PhotoCD—Music for Your Eyes—Part 1

The marriage of a digital data distribution product and conventional photography is a major new development in imaging. In this two-part article, Dennis Howe discusses the evolution of the Kodak PhotoCD system and reviews its important technical characteristics. The level of detail given should enable optical engineers to assess whether the PhotoCD or compact disc based optical data storage will be useful for enhancing products they are working on.

This is a story about how technical innovation in one industry (consumer audio electronics) affected market driven product development in a completely different industry. The Kodak PhotoCD system marries traditional silver halide photography with modern electronic image manipulation and storage technology. The technical basis for PhotoCD is a writeable (*i.e.*, user recordable) compact disc, an evolutionary variation of the Digital Audio Disc music system introduced by Philips and Sony in the early 1980s. This article reviews some of the issues pertinent to the novel use of this commercially viable (low cost) new data storage and distribution medium. It is hoped that it will benefit optical engineers interested in incorporating such a storage system in a product.

The PhotoCD Product Concept

It is clear that modern video cameras, and even today's electronic still cameras, cannot equal the quality of silver based photographic systems. It is also clear that electronic imaging has much to offer. The basic purpose of PhotoCD is to provide an electronic "back end" to silver based photography that would allow simple TV display of images that are *visibly* "better than the best" images that could be provided on a soft display by any reasonable cost electronic image capture technology. (Other features include user-interactive image manipulation—zooming, panning, etc.—and, with the help of a PC, enhancement, editing and electronic distribution of the images.) The perceived quality of the images obtained via PhotoCD is very important; in addition to providing a pragmatic product link to the future world of electronic imaging, Kodak is counting on PhotoCD to extend the life of silver based photography. To emphasize this, the role of PhotoCD was expanded to include positioning the PhotoCD disc itself as a digital negative that could be used as a source of high quality color prints and enlargements. (As we shall see, this significantly increases the amount of image related data that needs to be stored on each disc.) In what follows, we will gain some appreciation for how well these goals were met. It will be apparent that any mass appeal product like PhotoCD is by nature a compromise, but one that permits scientific, engineering, and financial realities to meet market needs.

Dennis Howe *was a Senior Research Associate at Eastman Kodak. He is now a Research Professor in the Optical Sciences Center, University of Arizona, Tucson.*

The Evolving Compact Disc

The compact disc (CD) itself is a familiar product. What is not well recognized is that there are a number of formats for CDs that have evolved to meet various needs. The first CD was the CD-DAD (Digital Audio Disc), which was developed by Philips and Sony. The format and specifications of the CD-DAD disc (as well as the playback hardware specs) are contained in what is known as the Philips "Red Book." (The "books" that specify various CD formats are distributed to licensees of CD technology.) In that standard, the recorded CD-DAD is specified essentially as a long, serially-recorded digital tape; it may contain up to 99 (numbered in binary coded decimal as 01 through 99) individual, variable-length program tracks (independent information files) that are separated by tape-like file separation fields (*e.g.*, long, variable-length segments in which specific data patterns are repeated to indicate end of track, start of track, etc.). Timing information, such as elapsed time from beginning of the disc and running time of the current track, is carried on the disc by synchronously inserting timing data into the input serial user data stream in a way that allows timing information to be recovered with a granularity of 1/75 second (which corresponds to 2,352 user bytes). To keep cost low, an error correction code that admitted to simple decoder implementation was chosen for CD-DAD. But to achieve the required data reliability with this coding, sequential input data must be widely interleaved (*i.e.*, spread out) when it is recorded on the disc, which in turn means that a long length of the disc must be read (about 3,500 bytes) to retrieve a single user byte from the disc. Two other tracks on the disc—the first (called the lead-in track and numbered as track 00) and the last (the lead-out track, numbered as track AA)—are reserved for system use. They are used to establish system tracking, synchronization, etc. In addition, the lead-in track carries disc-specific information such as the disc's table of contents (TOC), which specifies the number and location (in terms of elapsed time from the start of track 01) of the tracks on the disc. Finally, data is physically written on the CD-DAD using the highly-interleaved serial tape-like format just described.

The audio signal to be recorded on the CD-DAD disc is sampled at a rate of 44.1 KHz to a depth of 32 bits (16 bits for each of two stereo channels); the program (user input) data rate is therefore 176.4 Kbytes/sec. The 12 cm diameter disc is organized such that the lead-in track extends (nominally) from a 46 mm inside diameter to an outside diameter of 50 mm, the program information track(s) extend from the 50 mm outside diameter of the lead-in area to a maximum diameter of 116 mm, and the lead-out track extends to a diameter that is 1 mm

larger than the outside diameter of the program track(s) area. An 8 cm CD-DAD disc has also been defined; it is organized exactly as above, except the maximum outside diameter of the program track(s) is 75 mm. During recording (mastering) and playback, the RPM of the disc is controlled to maintain a constant linear velocity of the disc beneath the focused laser beam. For the CD-DAD player, this velocity is nominally 1.3 m/sec. Using the fact that the pitch of the continuous spiral recording on the disc is 1.6 μm, we can calculate that the maximum length of the spiral track in the program area of the disc is about 5,378 m, which provides for a maximum playing time (116 mm program area OD) of 4,137 seconds, or equivalently, about 730 Mbytes of audio data on the 12 cm disc (~208 Mbytes on the 8 cm disc).

ENTER CD-ROM

The use of CD as a random access (disc-like) digital storage system came about with the first variation on the CD-DAD theme, namely, the CD-ROM, which is specified in the "Yellow Book." The Yellow Book has essentially been incorporated into a European Computer Manufacturers Association (ECMA) standard (ECMA-130, entitled Data Interchange on Read-only 120 mm Optical Data Discs), dated July 1988. CD-ROM (CD-Read-Only-Memory) is an extension of the continuous, serial recording format of CD-DAD that permits constant block-size, addressable data structures (sectors) to be defined logically on top of the serial audio (DAD) format. This is done by logically associating all the serially recorded user data input during one smallest increment of the recorded audio timing information—1/75 second or 2,352 user bytes— in a way that enables the CD-ROM player to retrieve such a block of data as a single unit. Note that, due to the widely-interleaved physical recording format that underlies this logical data structure, about 10,000 serially recorded bytes have to be read from the disc before the desired 2,352 byte block can be decoded and retrieved. Two different sectored data formats are defined by the Yellow Book. In one of these, 2,336 of the 2,352 bytes that define a logical sector are user data. In the other, only 2,048 user bytes are contained in the sector since 276 sector bytes are reserved for the parity data of an additional level of error correction coding, and twelve additional bytes are reserved for system use. The maximum user data capacity of a 12 cm CD-ROM disc that contains a single data track will then be either 725 Mbytes or 635 Mbytes, depending on which high-level logical recording format is used. Note that in practice, discs are usually not recorded with the user data track(s) extending out to the maximum allowed diameter of 116 mm, CD-ROM discs usually contain a maximum of 550-600 Mbytes; this corresponds to the CD-DAD practice of recording only 60 minutes of audio per disc instead of the maximum allowed 68.9 minutes. Therefore, a Yellow Book compatible disc can carry information in three different data formats: in either of the two CD-ROM sectored data formats or in the serial CD-DAD audio program format. However, only one data format is allowed on a given disc track—when the data format is changed, a new track must begin. Each track on the disc has all of its information in a single format, and a total of 99 tracks per disc are allowed, excluding the required lead-in and lead-out tracks. To insure reliable, fast, random access performance, it is desirable that the entire disc be filled with contiguous, addressed data sectors, *i.e.*, that there are no non-addressed track segments (*e.g.*, file separation fields) that would disrupt the track/sector seeking process, on the disc. This means that in practice, the entire CD-ROM disc will be recorded with a single data format. The disc then contains a single information track, which implies that the entire 550-plus Mbytes of user data that can be stored on a single-sided, 12 cm diameter CD-ROM disk, or the 200 Mbytes that fit on the alternative-size 8 cm diameter disc, must be recorded in one write operation.

Next came an extended architecture CD-ROM, dubbed CD-ROM/XA. This system, which incorporates the earlier Red and Yellow Book specifications, extends the capability of CD-based storage by defining an additional high-level, logical file structure that enables digital sound to be intermixed with binary data in a sectored data format. A CD-ROM/XA disc with a single information track can therefore store both data and sound. (Although it did not have a "book" of its own—it was described by a specification addendum to the Yellow Book—CD-ROM/XA is important as it was the first standardized, digital "mixed-media" storage system.) A CD system that supports a specific logical file structure to store sound, data, graphics, and digitized video on the disc (thereby enabling standardized, interactive, multi-media application programs, which also can be stored on the disc), followed in 1990-91. Known as CD-Interactive (CD-I), this system is essentially a further reworking of the CD-ROM/XA logical file structure. The specifications for CD-I are contained in the "Green Book."

Compact Disc, CD, and CD-ROM are registered trademarks of N.V. Philips Inc.; PhotoCD is a registered trademark of the Eastman Kodak Co.