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On the Development of a Car use Rotary-Head Digital Audio Tape Recorder

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ON THE DEVELOPMENT OF A CAR USE ROTARY-HEAD DIGITAL AUDIO TAPE RECORDER

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ABSTRACT

The authors have developed a Rotary-head Digital Audio Tape recorder (R-DAT) for car use conforming to the technical specifications of the DAT conference. This recorder realizes not only high quality audio characteristics but also miniaturization (DIN size), facility of use by employing a rapid access music search system, and a small size mechanizm.
This paper describes the signal processing and the performance of a car use R-DAT.

1. INTRODUCTION

As for this consumer use digital audio equipment, the compact disc (CD) player with only a playback function has been prevailing in the market as a commercialized product, firmly expanding in its popularity. On the other hand, an appearance of the Digital Audio Tape recorder(DAT) having functions both of recording and playback has long been waited in public aspiration , thus in the mean time DAT conference which aimed to confer on the standardization of DAT has succeeded to summarize the technical specification of DAT in July, 1985 through about two years' endeavour since the commencement in June 1983, is in the final stage of discussion under the aim of commercialization of the product currently.

The purpose of DAT conference is to position the DAT in the place of the tape recorder for the next generation, conferring on the feasibility of standardization of the system to be applied to a variety of the fields covering from general audio to Hi-Fi audio in the like manner as the compact cassette system occupies in the market so that two types of tape recorders for recording and playback, namely R-DAT, and S-DAT, have been taken up as the objects of discussion. Thus, reaching to the status where both of these types are summarized in the forms of technical specifications currently, in which the former is a Rotary head digital audio tape recorder, incorporating a rotary head for recording and playback as like the set of a VTR, and the latter is a stationary head digital audio tape recorder, incorporating a stationary head for recording and playback, and letting the tape run as in the like manner as the case of conventional tape recorder.

The authors already reported about a proto model of a home use R-DAT based on the technical specification of the DAT conference. As the application of the R-DAT system of which the size is smaller than that of a home use one, we have developed a car use R-DAT. Though a R-DAT for car use has many mutual point with that for the home use, specifications peculiar to car use, small size, durability for vibration, must be shown. This report describes its system design, signal processing, and mechanism of this system.

2. OUTLINE OF THE SYSTEM

This system has been developed, aiming the accomplishment of the system performance superior than the conventional car use equipment, that is to say, not only the high quality audio characteristics but also the easy operation of the system are realized concretely.

Fig. 1 shows the appearance of the system, Fig. 2 giving the status of the equipment mounted on the dashboard.

2.1 SPECIFICATION AND FEATURES

Table 1 gives the specification of this system. As mentioned previously there are many mutual points between the car use and home use equipment, however the outstanding features of this system are as follows:

1. Dimension of the body DIN size being incorporated; in order to meet the purpose, a small size mechanism has been developed.

2. The slot-in type front loading mechanism is employed for cassette loading, so that the like manner of application as given for the conventional type is provided.

3. Fast tape running with the tape kept wrapped on the drum as it is feasible, and rapid access music search in the order of about 200 times normal tape speed is realized thanks to a newly developed high speed type reel motor incorporated for fast feed.

4. The system is so constructed as to be conform to two kinds of sampling frequencies by selecting automatically which prevail generally worldwide. 48/44.1 KHz

5. Capability of selecting a variety of music numbers is provided, the operability being also improved.

    1. Rapid access music search is facilitated in terms of music numbers.

    2. One touch skip to the starting position of the music under the play or starting position of the next music is facilitated.

    3. Repeating a specific number or all of the numbers is facilitated.

    4. Automatic play of the starting position of each music for 10 seconds (Intro scan) is provided.

6. Music number, time, repeat, intro scan, etc. are to be indicated on a wide liquid crystal panel, facilitating easy display for onlookers.

7. The size of the cassette is nothing but about 1/2 size of the conventional compact cassette, being able to provide 2 hour's play continuously.

3. SYSTEM CONSTRUCTION

This system is a equipment with only a playback function, so that the system is simplified by means of eliminating the circuit for recording.

The track format, the block format and a block diagram of the system are shown in Figs. 3, 4 and 5 respectively.

By means of a rotary head the reproduced signal picked up from the tape is drawn out, through a rotary transformer, to the outside, being inputted into the playback amplifier, where the signal is amplified, being improved on its frequency characteristics through equalizer, and the data taken out as a digital signal by means of the signal detector; these data are converted through a demodulator into 8 bit per 10 bit units, being provided with error correction by the decoder. At the decoder, the deinterleaving by which the order of the data are rearranged into the original sequence, and the processing by which the data companded the time base are to be expanded as the original to be taken out as continuous data are undertaken by means of incorporating a memory, the capacity of which requires 64Kbits times two pieces. By means of this memory being employed, the temporal axis deviations of the playback data accompanied with tape run deviations are completely removed, so that no Wah fluttering in playback sound will occur. The data provided with error correction enter into a DA converter, where they are converted into an analog signal, being removed of their unnecessary high frequency components through a low pass filter to be regenerated as the original audio signal. On the other hand, in the playback amplifier, besides the PCM data, the ATF signal which is divided in the domain and recorded, is also reproduced to be fed to the servo circuit for tracking and used for the tape feed control.

Besides the above, a micro computer is employed in order to execute overall system control, executing the processing of subcode, interface with operating key, driving the display device, etc.

4. ERROR CONTROL METHOD

As an error correction method, a R-DAT employs the Doubly Encoded Reed Solomon Code, which has powerful error correction capabilities, and two-track completed interleaving, which has strong interpolating capabilities.

4.1 INTERLEAVING

As shown in Fig. 6, the L and R channel data samples are divided into even samples and odd samples, and the data for one channel is disposed diagonally across the track.
By employing this interleaving, high reliability of reproduced data can be obtained, as either even or odd samples will be correct, even if all samples recorded in a track are lost by head clogging, or all samples recorded in the area between tape edge and center of tape are lost.
Fig. 7 shows details of data arrangement recorded on + azimuth track, giving the redundant parity of double Reed-Solomon Code, P and Q, at the same time. L and R show data of L channel and R channel respectively; the numerals in the suffix indicate the temporal series of data generated, the alphabet, u and l indicating the fact that 16 bit sample is divided into 8 bit symbols for the upper tier (U) and lower tier (l) respectively, and the hatching part shows the vacant slot. As shown in this figure, even in either an even or odd samples, those samples having the times of their generations coming in close to each other are kept recorded in different blocks respectively, so as for the compensated sounds not to be concentrated at a specific time. In case of playback, it is to be undertaken insequential order along with the recording direction from the block address 0 onward.

Fig. 8 gives the memory construction which is employed in this system.

Deinterleaving and time base correcting are executed by means of sequential reading-out of each of L and R channels in the sequential order starting from that given smaller number in suffix respectively after error-correction being provided on these data.

4.2 CODE CONSTRUCTION

As shown in Fig. 8, data recorded on a track consists of four i-k planes, and each plane is doubly encoded by C1 code and C2 code. C1 code is constructed by (32, 28, 5) Reed Solomon Code over CF (2^8), and C2 code is constructed by (32, 26, 7) Reed Solomon Code over GF (2^8). The parity check matrix of C1 code H1 and parity check matrix of C2 code H2 are shown below.

$$H1 = \begin{bmatrix} 1 & 1 & 1 & \text{-----} & 1 & \text{-----} & 1 & 1 & 1 \\ a^{31} & a^{30} & a^{29} & & a^{n} & & a^{2} & a & 1 \\ a^{62} & a^{60} & a^{58} & & a^{2n} & & a^{4} & a^{2} & 1 \\ a^{93} & a^{90} & a^{87} & \text{-----} & a^{3n} & \text{-----} & a^{6} & a^{3} & 1 \end{bmatrix} \qquad (1)$$

$$H2 = \begin{bmatrix} 1 & 1 & 1 & \text{-----} & 1 & \text{-----} & 1 & 1 & 1 \\ a^{31} & a^{30} & a^{29} & & a^{n} & & a^{2} & a & 1 \\ a^{62} & a^{60} & a^{58} & & a^{2n} & & a^{4} & a^{2} & 1 \\ a^{93} & a^{90} & a^{87} & & a^{3n} & & a^{6} & a^{3} & 1 \\ a^{124} & a^{120} & a^{116} & & a^{4n} & & a^{8} & a^{4} & 1 \\ a^{155} & a^{150} & a^{145} & \text{-----} & a^{5n} & \text{-----} & a^{10} & a^{5} & 1 \end{bmatrix} \qquad (2)$$

where a is the root of the primitive polynomial

$$X^8 + X^4 + X^3 + X^2 + 1$$

D (i, k) is a symbol disposed at the location (i, k) in a i-k plane. C1 code of the i-th column and C2 code of the k-th row in a plane are filled in the equations (3).

$$H1 \cdot \begin{bmatrix} D\ (i,\ 0) \\ D\ (i,\ 1) \\ D\ (i,\ 2) \\ \vdots \\ D\ (i,\ 31) \end{bmatrix} = 0, \quad H2 \cdot \begin{bmatrix} D\ (0,\ k) \\ D\ (1,\ k) \\ D\ (2,\ k) \\ \vdots \\ D\ (31,\ k) \end{bmatrix} = 0 \qquad \ldots (3)$$

4.3 DECODING ALGORITHM AND IT'S PERFORMANCE

Generally, a decoding algorithm has several variations. The authors employ an algorithm which has the burst error correction capability being enhanced as strong as that of code allows, and the random error correction capability stronger than that of CD. Decoding is conducted in such a manner that first C1 decoding is executed, then followed by execution of C2 decoding; the error correction may be executed up to 2 erros in C1 decoder, and if the number of errors is larger than 2, C1 flag shall be added, in the next stage of C2 decoding, the error correction shall be undertaken up to 6 erasers in the maximum as shown in Fig. 9 by means of C1 flag being incorporated.

Fig. 10 gives the random error correction capability of the decoding algorithm, and Fig. 11 gives burst error correction capability.

Provided the symbol error rate of the system is smaller than 10^{-3}, in general there are no problems involved in the practical uses, even if the practical system is considered as mingling with burst.

5. RAPID ACCESS MUSIC SEARCH

The rapid access music search is one of the outstanding features of R-DAT. Since the tape speed of R-DAT is 8.15 mm/sec, which is a considerable low tape running speed, compared with that of a conventional compact cassette, 4.76 cm/sec, it is favoured with Rapid Access Music Search, and moreover, in case of a drum of 30 mmø in diameter being used, the wrap angle will be 90°, so that it is feasible to drive the tape in high speed with the tape being kept wound on the drum as it is, and consequently it will facilitate the rapid access music search by means of its reading out the information concerning the music search from the playback signal, resulting in its substantial superiority in operability compared with the conventional compact cassette system.

In order to read-out the data for music search it is required to control the system so as to make the relative velocity between the head and tape kept constant, this system employes rotation control of the drum motor and reel motor so as to realize the constant relative velocity, and rapid access music search in order 200 times the normal tape speed is realized.

5.1 DRUM CONTROL

The rotation (in r.p.m.) of the drum in case of the tape speed being raised up to N times of normal playback speed under the relative velocity being kept constant shall be given by the following equation.

In forward direction:

$$V = \frac{60}{\pi D} \cdot (R + Ts \cdot N) \ (\text{r.p.m.}) \qquad \ldots (4)$$

In reversed direction:

$$V = \frac{60}{\pi D} \cdot (R - Ts \cdot N) \ (\text{r.p.m.}) \qquad \ldots (5)$$

Where D is the drum diameter (30 mmø), R being the relative velocity (3.13 m/sec) between the tape and head, and Ts is the tape speed (8.15 mm/sec) in the usual playback, in the rapid access music search in the forward direction, the drum revolution speed shall be raised up, and in the reversed direction it shall be lowered by control, where the drum driving rotation number shall be determined definitely by N.

5.2 REEL CONTROL

Fig. 12 gives the number of cross tracks with same azimuth reproduced during the 90° drum rotation, when the tape is run in the speed of N times under the constant relative velocity, which is given by the following equation;

$$T \fallingdotseq 7.5 \times 10^3 \frac{Ts \cdot N}{V \cdot Tp} \qquad \dots (6)$$

where Tp shows the track pitch (0.122 mm) in the direction of tape run; when N is specified, V is automatically determined, so that the drum motor is so controlled as to be the number of rotation in the drum servo, and consequently if the values of N and V are determined, T can be obtained by equation (6). Incidentally the envelope of playback signal for the azimuth recording has convex and concave parts, so that T is confirmed by counting the number of convex parts which are regenerated during the period of the head being in contact with the tape of 90°, relative velocity be controlled so as to be kept constant by means of executing the reel motor control so as for the counting number which can be taken by the internal counter of microcomputer as for the pulse signals generated when the convex part of the envelope detecting circuit is withdrawn to be in conformity with the value obtained by equation (6).
Fig. 13 shows the reproduced envelope at about 200 times tape speed running in the forward direction.

6. MECHANISM

Fig. 14 gives the appearance of the mechanism. The requirements for the car use mechanism shall be the compact size so as for the equipment to be mounted on the dashboard, and the durability against the vibration of the car.
Regarding the equipment size, the restriction is especially strict in the vertical direction, and since the total height of the set is limited to be 50 mm, the allowable height of the mechanism shall be about 70% of the total height, when the amount of electric circuits to be contained in the set is considered, i.e., it shall be 35 mm. In order to accomplish the requirements for this dimensions, a special purpose flat type

brushless motor has been developed for the purpose of application to the tape drive motors, (the drum motor, capstan motor, and reel motor), and a ring gear system is incorporated for the tape loading mechanism which is a special part of the rotary head mechanism, in which thinning is accomplished as of the parts.

As for the durability for vibration, an aluminum diecast base is incorporated for the mechanism foundation, which is strong against the vibration, and the base construction is accomplished by installing a separating wall at the center of the base, letting the rotary head parts and cassette parts separate into each of the shell constructions so as to enhance its rigidity.

In this connection no particular buffer etc. for vibration such as vibration proof rubber, etc. are employed in this equipment.

7. VIBRATION TEST

Fig. 15 shows the measurements of block error rate when vibrations are engaged in vertical direction on the system by means of vibration testing equipment. In spite of various vibrations being involved with the vehicle according to the variation of road conditions, and species of vehicles, evolving into varieties of vibration amplitude, and frequency components, if the system performance is qualified by $1G^{r.m.s.}$, there may be no problems such as intermittent sound cut, etc. in the normal driving of the car. The decoding algorithm employed in this system has, as mentioned previously, the capability practically being involved without problems up to about 10^{-3} of symbol error rate, and the ratio, symbol error rate vs. block error rate, is about 10:1, so that 10^{-3} in the former corresponds to 10^{-2} in the latter. This system does not employ any particular vibration protection material, however, since it is provided with a block error rate of 10^{-2} or less under the amplitude of vibration: $1G^{r.m.s.}$, so that it is deemed that there are no problems involved practically against vertical vibration. But durability against horizontal vibration and shock should be examined. The driving tests which were undertaken on the paved road, gravel road, and rough road with the equipment mounted on the dashboard, veryfied the assurance of playback sound of high quality maintained without any occurrence of compensated sound.

8. CONCLUSION

In the above, the system construction, signal processing and mechanism of the car use R-DAT which is based upon the technical specification given by DAT conference are revealed in descriptions.
In this system, equipment size is DIN size by developing a small size mechanism in order to be mounted on the dashboard and facility of use can be improved by developing a rapid access music search system.

9. ACKNOWLEDGEMENT

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Table 1 SPECIFICATION OF THE SYSTEM

Item		Contents
Number of Audio Channels		2
Sampling Frequency	(KHz)	48
		44.1
Quantization	(bits)	16
Frequency Response		5-20KHz±0.5db
Dynamic Range		more than 96db
Distortion		less than 0.005 %
Linear Recording Density	(KBPI)	61.0
Sub-code capacity	(KBPS)	273
Error Correcting Code		Doubly-encoded RSC
Modulation Scheme		8-10
Tracking Method		ATF
		(area divided)
Equipment Size	(mm)	50×178×165
Cassette Size	(mm)	73×54×10.5
Tape Width	(mm)	3.81
Tape Speed	(mm/m)	8.150
Track Pitch	(μm)	13.591
Drum Diameter	(mm)	30
Drum Revolution Speed	(rpm)	2000
Wrap Angle	(deg)	90.0

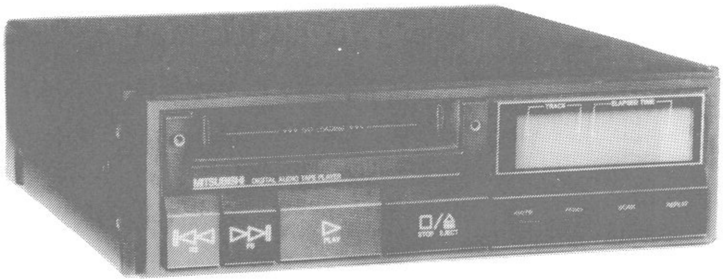


Fig 1 APPEARANCE OF THE SYSTEM

Fig 2　APPEARANCE OF THE SYSTEM MOUNTED ON THE DASHBOARD

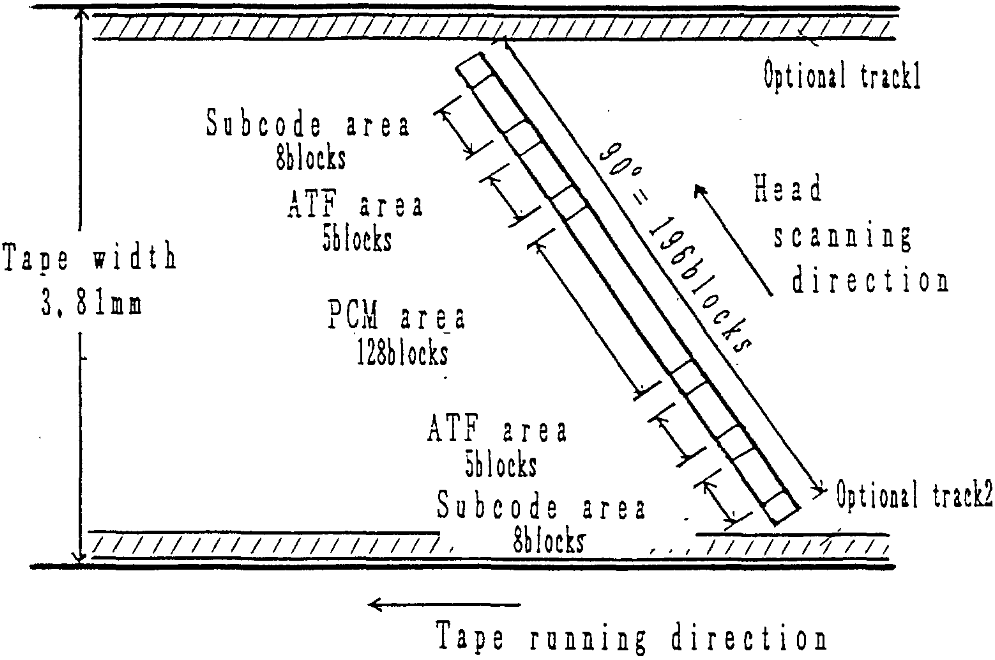


Fig 3 TRACK FORMAT

Sync 8 bits	Identify code 8 bits	Block address 8 bits	Parity 8 bits	Data (PCM data+parity) 256 bits (32 Symbols)

$\longleftarrow$ 288 bits (36 symbols) $\longrightarrow$

1 symbol = 8 bits

Parity = Identify code $\oplus$ Block address

$\oplus$ mod 2 addition

Fig 4 BLOCK FORMAT (PCM)

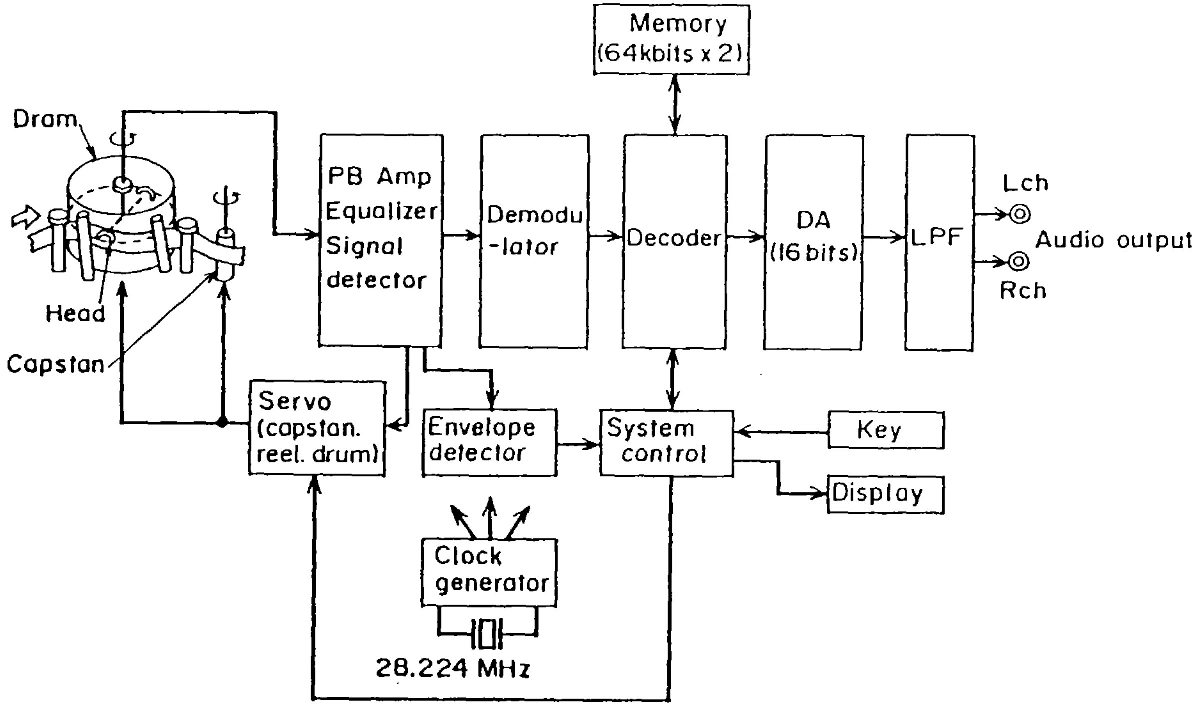


Fig 5 BLOCK DIAGRAM OF R-DAT SYSTEM

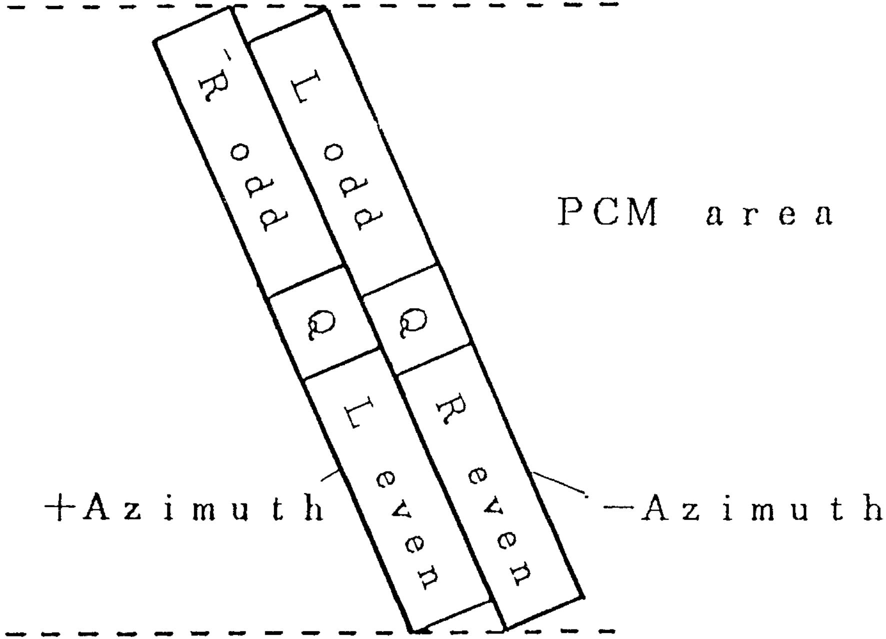


Fig 6 SCHEMATIC REPRESENTATION OF INTERLEAVING

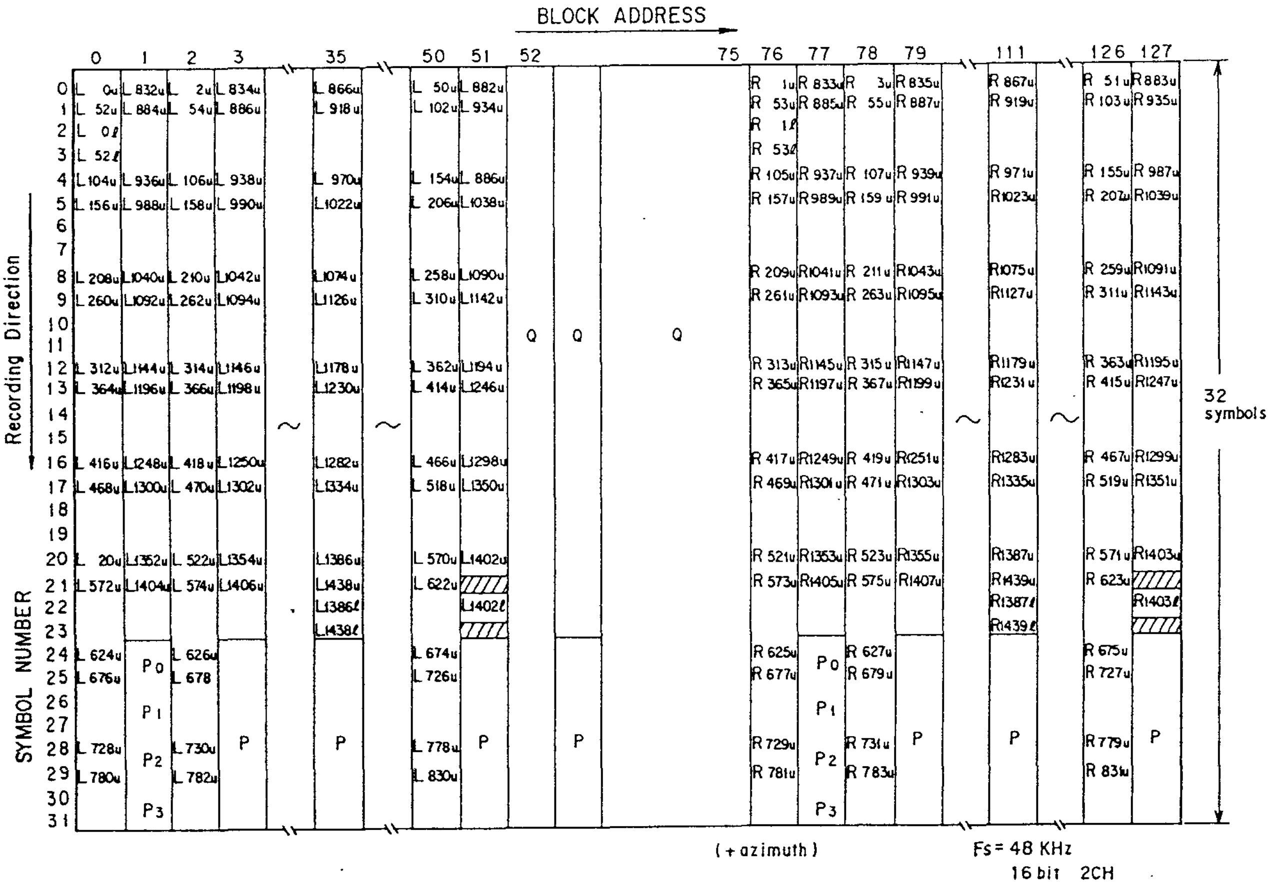


Fig 7 RECORDING ORDER

32 symbols

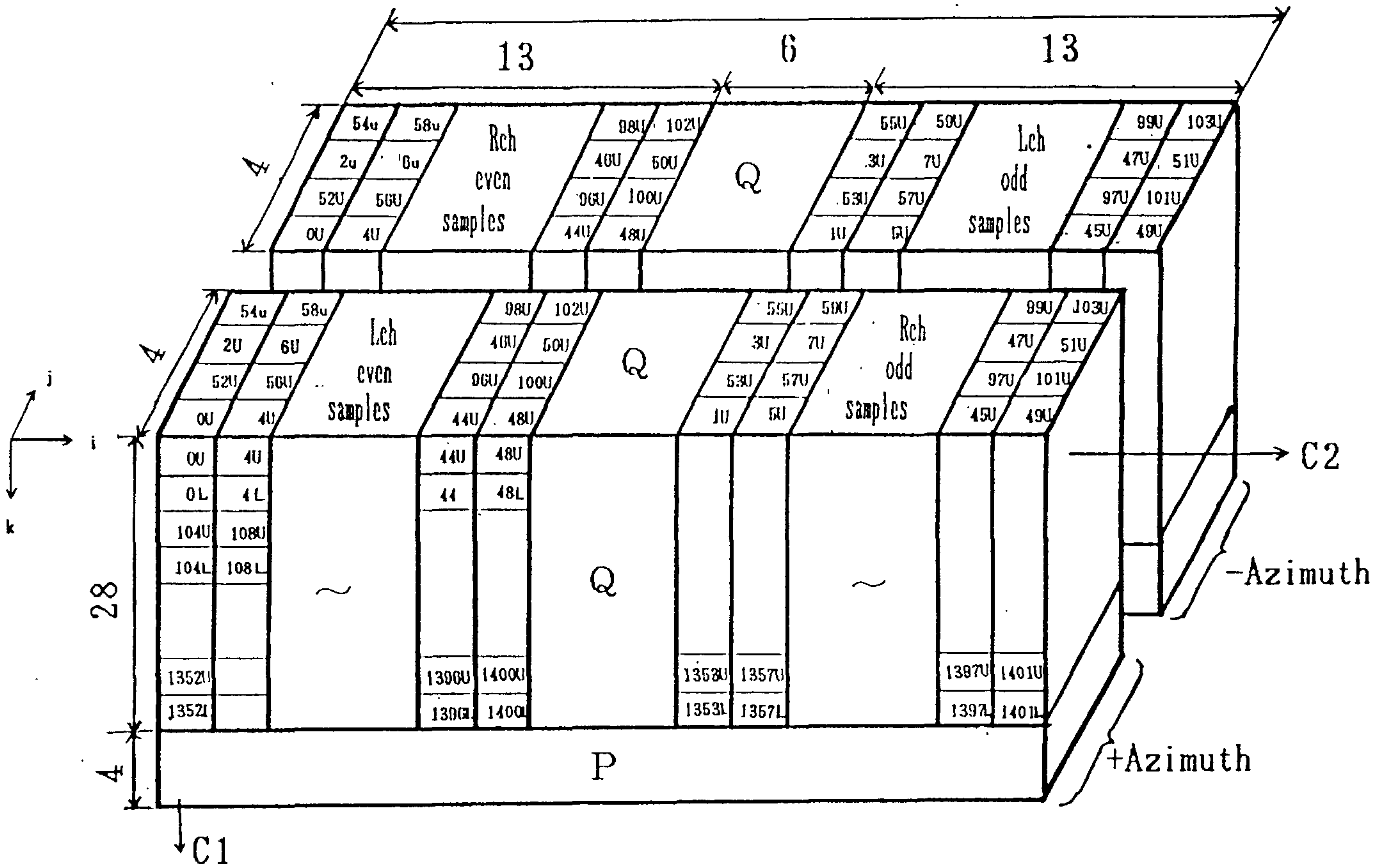
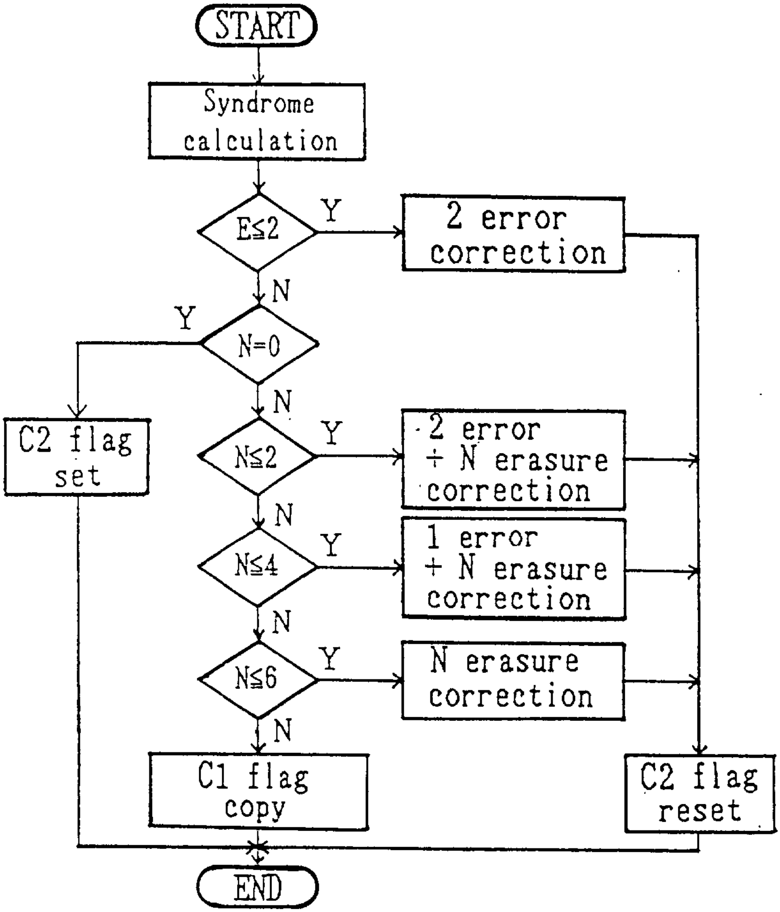


Fig 8 MEMORY CONSTRUCTION



where E : Number of errors

N : Number of c1 flags

Fig 9 C2 DECODING ALGORITHM

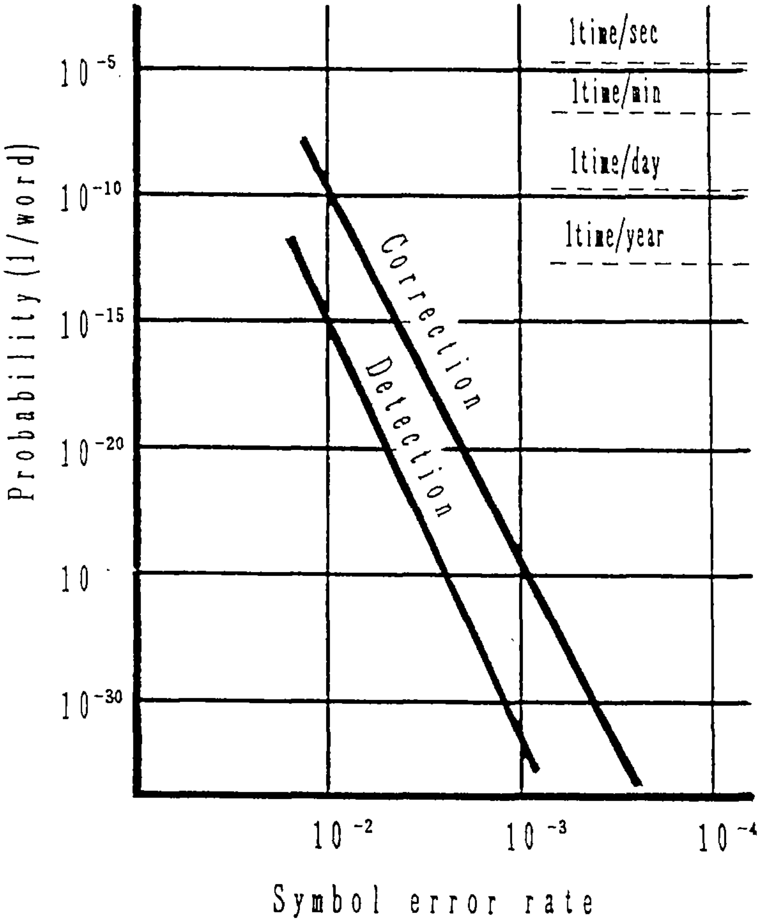


Fig 10 CAPABILITY OF RANDOM ERROR CORRECTION

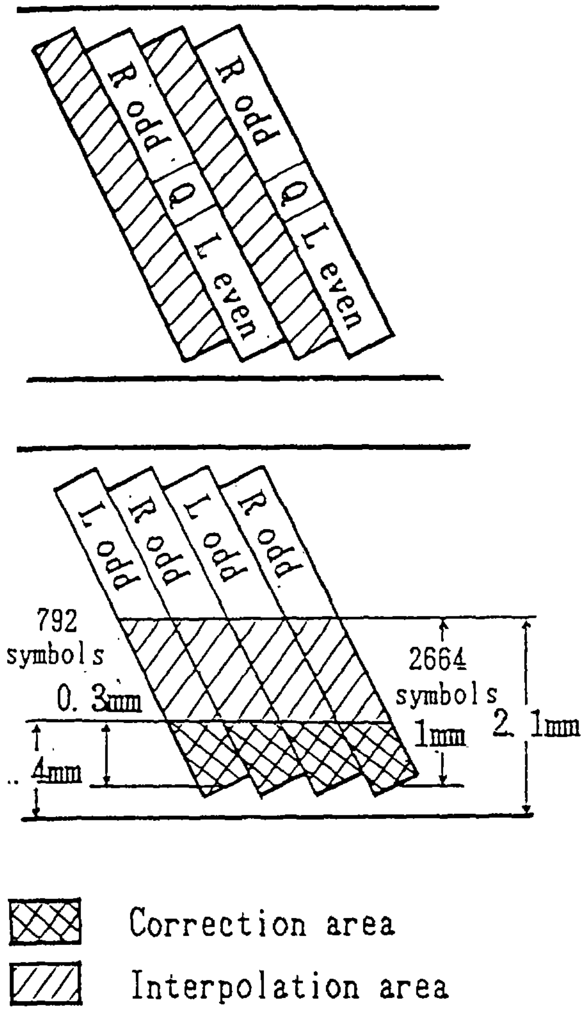


Fig 11 INTERPOLATION AND CORRECTION CAPABILITY FOR BURST ERROR

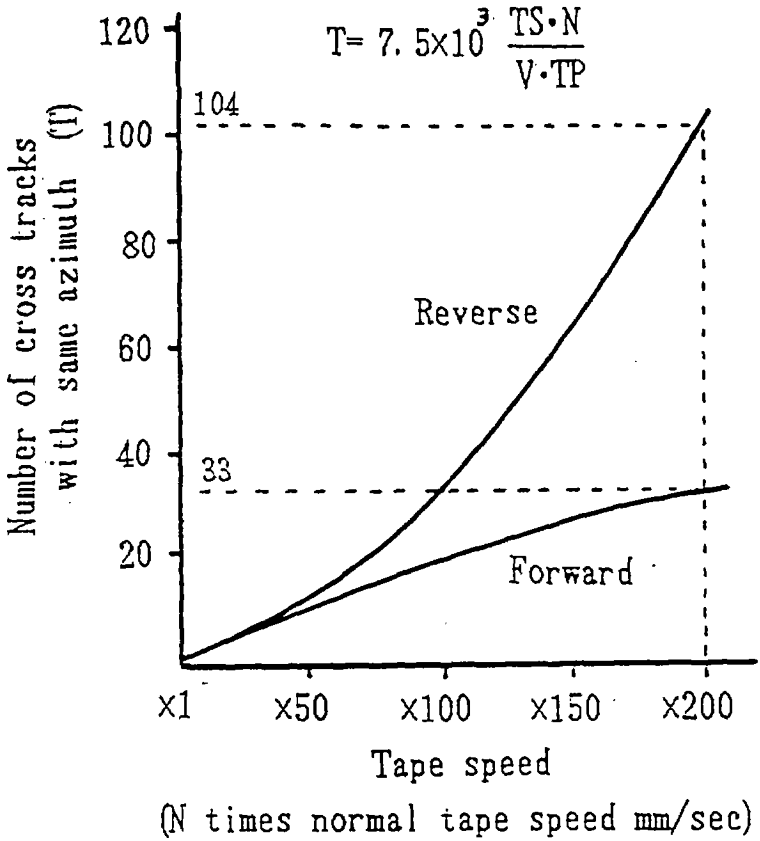


Fig 12 NUMBER OF CROSS TRACKS AT HIGH SPEED

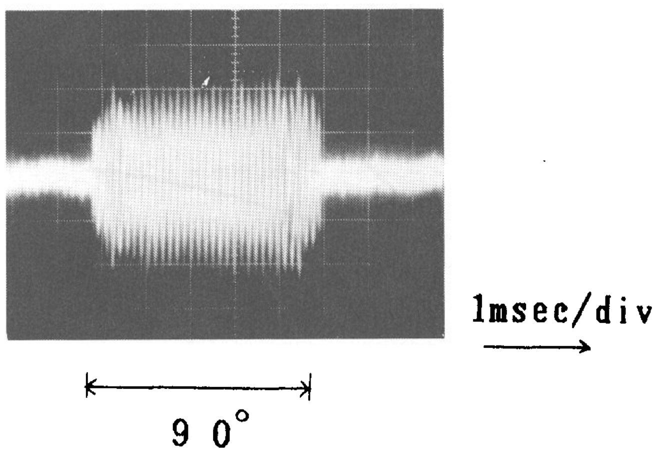


Fig 13　ENVELOPE AT 200TIMES
NORMAL TAPE SPEED

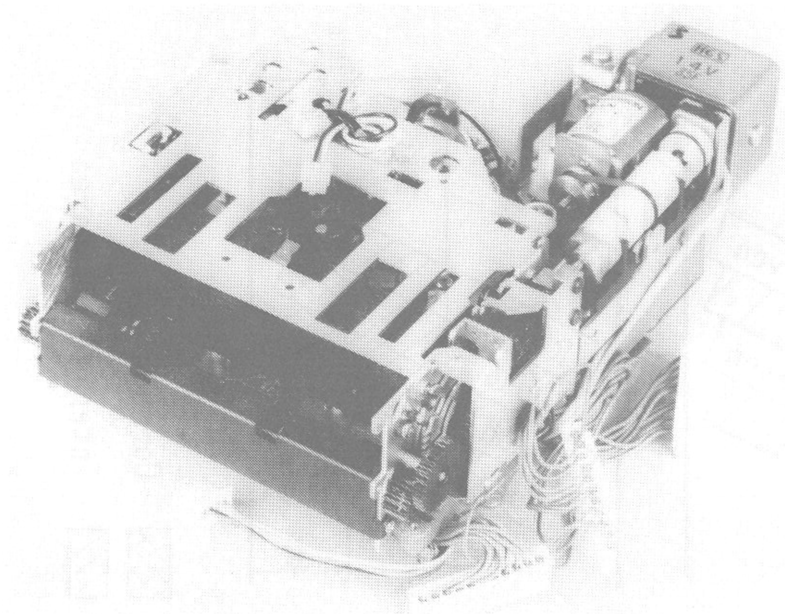


Fig 14　APPEARANCE OF MECHANISM

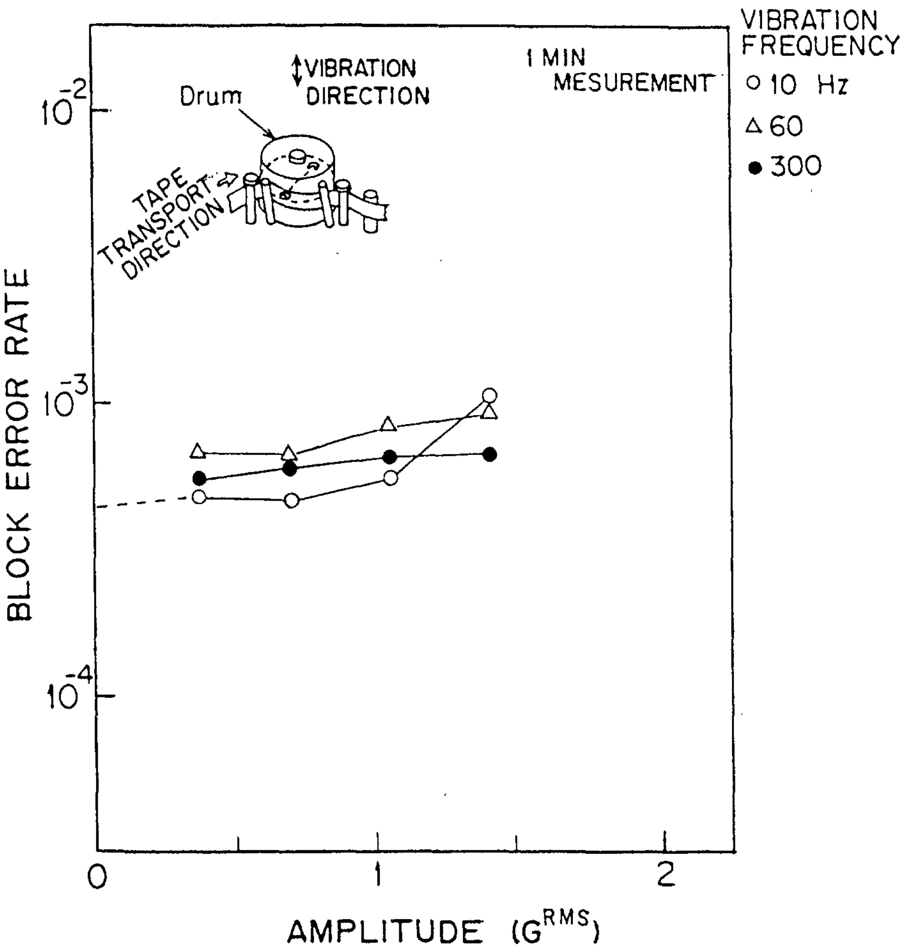


Fig 15 BLOCK ERROR RATE VS. VIBRATION