ON ERROR CORRECTABILITY OF EIAJ-FORMAT OF HOME USE DIGITAL TAPE RECORDERS

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**Presented at
the 64th Convention
November 2 through 5, 1979
New York City**

AN AUDIO ENGINEERING SOCIETY PREPRINT

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ABSTRACT

The signal system standards for PCM recording/reproducing using consumer cassette video systems have recently been prescribed by the IEAJ(Electronic Industries Association of Japan) technical files. In this paper, the code error correctability of the system is evaluated by computer simulation.

Three different decoding methods for code error correction are technically possible with this system:

1) Basic decoding

2) b-Adjacent decoding, and

3) crossword decoding.

With the assumption that the bit error ratio is the worst value possible in today's video systems(10^{-4}), the simulation results indicated that the miscorrection times per hour for each decoding method were 1, 10^{-1} and $5x10^{-3}$ respectively.

1. INTRODUCTION

Digital audio processors convert audio signals into digital signals and make up the digital audio recorder system in combination with video tape recorders. Several models of such processors have already reached to the point of development where they are usable in practical applications.[1][2]

Therefore, it has become necessary, both for the state-of-the-art in technology and for convenience that these signal configurations are standardized as soon as possible.

Last June, the EIAJ(Electric Industries Association of Japan) began formulating a technical file on PCM encoder-decoder systems employing the consumer cassette video systems.

Their objective informulating this file is to study the conditions necessary for signal formats, in order to reach a decision on the best of the various systems to establish the compatibility of recorded tapes and interchangeability of the encoder-decoders.

With the signal format described here, three different decoding systems are technically possible;

(1) Basic and simplest decoding using erasure method.

(2) b-Adjacent decoding in combination with CRCC code.

(3) Several classes of crossword code.

The code error correctability in these decoding methods is in this order: (1)<(2)<(3), and the complexity of electronic circuits is also: (1)<(2)<(3).

Accordingly, the decoding method should be selected with the reliability of the video system and the total cost of equipment taken into consideration.

The SONY PCM-10 and PCM-100 shown in Fig-1, 2 are the digital audio processors incorporating the EIAJ signal format and b-Adjacent decoding.

Table-1 shows the basic parameters of EIAJ signal format. The theoretical limitations of the characteristics of digital audio recording systems employing this format are shown in Table-2. Discussions in this paper are focussed around the code error correction scheme mentioned above and its correctability.

An analysis method of the correctability is also studied. The code errors are classified into burst errors and random errors by their characteristics.

The burst errors are caused by dropouts or fingerprints on the surface of the magnetic tape, and the random errors are caused by intersymbol interference, jitter, or other noises.

These characteristics can be impressed by two parameters derived from the Gilbert Model, "bit error rate" and "bit error correlation coefficient".

Gilbert Model parameters can be estimated from the distribution of measured code errors.

The statistical analysis for evaluation of code error correctability is carried out with variations in "bit error correlation coefficient" on the assumption that "the bit error rate" is the worst possible value ($=10^{-4}$) of the video system.

2. SIGNAL SYSTEM

Table-3 shows the signal format studied. Three words are included per channel, and in total, six words are put in one horizontal line, with two words added for error correction and one word (CRCC) for error detection. CRCC consists of 16 bits, but all other word are 14 bits.

Each word is dispersed by simple delay interleave as is shown in Table 3-1.

The waveform shown in Table 3-2 was chosen so as to minimize code errors for consumer cassette video systems like Betamax or VHS.

At the begining of each video field, a data control block is prepared, the details of which are shown in Table 3-4. A field synchronizing word is designed so that decoding by a simple tank circuit is possible less expensive machines.

Neither the data discrimination word nor address information word are defined. Four bits of control signal word are decided; (i) prohibition of digital dubbing for recorded tapes, (ii) discrimination of check word P and (iii) check word Q for simpler error correction for less expensive machines, and (iV) discrimination of emphasis. The characteristics of emphasis are shown in Fig-3.

The bit slot is 14-bit linear for each word. This does not mean the machines should be always designed as 14-bit linear. Any compounded quantization and linear quantization equal to or less than 14-bits is possible as far as they are compatible with 14-bit linear. Two's compliment is adopted in line with the recommendation of AES Digital Audio Standard Committee.

3. CODE ERROR CORRECTION SCHEMES

Table-4 shows outlines of error correcting schemes adopted in EIAJ signal format. Basically, it is a combination of

(1) delay interleave (see Fig-4), (2) b-Adjacent code,[3] (3) crossword code,[4] and (4) CRCC (Cyclic Redundancy Check Code).

The check words for b-Adjacent code[3] consist of exclusive-or type parity word P and a word Q generated by matrix calculation (Table 4-4). Erasure decoding as shown in Table 4-3 uses P only.

CRCC is used as an error detection (pointer) in the erasure decoding and b-Adjacent decoder systems, but it is used for error correction in crossword decoding.

3-1. ENCODER

The principle of the encoder shown in Fig-4 is rather simple. It consists of three blocks, a b-Adjacent encoder, CRCC encoder, and delay memories.

Fig-5 shows an example of a matrix circuit for b-Adjacent encoder, in which one shift of the shift register corresponds to multiplying the matrix T to each data word (see Table 4-4). Initially, data select switch is set to L_0, and one shift of the shift resistor will make TL_0. Then the switch changes to R_0, and the next shift of the resistor makes $T(TL_0+R_0)=T^2L_0+TR_0$. And the check word Q_n (Table 4, eq.(37)) remains in the resister.

The sub-blocks before the delay operation are in original sequence. Those after the delay operation form the sequence to be recorded in each horizontal line.

Fig-6 shows the sequence of the sub-block after it has been delayed. Each sub-block corresponds to a horizontal line, and related sub-blocks are separated from each other by 16 sub-blocks.

3-2. THE SIMPLEST BASIC DECODING SYSTEM

Fig-7 shows the simplest decoder, which utilizes only the parity word P_n (the check word Q_n are ignored). Each sub-block is checked by CRCC decoder and the error pointer of 1 bit is fed to the parity P-decoder after being given the same delay as the main information words.

In the decoder, a syndrome word

$$S_n = L'_n \oplus R'_n \oplus L'_{n+1} \oplus R'_{n+1} \oplus L'_{n+2} \oplus R'_{n+2} \oplus P'_n \qquad (1)$$

is calculated, where the prime mark indicates the received word which might be erroneous.

If $S_n=0$, or all the error pointers indicate no error, the words included in eq.(1) are considered to contain no errors. If $S_n\neq 0$, and error pointer of a certain word, for instance L'_n, is indicated to be erroneous, the error pattern of L'_n is considered to coincide with S_n, and error correction is carried out by the following formula.

$$L_n = L'_n \oplus S_n \qquad (2)$$

This error correction is well known as the erasure method. Error correction is possible as far as only one related sub-block is erroneous. Each related sub-block is separated from each other by 16 sub-blocks (see Fig-6), therefore a burst error within 16 sub-blocks (2048 bits) can be corrected by this method. However, a guard space of 96 sub-blocks is necessary for correction.

If errors exceed the correctability of the scheme, error concealment is possible. A burst error shorter than 64 sub-blocks (8192 bits) is dispersed by delay interleave, and an possible (see Fig-6).

3-3. B-ADJACENT DECODING SYSTEM

Fig-8 shows the b-Adjacent decoding system, in which the signal flow is similar to that of the basic decoder. The following syndrome S_{Tn} is formed in the b-Adjacent decoder by a matrix circuit similar to the one shown in Fig-5.

$$S_{Tn} = T^6 L'_n \oplus T^5 R'_n \oplus T^4 L'_{n+1} \oplus T^3 R'_{n+1} \oplus T^2 L'_{n+2} \oplus T R'_{n+2} \oplus Q_n \qquad (3)$$

Supposing L'_n and R'_{n+1} are erroneous, while others are not, their error patterns are defined as E_{Ln} and E_{Rn+1}, respectively,

$$L'_n = L_n \oplus E_{Ln} \qquad (4)$$

$$R'_{n+1} = R_{n+1} \oplus E_{Rn+1} \qquad (5)$$

It is known that the syndromes do not depend on the original data pattern, but are expressed only by error patterns. Thus, from eqs.(1),(3),

$$S_n = E_{Ln} \oplus E_{Rn+1} \qquad (6)$$

$$S_{Tn} = T^6 E_{Ln} \oplus T^3 E_{Rn+1} \qquad (7)$$

The error patterns are solved from eqs. (6), (7) as follows.

$$E_{Ln} = (I \oplus T^{3})^{-1} (S_n \oplus T^{-3} S_{Tn}) \tag{8}$$

$$E_{Rn+1} = S_n \oplus E_{Ln} \tag{9}$$

Where I is unit matrix, and reverse matrixes are stored in ROM's. Error correction is obviously carried out as follows.

$$L_n = L_n' \oplus E_{Ln} \tag{10}$$

$$R_{n+1} = R_{n+1}' \oplus E_{Rn+1} \tag{11}$$

This decoder can correct two arbitrary words using a CRCC pointer, therefore a burst error within 32 sub-blocks (4096 bits) can be corrected.

3-4. CROSSWORD DECODING SYSTEM

If an information word is related to plural syndromes, crossword decoding is possible by comparing those syndrome patterns. In the above format, syndrome S , S and residual of CRCC can be utilized.

Supposing L_0' , L_{48}' , and R_{48}' are erroneous, and their error patterns are E_{L0}, E_{L48}, E_{R48}, the error pointer from the CRCC decoder will point out the error of the sub-blocks H_0, H_{16}, and H_{32} (see Fig-6). This is a three-word error and cannot be corrected by the b-Adjacent decoding system shown in Fig-8. In this case, all the related words (L_0 , R_{-48}, L_{-95}, R_{-143}, L_{-190}, R_{-238}, L_{48} , R_0 , L_{-47}, R_{-95}, L_{-142}, R_{-190}, L_{96} , R_{48} , L_1 , R_{-47}, L_{-44}, R_{-42}) should be interpolated.

But, if we consider in detail, this error is actually one word error for the sub-block B_0 , and a two-word error for B_{48} , both before delaying, as is shown below.

$$B_0 = (\overset{x}{L_0}, R_0, L_1, R_1, L_2, R_2, P_0, Q_0) \tag{12}$$

$$B_{48} = (\overset{x}{L_{48}}, \overset{x}{R_{48}}, L_{49}, R_{49}, L_{50}, R_{50}, P_{48}, Q_{48}) \tag{13}$$

Where erroneous words are indicated by upper subscript . If the exact locations of the error words could be detected, both errors could be corrected.

The crossword decoding system shown in Fig-9 can correct this error pattern completely. The principle is described as follows:

In crossword decoder, the syndrome S_0 shown in eq.(1) is calculated first, and then, the following eight kinds of syndromes are calculated.

$$S_{L0} = \text{Res } (x^{114} S_0) \tag{14}$$

$$S_{R0} = \text{Res } (x^{100} S_0) \tag{15}$$

$$S_{L1} = \text{Res } (x^{86} S_0) \tag{16}$$

$$S_{R1} = \text{Res } (x^{72} S_0) \tag{17}$$

$$S_{L2} = \text{Res } (x^{58} S_0) \tag{18}$$

$$S_{R2} = \text{Res } (x^{44} S_0) \tag{19}$$

$$S_{P0} = \text{Res } (x^{30} S_0) \tag{20}$$

$$S_{Q0} = \text{Res } (x^{16} S_0) \tag{21}$$

Where, Res ( ) means residual of CRCC decoder, and x^i means i-times extra shift of the register. The sub-script of S in eqs. (14)-(21) expresses the possible error words, and x^i corresponds to the location of such words in the sub-block after delay.

letting the residual of the CRCC of each sub-block Hi be Ci, errors of eqs. (12) and (13) are expressed as follows (see Fig-6).

$$C_0 = \text{Res } (x^{114} E_{L0}) \tag{22}$$

$$C_{16} = \text{Res } (x^{114} E_{L48}) \tag{23}$$

$$C_{32} = \text{Res } (x^{100} E_{R48}) \tag{24}$$

$$C_{48} = C_{64} = C_{80} = C_{96} = C_{112} = 0 \tag{25}$$

It is evident that the syndrome S_0 of eq. (1) expresses the error pattern.

$$S_0 = E_{L0} \tag{26}$$

Then, from eqs. (14), (22)

$$S_{L0} = \text{Res } (x^{114} E_{L0}) = C_0. \tag{27}$$

On the contrary, if eq.(27) is satisfied, error in sub-blocks B and H is considered to be only $L_0^{\times}$. Consequently, L_0' can be corrected by erasure method, and if the pointer of H_0 is cleared after correction, errors of $L_{48}^{\times}$, $R_{48}^{\times}$ (sub-block of H_{16} and H_{32}) can be corrected by b-Adjacent decoder.

The algorism of crossword decoding is shown in Fig-10.

If there are further errors in sub-blocks H_{16}, H_{32}, H_{48}, H_{64}, H_{80}, H_{96}, H_{112}, or H_{128}, and B_{48} of eq.(13) which cannot be corrected by the b-Adjacent decoder, the more complex crossword decoding method can be applied to find the location of two arbitrary erroneous words in one sub-block. A brief explanation for that is as follows:

From eqs.(1), (14), (15),

$$S_{48} = E_{L48} \oplus E_{R48} \quad (28)$$

$$S_{L48} = \mathrm{Res}\ (x^{114} S_{48}) = \mathrm{Res}\{x^{114}(E_{L48} \oplus E_{R48})\} \quad (29)$$

$$S_{R48} = \mathrm{Res}\ (x^{100} S_{48}) = \mathrm{Res}\{x^{100}(E_{L48} \oplus E_{R48})\} \quad (30)$$

Next, another auxiliary syndrome is calculated from the residual of the CRCC decoder by adding some forward or backward shifting of the resistor.

$$C'_{16} = \mathrm{Res}\ (x^{-14} C_{16}) = \mathrm{Res}\ (x^{100} E_{L48}) \quad (31)$$

$$C'_{32} = \mathrm{Res}\ (x^{14} C_{32}) = \mathrm{Res}\ (x^{114} E_{R48}) \quad (32)$$

From eqs.(29)-(32),

$$\begin{aligned} S_{L48} \oplus S_{R48} &= \mathrm{Res}\{x^{114}(E_{L48} \oplus E_{R48})\} \oplus \mathrm{Res}\{x^{100}(E_{L48} \oplus E_{R48})\} \\ &= \mathrm{Res}\ (x^{114} E_{L48}) \oplus \mathrm{Res}\ (x^{114} E_{R48}) \\ &\quad \oplus \mathrm{Res}\ (x^{100} E_{L48}) \oplus \mathrm{Res}\ (x^{100} E_{R48}) \\ &= C_{16} \oplus C'_{32} \oplus C'_{16} \oplus C_{32} \end{aligned} \quad (33)$$

On the contrary, if eq.(33) is satisfied, error words are defined as L'_{48} and R'_{48} in the sub-blocks of B_{48}, H_{16}, and H_{32}, and they can be corrected by b-Adjacent decoder.

Fig-11 shows this higher level crossword decoding system, in which every possible auxiliary syndrome like eqs.(31) and (32) are calculated beforehand. If the error pointer indicates n-word ($n \gtrsim 3$) error in one sub-block before delay, every possible combination of two-word errors n(n-1)/2 should be examined as in equation (33).

4. EVALUATION OF CODE ERROR CORRECTABILITY

Fig-12 shows a rough procedure of statistical analysis of error correcting schemes.[5][6] The statistical characteristics of code errors are expressed as parameters of a model, which are estimated from measured data, and appropriate variation of parameter values is given in the calculation. The analysis is executed by the monte-carlo method or by simple statistical calculation.

Fig-13 shows a simple statistical model of code errors for magnetic recordings, which is called the modified Gilbert Model,[5] and is expressed by the Markov Chain.

Two parameters α and β are the probabilities to fall down into, and to recover from, the state of code errors, respectively. These parameters can be transformed into bit error rate p and bit error correlation coefficient δ by the following equations.

$$p = \frac{\alpha}{\alpha + \beta} \tag{34}$$

$$\delta = 1 - \alpha - \beta \tag{35}$$

The greater the value δ is, the more burst-like the errors are, and the smaller δ, the more random-like.

Fig-14 shows the results of computer simulation of various decoding systems in the EIAJ signal format. Bit error rate p is 10^{-4} constant, but bit error correlation coefficient δ is changed from 0.900 to 0.999. The measured value of δ is between 0.900 and 0.990, but the larger value is also important for strength against dust and scratches on tapes.

The vertical axis of Fig-14 is the frequency of miscorrection (times/hour) in each decoding system.

The curves of error concealment are not shown here, because there are so many possible methods. One of the methods for the basic decoder, in which erroneous word is always separated by one word without errors (one word interpolation), has a strength similar to the b-Adjacent error correction system.

5. CONCLUSION

Described here have been the details behind the code error correction method of the EIAJ signal format for PCM encoder-decoders using consumer cassette video systems.

Several computer simulations to prove the practical degree of code error correctability have also been included. The EIAJ signal format is not only appropriate to consumer equipment but is also applicable to use in automatic systems at an AM and FM broadcasting station in that it has;

1. A standardized signal format
2. A high degree of code error correctability
3. A possible dynamic range of over 80dB
4. Easy operation because cassette tapes are used

Digital Audio Processor PCM-10 and PCM-100 use the b-Adjacent code as their decoding system, but it should be noted from a technical standpoint that the basic decoding method, when used in combination with error concealment, may be reliable enough for practical use.

In such cases, 16-bit linear quantization may also be possible on the assumption that the Q area is used not as the check word but as a data area for two extra bits on each information word.

In closing, the authors would like to thank Dr. Heitaro Nakajima, Director, Audio Technology Center of SONY Corporation, for his useful advice and imaginative suggestions.

Thanks are also due to the members of SONY Digital Audio Project team for their helpful discussions.

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Table-1 The basic parameters of EIAJ signal format

VTR to be connected	≧Betamax or VHS
Number of channels	2
Sampling frequency	44.056kHz
Number of samples in one horizontal line	3 2 channel
Number of samples in one virtical field	735 2 channel
Source encoding	14 bit linear slot
Modulation	NRZ-FM composite video signal
Bit density	2.643Mbit/sec
Error correction	CRCC Interleave Parity word b-Adjacent code [3] Crossword code [4]
Redundancy without sync.	34.4%
SONY models	PCM-10, PCM-P10 PCM-100

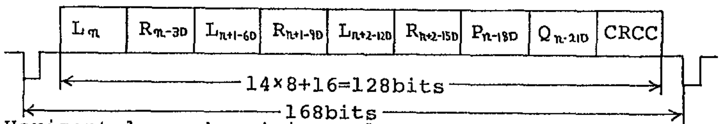
Table-2 The theoretical limitations of characteristics

Frequency Range	DC-20kHz
Dynamic Range	85.8dB (Noise Range 20kHz)
Harmonic Distortion	0.003% (Maximum Signal Level)
Wow and Flutter	Quarz Precision

Table-3

Signal format.
(Pseudo video signal: applies to NTSC standard video signal unless otherwise indicated)

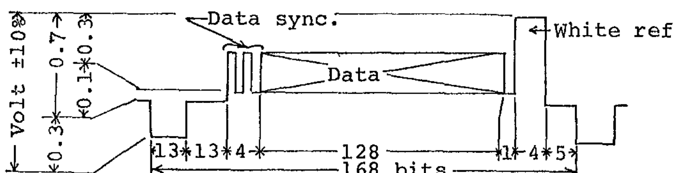
1. Signal Format for a horizontal line period.



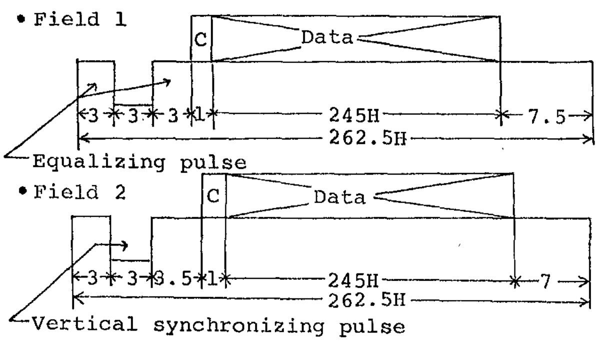
Horizontal synchronizing pulse

where L_n, R_n ; Data words for 2 channels. (= 14 bits)
P_n, Q_n ; Check words for error correcting. (= 14 bits)
CRCC ; Check words for error detecting. (= 16 bits)
D ; Delay for interleave. (= 16 words)

2. Waveform of a horizontal line.



3. Signal format for one field on Video Signal.



where H ; Length of horizontal line of Video Signal.
C ; Data control signal. (1H)

4. Configuration of Data Control Signal.

a) Field synchronizing word.
(Registration of '1100' pattern)

b) Data discrimination word. (All bits = '0' tentatively)

c) Adress imformation word. (All bits = '0' tentatively)

a	b	c	d	CRCC
11001100......1100	0..0	00..00		
56bits	14 bits	28bits	14 bits	16 bits
128bits				

d) Control signal word.
(Bit 1-10=0 tentatively, Bit 11-14 is indicated as follows)

Meaning of code	Control	Indication of bit	Bit position
Prohibition of digital dubbing	NO	'0'	11
Discrimination of P	YES	'0'	12
Discrimination of Q	YES	'0'	13
Discrimination of emphasis	YES	'0'	14

Table-4 Error detecting/correcting code

Error detecting/correcting code

A CRCC, Erasure decoding, b-Adjacent code, Crossword code, and interleave in combination.
Redundancy 34.4% except for synchronizing pulse.
53.3% including synchronizing pulse.

1. Error detecting code.

CRCC Generation polynomial $G(x)=X^{16}+X^{12}+X^{5}+1$
All of shift registers are reset in '1'

2. Interleave.

16-word simple delayed interleave.

3. Erasure decoding.

The erasure decoding can correct one random error in one block using the CRCC as the error word pointer.

4. b-Adjacent code.

The b-Adjacent code can correct two rancom errors in one block using the CRCC as the error word pointer.

$$P_n = L_n \oplus R_n \oplus L_{n+1} \oplus R_{n+1} \oplus L_{n+2} \oplus R_{n+2} \qquad (36)$$

$$Q_n = T^6 \cdot L_n \oplus T^5 \cdot R_n \oplus T^4 \cdot L_{n+1} \oplus T^3 \cdot R_{n+1} \oplus T^2 \cdot L_{n+2} \oplus T \cdot R_{n+2} \qquad (37)$$

where $\oplus$ means modulo 2 summation. (Exclusive OR)

$$T = \begin{pmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&1\\
1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&1&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&1&0&0&0&0&0&1\\
0&0&0&0&0&0&0&0&1&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&1&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&1&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&1&0
\end{pmatrix}$$

5. Crossword decoding.

The crossword decoding using the CRCC in conjunction with Pn can significantly improve random error correcting ability.

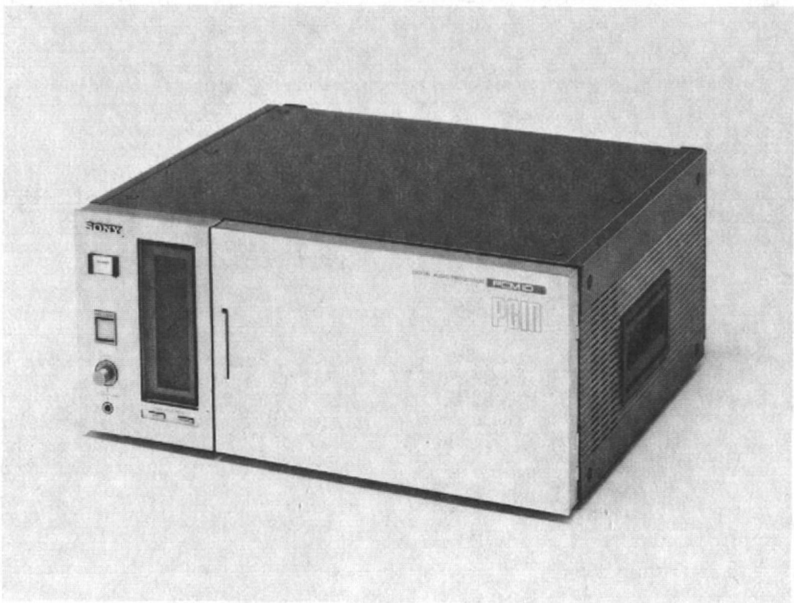


Fig-1 Consumer use digital audio
processor PCM-10 (SONY)

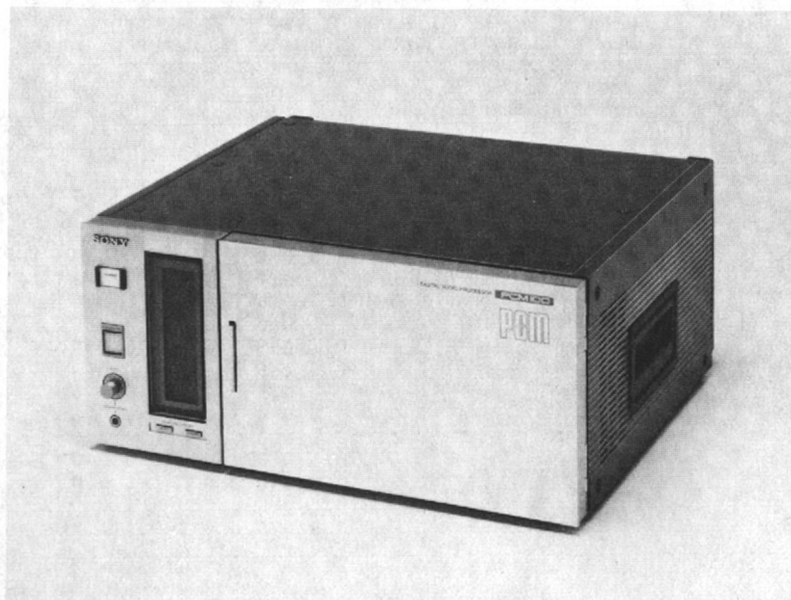
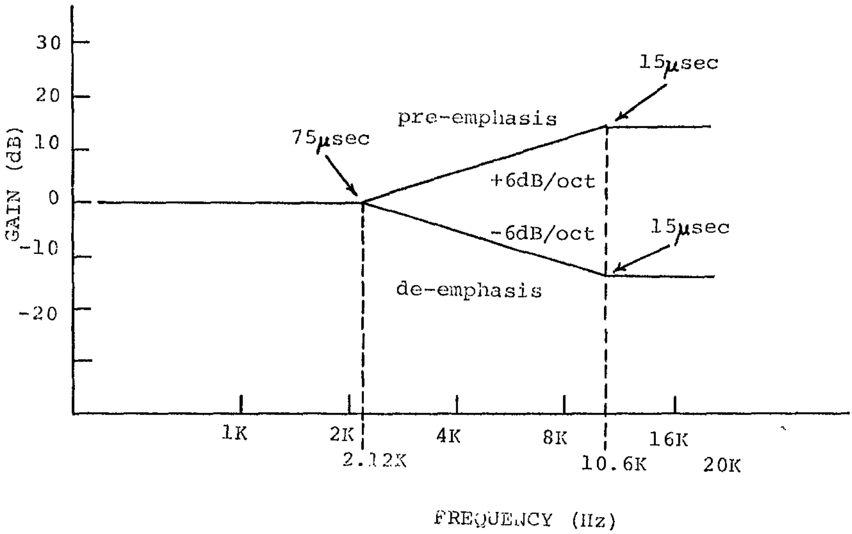


Fig-2 Professional use digital audio
processor PCM-100 (SONY)

Fig-3.

CHARACTERISTIC OF EMPHASIS.



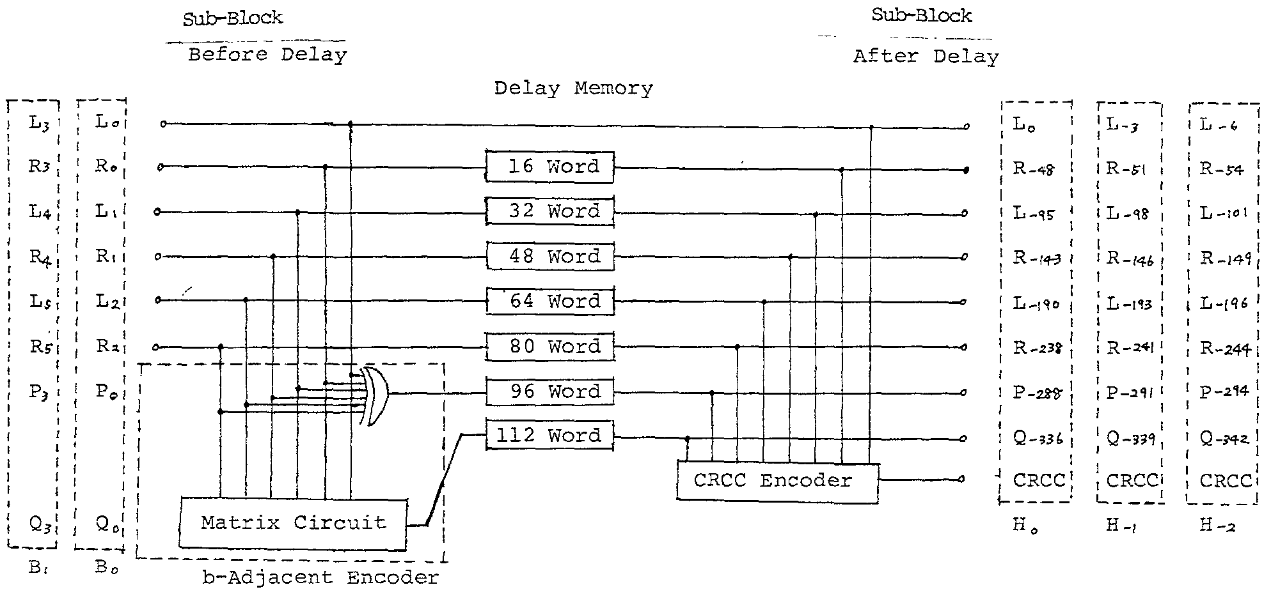


Fig-4. Encoder

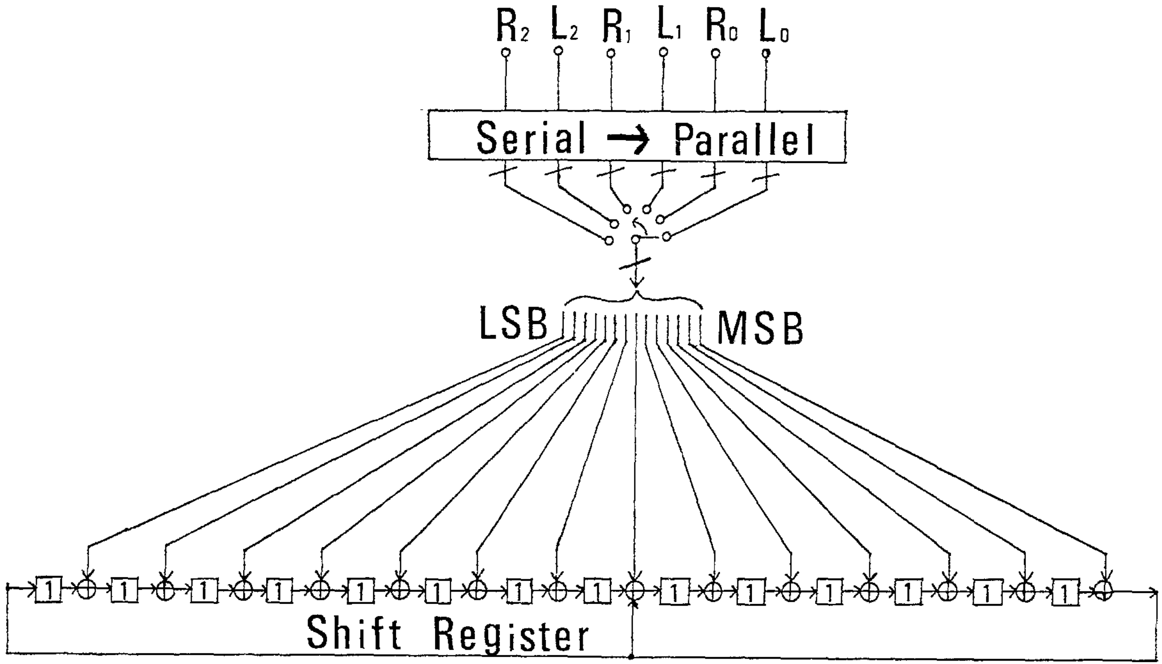


Fig-5. Matrix Circuit for b-Adjacent Encoding

H_{0}	L_{0}	R_{-48}	L_{-95}	R_{-143}	L_{-190}	R_{-238}	P_{-288}	Q_{-336}	CRCC
H_{16}	L_{48}	R_{0}	L_{-47}	R_{-95}	L_{-142}	R_{-190}	P_{-240}	Q_{-288}	CRCC
H_{32}	L_{96}	R_{48}	L_{1}	R_{-47}	L_{-94}	R_{-42}	P_{-192}	Q_{-240}	CRCC
H_{48}	L_{144}	R_{96}	L_{49}	R_{1}	L_{-46}	R_{-94}	P_{-144}	Q_{-192}	CRCC
H_{64}	L_{192}	R_{144}	L_{97}	R_{49}	L_{2}	R_{-46}	P_{-96}	Q_{-144}	CRCC
H_{80}	L_{240}	R_{192}	L_{145}	R_{97}	L_{50}	R_{2}	P_{-48}	Q_{-96}	CRCC
H_{96}	L_{288}	R_{240}	L_{193}	R_{145}	L_{98}	R_{50}	P_{0}	Q_{-48}	CRCC
H_{112}	L_{336}	R_{288}	L_{241}	R_{193}	L_{146}	R_{98}	P_{48}	Q_{0}	CRCC

Fig-6. **Interleave Sequence**

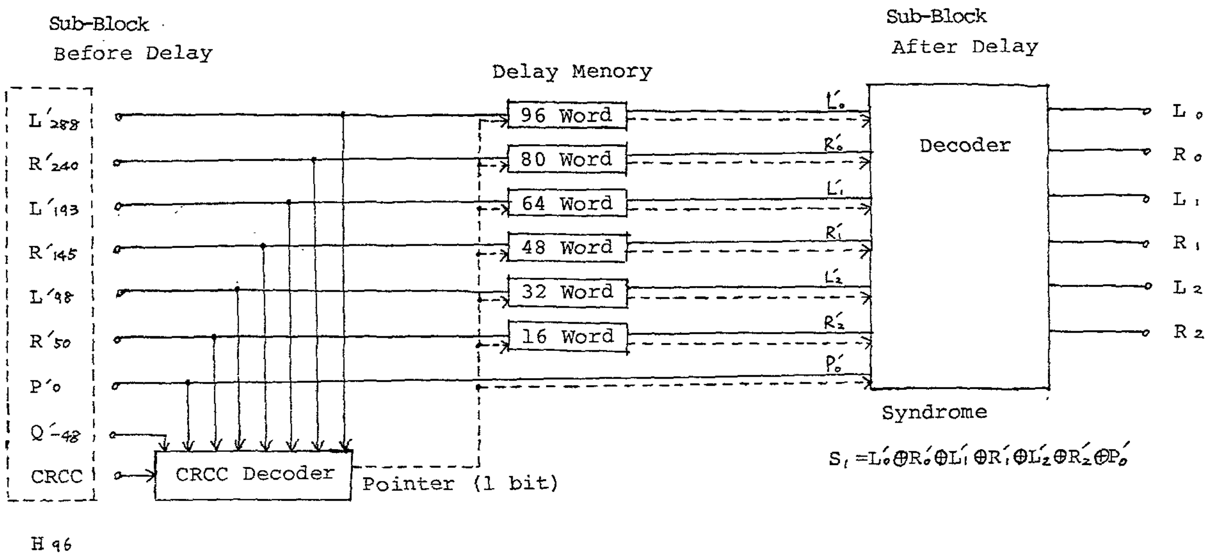
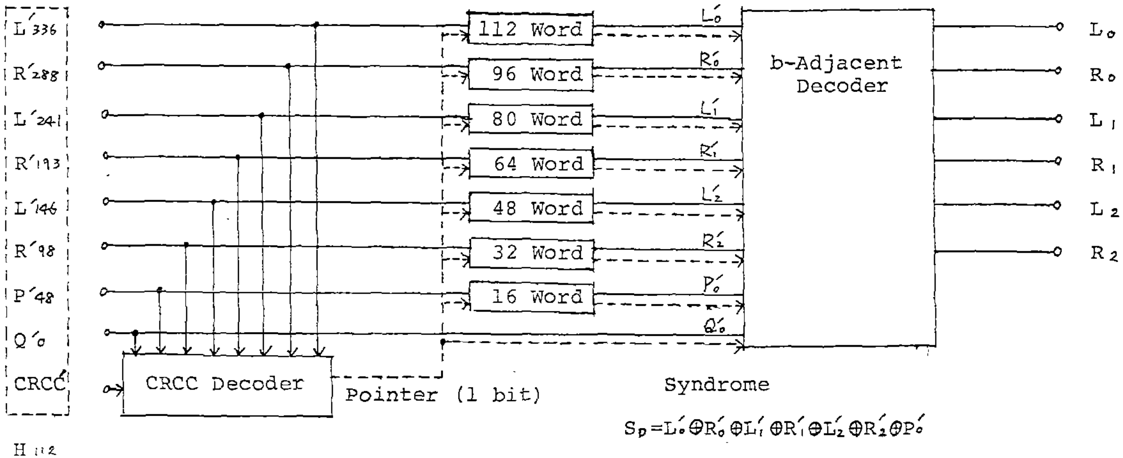


Fig-7. Basic Decoding System (Memory 336 Word)



$$S_P = L_0' \oplus R_0' \oplus L_1' \oplus R_1' \oplus L_2' \oplus R_2' \oplus P_0'$$

$$S_{T0} = T^6 L_0' \oplus T^5 R_0' \oplus T^4 L_1' \oplus T^3 R_1' \oplus T^2 L_2' \oplus T R_2' \oplus Q_0'$$

Fig-8. b-Adjacent Decoding System (Memory 448 Word)

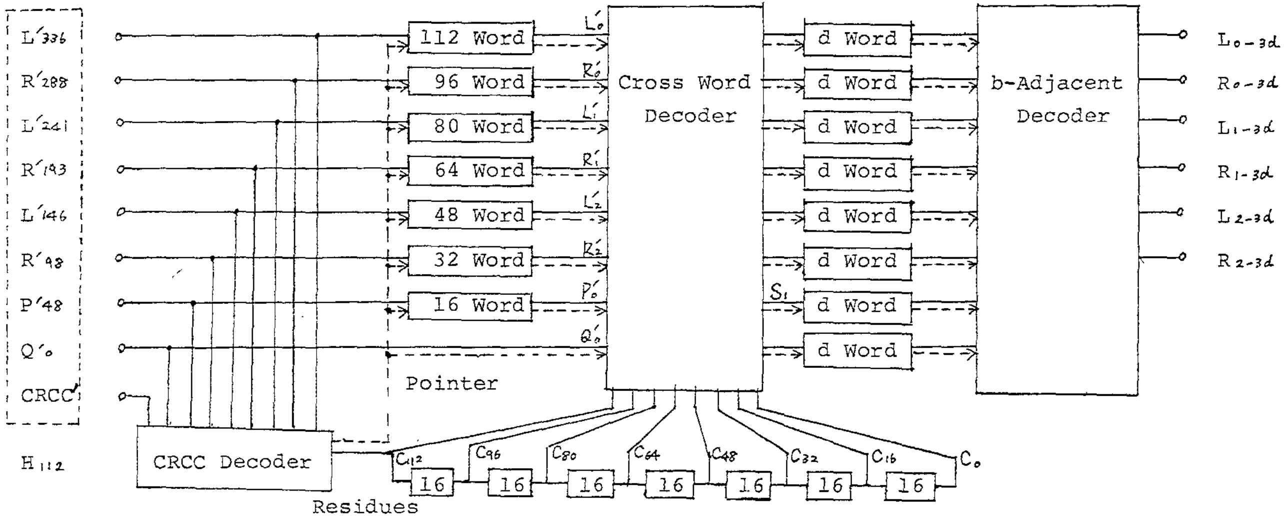


Fig-9. Crossword Decoding System (No. 1)
(Memory 560~1456 Word)

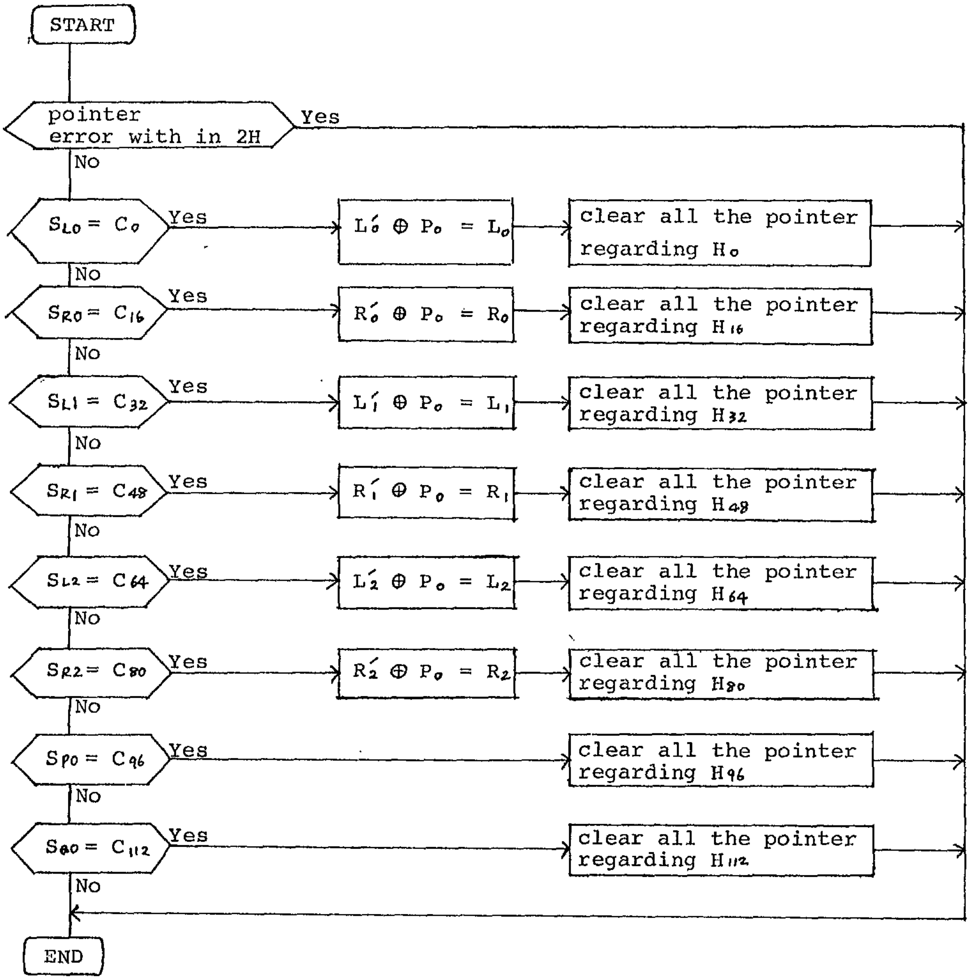


Fig-10. An Algorism of Crossword Decoder

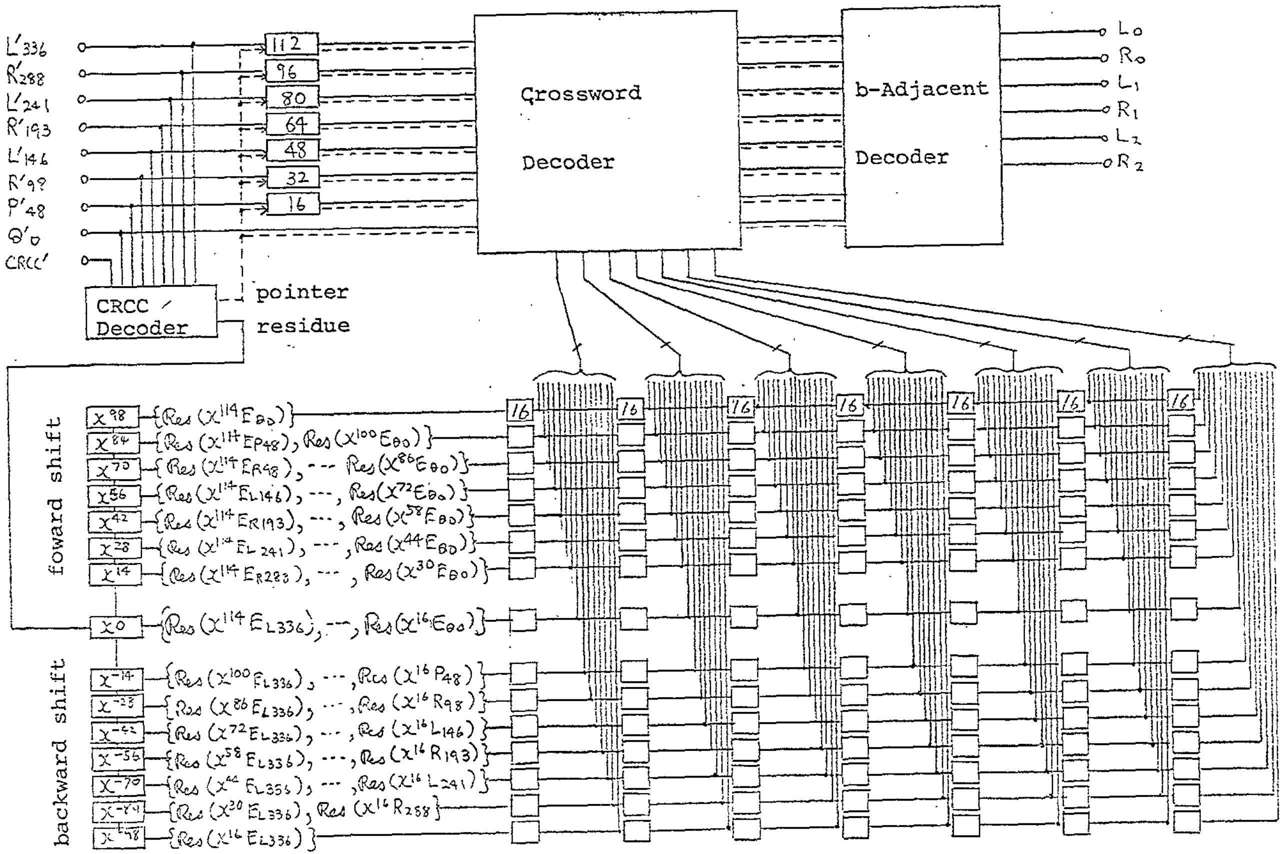


Fig-11. Crossword Decoding System (No.2) (Memory 2128 words)

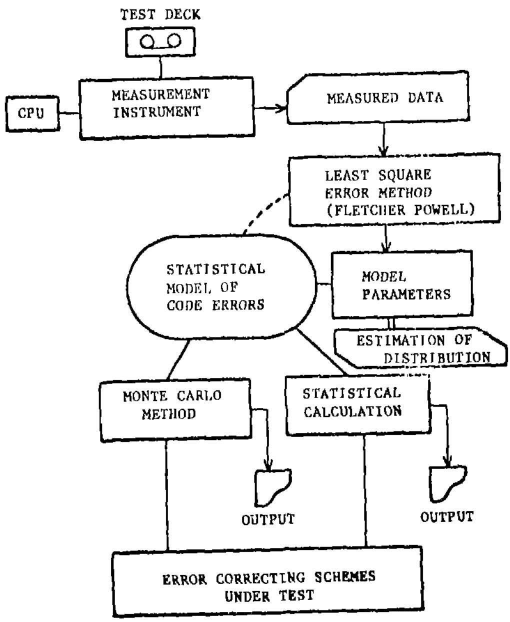
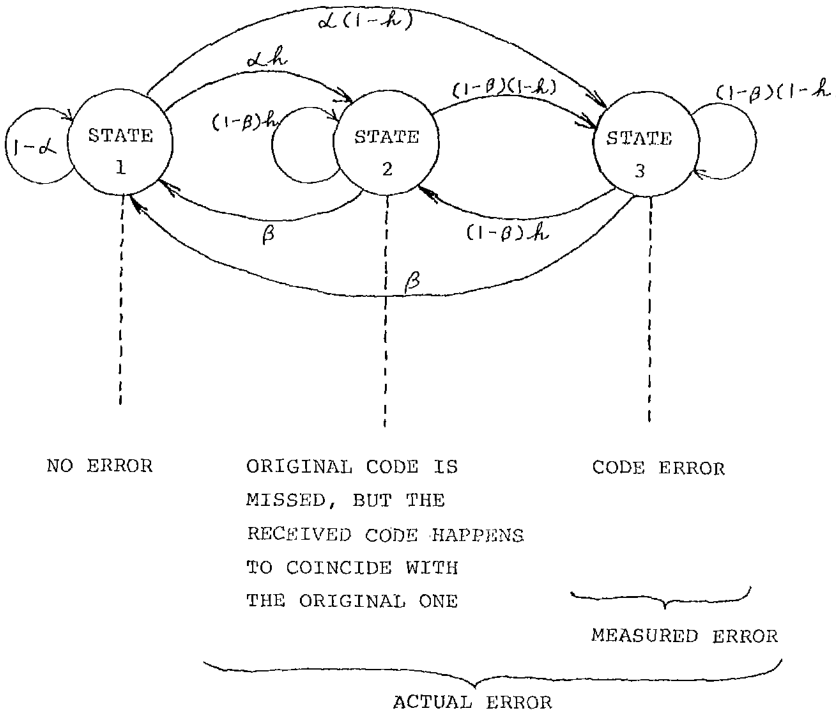


Fig-12.

STATISTICAL ANALYSIS OF CORRECTABILITY



α :PROBABILITY TO FALL INTO ERROR STATE 2,3

β :PROBABILITY TO RECOVER FROM ERROR STATE 2,3

h :PROBABILITY OF ERRONEOUS CODE ACCIDENTALLY COINCIDE WITH ORIGINAL ONE

Fig-13. A STATISTICAL MODEL OF CODE ERRORS (MODIFIED GILBERT)

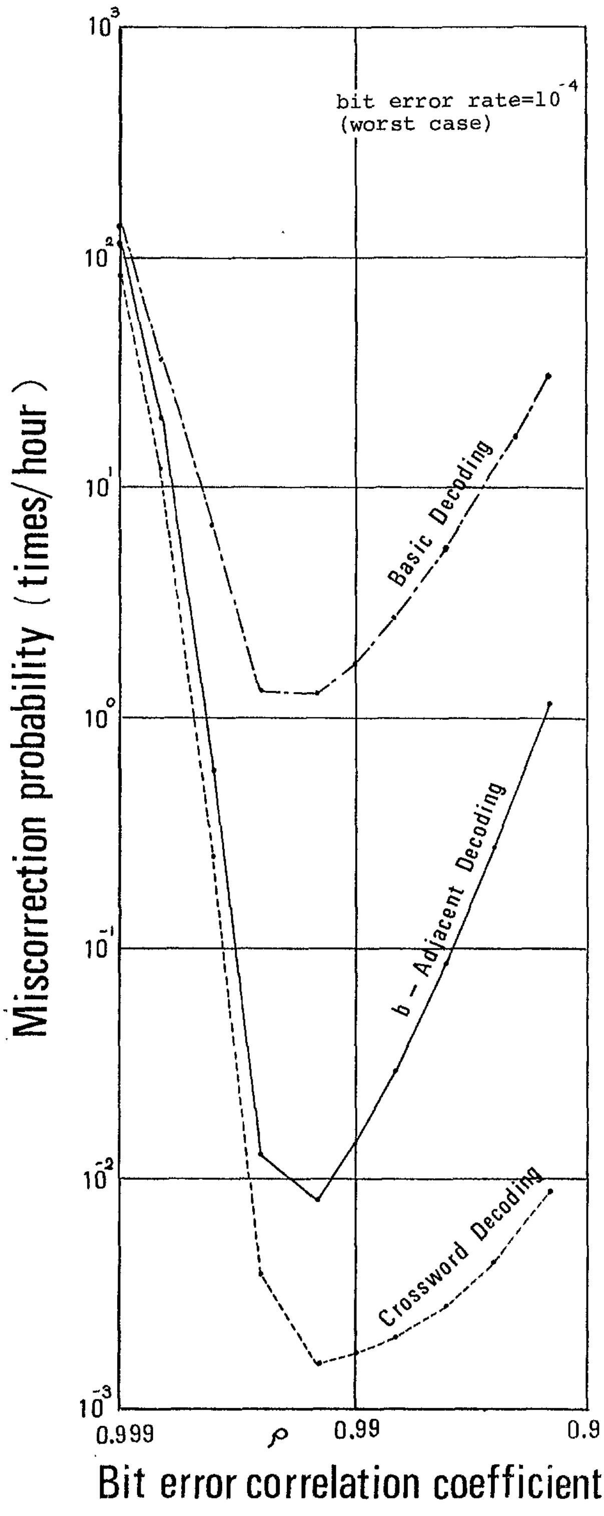


Fig-14.

RESULTS OF COMPUTER SIMULATION.