Error control codes used in CD

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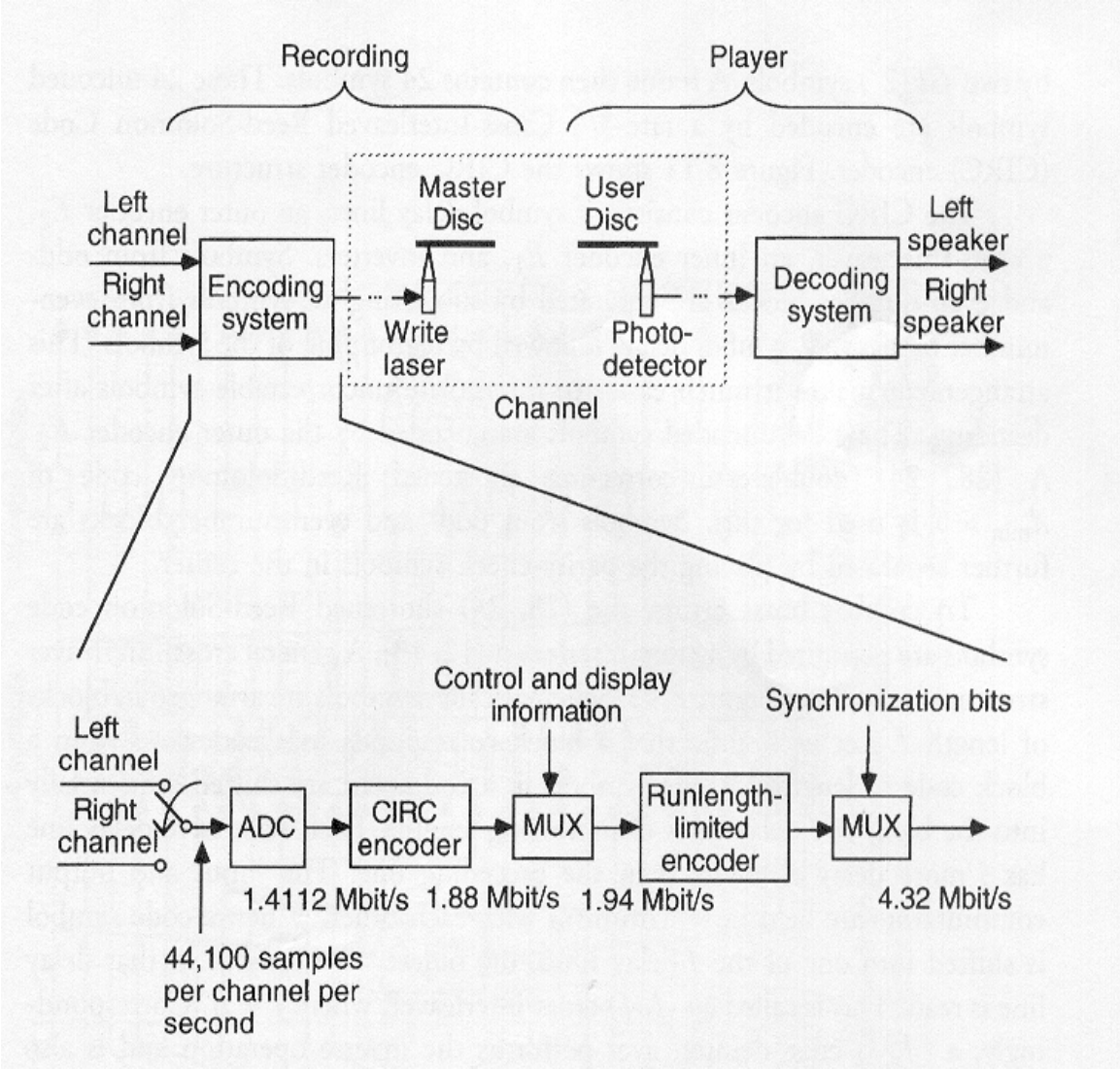
1. Block diagram of the CD recording and decoding system



- The channel can be thought of as consisting of a write laser, a master disc, a copy of the master disc, and a photo -detector.

2.Source of error

- In the case of the CD system,the errors caused in the process of disc production and signal tracing are as follows:

(1) Defects that caused in the process of disc production

- refuse and defect intermixed and adhered in the process of disc cutting and disc forming
- inferiority of disc pit forming, inter-mixing of bubble in the process of disc forming
- defects of aluminum reflecting film
- poor reflective index of transparent disc

(2) Defects of the disc caused in handling the disc. ex:fingerprints,scratches,and dust

(3) Variation and disturbance of the play-back mechanism.

- disturbance of servo mechanism (If the servo system , tracking , focusing , and CLV control are not stable , then code error will increase.)

(4) Jitter(the time swing of reconstructed 1 signal wave)

(5) Interference of signal code

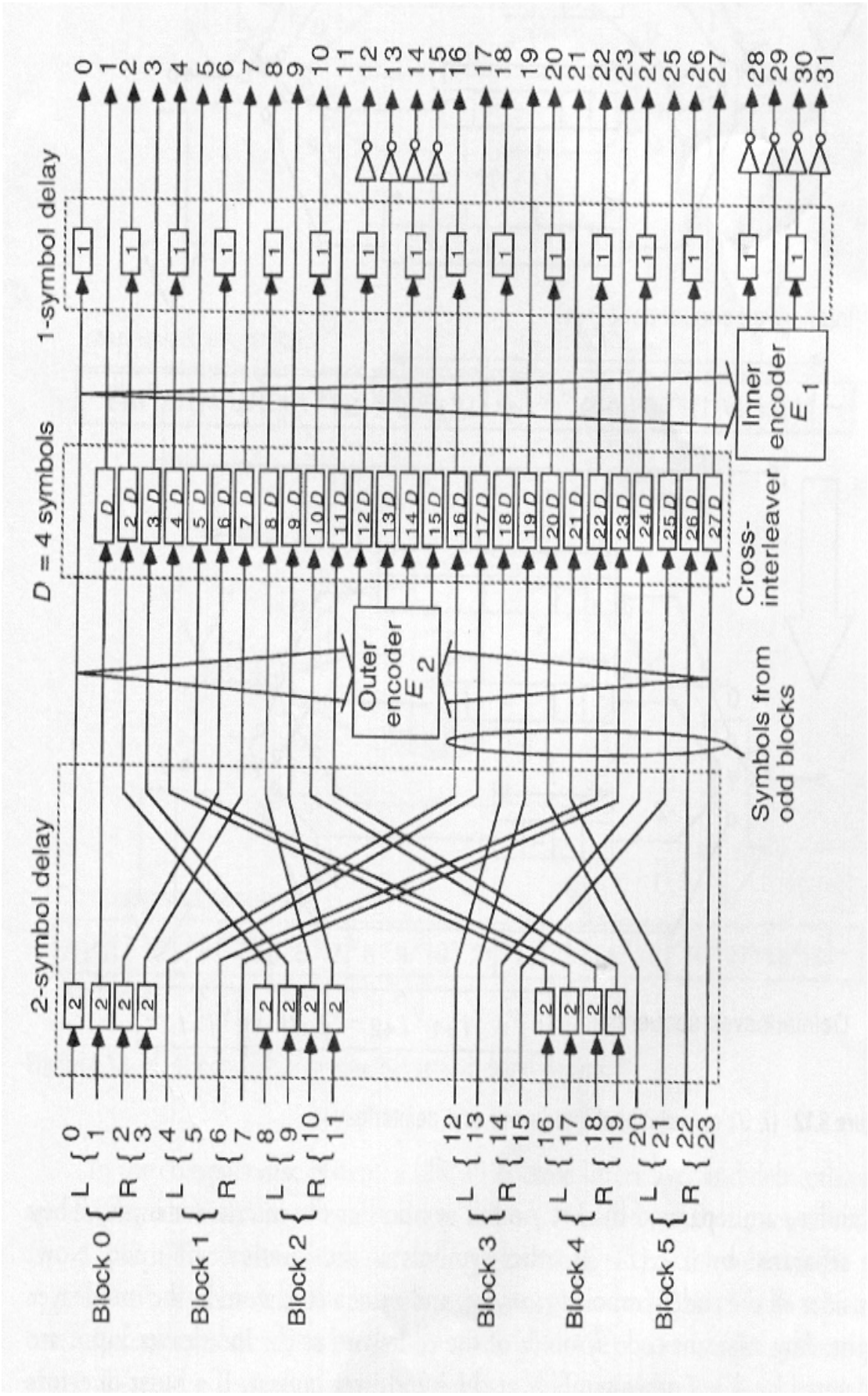
generally errors (1)～(3) are burst error ，while (4) and (5) are random error.

3.Encoding of CIRC

- In the CD system, it was necessary to develop a new effective error-correction method that could detect the burst and random errors.
  The new error correction method is named CIRC (Cross-Interleave Reed-Solomon Code)

- The CIRC encoding process for the CD system is standard
- Two correction codes for additional correcting capability
- C2 can effectively correct burst errors
- C1 can correct random errors and detect burst errors

- Three interleaving stages to encode data before it is placed on a disc.
- Parity checking to correct random errors
- Cross interleaving to permit parity to correct burst errors.


2-symbol delay
D = 4 symbols
1-symbol delay
Outer encoder E 2
Inner encoder E 1
Cross-interleaver
Symbols from odd blocks
Block 0
Block 1
Block 2
Block 3
Block 4
Block 5
L
R

- Encoder of CIRC

(1) Input Stage :

12 words (16-bit, 6 words per channel) of data per input frame divided into 24 symbols of 8 bits

(2) C2 Reed-Solomon code :

- 24 symbols of data are enclosed into a (28,24) R-S code
- (28,24) R-S code is a shortened Reed-Solomon code over GF(256)
- Double-error-correcting and dmin=5

- parity check matrix is as follow,where

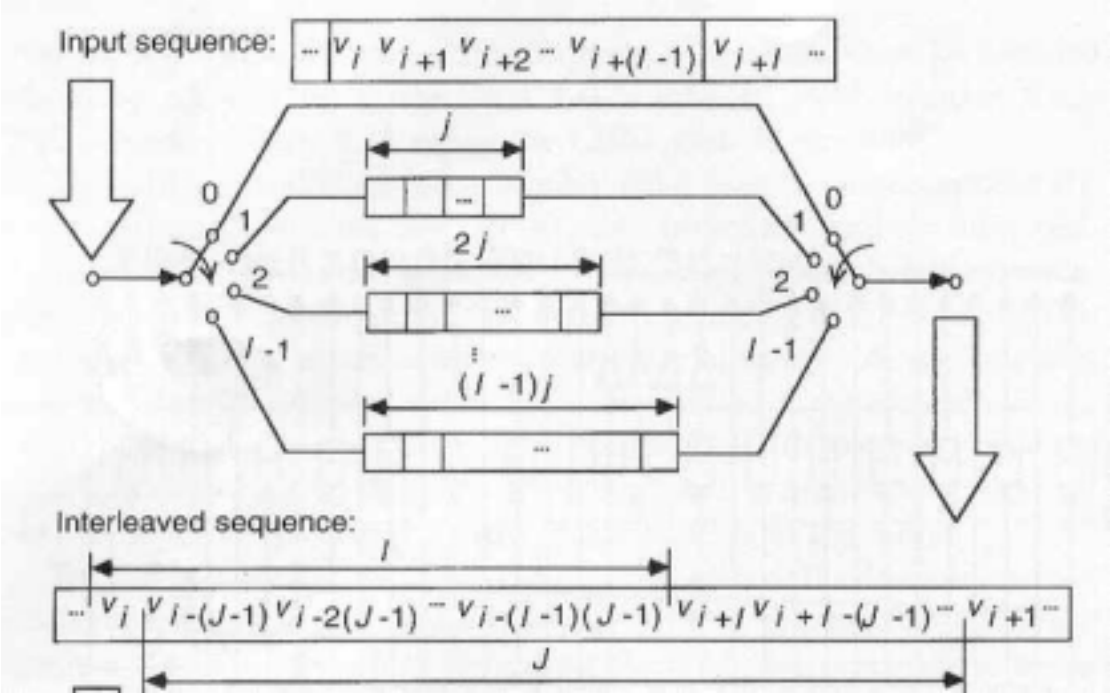
  α is the root of $x^8+x^4+x^3+x^2+1$

$$H = \begin{bmatrix} 1 & 1 & \ldots\ldots\ldots & 1 \\ \alpha^0 & \alpha^1 & \ldots\ldots\ldots & \alpha^{n-1} \\ \alpha^0 & \alpha^2 & \ldots\ldots\ldots & \left(\alpha^2\right)^{n-1} \\ \alpha^0 & \alpha^3 & \ldots\ldots\ldots & \left(\alpha^3\right)^{n-1} \end{bmatrix}$$

Let C= (C_0 C_1 ……C_{n-2} C_{n-1}) be the Codeword , then $C \cdot H^T = 0$

where n=32 for C1 sequence and n=28 for C2 sequence

(3) Cross interleaving



- Code symbols in a codeword are shifted sequentially into bank of I delay lines of increasing lengths.
- Each successive delay line has *j* more delay elements than the preceding one.
- The input and output commutators are held in synchronism with each other.
- When a code symbol is shifted into one of the *I* delay lines, the oldest code

symbol in that delay line is read.

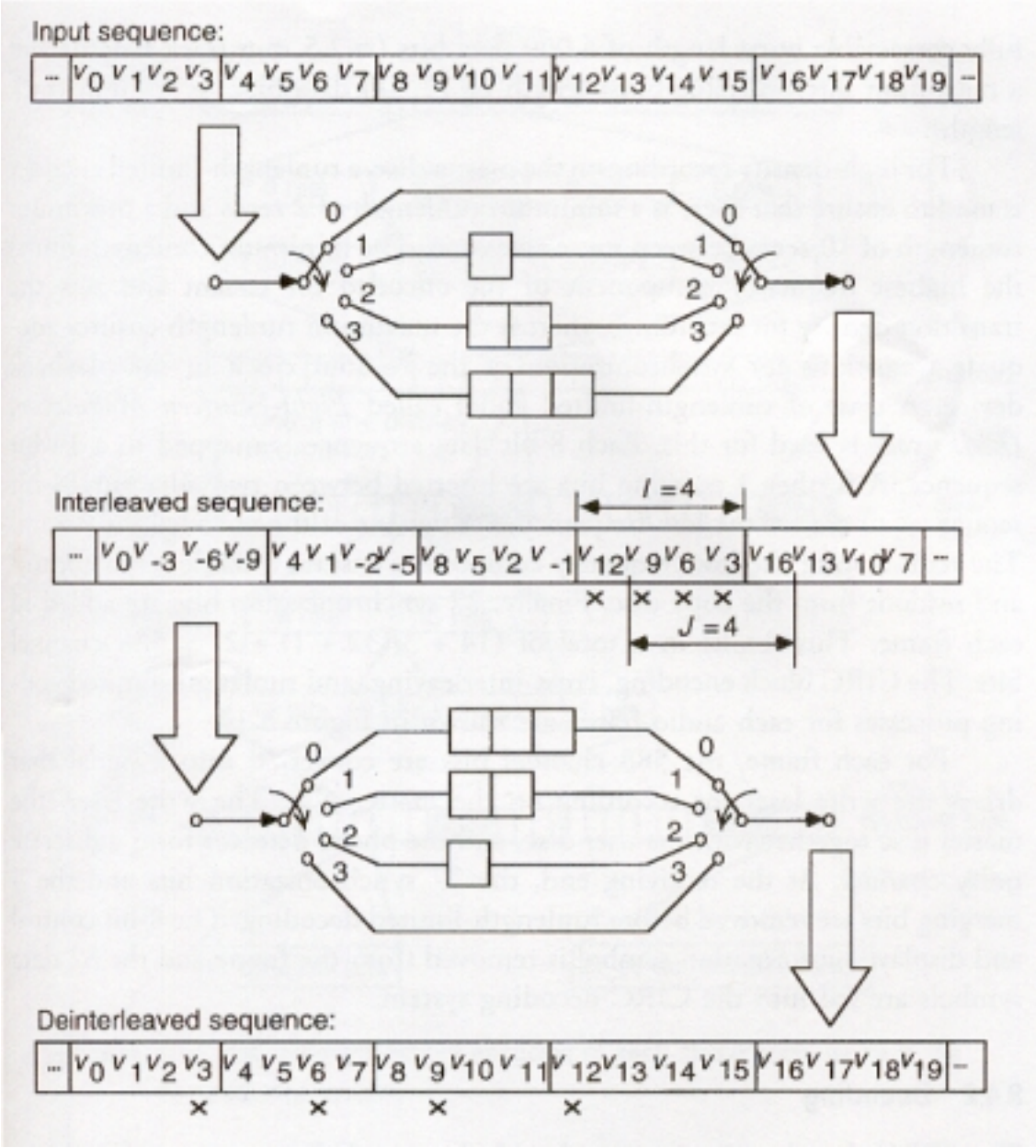
- This is called an (I,J) cross-interleaver, where $J=Ij$.
- Correspondingly, a (I,J) cross-interleaver performs the inverse operation.
- Sometimes, a cross-interleaver is called a convolutional interleaver.
- To guard again the burst errors
- To prevent the occurrence of the all-zero codeword,all parity-check symbols are inverted

(4) C1 Reed-Solomon code :

- cross-interleaved 28 symbols of the C2 code are encoded again into a (32,28) R-S code.
- effective for random-error correction and burst-error detection

Example：

(I=4,J=4) convolutional interleaver and deinterleaver circuit.



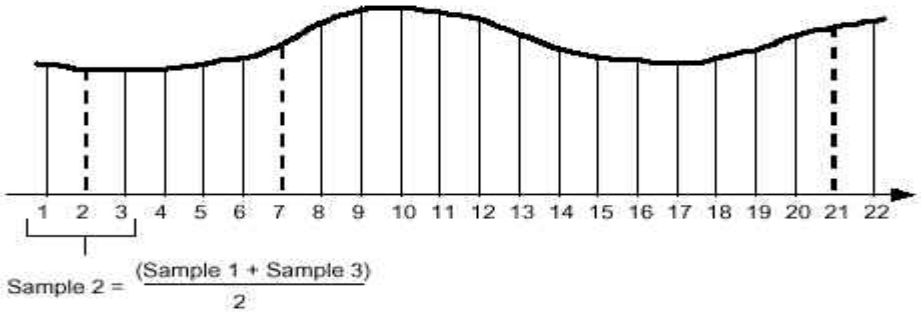
- Consider all the code v_4, v_5, v_6, and v_7 of a codeword at the interleaver input. Any adjacent code symbols of the codeword at the interleaver input are separated by J=4 other symbols at the interleaver output.
- If a burst of errors affects the code symbols v_{12}, v_9, v_6, and v_3 in a codeword, the burst length is 4. There is only one error per block at the deinterleaver output.

4.Decoding of CIRC

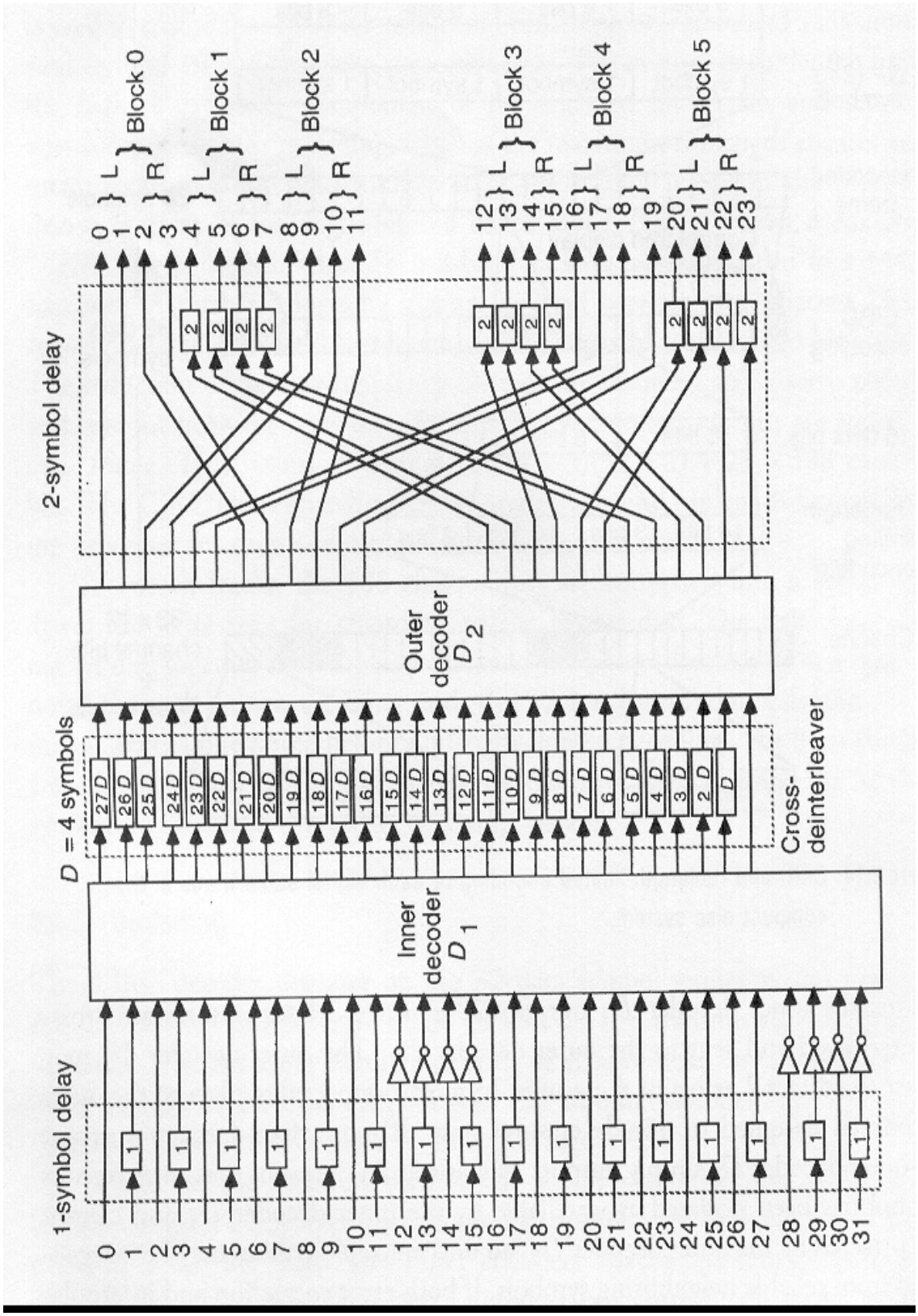
- The decoding method has not been standardized and it is up to each compact disc player manufacturer to optimize the performance of their product.
- Since the inner and outer encoders have a minimum distance of 5, the inner and outer decoders can correct any combi-nation of v errors and f erasures,where $(2v+f)<dmin=5$
- In most decoding strategies, the inner decoder D1 is designed to correct single error. If more than 1 error occurs, the inner decoder D1 outputs 28 erasures. These erasures are cross-deinterleaved and sent to the outer decoder D2.

The outer decoder D2 may be set to correct 2 errors or 4 erasures. In most compact disc players , the outer decoder is designed to decode erasures only (an inexpensive solution). If more than 4 erasures occur , the outer decoder D2 simply outputs 24 erasures.

- In the event that an erroneous symbol has been declared as unreliable by the inner decoder D1 and cannot be corrected by the outer decoder D2 , an uncorrectable symbol may be interpolated from reliable neighboring symbols.



- If both error correction and interpolation fail , the sounds associated with erroneous symbols can be muted.


1-symbol delay
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D = 4 symbols
Inner decoder D1
Outer decoder D2
Cross-deinterleaver
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5.Performance of CIRC

- Both R-S coders (C1 and C2) have four parities, and their minimum distance is 5
- If error location is not known, up to two symbols can be corrected.
- If the errors exceed the correction limit, they are concealed by interpolation.
- Since even-numbered sampled data and odd-numbered sampled data are interleaved as much as possible, CIRC can conceal long burst errors by simple linear interpolation.
- Max. completely correctable burst length is about 4000 data bits (2.5 mm track length).
- Max. interpolatable burst length in the worst case is about 12,3000 data bits (7.7 mm track length).

- Sample interpolation rate is one sample every 10 hours at BER (Bit Error Rate) = 10^{-4} and 1000 samples per minute at BER = 10^{-3}.
- Undetectable error samples (clicks) less than one every 750 hours at BER = 10^{-3} and negligible BER = 10^{-4}.
- The channel itself is binary.When a burst of errors occurs , it may affect many consecutive received bits.Since the RS decoder does not care whether a symbol error has been caused by 1 bit error or 8 , we obtain some significant burst-error correcting capability.
- The signal format has been designed in such a way that 4 channels are possible in the future , without changes in the error correction

6. Conclusion

- It has been said that “without error correcting codes, digital audio would not be technically feasible” , so the importance of error control coding is evident.

7. Reference

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