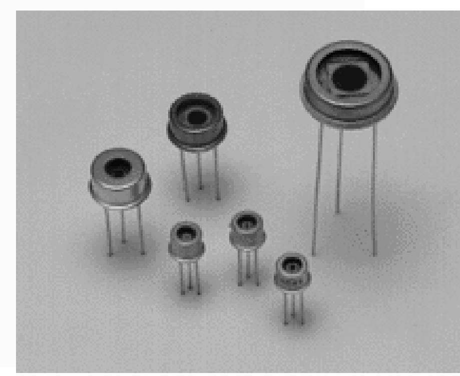


Optics of Readout

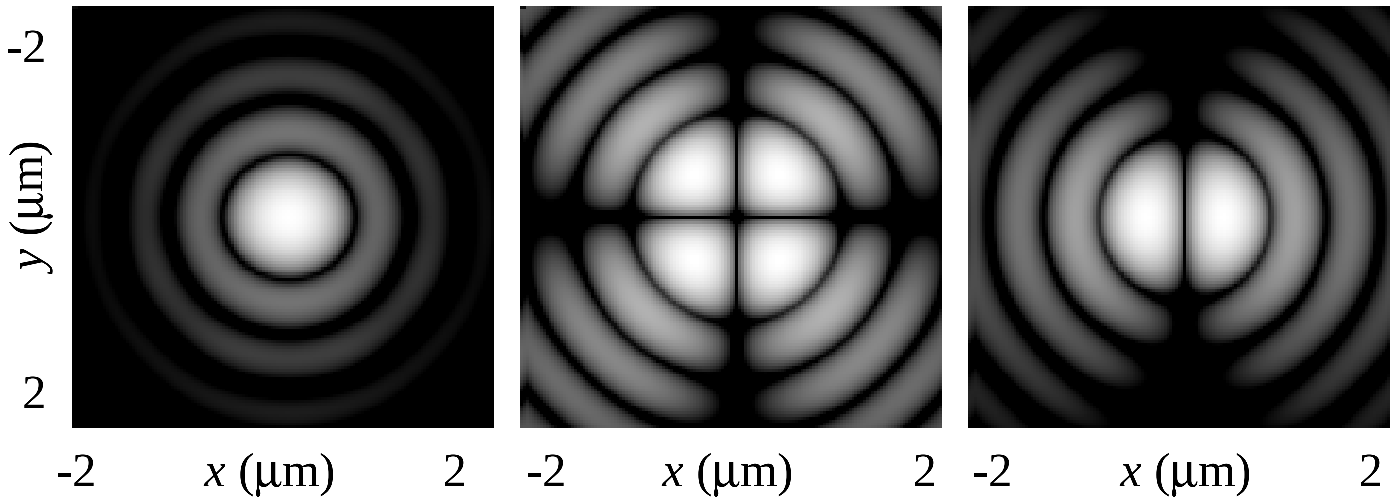






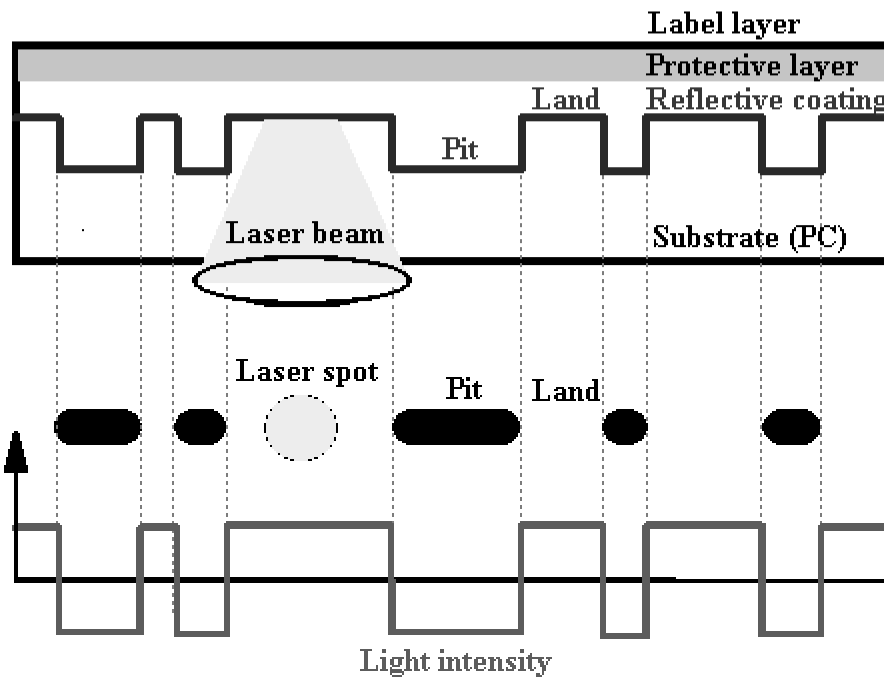


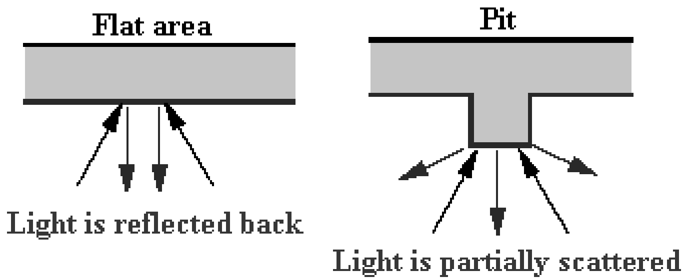
Intensity Distribution in the Focal Plane



Logarithmic plots of intensity distribution at the focal plane of a 0.615NA objective at λ = 633 nm. The incident uniform beam is linearly polarized along the X-axis. From left to right: X-, Y-, Z-components of polarization at best focus. The integrated intensities of these three components are in the ratio of 1 : 0.002 : 0.113.

Focused Laser Beam Reading the Pits on a CD Surface

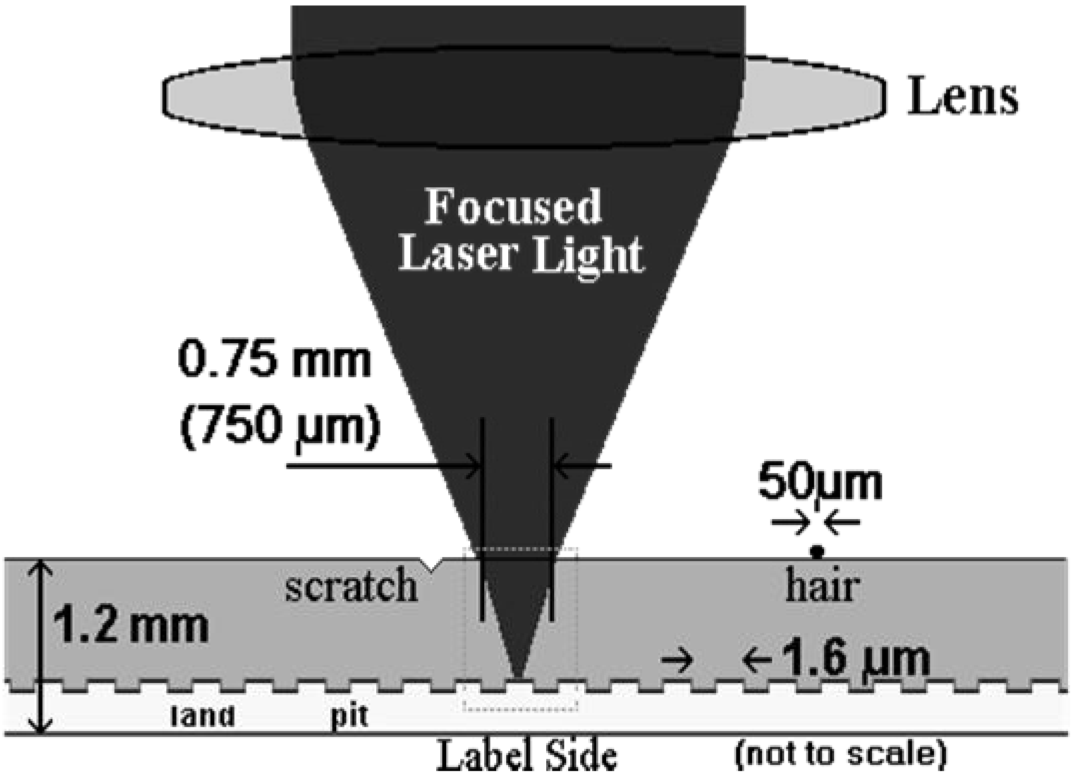




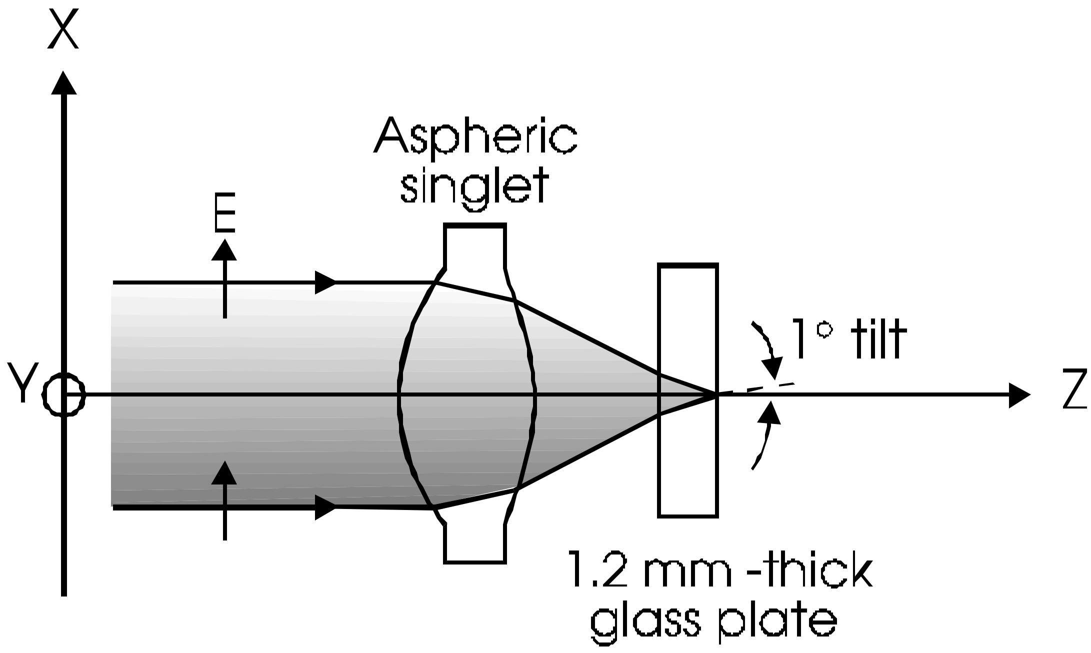
Pits are 120 nm deep and 600 nm wide. Laser beam scatters when it scans a pit, which translates into a drop in reflected beam intensity.

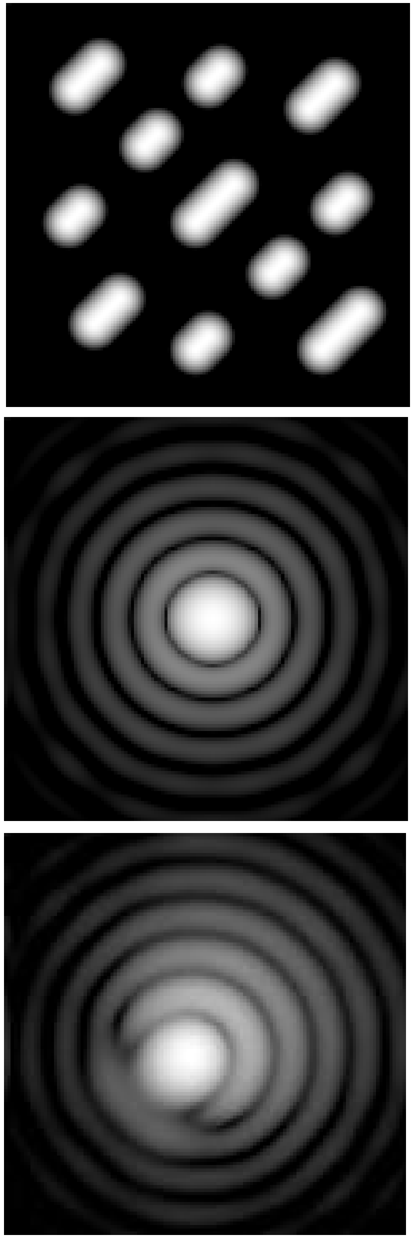
The laser beam (wavelength ~ 780 nm) is focused onto the data side of the disk (focused spot diameter ~ 1µm). The laser moves in the radial direction over the fast spinning disk and scans the data track.

Why Focus the Laser Light through the Substrate?

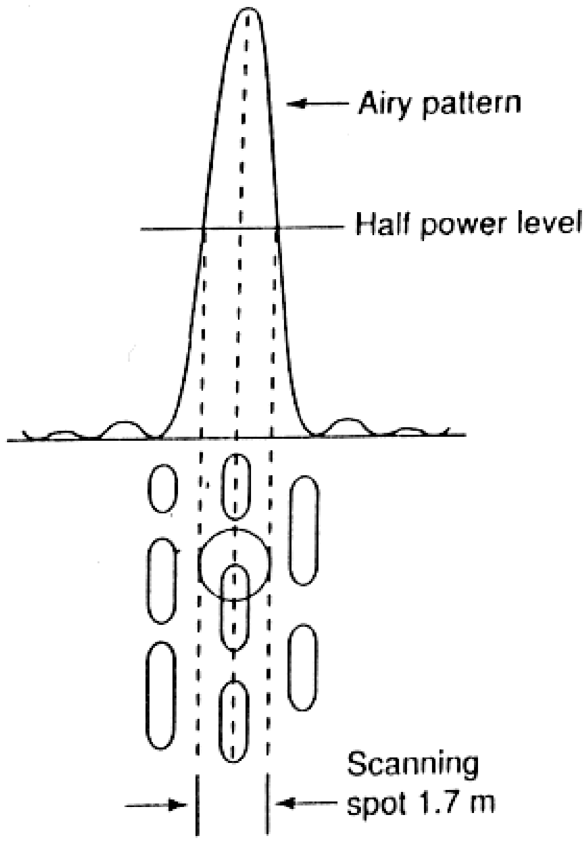


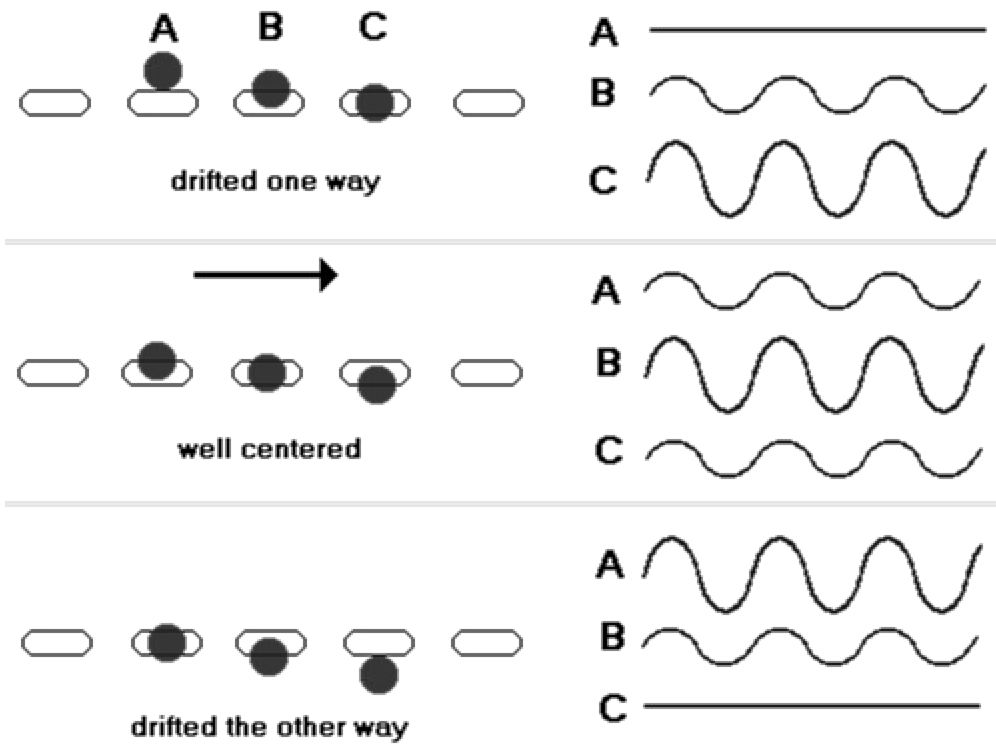
Substrate Tilt





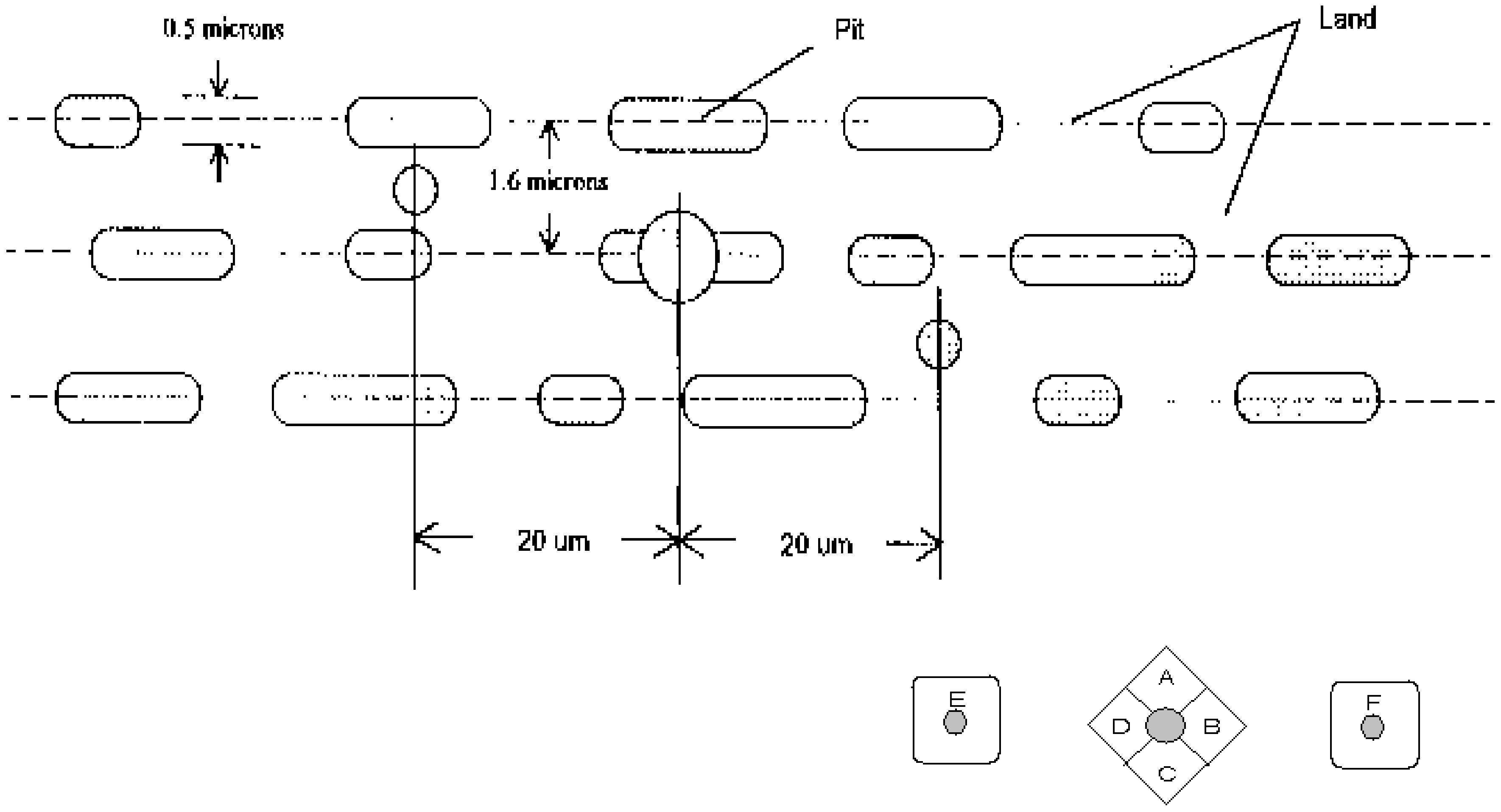
Three-beam Tracking



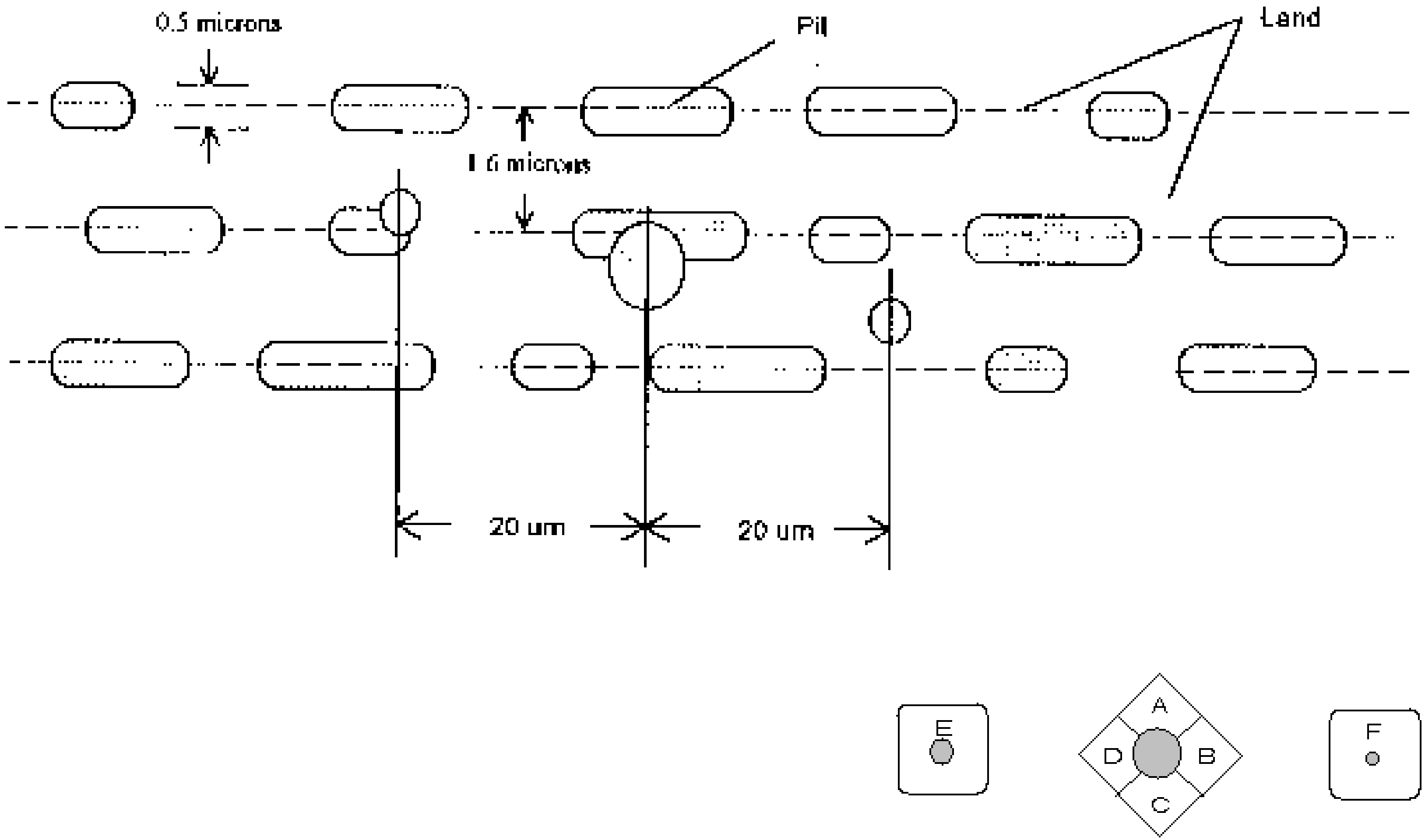


On the top and bottom frames, the central spot B has drifted to one side of the track and the modulation is greatest in one of the side beams A or C. In the center frame, the central spot B is correctly located over the track and the modulation from the central spot is a maximum.

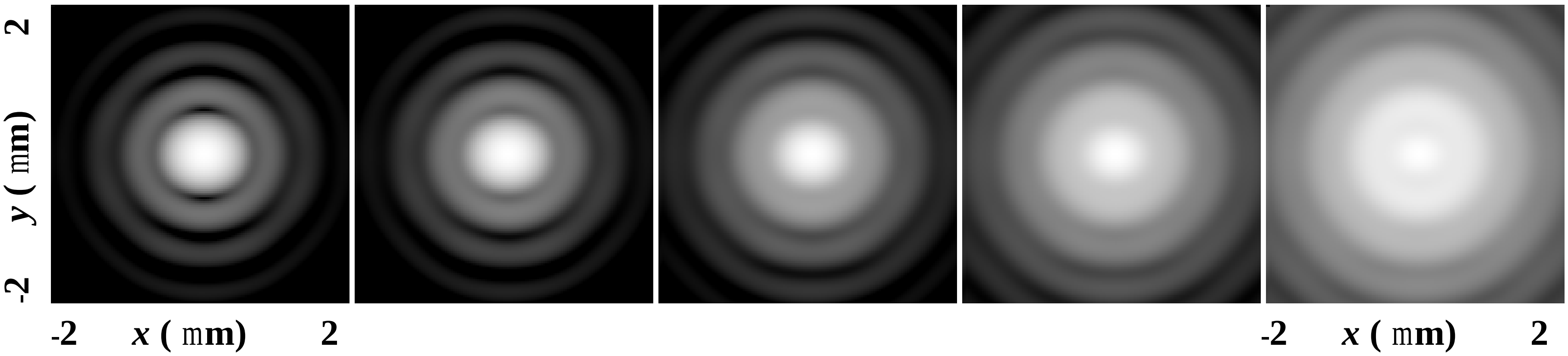
Three-Beam Tracking



Three-beam Tracking

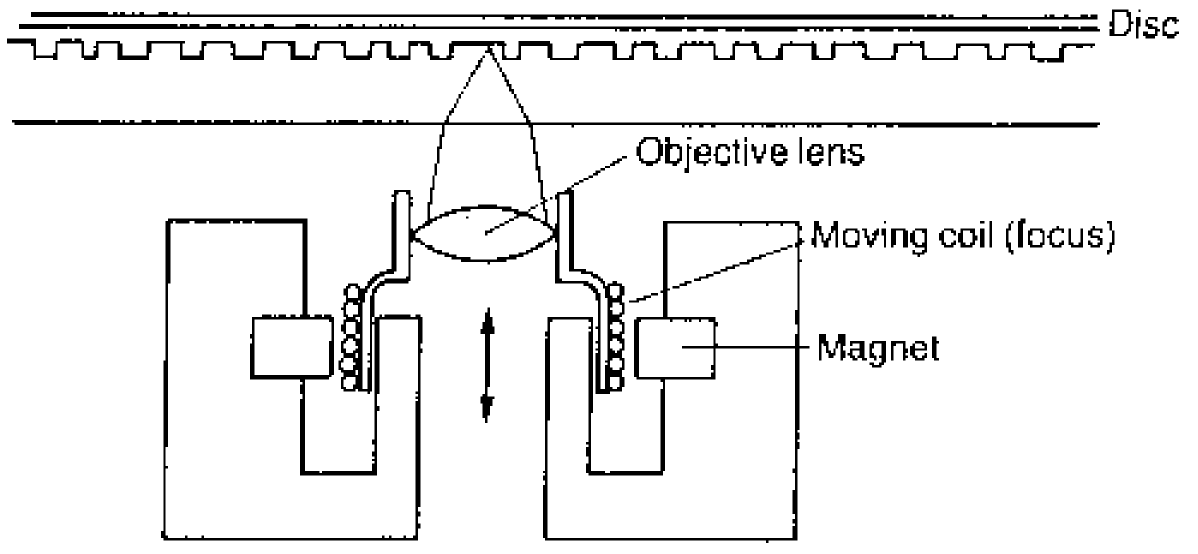


Effect of Defocus on Focal Plane Intensity Distribution



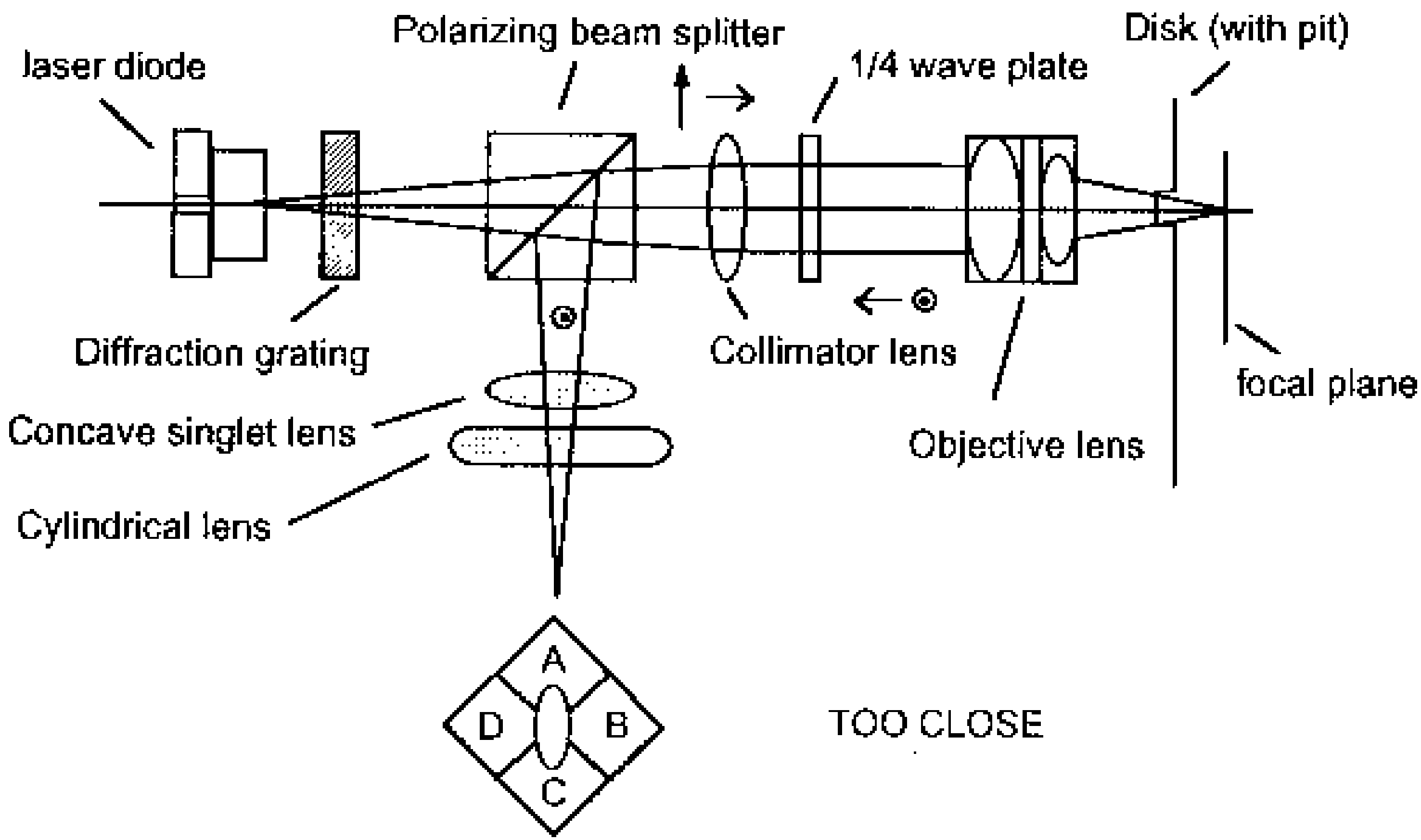
Logarithmic plots of total intensity distribution at and near the focus of a 0.615NA objective at λ = 633nm. From left to right: Δz = 0, 0.5μm, 1μm, 1.5μm, and 2μm. Because of symmetry between the two sides of focus the distributions for ±Δz are the same. At best focus the spot's FWHM is 0.57μm along X and 0.51μm along Y.

Focus Actuator

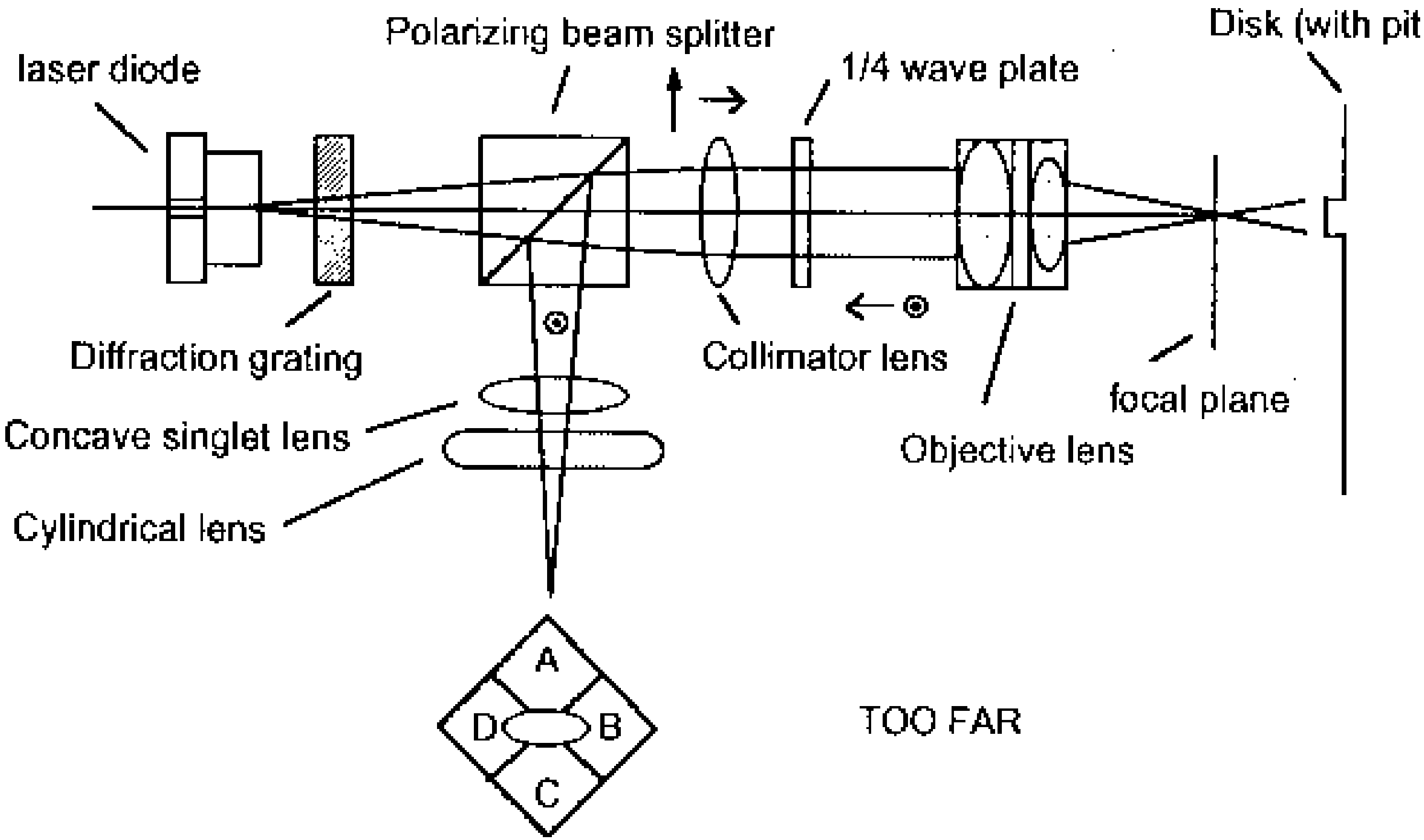


Inside the drive, the disk and the drive's optics are separated by a distance of about 1 mm, making mechanical interaction and crashes, even with wavy disks and imperfect clamping almost impossible.

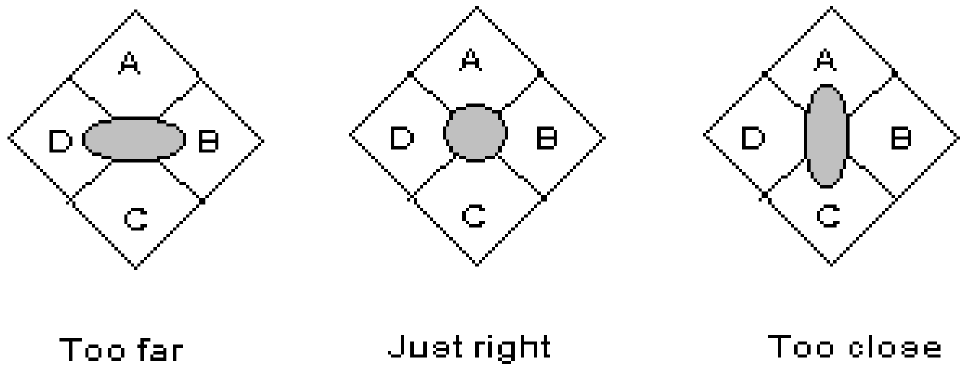
Automatic Focusing

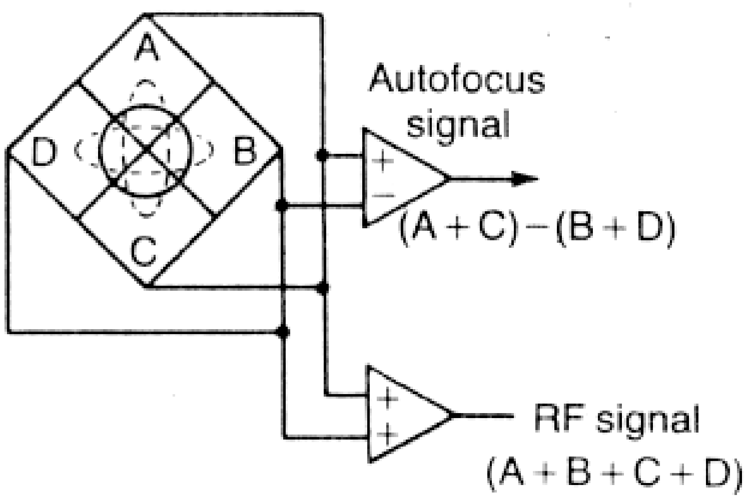


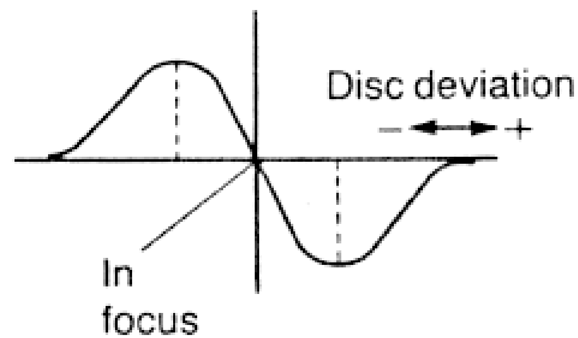
Automatic Focusing



Automatic Focusing







How Many 8-letter Words Are There?

AAAAAAAA
AAAAAAAB
AAAAAAAC
.
BROADWAY
.
CONSTANT
.
.
WILDCATS
.
ZZZZZZZZ

$26^8 = 208{,}827{,}064{,}576$

$2^8 = 256$

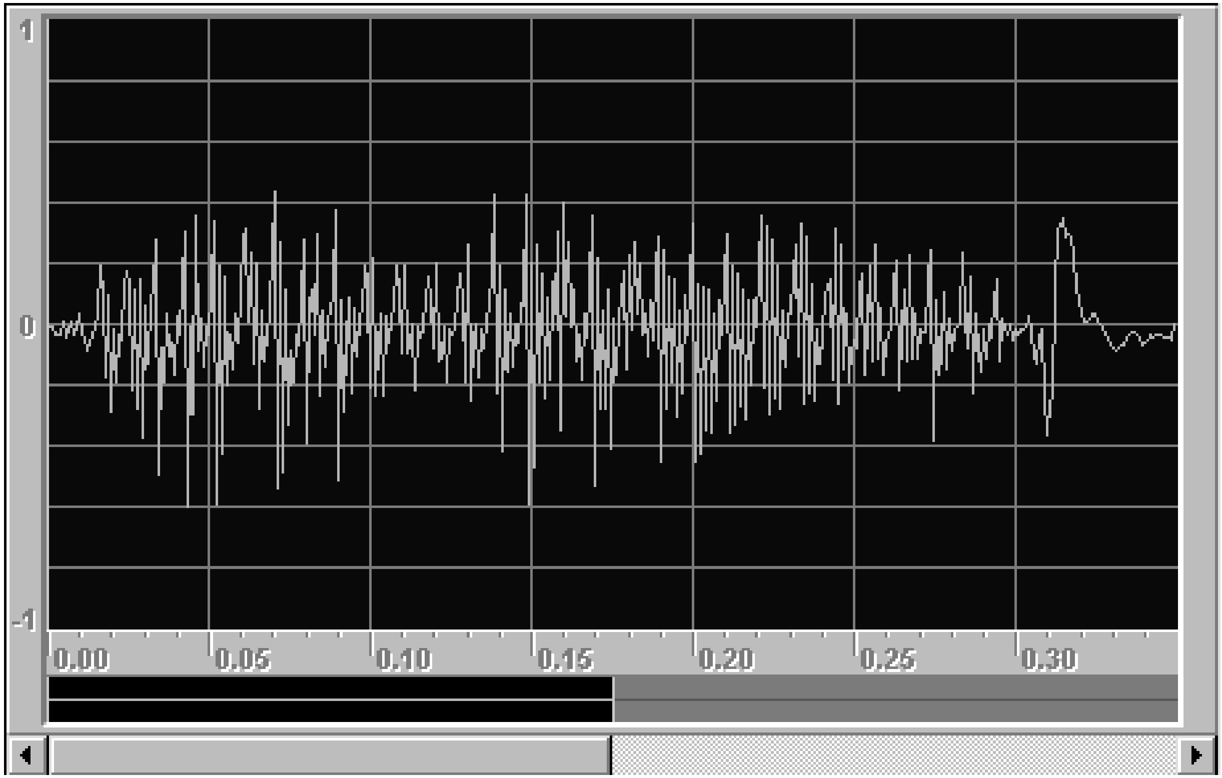
00000000
00000001
00000010
.
00100010
.
01001011
.
.
11100010
.
11111111

The ASCII Code

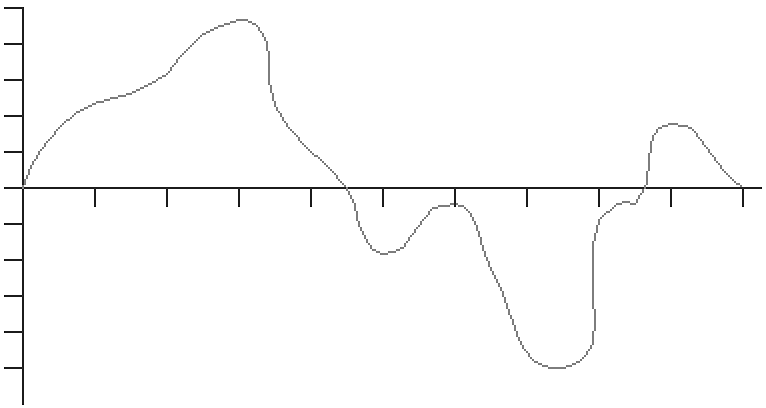
```
A → 00101101
B → 00101110
.
Z → 11011001
1 → 01010101
2 → 10101111
.
9 → 11001100
? → 10101001
  → 00101001
( → 11100010
.
.
```

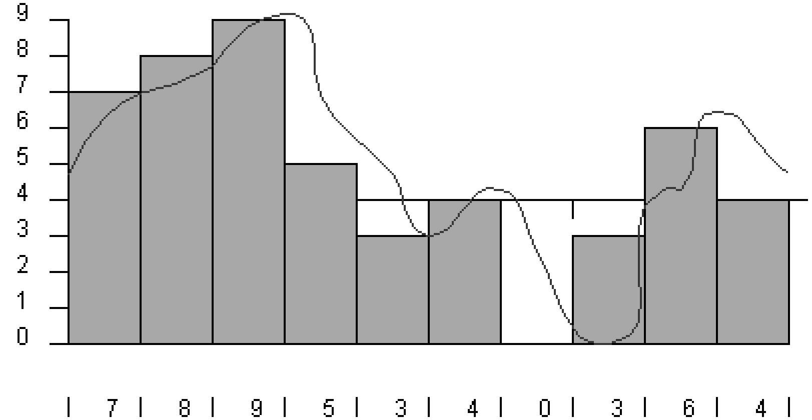
Any English text can therefore be translated into the language of 0's and 1's (the Binary Language) with the aid of the ASCII code.

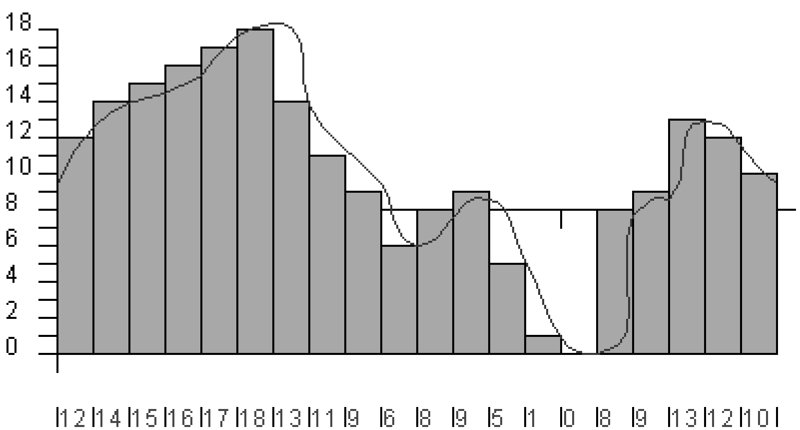
Audio Signal

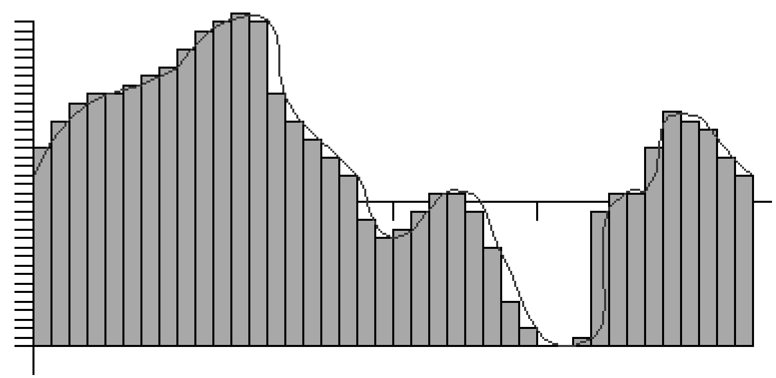


Electrical Waveform







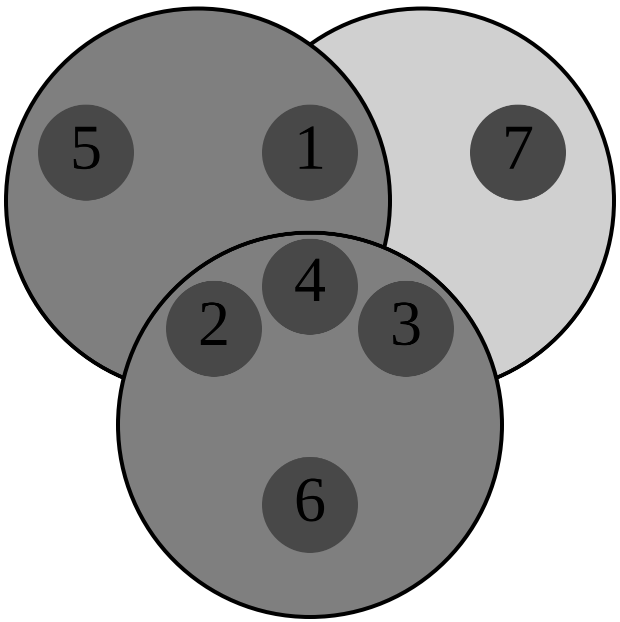


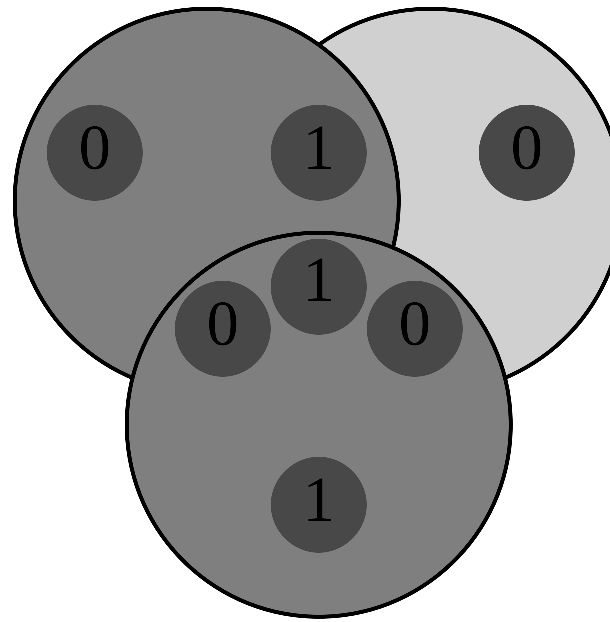
Sampling and Analog to Digital Conversion (ADC)

As the sampling rate and precision of analog to digital conversion increase, the fidelity (i.e., the similarity between the original wave and the “digitized” wave) improves. In the case of CD sound, the sampling rate is 44,100 samples per second and the number of gradations is 65,536 (corresponding to 16 bits per sample). At this level, the playback signal so closely matches the original waveform that the sound is essentially perfect to the human ear.

Error Correction Coding

Data Bits				Check Bits		
1	2	3	4	5	6	7
1	**0**	**0**	**1**	**?**	**?**	**?**



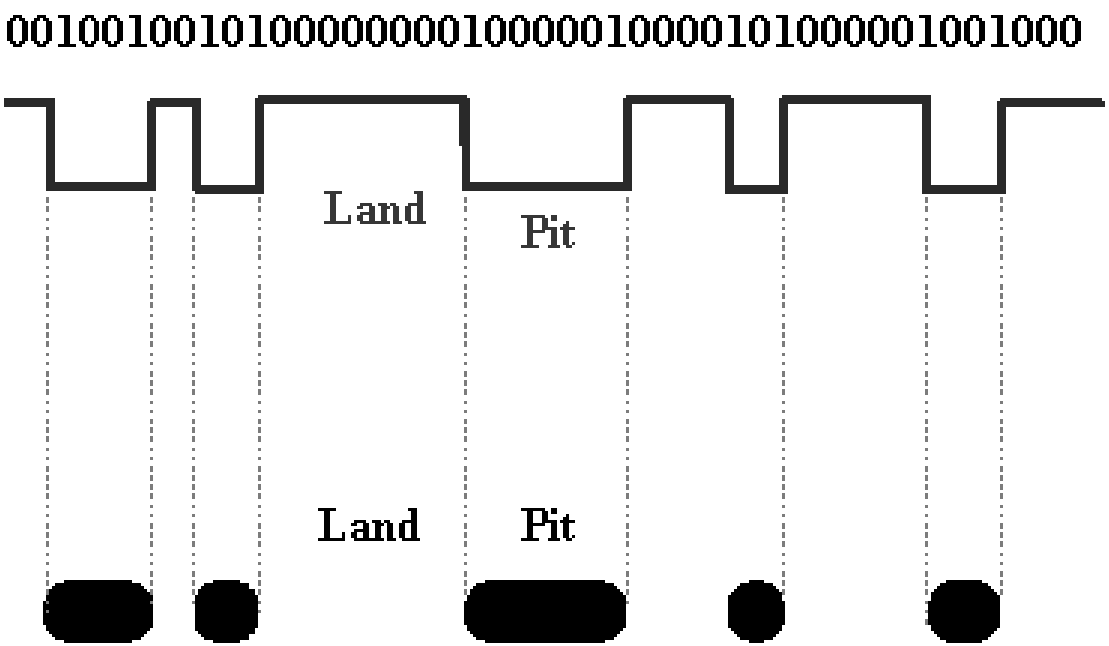


Sector Format

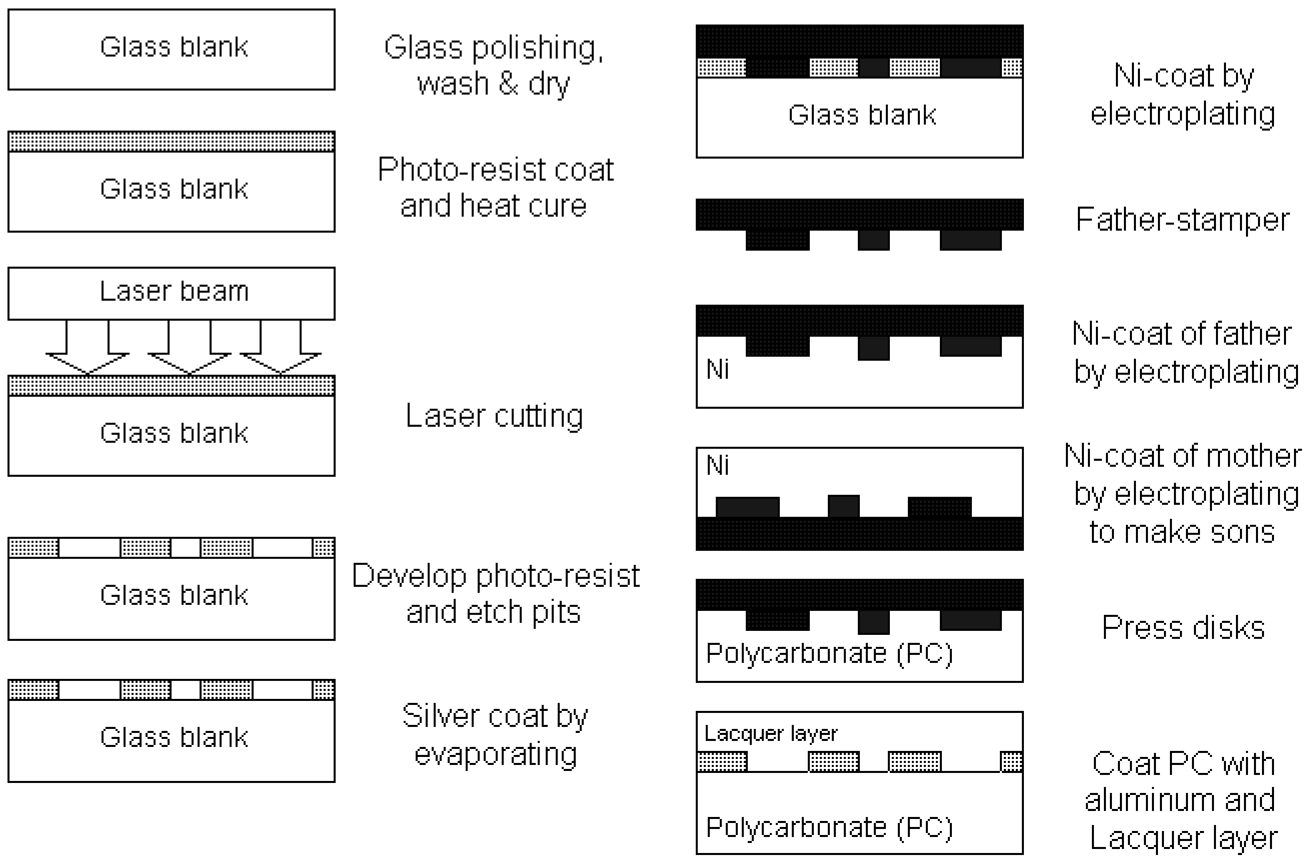
A basic unit of information stored on a CD is called a *frame*. The frame equals to 24 17-bit symbols combined with the synchronization pattern, a control and display symbol, and 8 error correction symbols. Frames are grouped together to form *blocks* (also called *sectors*). Each block has 2352 bytes of user data in the CD-DA standard or 2048 bytes in the CD-ROM standards (due to tighter error correction technique and more error correction bytes). The figure below shows structure of one CD-ROM block. The first CD drives played back 75 blocks per second, which translated into the data transfer rate 1X equal to about 0.15 MB/s.

00	FF x 10	00	MIN	SEC	SECTOR	MODE	DATA	LAYERED ECC
12 bytes (synch)			4 bytes (ID)				2048 bytes	288 bytes
<------------------------------------ 2352 bytes --->								

Translating Binary Digits to Pits



Mastering and Pressing Disks



Mastering and Pressing Disks

***Mastering* involves physical transfer of the data into the pits and lands. First, a layer of light-sensitive photoresist is spin-coated onto the clean glass master-disk from a solvent solution. Then, the photoresist is exposed to a modulated beam of a short-wavelength light, which carries the encoded data. Next, the master is developed in a wet process by exposing it to the developer, which etches away exposed areas thus leaving the same pattern we will find later on the CD. Next, the master is coated (using electroplating technique) with a thick (about 300 mm) metal layer to form a *stamper* - a negative replica of the disk. The photoresist layer is destroyed during this process, but the much more durable stamper is formed and can be used for CD replication. Usually, a stamper can be used to produce a few tens of thousands CDs before it wears out. Finally, the process of injection molding is used to produce a surface of the compact disk. Hot plastic (PC) is injected into a mold, and then is pressed against the stamper and cooled, resulting in the CD. At the very end, the pits and lands on the surface of a CD are coated with a thin reflective metal layer (aluminum), then coated with lacquer and supplied with the label.**

X Rating of CD-ROM Drives

The X ratings of CD-ROM drives are based on comparison with the first generation drives with the data transfer rates of 150 KB/s or 1X. Today's drives operate at more then 32X boosting data transfer rates beyond 4.8 MB/s, and the improvement has mostly come from the increase in spin rates. The other components have mostly remained unchanged. It seems at this point, that further increase in spindle speed may be impractical due to loss in drive performance.

Previously, CD-ROM drives (slower than 12X) were designed on the basis of the *constant linear velocity* (CLV) principle, where the angular speed of the drive (rpm) was continuously adjusted following the read head to keep the laser spot moving over the disk surface at constant velocity. This provided uniform spacing of the pits along the track and a constant data transfer rate independent of head positioning over the disk. At some point, this principle was sacrificed to keep up with the need for faster motors, which is much easier to achieve with the constant-angular speed motors. The newest CD drives operate at *constant angular velocity* (CAV). Now, the transfer rate is a function of the data radius. This also means that the average data transfer rate of the drive is much lower than the drive's maximum rate specified by its X-rating.

Plenty of Room at the Bottom

Suppose, to be conservative, that a bit of information is going to require a little cube of atoms 5 ´ 5 ´ 5, that is 125 atoms. Perhaps we need a hundred and some odd atoms to make sure that the information is not lost through diffusion, or through some other process. I have estimated how many letters there are in the Encyclopaedia, and I have assumed that each of my 24 million books is as big as an Encyclopaedia volume, and have calculated, then, how many bits of information there are (10^{15}). For each bit I allow 100 atoms. And it turns out that all of the information that man has carefully accumulated in all the books in the world can be written in this form in a cube of material one two-hundredth of an inch wide -- which is the barest piece of dust that can be made out by the human eye. So there is *plenty* of room at the bottom! Don't tell me about microfilm!

Richard P. Feynman, December 1959