

Error correction and iVerify for archival data storage

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Panasonic

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1 Introduction

Long media life and reliability of written data are the most important factors for archival data storage. Storage data will increase significantly and reach up to several tens of zettabytes by 2020. To protect from data loss, error correction performance of written data is required to be improved for long time archival storage. In addition, verification of writing process is required to be confirmed whether the data has been written correctly or not but the tradeoff is that the write transfer rate will be slowed down to half. Panasonic Optical Disc Drive is incorporated with iVerify function that can guarantee the correctable write process without verify. This document reports the performance of the error correction of 300GB Archival Disc and the validity of iVerify function.

2 Error correction of 300GB disc

2.1 Error correction code (ECC) block

Figure 1 shows the error correction code (ECC) block of 300GB AD (Archival Disc). The ECC block consists of Long Distance Code (LDC) that is 248 bytes with 32 bytes parity and Burst Indicator Sub-code (BIS) that can detect burst error in the ECC block to take care defect on disc. The ECC block is generated by 2 Sync codes, 304 LDCs and 6 BISs to the horizontal direction. Data on disc is written to the horizontal direction of the ECC so written data on the disc is interleaved by 310 bytes distance for LDC. If there is a defect on disc, errors in the ECC continue to the horizontal direction (solid line in Figure 1). The portion between two BIS that are detected error (blue portion of the solid line) or Sync code and BIS that is detected error (red portion of the solid line) is determined by the BIS error byte. If the position of the error byte in LDC is detected by BIS, the error can be corrected by using only 1 byte parity code but other random error (x red mark) needs 2 bytes parity for correcting the error. Therefore AD ECC has 2 times capability for defect error on disc by using BIS.

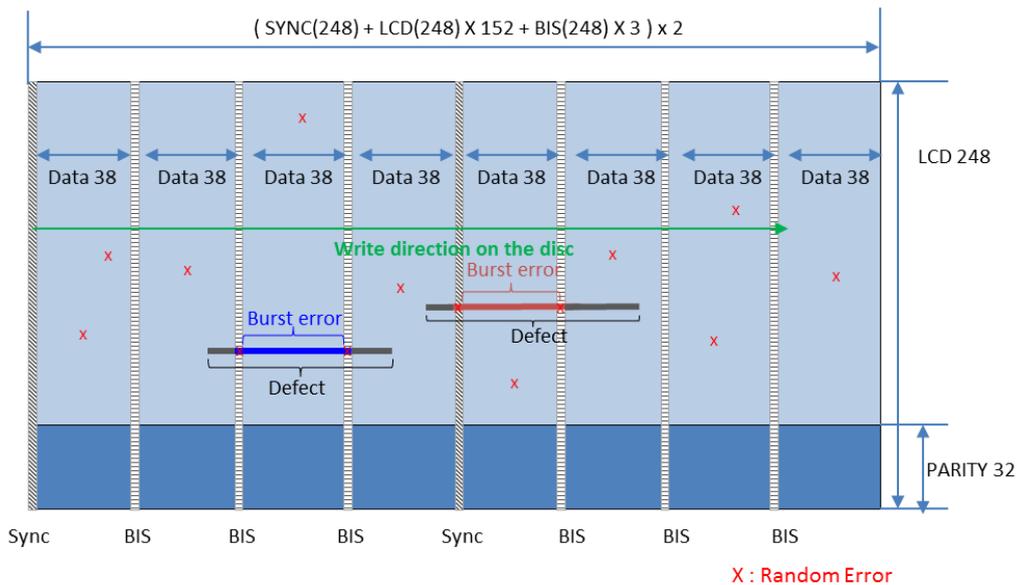


Figure 1 Error correction block of 300GB disc

2.2 Benchmark of 300GB ECC with LTO and HDD

As optical disc has been handled without cartridge in the consumer market, ECC of optical disc was developed to take care of finger prints and scratches on disc to adapt to the market needs and ECC capability was improved by increasing the block size of ECC. Table 1 shows the ECC capability for HDD, LTO and Archival Disc. The error correction capability is increased in proportion to the ECC data size and the error correction capability of Archival Disc is higher than Tape and HDD. In addition, Archival disc has the burst error detection scheme so Archival Disc can realize lower bit error rate than HDD and Tape.

Table 1 ECC comparison

Media	Error correction capability	Burst error detection scheme	Bit error rate
HDD	Low	-	1.0 x 10 ⁻¹⁵
LTO		-	1.0 x 10 ⁻¹⁹
Archival Disc / BD	High	Detection by BIS	1.2 x 10 ⁻²¹

2.3 Bit error rate calculation method after ECC

The bit error rate of Archival Disc after error correction cannot be measured because the error rate is very small. To measure 1.2 x 10⁻²¹ error rate, it is necessary to read more than 1 ZB of data but the actual measurement is unrealistic. Bit error rate after error correction can be calculated by the input error rate of the error correction circuit. The formula is showed below.

When LDC length is l, error rate of LDC code is p. Probability that has under e error in LDC is calculated as follows;

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$$LDC_{ok} = \sum_{i=0}^e {}_l C_i p^i (1-p)^{l-i} = \sum_{n=0}^{\infty} p^n \frac{l!}{n!(l-n)!} \left(\sum_{i=0}^{\min(e,n)} \frac{n!(-1)^{(n-i)}}{i!(n-i)!} \right)$$

Where, the binomial theorem

$$(a+b)^n = \sum_{i=0}^n {}_n C_i a^{n-i} b^i \quad (n \neq 0, a = -1, b = 1)$$

$$(-1+1)^n = \sum_{i=0}^n \frac{n!}{i!(n-i)!} (-1)^{n-i}$$

$$\sum_{i=0}^n \frac{n!(-1)^{n-i}}{i!(n-i)!} = 0$$

$$\text{When } \min(e, n)=n \quad \sum_{i=0}^{\min(e,n)} \frac{n!(-1)^{(n-i)}}{i!(n-i)!} = 0 \quad (n \neq 0)$$

Therefore

$$\begin{aligned} LDC_{ok} &= 1 + \sum_{n=1}^e p^n \frac{l!}{n!(l-n)!} \left(\sum_{i=0}^e \frac{n!(-1)^{(n-i)}}{i!(n-i)!} \right) + \sum_{n=e+1}^{\infty} p^n \frac{l!}{n!(l-n)!} \left(\sum_{i=0}^e \frac{n!(-1)^{(n-i)}}{i!(n-i)!} \right) \\ &= 1 + \sum_{n=e+1}^{\infty} p^n \frac{l!}{(l-n)!} \left(\sum_{i=0}^e \frac{(-1)^{(n-i)}}{i!(n-i)!} \right) \end{aligned}$$

LDC error probability that has error larger than e in LDC is bellow

$$LDC_{err} = 1 - LDC_{ok} = - \sum_{n=e+1}^{\infty} p^n \frac{l!}{(l-n)!} \left(\sum_{i=0}^e \frac{(-1)^{(n-i)}}{i!(n-i)!} \right)$$

The bit error rate of the ECC block after error correction can be calculated from the LDC error probability. Figure 2 shows the bit error rate after error correction that depends on the input error rate without the media defect error. Panasonic manages the criteria of media life test and drive inspection at production under 1.0×10^{-3} raw bit error rate. In this case, bit error rate after ECC is less than 1.2×10^{-21} if there is a burst error of 600 bytes that corresponds to 0.25 mm defect in ECC (Blue line). Defect of all ECC block in 300GB disc is managed to be kept under 600 bytes in media production process.

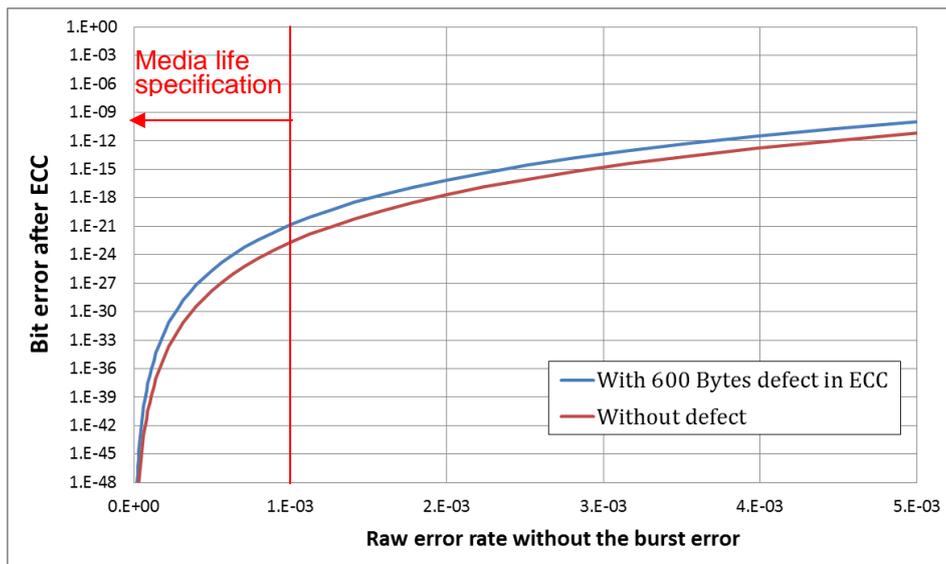


Figure 2 Bit error rate after ECC

3 iVerify function

3.1 Writing process of optical disc

Table 2 shows failure factors that can occur in the writing process of HDD, Tape and Optical disc. Blue letter in Table 2 shows controllable items by servo system or recoverable items by performing sector replacement if problem is detected in the writing process. Previous generation optical discs (DVD and CD) did not have replacement data area so burning process was stopped sometimes by media issue. Red letter in Table 2 shows uncontrollable and undetectable items if error occurred in the writing process. There are many red factors in Tape system because spacing and tracking of written track is open control that makes it difficult to check the directory. Also Tape system is one direction recording therefore recovery is difficult by sector replacement. From this technical reason, Tape system has to verify the written data after recording to guarantee the data reliability. On the other hand, error factors for HDD and Optical disc system are mostly blue which allows the failure in the writing process to be detected and data to be replaced to replacement area. Therefore the Optical disc system is not required to verify written data after recording alike HDD. In HDD system, spacing issue is undetectable error factor. Spacing of HDD is reaching under 1nm so a problem will occur with nm size dust inside HDD. This is a serious problematic factor for HDD reliability. In Optical disc, most factors are blue, furthermore focusing and tracking is controlled by active servo system so the servo reliability is higher than HDD. In addition, Panasonic Optical disc drive is incorporated with the iVerify function to keep the low raw error rate of the recording data.

Table 2 Error factor in the writing process for HDD, Tape and Optical Disc

Storage	HDD		Tape		Optical Disc (300GB AD / BD)		Remark
Verify function	Not need		Verify after write		iVerify		
Error factor	Control	Error Detection	Control	Error Detection	Control	Error Detection	
Head Spacing error or Defocusing error	Air Suspension	No	No Control	No	Servo System	Yes	
Tracking error	Servo System	Yes	Servo System by ref-track	No Direct	Servo System	Yes	
Defect error by Media	Pre-check by format	-Yes	No Check	No	Media Production	No	Correct by ECC
Address error	Replace	Yes	No replace?	Yes	Replace	Yes	
Sync-error	Replace	Yes	No replace?	Yes	Replace	Yes	
Media variation	Unknown	Unknown	Unknown	Unknown	Laser Power Control	Yes	

3.1 iVerify method

iVerify is performed to keep a low bit error rate without a full data verify on the disc. Figure 3 shows the schematic that explains the iVerify process. 300GB disc consists of 3 layers and each layer is prepared with spare areas on inner (ISA) and outer (OSA) of disc. iVerify is performed at two different timings. One is executed at the first write timing when disc is loaded to drive or when disc is written after the suspension of drive. At this timing, the writing condition can be changed by temperature change or media variation. Another is performed periodically at the beginning of zones in the data area. The data area (34mm size) from radius 24mm to radius 58mm is separated into short zones which the sizes are 0.7mm to 1.7mm and check is executed within 1.7mm period. The operation of iVerify at the start of each zone minimizes the bit error rate for all of the data area on disc even if media characteristic changes. This is because media characteristic is verified within each of the short and constant distance zone. Tape media writes on very wide area which the length is near to thousand meters but optical disc data area is only 34 mm so verification of written data can be performed periodically.

To minimize raw error rate, iVerify uses Distortion index to optimize recording laser power. Figure 4 shows the dependency between the recording laser power and the Distortion Index / Raw bit error rate. The Distortion index has good correlation to raw bit error rate therefore if recording laser power is controlled to align near to the target distortion index (red dot line in Figure 4), raw error rate can be minimized. iVerify can control the Distortion index within +/-5.0% of the target distortion index (blue area in Figure 4) by changing the recording laser power so that the raw bit error rate in blue area is low enough to keep the bit error rate after ECC under 1.2×10^{-21} . Furthermore if the written data by the iVerify process is over the distortion threshold or unreadable, the written data is replaced to the spare area automatically so that the written data by iVerify can be guaranteed under the threshold as well.

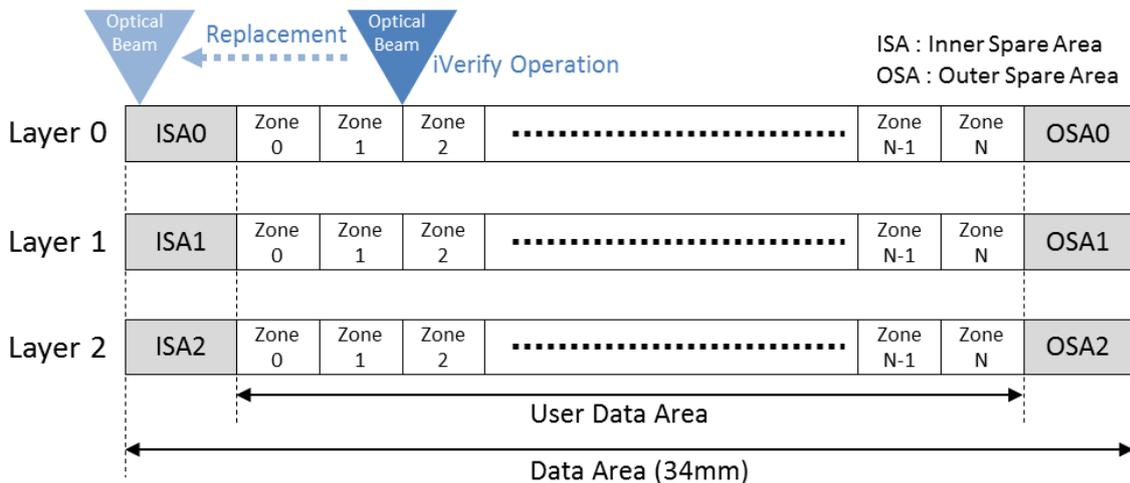


Figure 3 iVerify Operation

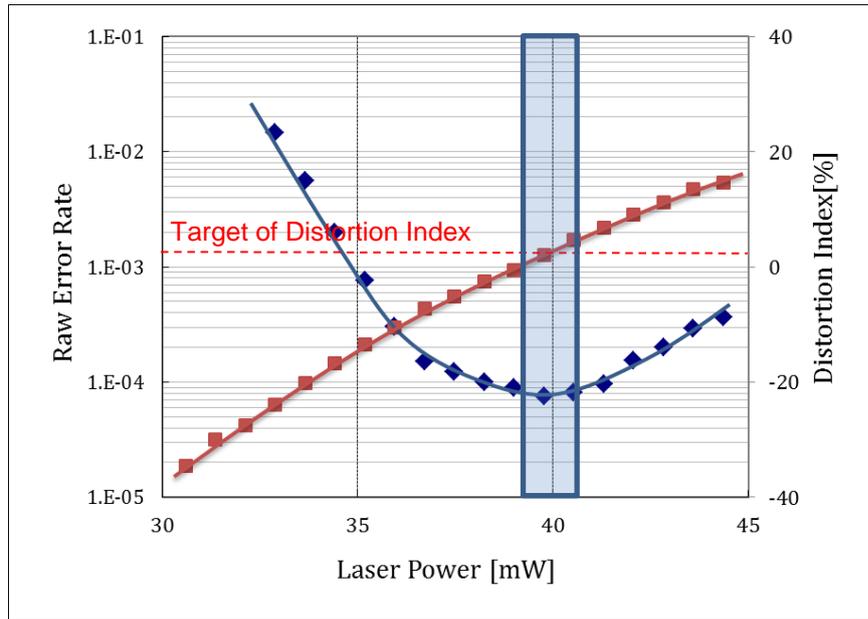


Figure 4 Relations between Raw Error Rate and Distortion Index

4 Conclusion

Panasonic optical disc drive with Archival Disc format is incorporated with data replacement function that is same as HDD if the problem of the writing process occurred. The Optical disc can detect most of the failure modes that are related to focusing, tracking accuracy, address error and synchronization. This feature exceeds HDD's focusing system aspect that corresponds to the head spacing control. In addition, Panasonic optical drive is incorporated with iVerify function to improve writing quality. Two of these functions allow to realize higher reliability than HDD or Tape without data verify.