DataPlay's Mobile Information Distribution and Storage Technology

A PORTABLE SYSTEM USING SMALL, HIGH-DENSITY OPTICAL DISCS WITH PRERECORDED CONTENT AND SPACE FOR CONSUMER-WRITTEN DATA GIVES CONTENT OWNERS NONINVASIVE ACCESS CONTROL.

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DataPlay

The Internet and the World Wide Web have stimulated the development of novel products and devices that provide a new dimension in interactivity. Further development of wireless-based technology and its growing interleaving with the Internet foreshadow even greater advances in Web-based portable communication and information products.

Nevertheless, several key technology components still lag, preventing this information revolution from reaching its potential. These include sufficient bandwidth, truly portable and inexpensive local storage, and a timely and cost-effective way to distribute content—especially the large files required for video and images. Moreover, any content distribution technology must provide adequate protection for the rights of content and copyright owners. Despite these limitations, many devices exist that seek to meet consumer expectations, and availability of these mobile information distribution platforms has driven the development of the DataPlay digital media and micro-optical engine[1] for using, distributing, storing, and protecting information.

The DataPlay disc is a 32-mm optical disc on which users can record up to 500 Mbytes of content and that alternatively could contain up to 400 Mbytes of prerecorded data in a low-cost embossed format, similar to a CD or DVD. Prerecorded content and read/write capabilities are seamlessly combined on the same disc up to the 500-Mbyte capacity. The DataPlay disc is compatible with the most advanced forms of music, data, and video digital compression. For example, MPEG-4 Advanced Audio Coding music compression at 192 Kbps or MPEG-4 video is readily utilized with the DataPlay player/recorder. Therefore, it can contain the equivalent of several complete compressed music CDs and still have space for music videos, lyrics, text files, still images, and so on. Because providers can selectively control access to content, they can protect secondary content after the disc's initial purchase and make it available in subsequent transactions.

Content owners can write unique encryption and conditional access keys to the media that specify a desired content protection scheme. For example, keys written to the disc follow the content of the disc through multiple generations of copies and allow for permissible copying while preventing wide-scale illegal distribution. The content protection scheme counts how many copies a user makes and tracks this count on the disc itself through the generations, following the rules set by the content owner. Binding these keys to the disc ensures that content protection is disc based rather than host based, so that the

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disc can be played on any DataPlay-compatible player. Thus, content control and protection are generally transparent to the user, unless content rules are violated.

The 32-mm discs are played and recorded on the DataPlay micro-optical engine. The device uses a mixed-signal CMOS controller integrated circuit (IC) developed jointly by DataPlay and ST Micro. This custom application-specific integrated circuit (ASIC) provides the channel, interface, decode/encode functions, and an integrated error-correcting code (ECC) scheme. The optical engine's tilting rotary actuator permits rapid data access in a simple mechanism. The actuator uses a very small integrated optical pickup head that weighs only a few milligrams. Combining low-mass optics and mechanics and the ability to write to the disc with minimal laser power results in a low-power-consumption system that dissipates only a few hundred milliwatts (mw) for typical applications.

The device's storage engine permits digital storage without regard to the data's source or format. The storage media is removable and can maintain data integrity for many years. Because of their small physical mass, the disc and its associated player/recorder are compact enough to fit into handheld portable appliances such as cell phones and PDAs.

Media

The 32-mm disc is enclosed in a 41- × 33.5- × 3-mm molded cartridge. This cartridge—constructed from two identical molded halves sealed together—is impact-resistant polycarbonate and protects the disc from dust, handling, and wear. Disc access is through a movable metal shutter that operates independently on each side of the cartridge. For further protection, the shutter is locked during normal operation and is opened only by the recorder/player mechanism.

The cartridge is moldable on simple, conventional injection-molding equipment and is further contained in a molded pocket case to simplify packaging and use. The pocket case and cartridge also provide a mechanism for attaching content labels and for stacking and distribution. G. Volan discusses the design principles and specific features of the cartridge, pocket case, and associated mechanisms.[2] Extensive data integrity testing under accelerated temperature and humidity conditions has confirmed the media's stability and allowed the DataPlay engineering team to predict a minimum 100-year data life. Figure 1 shows the disc and its cartridge.

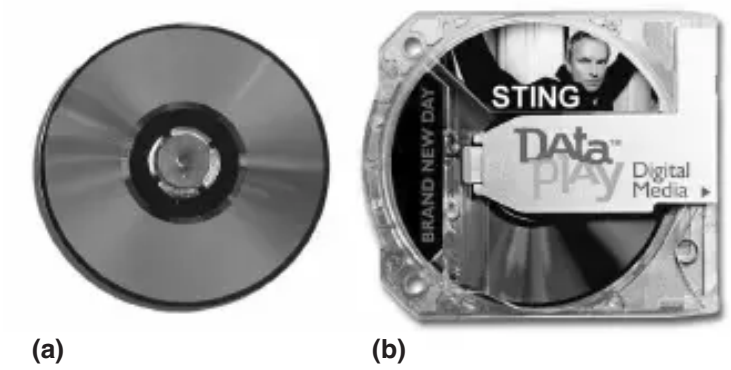


Figure 1. DataPlay's 32-mm disc (a) and the disc in its cartridge (b).

The storage media itself consists of a double-sided, 0.6-mm-thick polycarbonate disc molded as a single piece with the embossed data simultaneously pressed on both sides. Industry-standard EFM+ encoding of the digital data stream facilitates development of a broad range of content.[3] The disc's recordable area is grooved, and encoded address marks let the system locate data, facilitating random access and data seeks. The tracks are *wobbled*—that is, a fixed spatial amplitude modulation is applied to the groove in the plane of the disc—to provide a timing reference on the disc. A digital formatter, provided by external vendors operating under license from DataPlay, encodes the address marks on the disc using the high-frequency wobble mark (HFWM) method. Figure 2 (next page) illustrates this method, showing the HFWMs and the push-pull signal from the tracking servo as a function of tracking position. The wobble frequency is 128 kHz, and the added HFWM frequency is 641 kHz. The track pitch is 0.74 micron, the minimum recorded feature size is 435 nanometers (nm), and the device uses constant-linear-velocity recording at 2.9 meters per second (Mps). A.B. Marchant describes the push-pull concept used for tracking.[4]

The write marks on the media result from an amorphous-to-crystalline phase change. The material[5] is reflective enough in the 650-nm range to serve as the reflector for tracking and focusing, and it can be written to with

low write power. Figure 3, a photomicrograph of an actual EFM code sequence with written data adjacent to embossed data, shows the combination of recordability and writability.

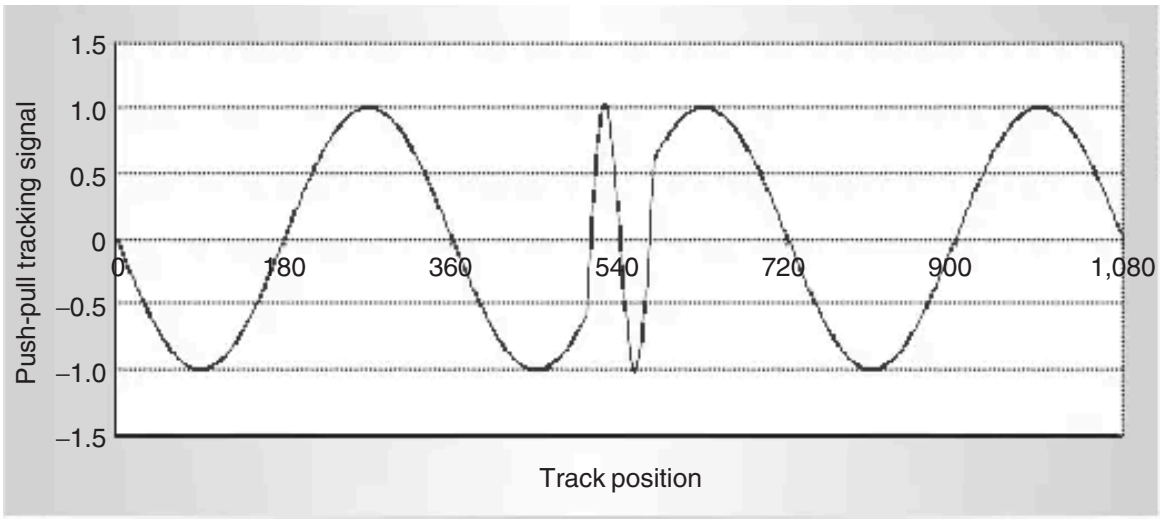


Figure 2. The wobble and high-frequency wobble mark address marks.

The power series data in Figure 4 illustrates the low write power. Fully optimized write marks require less than 2 mw of power at the disc surface; read power is typically 250 microwatts. Special stabilization methods ensure stable laser operation. The laser emits nominally at 650 nm (in the red region of the optical spectrum). Figure 4b shows the second harmonic performance, or minimum distortion point, of these 4T marks and the adjacent-track crosstalk performance. (T represents the minimum timing interval of the EFM+ code.) The carrier-to-noise ratio (Figure 4a) achieved at 2 mw is a more than adequate 50 decibels (dB). The media is stable through essentially unlimited reads at the nominal read power levels. Moreover, it increases in reflectivity upon writing, and once written to the media doesn't permit rewriting. This write-once recording is archival and permanent. Wrobel provides more details regarding the physics of write-once optical recording.[6]

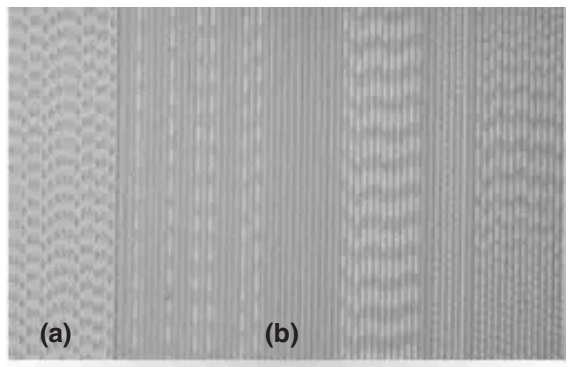


Figure 3. Embossed (a) and written data (b) on the same disc.

Because the disc also contains pre-embossed data, it is important for the molded information to have high data quality. Data-to-data

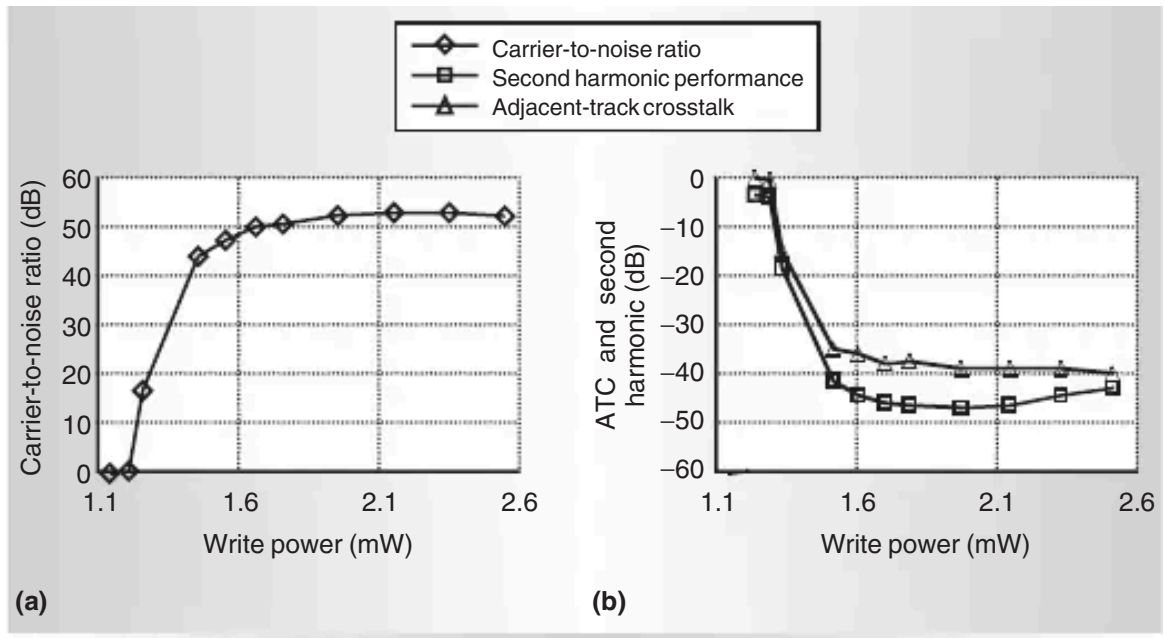


Figure 4. Typical power series data for DataPlay media, showing carrier-to-noise ratio (a) and second harmonic performance and adjacent-track crosstalk performance (b). Write power is defined as at the disc surface on the basis of 4T marks from the EFM+ code.

jitter is a critical test of how well the read data from the disc falls within the preassigned timing window for all pulse lengths of the code. The jitter values for prerecorded data are about 6 percent of the timing window; jitter values for user-recorded data are slightly higher at about 8 percent, but still well within specification. Arnoldussen and Nunnelly provide further information regarding jitter determination and performance in storage media.[7]

Optical pickup

The optical head in the player/recorder detects data and keeps the sensing laser on track and in focus. In traditional optical drives, the optical head is generally large and has significant mass. This is partly to provide a motorized drive for the objective lens and heat sinking for the laser. DataPlay's optical head doesn't have these restrictions. It is extremely small and light—weighing less than 10 percent of a traditional head—and thus lets the recorder/player meet the design height target of 11 mm.

The optical pickup, diagrammed in Figure 5a, is an integrated monolithic structure consisting of two subassemblies: the optical prism assembly (OPA) containing all optics, and the silicon submount, both shown in Figure 5b. The OPA is assembled using machine vision robotics equipment and consists of a finite conjugate objective lens, a spacer, a quarter-wave plate, a periscope beam splitter, and the optical element block. Wafer-scale and semiconductor assembly methods produce the silicon submount, which contains the laser diode, a high-frequency oscillator IC, a folding mirror, and photo detectors.

The silicon submount connects to a heat sink and is wire bonded to a flexible circuit. During bonding to the silicon submount, active alignment monitoring signals from the photo detectors on the silicon help in aligning the OPA. This completes the optical pickup assembly, which is then bonded to the actuator arm via the heat sink, providing good thermal coupling of the laser diode to the arm. The complete optical pickup measures 4.75 × 3.3 × 1.4 mm.

Actuator

Large optical heads have hampered the use of rotary actuators in optical recording. Using a miniature integrated head on the actuator, however, can overcome this limitation. DataPlay's rotary optical actuator is well suited for a miniature optical drive.

The actuators must maintain a focus point that keeps the laser's image at the disc's surface while it rotates. Designers accomplished this by having the actuator tilt, under control of the focus servo, to maintain focus. The actuator permits rapid rotation and hence rapid data access. Typical seek time is a few hundred milliseconds, and the channel data rate is 20 megabits per second (Mbps).

Because of the optical head's small mass, the actuator stiffness, and the short seek distances, a single voice-coil motor, appearing at the left end of the arm in Figure 6 (next page), and a cartridge pivot bearing enable both radial positioning functions (fine track following and coarse seek). A voice-coil motor at the center of the arm and a flexure that pivots about an axis that intersects the tracking pivot enable focus acquisition and focus following.

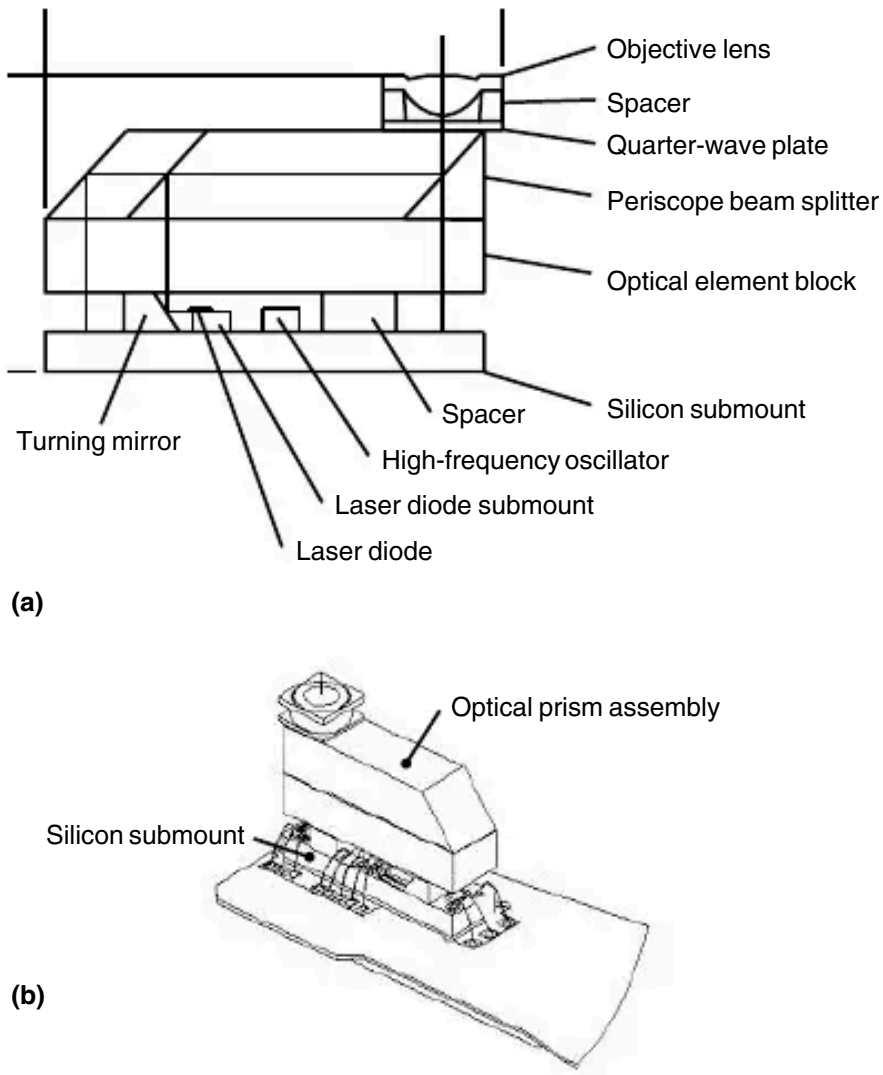


Figure 5. Diagram (a) and 3D layout (b) of the optical pickup.



Figure 6. The DataPlay actuator with tilt and rotary actuation. The actuator arm consists of a composite laminated sheet material constructed in multiple layers to achieve the desired stiffness in the pitch and roll directions.

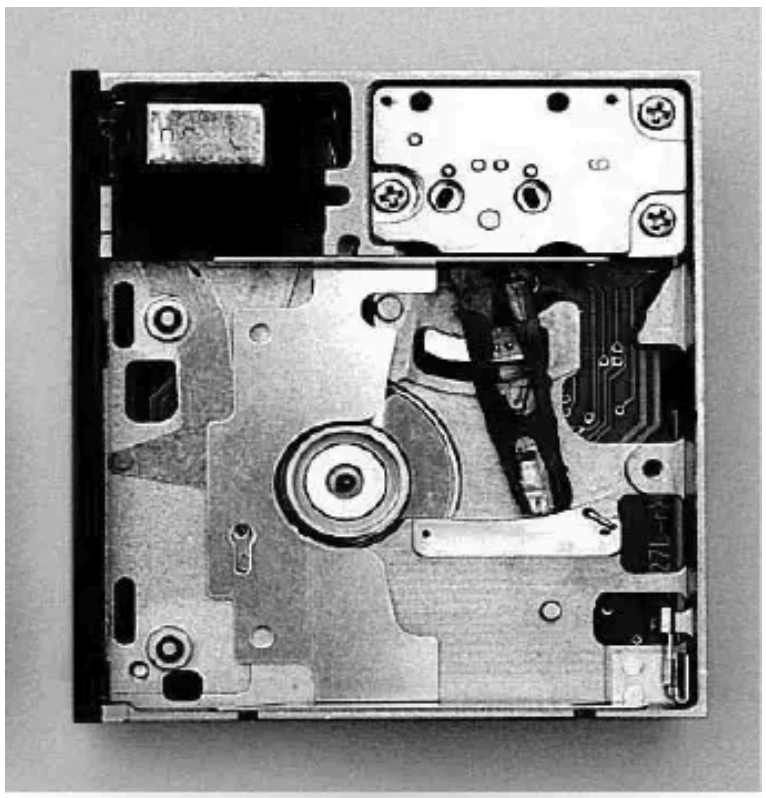


Figure 7. The DataPlay micro-optical engine, shown without load tray and cover, measures 52 mm by 47.5 mm by 11 mm.

Focus and tracking stops built into the actuator design act as fail-safe devices to prevent the optical head from touching the disc surface except under extreme conditions. Primary control for this function is based on the optical servo system that directs the actuator's position in both dimensions. If it detects that the head is moving into a collision mode, this system automatically withdraws the head. The built-in stops provide further physical protection.

Player/recorder mechanism

A power-driven load-and-eject mechanism implements digital media ejection. Several advantages accrue from this method. Software commands are used to address the electrical system that drives the mechanism. Fail-safe methods to ensure that the actuator is parked and the disc is no longer spinning have been incorporated into the eject command so that the disc will not eject until these conditions are met. Ejection and insertion, which take a fraction of a second, rely on a small drive motor with a gear train and lead screw built into the mechanism. Upon insertion, the disc drops onto the alignment and registration pins, and the shutter lock and the shutter itself both open. A door covering the front of the entirely encased mechanism, shown in Figure 7, is normally closed.

Other player/recorder components include a metal base plate and cover, the spin motor that rotates the disc at a constant linear velocity of 2.9 Mps, and an electronic board that provides all electrical and firmware control.

Electronics

The electronics and firmware in any digital read/write system must not only read, write, and correct data but also perform five other major functions:

- interface with the external world,
- maintain the servo system that keeps the head focused and tracking,
- seek for tracks and perform associated reading of address codes,
- control the spin motor, and
- manage ancillary functions such as eject modes.

A 15-square-mm custom ASIC manufactured in a 0.25-micron CMOS process is central to the system and combines mixed analog and digital functions. A block layout of the chip appears in Figure 8. Some of the digital functions are performed by two ST Micro ST10 microprocessors, one of which is integrated into a digital signal processor (DSP) block that performs several functions, including servo control. The ASIC has an integrated analog read channel and read and write

data paths. An integrated write strategy controls the write process. The data rate at the disc surface is 20 Mbps.

Other system components are a 2- to 4-Mbyte block of DRAM, the motor control ICs, and up to 512 Kbytes of flash memory. The system also contains transimpedance amplifiers and motor controllers.

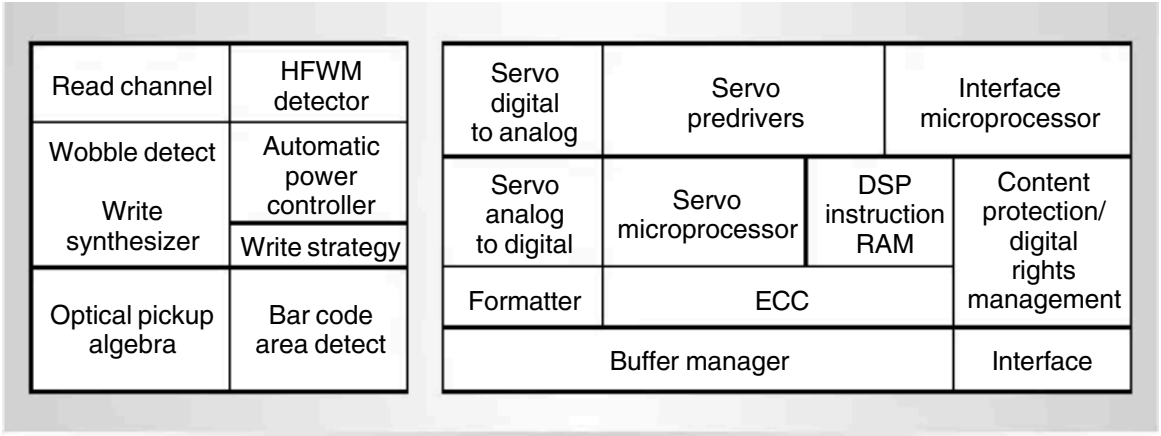


Figure 8. Block layout of the custom ASIC controller, which includes a third-level encryption engine and an error-correction system.

The photo detectors in the integrated silicon submount shown in Figure 5 detect signals from the optics of the head. The four quadrants of the photo detector are used to separate the optical responses from the disc surface into separate signals. These signals are used for tracking (on the basis of the reflected pattern's symmetry on the detector), focusing (on the basis of the reflected image's size), and for detecting the presence or absence of data (on the basis of the signals' integrated intensity). The DSP servo code uses the tracking and focusing signals to drive small motors that move the optical head into focus or onto the track. The read channel analyzes the data and from the intensity transitions extracts the digital data using a conventional slicing-level channel scheme. This data is then assembled into code words that the ECC block analyzes for correctness. The ECC scheme, illustrated in Figure 9, is built on the two-dimensional product code method used for DVDs but with an added layer of correction power. K.A.S. Immink provides more information on ECC methods and codes used in optical recording.[9] A general guide to certain aspects of the technology is available at http://www.dvdforum.org.

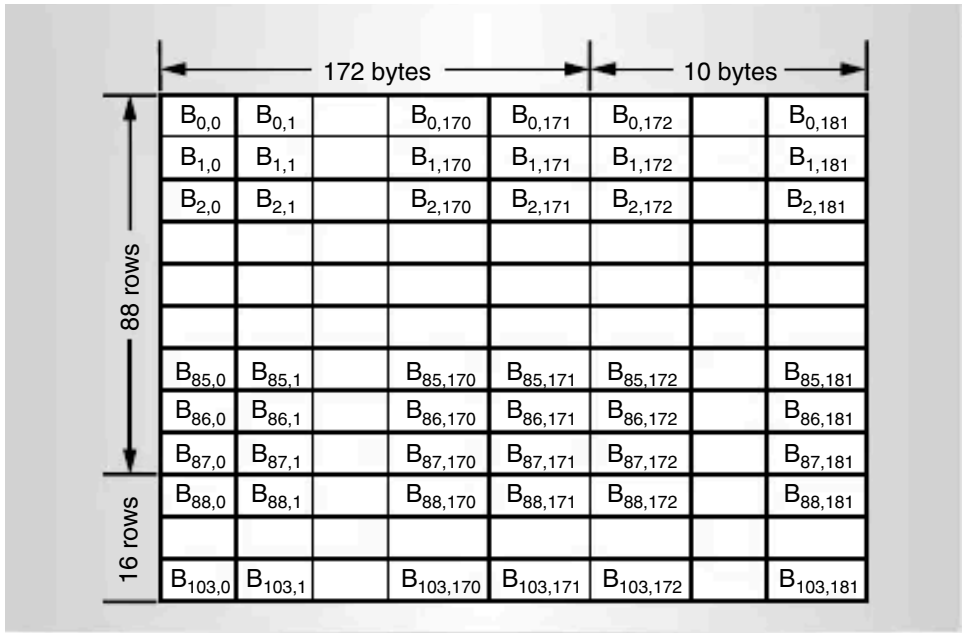


Figure 9. DataPlay's error-correction-code block arrangement. The ECC method assembles the data into a matrix and uses data blocks that are 172 bytes wide and stacked 88 rows deep. Parity correction blocks are added (10 bytes to each row and 16 rows to each column). J. Taylor illustrates in simple fashion the basis for all ECC parity block methods.[8]

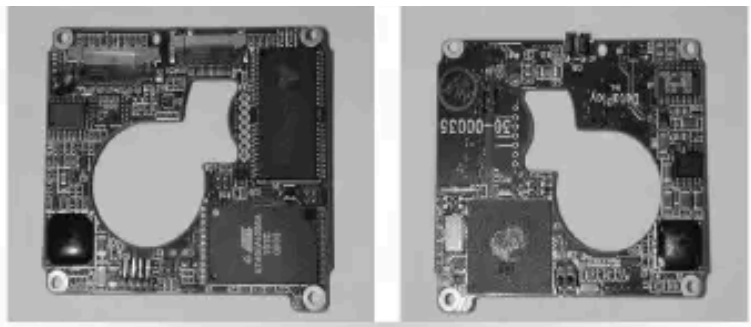


Figure 10. The DataPlay engine printed circuit board assembly seen from opposite sides.

This ECC scheme, together with the protective cartridge, permits front-surface recording. DataPlay has shown in practice that the ECC scheme can reliably correct discs having 5 percent of their data initially in error. Of course, this depends on the size and distribution of the errors, but DataPlay's testing of discs having contaminants ranging from dust to oils on the surface has confirmed the utility of the combined cartridge and ECC scheme.

Five other ICs complete the electronics system. Figure 10 shows the six-layer printed circuit board assembly layout consisting of the ASIC as well as the other system components described above.

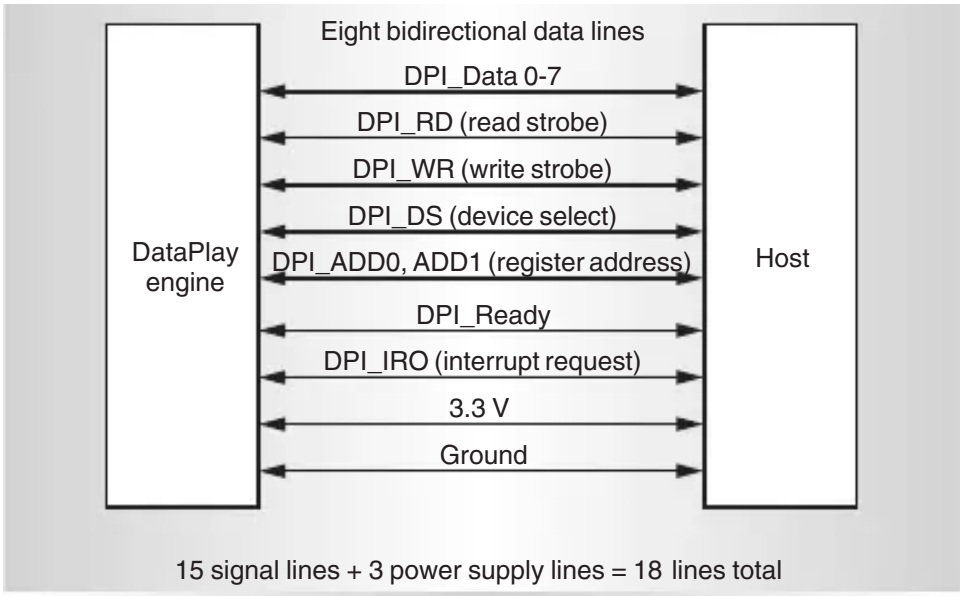


Figure 11. The DataPlay electrical interface (DPI) achieves a high level of data security and simplicity through the use of a file-based protocol.

The DataPlay file-type interface, illustrated in Figure 11, resembles those used in network-attached storage devices. The user-sustained data rate is 1 Mbyte/s; the burst rate can reach 10 Mbytes/s.

A buffer memory provides shock stabilization. Data is both read and write cached, allowing the use of sophisticated shock sensing and detection methods and minimizing the impact of shock events. The media (the product's only removable part) has a shock specification of 2,000-g acceleration, and the engine (without added shock buffers in the application device) can withstand 600-g shock in nonoperational and 150-g shock in operational mode. The noncontact read/write process permits the read/write head to remain nearly half a millimeter off the surface.

Content protection technology

The ability to emboss the media with content as well as let consumers write to it permits a form of content protection that DataPlay calls ContentKey. Depending on the content owner's needs, part or all of the content may not be accessible to the user.

When the disc is first placed in the recorder, a unique and permanent identifier is written to the disc on a designated inner track. By completing a suitable Web transaction—say, a monetary payment or some demographic data transmission—the disc purchaser may then download a software key that, in conjunction with the unique disc identifier, unlocks the disc to allow access. Unlocking may consist of decryption, or it may create a file on the disc that gives the system permission to access previously locked content. It could involve both. Such file access could be complete, partial, or time dependant, as determined by the enabling transaction.

Because ContentKey is media rather than player based—unlike some other enabling-key technologies—users have unrestricted use of the media in other DataPlay-compatible players. As well as being downloaded to an inaccessible area of the disc, the key written to the disc is itself encrypted by the ASIC-based encryption system. These two layers of protection can supplement the digital rights management methods that the content industry is developing. State-of-the-art DRM methods, accessed by writable keys bound to the disc, give the DataPlay system and compatible consumer electronics devices a way to guarantee content owners that their use rules travel with each disc through as many generations of disc copies as desired.

DataPlay expects that 2002 will see the commercial availability of several DataPlay-enabled products with applications ranging from music recorder/players to digital cameras. MICRO

Acknowledgments

I gratefully acknowledge the contributions of the DataPlay engineering team in this technology's development, and in particular the creative and innovative input from Steve Volk, Ian Redmond, Mike Braitberg, and Dan Zaharris, who pioneered many of the concepts.

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