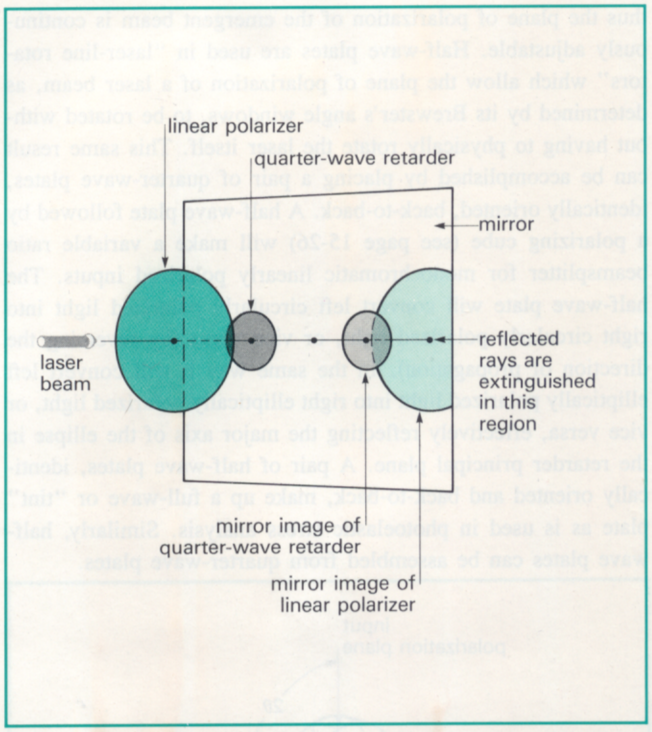
# OPTICAL ENGINEERING NOTE #12:
# VIDEO DISC PLAYER GUTS

Optical disc readers are everywhere. Although they may read a variety of formats, audio, video, or data, they are all a variation of an optical isolator system.

The unit demonstrated in class was purchased from MWK Industries*. It came out of an early '80's Pioneer Video Disc Player, which read 12" discs with digitally encoded video frames. This format did not become as popular as hoped, unlike the ubiquitous 4" audio or CD-ROM. Perhaps this form of video record will return with the advent of HDTV.

Light from a polarized laser, in the case of our sample a Helium Neon, but more commonly a diode laser emitting at 780nm, first passes through a diffraction grating to generate multiple spots, with the central zero order picking up information while the plus and minus first orders ensure tracking in the groove. A lens to focus the beam to a small spot onto the disc follows. In contemporary CD's the lens is last.



**QUARTER-WAVELENGTH RETARDER ISOLATOR CONSTRUCTION. The incident laser beam encounters first the polarizer, next the quarter-wave retarder, and finally the mirror. Specular reflections (not diffuse reflections) are extinguished upon their return to the polarizer. The crystalline optic axis of the quarter-wave plate must be oriented at precisely 45° to the plane of polarization (plane of allowed electric field vector orientations) of the polarizer.**

Figure One: Optical Isolator Circuit, from Optics Guide by Melles Griot.

The next optic is a **polarizing beamsplitting cube.** It is composed of two right angle prisms, cemented together along their hypotenuses with a dielectric coating that lets almost all the light of one polarization vector orientation pass while the other reflects. At this point the laser beams polariztion is oriented so that almost all the light will pass.

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*MWK Industries,

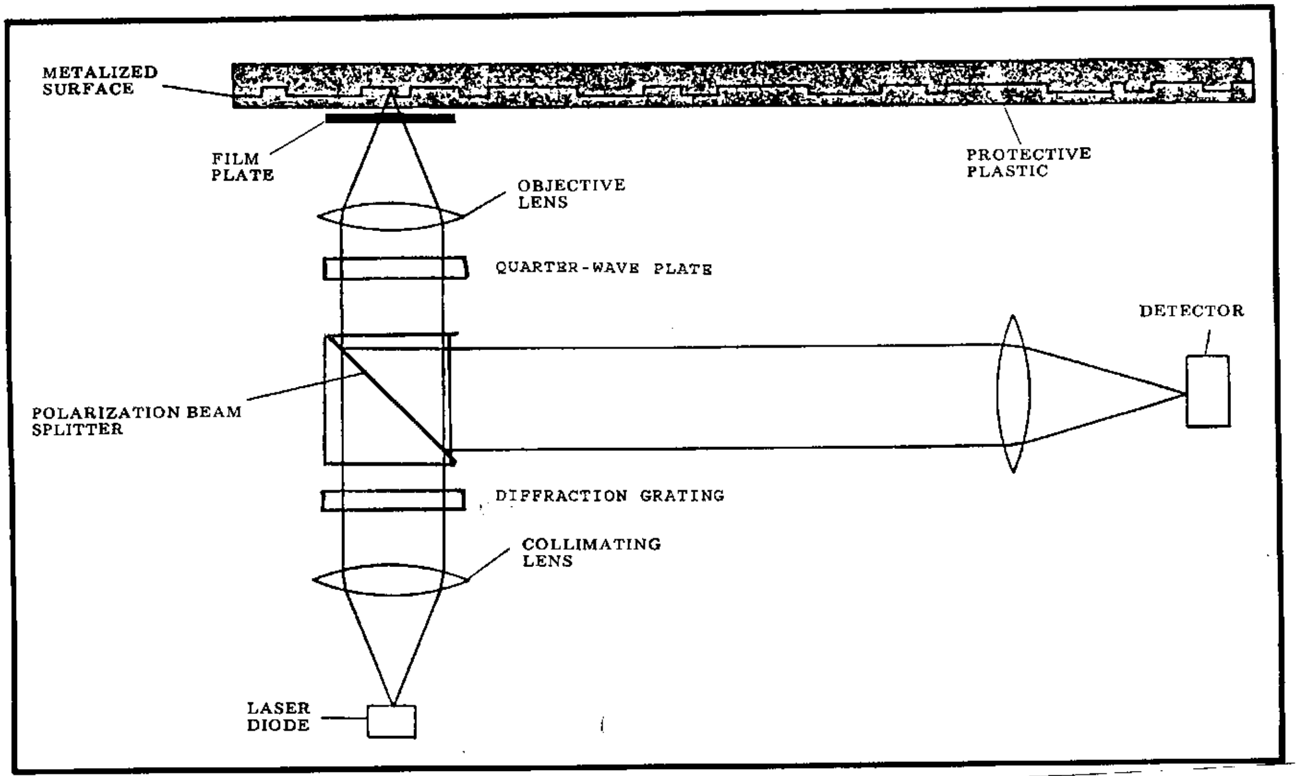

**Figure One: Digital Disc Reader Design, not exactly like the one in class but close enough, from <u>holosphere</u>, Volume 15, Number 1, Spring 1987, "The Department of Partly-Baked Ideas."**

**After the cube, the light encounters a 1/4 wave retardation plate with its axis oriented to circularly polarize the incoming linearly polarized light. When the circularly polarized light incident along the normal to the disc is reflected off of its metallic coating, the returned beam is still circularly polarized but in the <u>opposite</u> sense; e.g., if the light were polarized in a clockwise sense, then it is retroeflected in a counterclockwiswe direction.**

**The return beam encounters the 1/4-wave plate, and since this optic can change linearly polarized light into circularly polarized light, it can then revert circularly polarized light into linearly polarized light. However the circulary polarized light's polarization vector is spinning opposite to the way it entered; the light exiting the retardation plate is reverted to linearly polarized light, but at an orientation at 90 degees from the way it entered.**

**Now the beam heading directly back to the laser encounters the polarizing beamsplitting cube, but this time with its polarizing vector set not to pass but to reflect off the cleave in the cube. It emerges from the cube's side, and there the three beams are**

focussed by very short focal length cylindrical lenses onto the detectors which control the tracking of the beam and the information readout.

This sample is much larger than the read heads that come with the typical CD player nowadays. The diode laser is part of the package, but the optical layout is the same, as evidenced by the Tee-shape of the unit. But in the early '80's diode laser technology was not as mature, so the decision was made to incorporate He-Ne lasers into these early, over-designed first consumer generation players.

**BONUS TRACK!** The original article from <u>holosphere</u>, Volume 15, Number 1, Spring 1987, "The Department of Partly-Baked Ideas," which yielded the illustration of the reader.

## DPBI

Ed Wesly

Manufacturers brought out videodiscs not just to improve prerecorded video images but also to prevent bootlegging of programs, since expensive equipment is necessary to replicate them, unlike the videocassette. The demise of the disc was due to lack of standardization. Three systems appeared on the scene simultaneously, so none could survive splitting up a small market. Audio discs seem to be doing much better, since all discs work in all players. Sources of audio discs, also known as Compact Discs, herein referred to as CD's, smugly assert that their products deliver better sound reproduction, and charge about twice as much for a CD as for a record or cassette. They must feel that they are invulnerable to the pirating that occurs with the audio cassette.

Or are they? Certainly producers of embossed security holograms thought that they were counterfeitproof, but Jeff Blythe has blown that ship out of the water.[1] Could it be possible to duplicate the CD holographically?

This is not such a silly idea. The CD works optically, and as readers of this magazine we all believe that a hologram is the optical equivalent of the object holographed. In principle then the hologram of the CD should work just as well as the original!

The problems in attempting to prove that this works are not insurmountable. A Denisyuk recording scheme would be the logical way to start, simply contact copying the disc should suffice. The major obstacle is to get the hologram to replay at the wavelength of the laser in the disc player. CD units use near IR laser diodes, so if the disc were copied using He-Ne there would not be good Bragg diffraction at the longer wavelength. Swelling with triethanolamine could work, but trying to fine tune the reconstruction color in the infrared could be painstaking.

What I propose is to simply place the holographic film next to the disc and expose it as it plays! Our research at Northwestern University has shown that Agfa 10E75 has some sensitivity at 780 nm as we have made holograms on it using a Diolite IR Laser. I assume that 8E75HD has a similar spectral sensitizing dye or perhaps a more suitable recording medium could become available in the future.

Exposure could be accomplished while the unit is running as then the reference angle will be exactly duplicated. A possible problem is that the thickness of the film may not let the information be read properly. The test would be to listen if the disc is being played while exposing. Good fringes will be formed regardless of the spinning motion, as it is the relative phase of the incoming beam and the one returned from the disc's surface that count. So the film must be stuck to the CD rather well. Because the beam interrogating the disc is focused well, there is the slight possibility of over exposing the film on a single playing/exposure, but what is more likely is that many passes are necessary or to run at a slower speed to suitably darken the film. A non-shrinking develop-rehalogenating bleach processing scheme like CWC2 is a must.

This magazine is prepared to give a *Lloyd Cross Award* to anyone who can make this work. It would certainly be fun if holographers could have their own exclusive disc-swapping network!

References

1 Jeff Blythe, *Security Display Hologram to Foil Counterfeiters*, Proceedings SPIE Volume 615, (1985) p. 18.

2 D. Cooke, A. Ward, *Reflection-hologram Processing for High Efficiency in Silver-halide Emulsions*, Applied Optics, Volume 23, No. 6, 15 March 1984, p. 934.

# Spinning Sound in a Different Direction

Although the invention of the compact disc system seems fairly new, its development has been ongoing for almost two decades now. In 1974, Philips Corp. of the Netherlands investigated the possibility of digitally encoding information on optical disc. Simultaneously, Sony Corp. of Japan studied methods for error correction of an optical, audio disc. While several other companies were also exploring the concept, in 1979 Philips and Sony decided to collaborate. Within the next few years, the semiconductor laser and signal processing for digital/analog (D/A) conversion had advanced to the point that the first compact disc system could be unveiled in 1982 in Japan and Europe; it arrived soon after in the U.S.

## CREATING THE MASTER

To fully comprehend the compact disc system, the manufacturing and encoding process of the compact disc must first be understood. To make the original disc, a glass plate is lapped, polished, cleaned, and inspected in a clean room, placing rigid restrictions on flatness and surface roughness. A uniform layer of photoresist is then applied to the plate with a spin-coater (Fig. 1a). Adjustment of the speed of the spinner rotation and the viscosity of the photoresist set this layer thickness at 0.1 μm.

Because photoresist is sensitive to ultraviolet light, a low power laser such as argon (457.9 nm) or He-Cd (441.6 nm) is focused onto the coated plate to encode information. The laser modulation is synchronized to the digitally recorded signal, which was sampled in stereo at 44.1 kHz.

The photoresist reacts where it has been exposed to the laser light and, upon development, erodes in these areas, leaving pits behind (Fig. 1b). These pits have a constant width of somewhere between 0.5 and 0.8 μm, a depth of 0.1 μm (exposed photoresist is entirely consumed), and consist of nine different lengths ranging from 0.87-3.18 μm. The resulting pattern of pit lengths and flats (areas between pits) on the disc functions as a map of the originally recorded signal. Digital recording also allows the inclusion of subcoded nonaudio information on the disc, such as a "table of contents" including the track number, duration of selection, and total elapsed time.

A helical track (total length of 5 km) is created by slightly moving the light beam perpendicularly to the track as the disc rotates. Unlike a record, this track begins at the inside of the disc and spirals outward. An optical feedback system sets the track pitch (spacing) at 1.6 μm. The glass master has now been formed.

## SETTING THE STAGE FOR MASS PRODUCTION

A metal counterpart (the "metal master") to this glass master is then created by sputtering a layer of silver onto the exposed and developed photoresist, and immersing the resultant in a nickel bath (Fig. 1c). The final series of "stamper discs," also made of nickel, are produced from metal submasters via a mother disc transfer (Figs. 1d and 1e).

Thousands of compact discs can be created from each stamper by compression molding, injection molding, or photo polymerization (Fig. 1f). Because of its low vapor absorption, heat resistance, and malleability, polycarbonate material is most often used for this step. A 100-nm layer of aluminum, silver, or gold is evaporated onto the pit surface for reflectivity. For protection, a 10-μm acrylic layer is then applied using spin-coating, and is ultraviolet cured (Fig. 1g). The label adheres to the top of this layer.

## DECIPHERING THE CODE: DISC PLAYBACK

The compact disc player views the disc from below through the polycarbonate layer, seeing pits as bumps. Because the signal is recorded at a constant velocity of 1.2-1.4 meters per second, the rotational speed upon playback must decrease from 8 to 3.5 revolutions per second as the beam travels from the inside to the outer edge of the track, to replicate the sound correctly.

The disc rotates in the direction opposite from a conventional phonograph. However, since the laser (analogous to the phonograph needle) views the disc from below while a phonograph needle plays from the top of a record, the functional direction is the same.

To increase the accuracy of the playback, the disc is commonly oversampled with a digital filter at some integer multiple of the base 44.1 kHz sampling rate. Products on the market today can oversample as many as eight times.

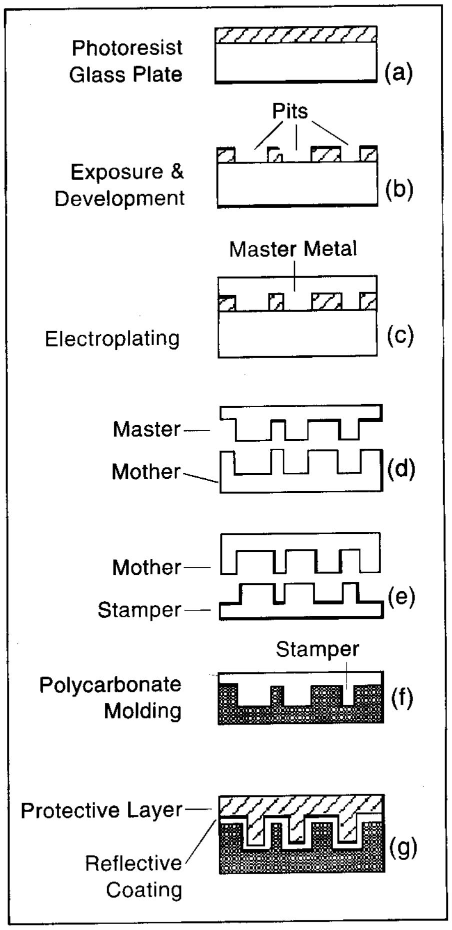

**Figure 1**. Compact disc manufacturing process.

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## LOOKING INSIDE YOUR CD PLAYER

The optical portion of the disc player is called an Optical Pickup System (Fig. 2). As the disc rotates, the optical pickup system follows the track on the disc and reads the information encoded there. A typical GaAlAs laser beam (780 nm) passes through a diffraction grating; the resultant primary beam reads data. The two first order beams keep the central beam on track by using a feedback circuit to ensure that each stays on a continuous flat on either side of the pit track being mapped. The output power of the semiconductor laser is controlled using feedback from a monitor photodiode positioned adjacent to it.

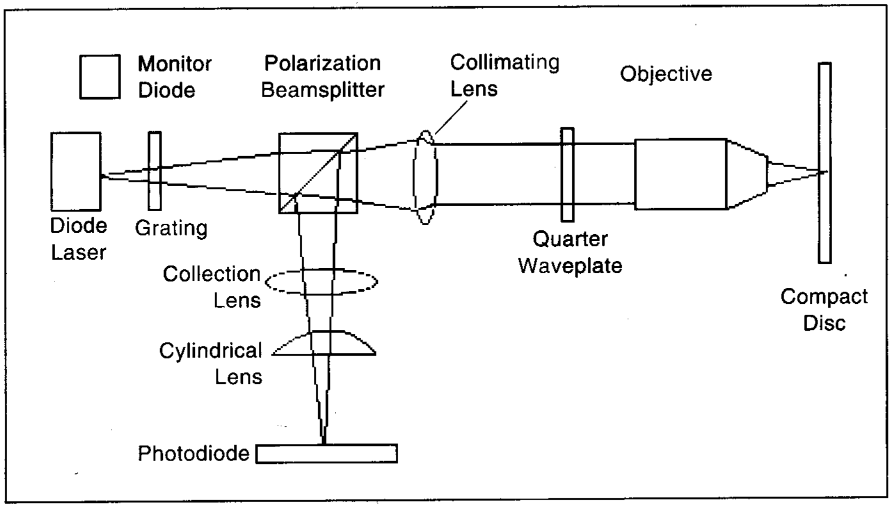

**Figure 2**. Optical pickup of compact disc player.

The next element in the light path is a polarization beamsplitter, which passes horizontally polarized light to a collimating lens (it may sometimes be placed before the beamsplitter). A quarter waveplate introduces a phase shift, and then an objective lens focuses the beam down to the disc surface.

To allow for disc tilt [proportional to $\lambda/(\mathrm{NA})^3$], inconsistent disc thickness [$\lambda/(\mathrm{NA})^4$], and appropriate depth of focus [$\lambda/(\mathrm{NA})^2$], the ratio of the wavelength to the numerical aperture of the focusing lens must be $\leq 1.75$. Since the refractive index of the polycarbonate layer is 1.55, the thickness of this layer is specified at 1.2 mm such that at the reflective surface of pits and flats, the beam diameter measures 1.7 μm—only slightly larger than the pit width of 0.5 μm.

The reflection from a flat area between two pits almost equals the intensity of the incident beam, and the reflection from a pit (bump from this side) is very close to zero. Because the pit depth has been fixed at approximately one-quarter of the wavelength of the laser light in polycarbonate (0.1 μm), destructive interference occurs between the part of the beam reflected from the pit and that reflected from the flat. This information translates into binary code by tagging a change in intensity as a 1 and no change as a 0.

The encoded beam reflects off the disc and passes back through the lens system, which includes another phase shift at the quarter waveplate. Therefore, it is vertically polarized when it reaches the polarization beamsplitter, and reflects at 90°, to the photodiode leg of the system.

At this point, the beam passes through a collection lens followed by a cylindrical lens. This focuses the beam onto a four-quadrant photodiode, which has a dual purpose. It first serves as a feedback system to keep the laser properly focused onto the disc. To correctly transmit interference data on such a small scale (there is only a 100 nm difference between pit and flat), the system must be focused to within a tolerance of ±0.5 μm. When the beam converges to its focal point at the reflective surface of the disc, the laser spot is centered on the quad-cell, implying correct objective positioning. If the lens position is incorrect, astigmatism creates an ovular spot. An iterative communication loop between the photodiode and the system electronics then corrects the error.

This photodiode also translates the optical data received into the electrical information that eventually becomes sound. The radio frequency (RF) signal from this unit consists of a pattern of high frequency sine waves that are transformed into square waves. This signal is demodulated, demultiplexed, and corrected for error to create the digital audio information. At this point, D/A converters and low-pass filters (both analog and digital) generate the signal, which is amplified for the loudspeaker.

Compact disc system development continues today. Significant advances have already been made toward the replacement of infrared lasers with blue/green diode lasers. Shifting to a shorter wavelength would increase the efficiency and information capacity of the discs substantially. The disc substrate thickness may be cut in half in the future as well. Designers look toward shrinking the disk drive height and decreasing the complexity of the optical design. Perhaps the price may even shrink as a result.

## FURTHER READING

Benson, K.B., *Audio Engineering Handbook*, McGraw-Hill, New York, N.Y. 1988.

H. Nakijima and O.Ogawa, *Compact Disc Technology*, Ohmsha,Ltd., Tokyo, 1992.

Pohlmann, Ken C., *Principles of Digital Audio*, Howard Sams & Co., Indianapolis, Ind. 1985.