A ROTARY-HEAD PCM RECORDER EMPLOYING ERROR CORRECTION TECHNIQUE

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ABSTRACT

A digital audio system now includes a home use VTR as record and reproduce media. In this system, audio signal is converted into digital codes by PCM, which are again converted such that the resultant signal be identical with NTSC TV format. This insures ready use of existing TV equipments, their peripherals, and networks.

The paper mainly describes possible error detection and correction schemes for dropouts, and choice criteria of sampling rate.

1. INTRODUCTION

Recent progress in developing digital audio recorders is quite rapid and amazing. This reflects the everlasting need for ultra HiFi sound recording and reproduction system on part of both professional and consumer users.

Above all, consumer application(1),(2) requires lower cost and smaller size, observing the features of digital recording.

The paper describes the system designing of a VTR based home use PCM recorder.

2. SYSTEM DESIGNING

2-1 Specification

The system designing that follows may be better understood by listing the major specifications of the system at the beginning.

SPECIFICATIONS

Channels	2 cH With bias recording 1 cH
Frequency response	DC-20 kHz (±0.5 dB)
Dynamic range	Better than 90 dB
Distortion	Less than 0.03%
Wow and flutter	Equivalent to crystal oscillatpr accuracy
Sampling rate	44.0559 kHz
Coding	13 bits logical companding
Dropout compensation	Correction by CRC and Parity
Signal format	NTSC TV format with video replaced by PCM signal

2-2 Choise of Sampling Rate

In choosing sampling rate F_s, the following requirements were taken into consideration.

(1) Audio frequency band

As noted in (2-1), the audio frequency band is DC to 20 kHz. Shannon's sampling theorem indicates the minimum sampling rate is twice the transmission band width. However, practical designing of antialiasing filter suggests the sampling rate chosen greater than that calculated by the theorem.

Hence,

$$F_s > 42 \sim 43 \text{ kHz} \quad (1)$$

It should be noted that excessively high sampling rate is not only useless but also results in raising bit recording density, which must be avoided.

(2) Conversion of PCM signal to TV format

Since the recording mechanism is from a home use VTR (Rotary two heads), the digitalized audio signal (PCM) must be reformed into the standard TV signal format with video signal part replaced by PCM signal. (Fig. 1)

As shown in Fig. 1, TV signal has some blank space where no data can be recorded. This space includes vertical sync pulse, equalizing pulse, and head switching allowance.

The basic relationship between sampling rate F_s and TV's horizontal sync frequency F_H, in converting the PCM data into TV format, is,

$$F_s = M \cdot F_H \cdot \frac{525-x}{525} \quad (2)$$

$$= M \cdot F_H \cdot \frac{n}{m} \quad (3)$$

where M: Total samples per line (1H).
x: Total nonrecordable lines per frame.
n/m: Reduced fraction.

Note: We assume NTSC TV format.
F_H = 15.73426 kHz

To reduce bit rate as low as possible under observance of equation (1), total samples M per line was chosen 3.

The equations other than eq. (1) may be found satisfying requirements needed to convert PCM data to TV signal format, yet they will bring about

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extremely complicated system and so excluded for simplicity reason.

In equation (3), m and n should be chosen as small as possible to give freedom to the system designing as described later.

The non recordable space per field includes 9H for equalizing period, 3H for head switching allowance, and additional 3∿4H for some other purposes.

Hence,

$$x \geq 32H \quad (4)$$

Table 2 shows possible examples of x, m, n, and F_s.

Based on the above discussions, we chose 44.0559 kHz as the sampling rate. As noted elsewhere, we assumed NTSC TV format. For monochrome 525 line and PAL/SECAM TV system, 44.1 kHz will be suitable.

2-3 Nonlinear Coding by Logical Companding

One of the conspicuous features of the PCM recording is in its extremely wide dynamic range reproduction capability. As listed at the outset, we specified this by better than 90 dB to avoid probable clipping when recording ultrawidely dynamic programs. Simple solution to achieve 90 dB may be the use of 16 bit A/D, D/A converters, yet they are very expensive and contrary to bit rate reduction. This is particularly true in designing a home use PCM tape recorders.

We now turned to the use of far less expensive converters (12 bits) along with logical companding method. Conventional analog companding was not employed for accuracy reason.

Fig. 2 and Fig. 3 show how the signal is processed. When an input signal stays in the Range (I), Range detector generates "1", actuating the selector to pass the amplified signal by m to the A/D converter (12 bits), while in Range (II), "0", non amplified signal is selected. This means the S/N of a small signal under the leverl of F_s/m is improved by the factor m, because the amplification before A/D conversion gets the signal through more quantizing steps than otherwise, hence higher resolution.

Resulted dynamic range is 86 dB for m=4, and 92 dB for m=8 theoretically. We chose the latter one.

2-4 Error Correction Scheme

2-4-1 The Nature of Tape Dropouts

In PCM recording, data errors caused by inherent tape dropouts must be perfectly controlled to avoid serious deterioration in the quality of reproduced sound. To design the suitable error control system, it is inevitable to know the nature of the tape dropouts. They have a distribution from very short, say a single bit size to some hundreds of bits size. The distance between two consecutive dropouts is enormously long. This sort of data error is known to be a burst error. The burst distribution can be observed on the TV screen because in our system, the same cassettee tape for VRT is used.

2-4-2 Limitation of Error Concealment[3]

The simple error concealment method is to replace the error data by mean values or repeated data of the adjacent correct data. This method is more improved when combined with interleaving or reordering of data before recorded so that burst error is segmented, scattered, and transformed into small size random error.

However, concealment system, fundamentally generates noise, and is not sufficient for recording music programs having high frequency components. In particular, sine wave can not be reproduced by this system without audible concealing noise.

2-4-3 Error Correction

There are many error correcting codes ever developed mainly in the field of computers. However they are not usually suitable to cope with video tape dropouts affecting some hundreds of bits.

The simplest error correction method for the burst error is double recording. In this method, the real time data and its delayed are time division multiplexed (TDM) and recorded on the tape. (Fig. 4) Thus reproduced data stream contains the same information doubled. Consequently, even if a burst takes place and damages some portion of data, the same data recorded on the different part of the tape, will be the correct data with very high probability. Then, the correct data stream is reproduced.

The double recording is simple and effective. But is raises the bit rate because the same data is recorded two times.

2-4-4 Less Redundant Error Correction[4]

To reduce the bit rate, it is not wise to record the same data twice. Instead, the parity bits P is generated based on the following equation.

$$P_n = L_n \oplus R_n \quad (\text{mod } 2) \quad (5)$$

Now, the data recorded on the tape consists of only $\{L_n\}$, $\{P_n\}$, and $\{R_n\}$, where $\{P_n\}$ and $\{R_n\}$ are delayed by ℓ and 2ℓ respectively, before recording. (Fig. 5) Then due to the delay effect mentioned above, a burst error is scattered to be a random error. As understood from the nature of the burst error distribution, it is rare to have more than one damaged out of L_n, P_n, R_n recorded on the three different ℓ spaced points on the tape at the same time. Then, if the damaged data is only one, it is perfectly corrected by modulo two addition of other correct two data. Concealment method is applied if more than one data is damaged.

The complete correction algorithm is given in Table 2.

2-4-5 Error Detection

The simple error detection is done by a single parity method. But its detection probability is only 1/2, and too vulnerable to burst errors in question. We used CRC (Cyclic Redundancy Charactor) check method, quite powerful for burst error detection. The generating polynominal G(x) is,

$$G(x) = X^{16} + X^{12} + X^5 + 1 \quad (6)$$

Note: Based on CCITT V. 41

The detection probability of this is better than $(1 - \frac{1}{2^{16}})$.

2-5 Data Format

With the chosen sampling rate, total bits per sample, and L, P, R error correction method, we are now ready to form an exact PCM signal based on the NTSC TV format.

1H contains 3 audio samples from L cH and R cH, respectively, 3 parity samples, and 16 bits CRC, totaling 133 bits at least. Furthermore close to 17% of 1H should be provided for H blanking period.

Then,

$$N \geq 160 \quad (7)$$

where N: Total bits per line.

Now let F_c be the bit rate, then,

$$F_c = NF_h \quad (8)$$

Equations (2) and (8) reduce to,

$$F_c = N \cdot \frac{15}{14} F_s \quad (9)$$

Note: M=3, x=35

N should be the multiple of 14 to reduce the clock rate F_c, Hence facilitating the production of a crystal oscillator, and simple system designing. The best couple of F_c and N is,

$$F_c = 2.64 \text{ MBPS} \quad (10)$$

$$N = 168 \text{ bits} \quad (11)$$

A home use VTR can handle this bit rate without any remodeling. Fig. 6 shows the eye diagram of the replayed data. Fig. 7 shows the complete data format recorded in 1H. Fig. 8 shows the schematic block diagram.

3. SOME DISCUSSIONS

Data, L_n, P_n, and R_n will be called a word. Let P_w be the probability of word producing an error. It is for 2 word error and for 3 word error out of L_n, P_n and R_n that error correction can not be applied and is replaced by error concealment. (See Table 2)

Let P_2 be the probability of 2 word error, P_3, 3 word error. Then,

$$P_2 = {}_3C_2 P_w^2 = 3P_w^2$$

$$P_3 = {}_3C_3 P_w^3 = P_w^3$$

The probability P_w varies from tape to tape and ranges $10^{-3} \sim 10^{-5}$. Total word in a second is given by 3 F_s. Then concealment frequency F_2, and F_3, corresponding to P_2 and P_3, can be estimated theoretically. Then,

	$P_w = 10^{-3}$	10^{-4}	10^{-5}
$F_2 \fallingdotseq$	1 in 3 sec.	1 in 5 min.	1 in 9 hr.
$F_3 \fallingdotseq$	1 in 3 hr.	1 in 116 days	1 in 10^5 days

Fig. 9 shows the measurement of error concealment frequency, in relations to the delay length ℓ. The word error rate P_w of the tape used, was approximately 10^{-4}.

Theoretical estimation matches well the actual measurement.

In actual system, error checking is operated for 1H, consisting of 9 words. However, the discussion given above will be good enough for approximate estimation of error behavior.

4. CONCLUSION

System designing for a VTR based PCM tape recorder was described. Since the signal format recorded on the tape is exactly based on the standards of NTSC TV signal, the system is readily used for many applications, such as transmission of audio PCM over television networks, etc.

5. ACKNOWLEDGMENT

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(3) 'Pulse Code Modulation for High Quality Sound Signal Distribution: Protection against Digit Errors'. BBC Research Department Report No. 1972/18.

(4) F. Bellis and M. Brookhart. 'An Error Correcting System for a Multichannel Digital Audio Recorder'. The 58th AES Conventional Preprint No. 1298 (M-2). (1977-11)

Table 1

	x	n	m	F_s (kHz)
	32	493	525	44.32567
	33	164	175	44.23576
	34	491	525	44.14585
▷	35	14	15	44.05594
	36	163	175	43.96603

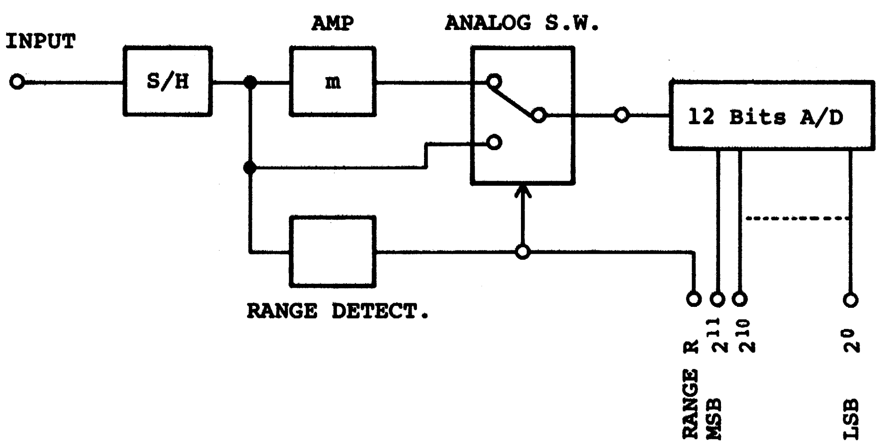


Fig. 3 MODEL OF LOGICAL COMPANDING.

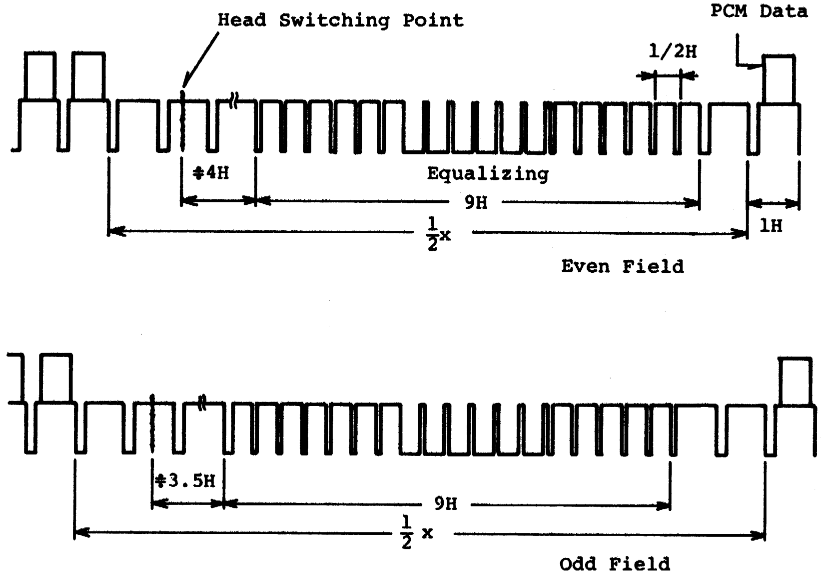


Fig. 1 NTSC TV SIGNAL FORMAT WITH PCM DATA RECORDED.

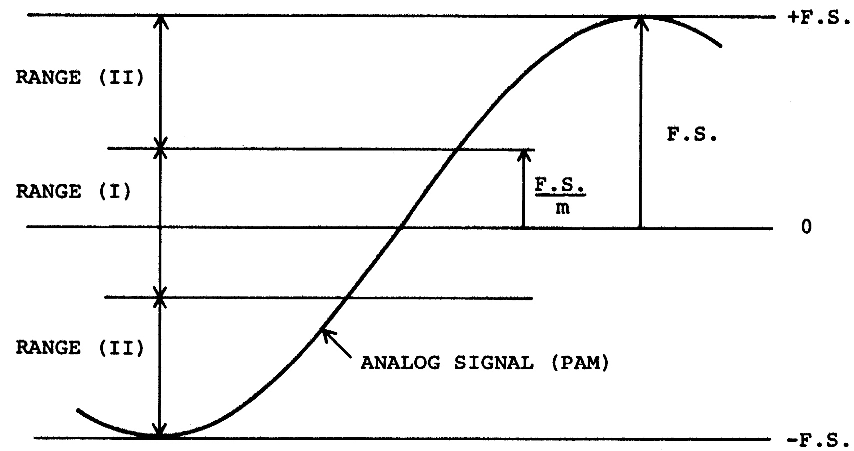
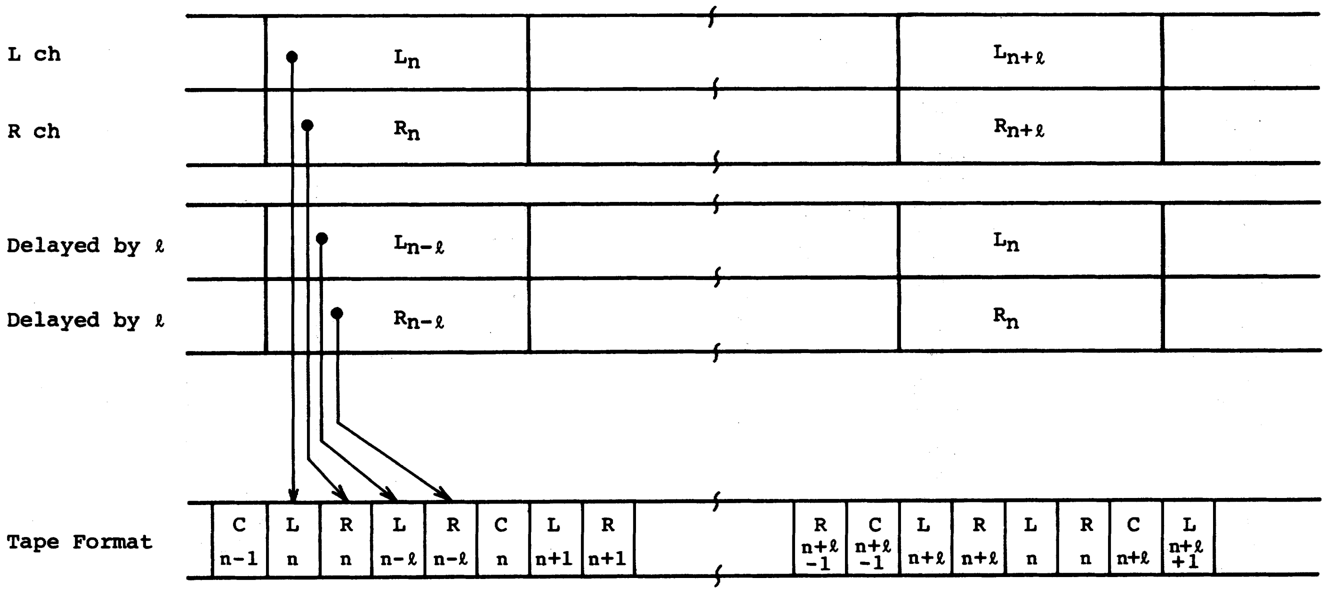
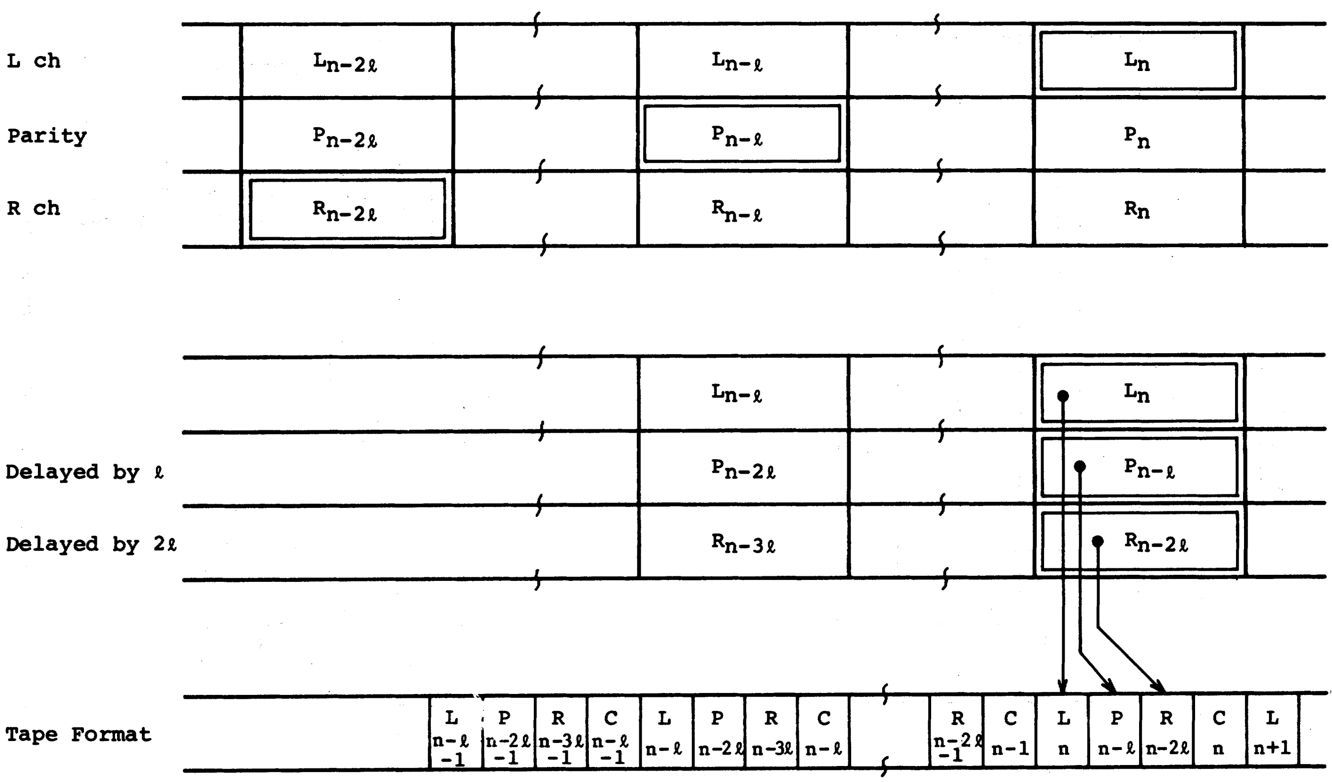


Fig. 2 ILLUSTRATION OF RANGES.



Note: C_n = CRC for checking $\{L_n, R_n, L_{n-\ell}, R_{n-\ell}\}$.

Fig. 4 DOUBLE RECORDING ERROR CORRECTION SCHEME



Note: C_n = CRC for checking $\{L_n, P_{n-\ell}, R_{n-2\ell}\}$.

Fig. 5 L, P, R, ERROR CORRECTION SCHEME

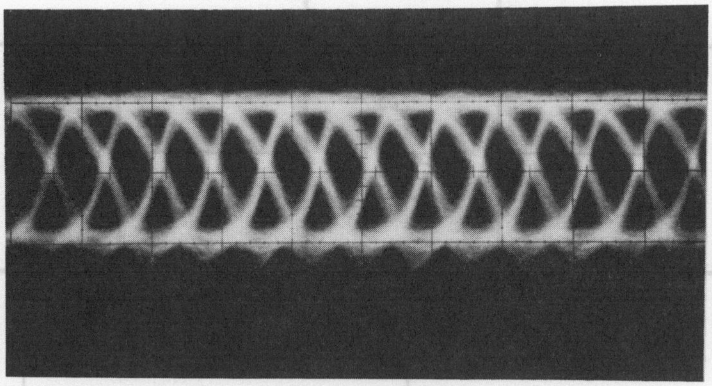
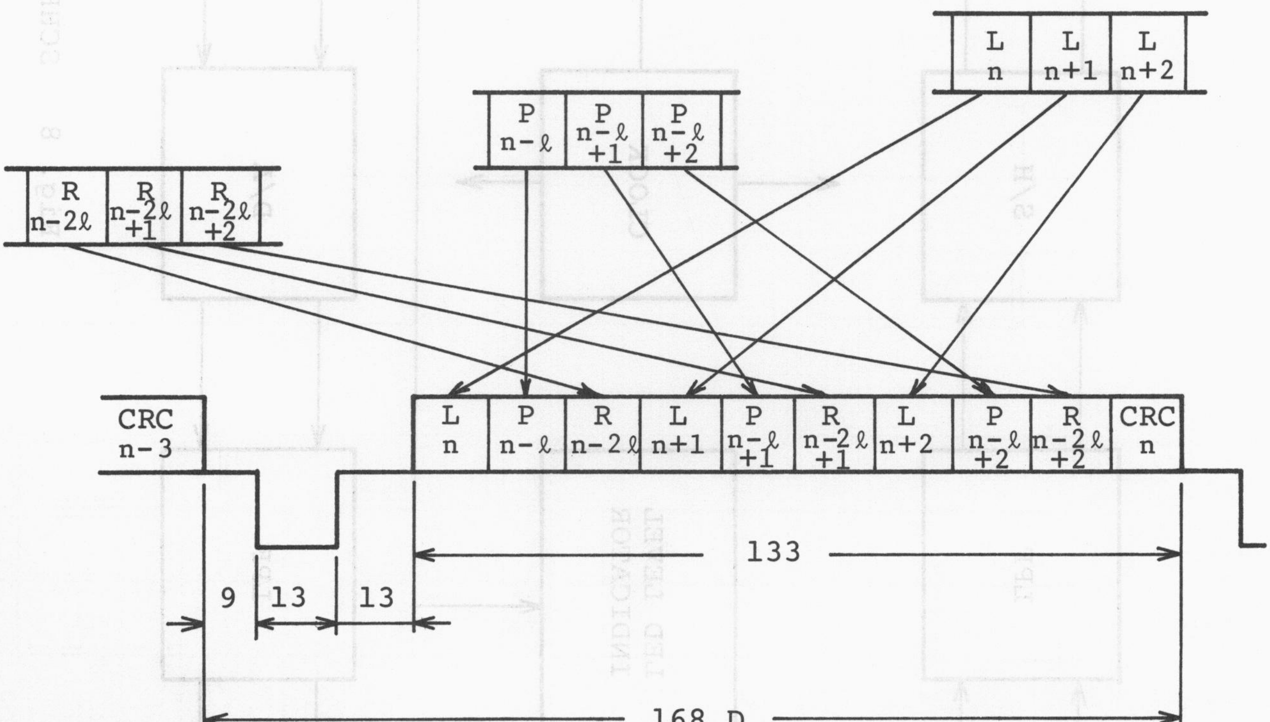


Fig. 6 EYE DIAGRAM



Note: 1H=63.556μs, 1D=379ns.

Fig. 7 COMPLETE 1H FORMAT.

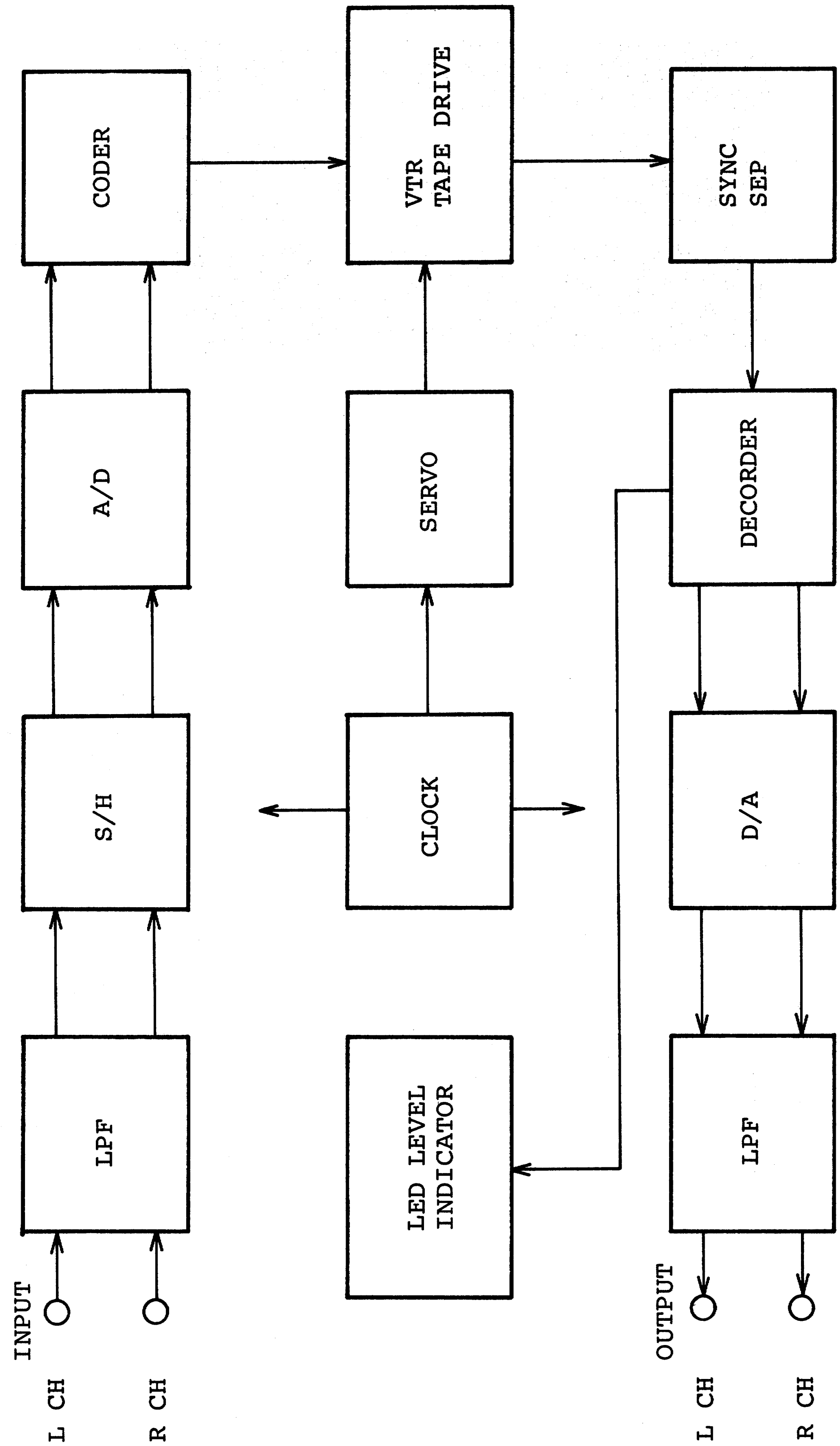


Fig. 8 SCHEMATIC BLOC DIAGRAM.

Table 2 Correction Algorithm

L_n	P_n	R_n	OUTPUT L	OUTPUT R
0	0	0	L_n	R_n
0	0	1	L_n	$L_n \oplus R_n$
0	1	0	L_n	R_n
0	1	1	L_n	$\hat{R}_n$
1	0	0	$P_n \oplus R_n$	R_n
1	0	1	$\hat{L}_n$	$\hat{R}_n$
1	1	0	$\hat{L}_n$	R_n
1	1	1	$\hat{L}_n$	$\hat{R}_n$

Note (1) Symbol "0" indicates no error.
Symbol "1" indicates error.

(2) Symbol $\wedge$ indicates error concealment.

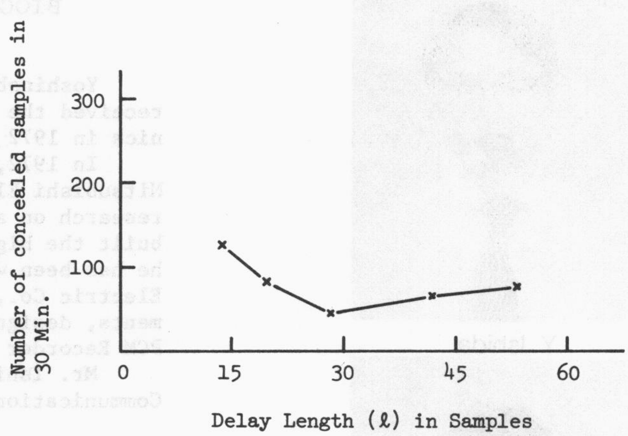


Fig.9 Frequency of Error Concealment vs. Delay Length.

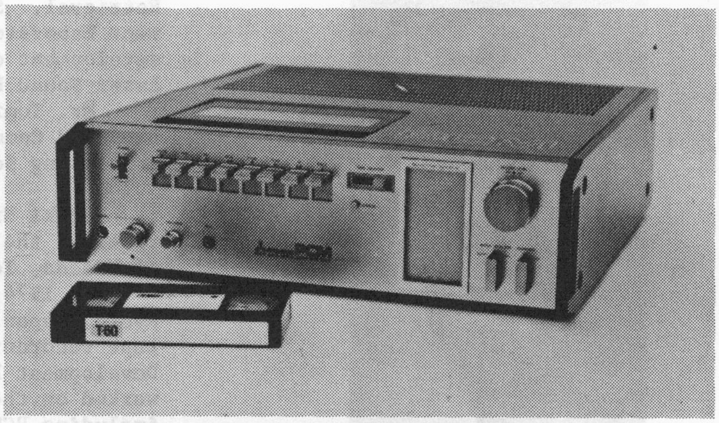
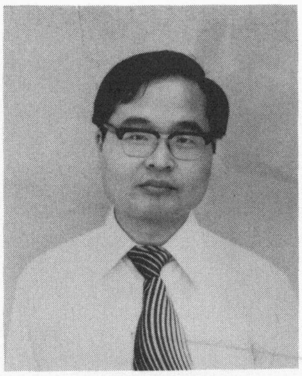


Fig.10 External View of the Rotary Head PCM Recorder.

BIOGRAPHIES



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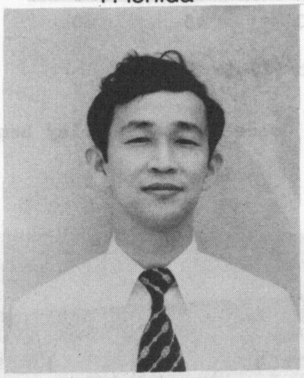

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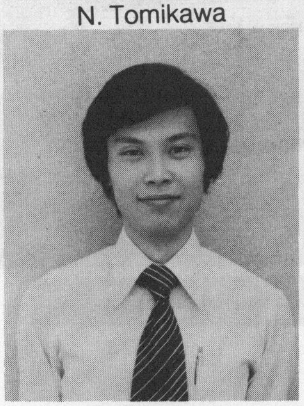

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