A PROFESSIONAL R-DAT RECORDER

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ABSTRACT

A professional use R-DAT recorder must, in addition to the DAT format specified for consumer use, possess functions of record and playback of SMPTE/EBU time codes, slave operation, off tape monitoring, punch in/out, pitch control, external sync, etc. We have already proposed a format for recording and playback of SMPTE/EBU time codes but this time, we would like to present outline of the professional recorder we have developed which incorporates all the functions of the variable speed technique developed, based on this time code, to let it have the slave function, and the 4 heads technique necessary for individual recording of this time code and audio data, and also for off tape monitoring.

1. INTRODUCTION

Should the consumer DAT format [1] be applied to professional use, by reason of its high quality audio characteristics and high degree of error correcting capability, its basic audio performance fully satisfies the requirements in professional applications. Additionally, the cost merit is large as the LSI and tape developed for consumer use can be used directly. Moreover, by the fact that there is interchangeability of audio data between it and that of the consumer tape recording, they can be playbacked by either equipment and prerecorded tape can be directly used in professional applications, and there is also the convenience in playback of tapes under production at any location where a consumer equipment is available. However, especially when post production application is assumed, many functions are necessary in addition to those in a consumer equipment.

These functions are: 1) Record and playback of SMPTE/EBU time codes, 2) off tape monitoring, 3) punch in/out, 4) slave operation under synchronizer control, 5) pitch control, 6) external sync, 7) locating, etc.

Details on the practical methods in realizing these functions and technical problems to be solved will be presented below and the actual recorder system we have developed will be explained in the last part.

2. DESIGNING CONCEPT

2.1 Outline of the DAT format

In the following, a brief explanation focused on track configuration and recording pattern of the consumer R-DAT specifications will be presented, and then details on essential functions required in professional equipments.

In R-DAT, two heads, A and B, with different azimuth angles (+20°, -20°) are located 180° apart on a 30mm diameter rotating drum and record/playback made by wrapping the tape over 90° of this drum. (Fig. 1)

The tape thus recorded contains a recording pattern shown in Fig. 2.

A superior error correcting capability can be obtained as a double Reed-Solomon error correcting code completed in one track units are added to the digitized data. Track pitch is 13.591μm. The magnetic head track width is about 21μm and recording is by guard bandless overwrite recording as shown in Fig. 3.

At playback, the centers of the tape track and the head track width will coincide with each other since tape speed is controlled such that the amount of pilot signal leaking from the ATF area on both sides of the track to be traced, will be equal.

Also, the configuration of one track is as shown in Fig. 2. The peculiarity is that, centered around the main data area in which the audio signal data and others are recorded, there are two ATF (Automatic Track Finding) areas on both sides of it and another two sub data area, further outside them. Therefore, the main data area and sub data area can be separately recorded.

2.2 Indispensable requirements for professional applications

2.2.1 Record and playback of SMPTE/EBU time code

The format for recording SMPTE/EBU time code in the sub data area have already been presented and proposed (AES 1988, Paris [2]). Naturally, record/playback of this time code must be absolutely separate from the audio signal. In other words, it must be capable of recording the time code before the audio signal, at the same time, or after.

In R-DAT, a completed one track of data must always be recorded even though there may be no information. Therefore, if individual recordings are to be made in the main data area and sub data area, data recorded afterward should be done by overwriting. For this reason, if the audio signal is to be recorded first in the main data area and the SMPTE/EBU time code recorded later in the sub data area, a previous recording in the sub data area, for example sub-ID, absolute time, etc. will be lost as data in the sub data area are recorded by overwriting. Due to this situation, time code cannot be recorded separately in a conventional two head type recorder.

As a method in solving this problem, we designed the 4 heads system. This consists of the one head pair, in the normal head drum, which will be the trailing pair used for recording, and an additional pair of plus and minus azimuth heads traveling ahead for playback. In such an arrangement, previously recorded data will all be read by the leading head and by storing them in the memory, it can be recorded again, and thus no data will be lost. Moreover, there will be no deterioration or drop out of the signals by this rewriting process as error correction is applied to all data.

2.2.2 Off tape monitoring

This is the function of immediate playback monitoring of the tape signals during the recording mode. This can also be solved in the same way by the previously mentioned 4 head system. In this case, the leading head is used for recording and the trailing head for playback. It will naturally require two sets of audio data processing and head output amplifying circuits.

2.2.3 Punch in/out

In an analog recorder, the sound will not be disrupted if record and playback is switched at the edit point using a dual purpose record/playback head. On the other hand, in a digital recorder, the playback signal and recording signal cannot be switched at the same point as a certain length of time is required in processing the digital signal. This time lag is 60 milliseconds in R-DAT. The time lag can be absorbed by positioning the distance between both heads so that it coincides with the time lag on the tape. The above three items are thus combined to complete the 4 head technique.

2.2.4 Slave function

It is, of course, necessary that slave operation capability by control from the synchronizer via SMPTE/EBU time code be incorporated into this recorder and also that it can read out the time code during both normal speed operation and high speed winding but it is absolutely essential that speed be controllable by the variable speed control signal of FM 9.6KHz from the synchronizer to synchronize in sub frame units.

2.2.5 Pitch control

Pitch control means determining the above mentioned variable speed by manual panel controlling and is also an important function.

2.2.6 External sync

It is necessary that the recorder be able to synchronize with all video sync signals and word sync signals (48, 44.1KHz). This is accomplished by making the variable speed circuit to synchronize with the external sync signal.

The above three items are combined to complete the variable speed technique.

2.2.7 Self locating function

This is the function of locating the tape to the specified position without relying on external equipment such as a synchronizer. We have decided to employ the absolute-time in the sub data area standardized in the consumer R-DAT format, for the reference time axis at locating. As absolute-time is automatically recorded with BOT (Beginning Of Tape) as zero time at recording the audio signal, it is the most accurate absolute address on the tape. This data also has the merit of being able to be read at high speed winding. Consequently, the necessity of locating to any point and the necessity of repeat operation can be readily fulfilled by storing the objective locate point addresses in the memory.

When this feature is utilized, locating becomes possible for a tape recorded on another consumer type recorder with no SMPTE/EBU time code.

3. TECHNIQUES

3.1 Technique in conversion to 4 heads

Problems to be solved in producing a practical 4 heads type rotary head are as follows.

1) Head-to-head crosstalk.
2) Track trace timing of the leading and trailing heads.
3) Method in applying ATF (Tracking).

1) Head-to-head crosstalk

The biggest problem in producing a 4 head cylinder is head-to-head crosstalk. In this system, when one head pair is in the record mode, the other pair will always be in the playback mode. As a result, the recording current will leak into the playback circuit and pose a problem.

The cause is clearly in the rotary transformer which is an important component in a rotary head. The rotary transformer presently used in R-DAT is the coaxial type widely used in home VTR. This type of rotary transformer, cross section shown in Fig. 4, consists of two circular plates, a coil installed in the concentric groove of each plate, and the face-to-face core plane is separated by a narrow gap. One core is installed on the rotary cylinder on which the heads are installed, and the coils are connected to these heads. The other core is installed on the fixed cylinder and the head output obtained or recording current applied through this coil.

The number of channels will be limited as the surface area of the cylinder is limited and as there will be less space for ample shielding, increase in crosstalk by an increasing number of channels cannot be avoided.

We have solved this problem by reviewing the time division processing technique of the signals from each head. In the 4 heads type R-DAT, the heads are customarily positioned 90° apart on the cylinder. However, this angle is not exactly 90°. As the track pattern is not perpendicular to the tape lower edge, an angle of θ must be introduced as shown in Fig. 5. This angle θ by calculation is 92.1°. By introducing this angle, there will be no overlap in operating time between the two head pairs and each head signal will be accurately 90° split processed on the time axis. This method thus solves the crosstalk problem. (Fig. 6)

2) Track trace timing of the leading and trailing heads

Functions demanded of a 4 head for professional R-DAT can be largely divided into two.

First is the "off tape monitoring function" explained in item 2.2, and the second is the "punch in/out function of the sub code and PCM signal at a random point" mentioned in items 2.1 and 2.3. In the off tape monitoring mode, the leading and trailing heads, respectively, will be used for record and playback. In this case, in addition to the delay between input signal and playback monitor signal due to the distance between the record and playback heads - the same phenomenon seen in the analog recorder - in DAT, processing time is required, as shown in Fig. 7, by necessity of generating correcting codes after interleaving in frame units during recording and playback of the signal. However, time lag is in the order of slightly more than 100 msec. (150 msec. in our model) which is almost the same as in an analog recorder, and this poses no problem in practice.

On the other hand, in order to allow operation of the previously mentioned second function of punch in/out, the leading head and trailing head functions must be switched to playback for the leading head and record for the trailing head. In this process, when the previously recorded signal is playbacked by the leading head and its content rerecorded by the trailing head, no time difference must occur between the recorded content on the tape. However, as previously mentioned, a total time equivalent to 2.25 frames is required, as shown in Fig. 7, for playback processing of the tape digital signal and for rerecording this data. For the purpose of absorbing this time delay of 2.25 frames, the playback head track trace timing is made to lead the recording head by 2.25 frames so that it will read in advance. This is equivalent to a track pitch of 4.5 (Fig. 5) and is realized by providing this much difference in mounting heights of the leading and trailing heads.

3) Method in applying ATF (Tracking)

The tracking method itself will be by the R-DAT standard ATF system but the problem is which head should be used for detecting the ATF signal. One representative peculiarity in a commercial tape recorder is punch in/out in which a section of a prerecorded tape must be rewritten. It has already been mentioned that this problem can be cleared by converting to 4 heads in R-DAT but in order to rewrite a prerecorded track while tracing it requires that it be tracked by ATF.

The routine in punch in/out are varied such as, time code punch in/out in which it is sufficient to re-write the sub code area only; audio signal punch in/out in which all areas must be re-written except for ATF; and at punch in recording in which all areas including ATF must be re-written; and in each situation, there are merits and demerits depending on which head is used to obtain the ATF signal but we had put priority on simplicity and decided on always obtaining the ATF signal by the leading head, and at the same time, employed a method of raising mechanical dimension precision of the height between the leading/trailing heads so that if the leading head can trace the tape track center, then the trailing head can also accurately trace the tape track center.

The following problems will also be encountered at punch in/out.

In the R-DAT 1TP mode, over write recording is done so that track pitch on the tape will be 13.591μm using the head with about a 21μm track width. Due to this, if the trailing head is used for recording while ATF tracking by the leading head during after-recording, width of the track immediately before the starting point of after-recording, will become narrow, as shown in Fig. 8, to momentarily degrade the error rate as ATF operates such as to match the tape track center with the head track width center. The problem at the punch in point can be solved if the head trace position is shifted by applying offset to ATF but this is unsatisfactory as the problem at the punch out point will become further pronounced. This problem can only be solved fundamentally by not over write recording but to use the 1.5 TP (Track Pitch) mode in which the head track width and tape track pitch becomes equal. In the normal 1 track pitch mode, the best method is to reduce to a minimum the difference between the tape track center and the head track width center, including all mechanical errors.

3.2 Variable speed technique

3.2.1 Master clock circuit

Two different clocks are normally used in R-DAT. One is the 24/22MHz clock used for digital signal processing and the other the 37MHz clock used for controlling the cylinder revolution of the rotary head. These two clocks must be varied simultaneously for variable speed control. Further, it must synchronize with all other companion equipments.

The synchronize signals are as follows.

(1) External synchronizing

a) Frame sync — 29.97 frame/sec.
30 frame/sec.
25 frame/sec.
24 frame/sec.

b) Field sync — This has a figure twice that of frame sync.

c) Word (Sampling frequency) synchronizing

(2) Internal synchronizing

a) 48KHz

b) 44.1KHz

Additionally, it is required that continuous variable speed control be possible (±12% in our model) in all these modes. These multiple number of combinations accounts for the master clock circuit to be so complicated.

The previously mentioned two types of clock must be changed simultaneously at variable speed control and, as shown in Fig. 9, these clocks are generated by two independent PLL circuits (PLL-1, PLL-2) designed with a frequency dividing ratio ($1/N_1$, $1/N_2$) such that the reference signal frequencies (REF1 and REF2) be the same. Thus, fundamental variable speed control is accomplished by changing these reference signals of the PLL circuits.

In addition, PLL-3 was added for generating the internal clock synchronized with the previously mentioned external sync signal.

In regards to the master clock circuit performance, the especially important item is jitter. When jitter becomes worse in the 24MHz clock, special care must be taken as it will lead to deterioration of distortion and wow/flutter due to fluctuations in sampling frequency. When jitter becomes worse in the 37MHz clock, the recorded waveform on the tape will also carry jitter elements and at extremes, will lead to error rate deterioration.

In order to solve these problems, we had used not only a crystal controlled VCO in the PLL-3 circuit but practiced care in component installation such as individual shielding of each PLL circuit which resulted in good performance.

3.2.2 Data strobe circuit

In R-DAT, the 8-10 conversion method is employed for modulation when recording data on the tape. For this reason, it is necessary at playback to regenerate a 9.4MHz bit clock in a data strobe circuit using the waveform equalized data chain.

The data strobe circuit is based on the PLL circuit shown in Fig. 10.

In general, the capture range which indicate the permissible frequency fluctuating range, and jitter are in mutually opposite relation in such a PLL circuit. As increase in jitter in the data strobe circuit leads to degrading of the error rate, there is a limit to extending the capture range.

Normally, increase in capture range error rate which can be neglected is less than 3 ∿ 5%. This capture range is fully satisfactory at normal speed playback but is insufficient at variable speed playback. Therefore, we employed the method of switching in 6 steps, the PLL circuit VCO center frequency in increments of about 3% each, interlocked with the variable speed control signal of the master clock circuit. We were able to accurately regenerate the bit clock even during ±12% variable speed control.

4. COMPOSITION OF FOSTEX'S DIGITAL MASTER

Block diagram of this professional R-DAT recorder is shown in Fig. 11. Largely divided, it consists of the sound signal processing block from line in to line out; 4 head mechanism; servo block for controlling normal running and high speed winding; master clock block which generate the internal clock by an external clock; the MPU block which has the function of system control, record/playback of SMPTE/EBU time code as sub data and restoring it to the original time code data stream.

Basically, the sound signal processing block and servo block is no different from the consumer type. Low cost is maintained by using the consumer type LSI as it is. For sound processing, 2 systems of processing circuits are required due to the 4 heads. Mutual synchronizing is necessary in this process.

The audio signal quantized by the 2 channel independent A/D converter and the double oversampling digital filter, then enters the control block, one frame (30msec.) of the digital signal stored in the RAM, a double Reed-Solomon error correction code calculated by the ECU block and added. This signal is 8/10 modulated and recorded by one head set. The playback signal from the head is amplified by the playback preamplifier, waveform equalized by the equalizer, and the clock and data extracted in the data strobe block. This data strobe circuit will be a special type which comply to the variable speeds demanded in this professional R-DAT recorder. After this, the digitized audio signal enters the control block, 8/10 demodulated and error corrected or concealed by the ECU block. Then, it passes through the digital filter and restored to its original analog signal by the D/A converter. The selector located before the digital filter is the block for switching between off tape monitor mode and normal mode (punch in/out mode). In the punch in/out mode, the audio digital signal can be fade in/out by the cross fader block.

Audio in/out has an AES/EBU digital interface.

The servo block, in sync with the control block, controls speed of the rotating cylinder and capstan motor. At high speed search, the RF frequency is detected to control the cylinder speed such that relative speed between tape and cylinder are constant. This section is identical with the consumer type and the same LSI is used.

The master clock block is for external sync signal input and for variable speed control.

For inputs of sub codes, it has an independent one for SMPTE/EBU time codes. Time code signals that are input is Bi-Phase demodulated, phase information counted by the MPU and recorded as sub data in the sub data area by the control block. Further, data such as A-time are simultaneously recorded. These sub data are playbacked in both normal playback and high speed search modes. These data are restored as time codes in sync with the sound by the MPU. In restoration at high speed search, the playback signal is formed into a ring and output as one frame of time code data.

Specifications of this recorder is presented in Table 1 and its physical appearance in Fig. 12.

5. CONCLUSION

SMPTE/EBU time code record and playback, variable speed and other functions for slave operation, were matter-of-fact requirements in professional recorders from the analog equipment era. Meanwhile, the possibility of a 4 head system had been foreseen from the time DAT was first developed.

However, many difficulties were encountered in materializing this as mentioned in this report. We are happy to announce the "Digital Master Recorder" in which these problems were solved. There are, however, many more requirements in a DAT for professional use. For example, 16 bit quantization is insufficient for dynamic range and if possible, should be 18 or 20; should develop the multi-channel recorder, etc. but then, many problems will be encountered such as loss of interchangeability since it must largely deviate from the DAT standard in order to realize them. This is a subject which must be studied in the future for an even better professional system.

6. ACKNOWLEDGMENTS

Appreciation is expressed to Mr. H. Shinohara, president, Fostex Corpration, who granted us the opportunity in developing this recorder; Mr. M. Matsumoto, chief, R & D; Mr. H. Yamazaki and Mr. M. Ogata, staff, R & D, who joined in actual study of the functions for this recorder.

References

[1] The DAT Conference Standard; DIGITAL AUDIO TAPE RECORDER SYSTEM (June 1987)

[2] H. Yamazaki, et al. "Time code in sub data area of R-DAT," 84th AES Conv. No. 2589 (E-1), (Paris, March 1988)

Table 1 The specifications of Fostex's Digital Master Recorder

Error correction	Double encoded Reed Solomon Code
Tape speed	8.15 mm/sec.
Recording time	Maximum 120 min. (with 120 min. cassette)
Rewind and fast forward time	Approx. 80 sec. (")
Tape	Metal powder DAT tape
Sampling frequency	48KHz and 44.1KHz (switchable)
Quantization	16-bit linear
Dynamic range	More than 90dB (Emphasis at 1KHz)
Frequency response	20 ∿ 20,000Hz
Total harmonic distortion	Less than 0.05%
Wow and flutter	Below measurable limit
Crosstalk	More than 80dB (20 ∿ 20,000Hz)
Emphasis	ON/OFF (switchable)
Input/output	
Line in	XLR-3-31 x 2 Nominal level: +4dBm, max. 28dBm Input imp.: 20KΩ balanced
Line out	XLR-3-32 x 2 Nominal level: +4dBm, balanced
Monitor out	Standard phone jack x 2
Headphone out	Stereo phone jack x 1
Digital in	XLR-3-31 x 1 AES/EBU format
Digital out	XLR-3-32 x 1 AES/EBU format
Time code in	XLR-3-31 x 1 Nominal level: +4dBm, Input imp.: 20KΩ balanced, SMPTE/EBU format
Time code out	XLR-3-32 x 1 Nominal level: +4dBm, balanced, SMPTE/EBU format
Sync in	BNC, TTL level
Remote	FC connector 20P for Fostex 4030
Serial port	RS-422
Power supply	240V/220V/100VAC, 50/60Hz 60 W
Dimensions	482(W) x 150(H) x 472(D) mm
Weight	Approx. 15kg.

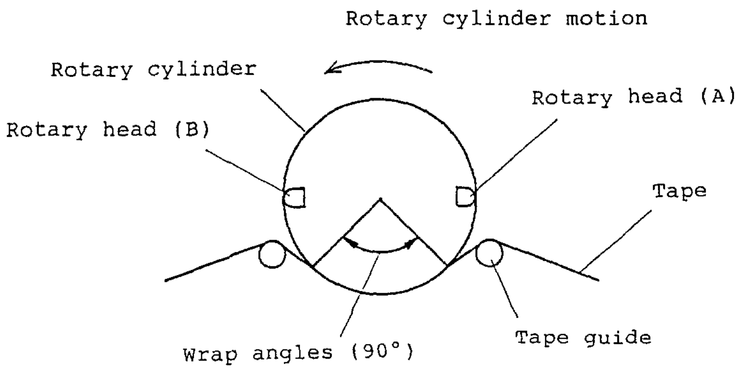


Fig.1 Rotary head and tape

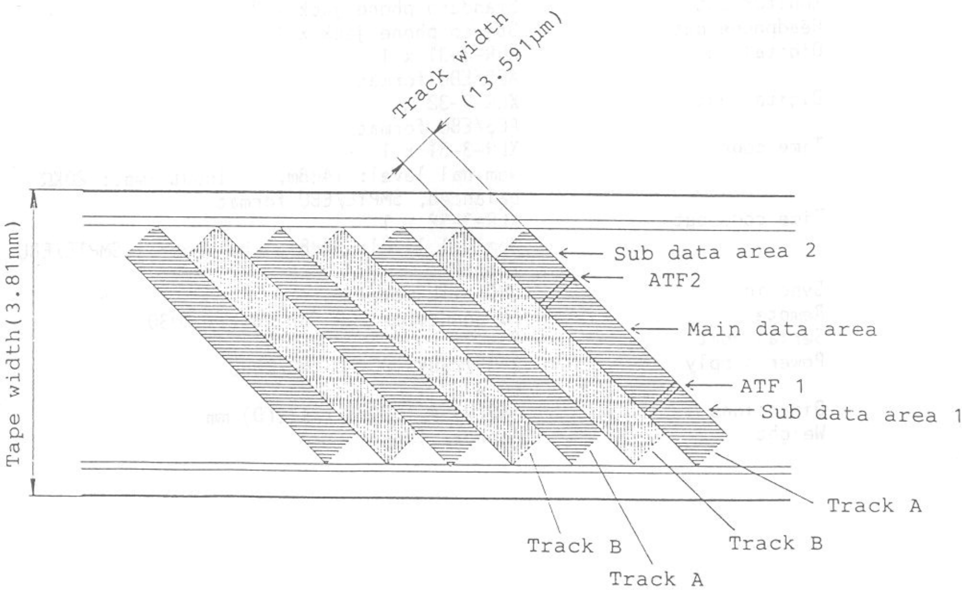


Fig.2 Recording pattern and track configuration

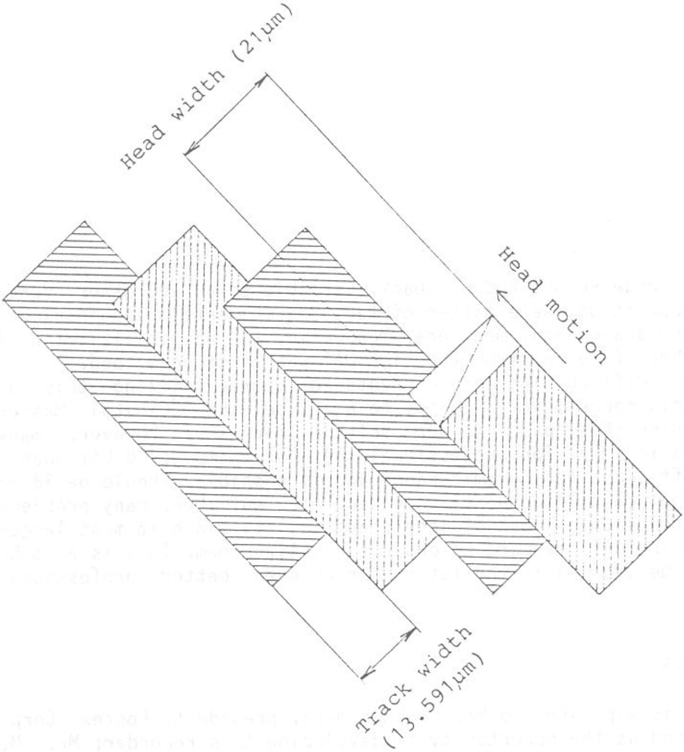


Fig.3 Overwrite recording pattern

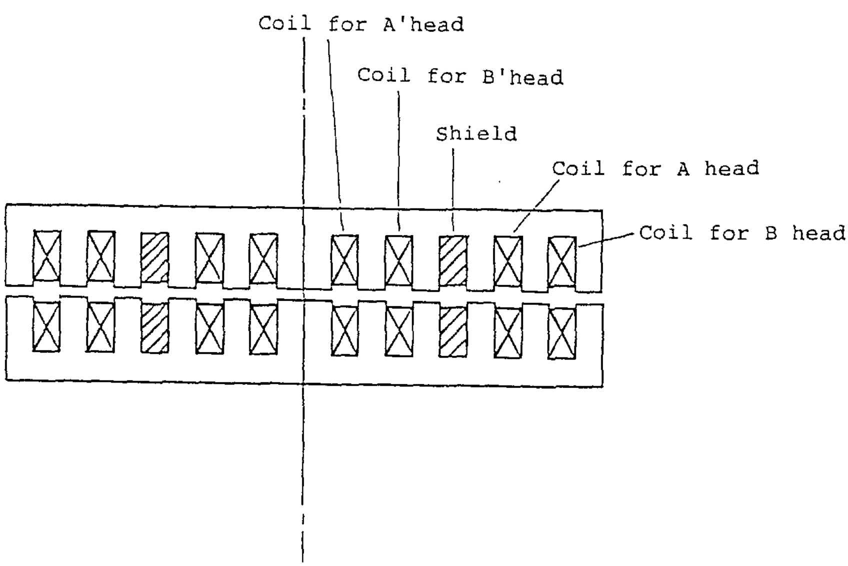


Fig.4 Rotary transformer (Cross section)

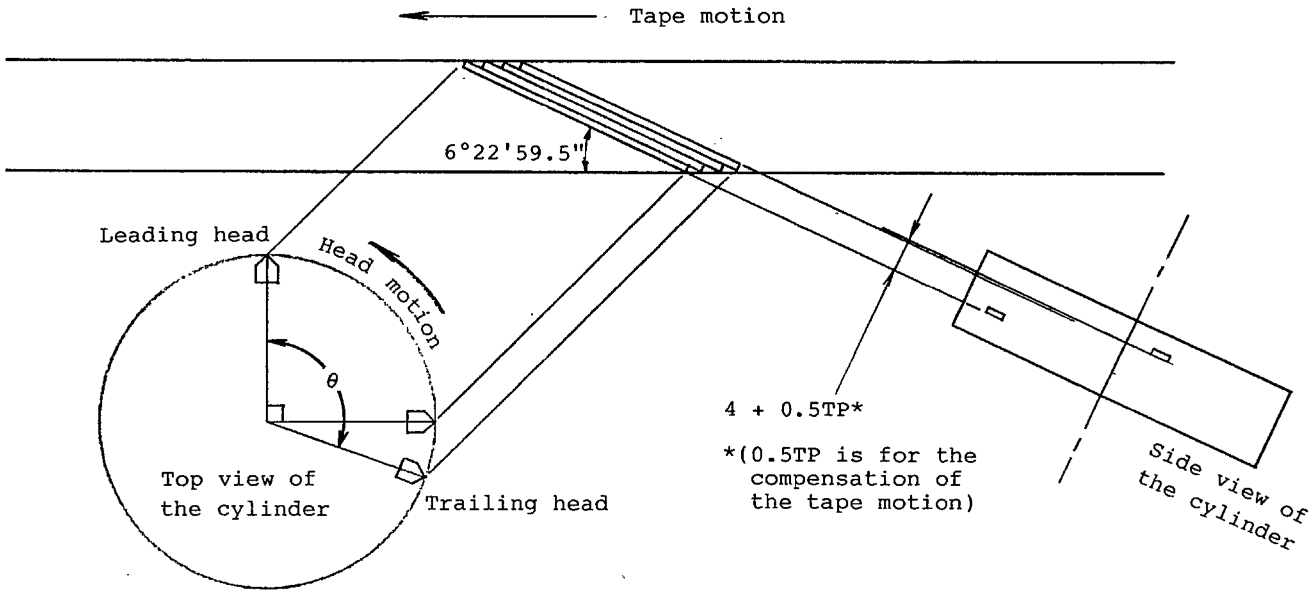


Fig.5 Relation of leading and trailing head

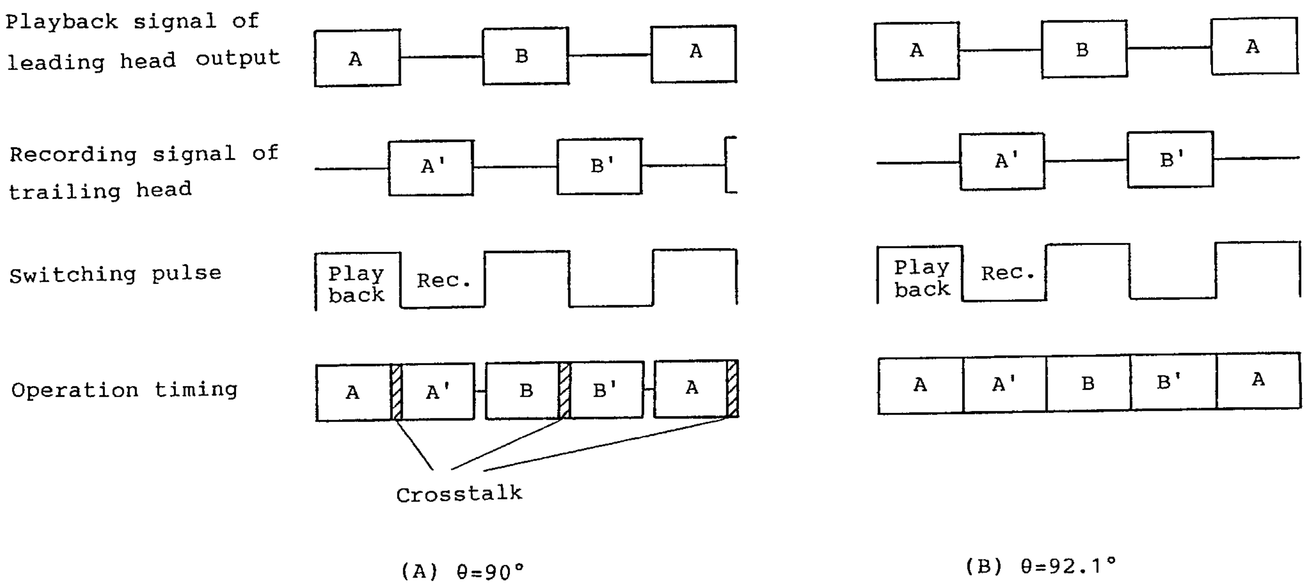


Fig.6 Timing chart of playback/recording data in 4 heads system.

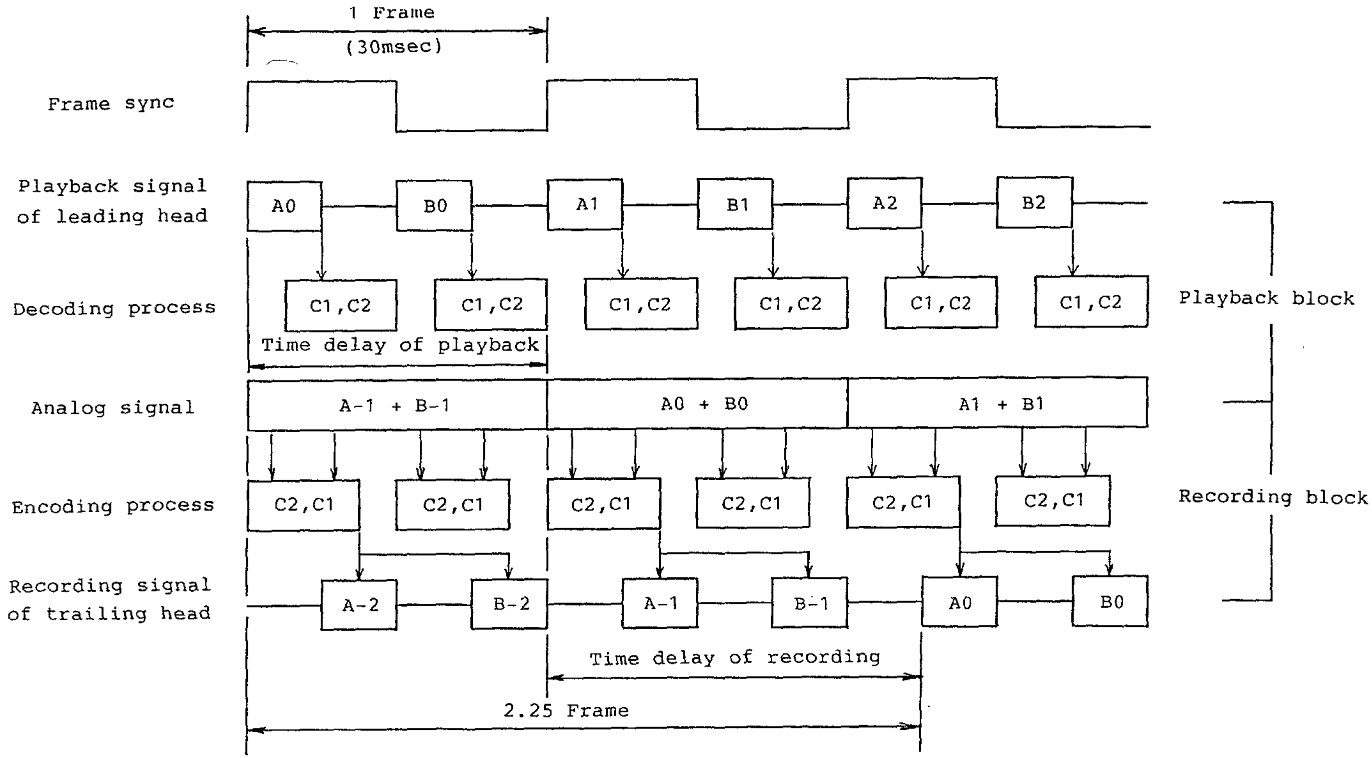
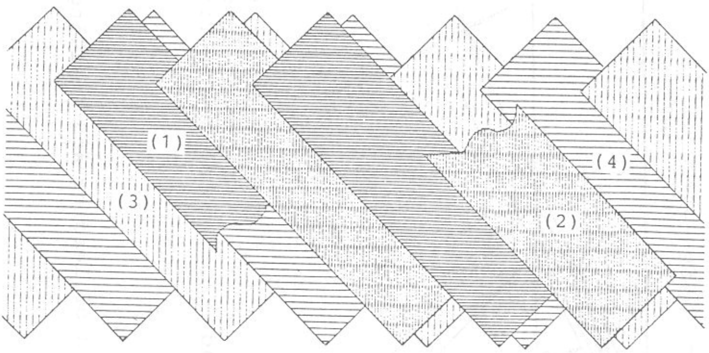


Fig.7 Time chart of data processing



(1) Punch in track
(2) Punch out track
(3) Punched in and narrowed track
(4) Punched out and narrowed track

Fig.8 Recording pattern at re-writing

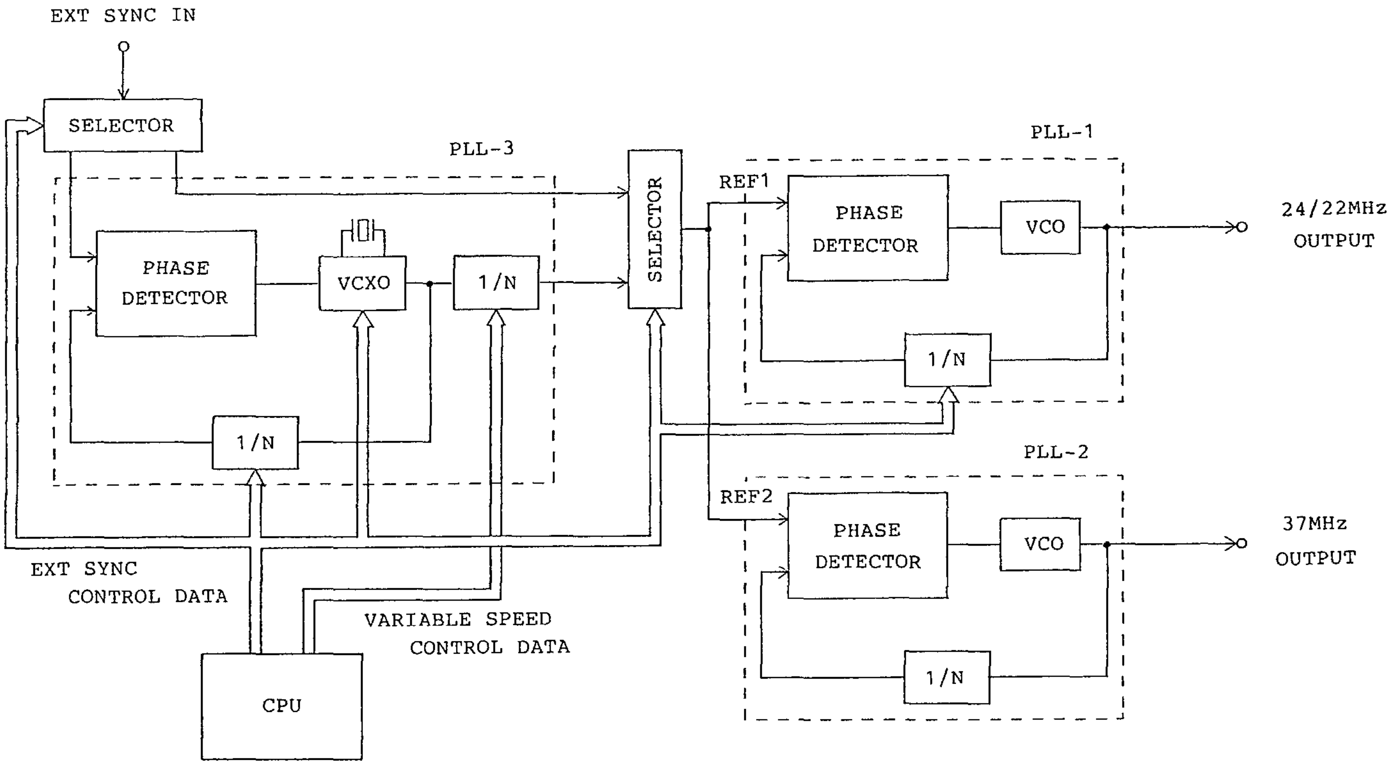


FIG.9 Block diagram of Master clock circuit

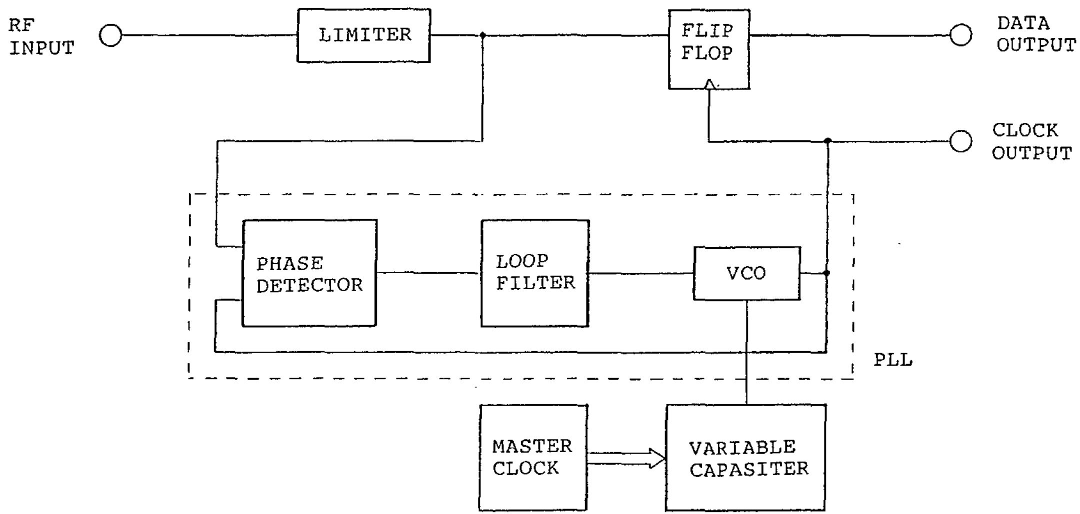


Fig.10 Block diagram of Data strobe circuit

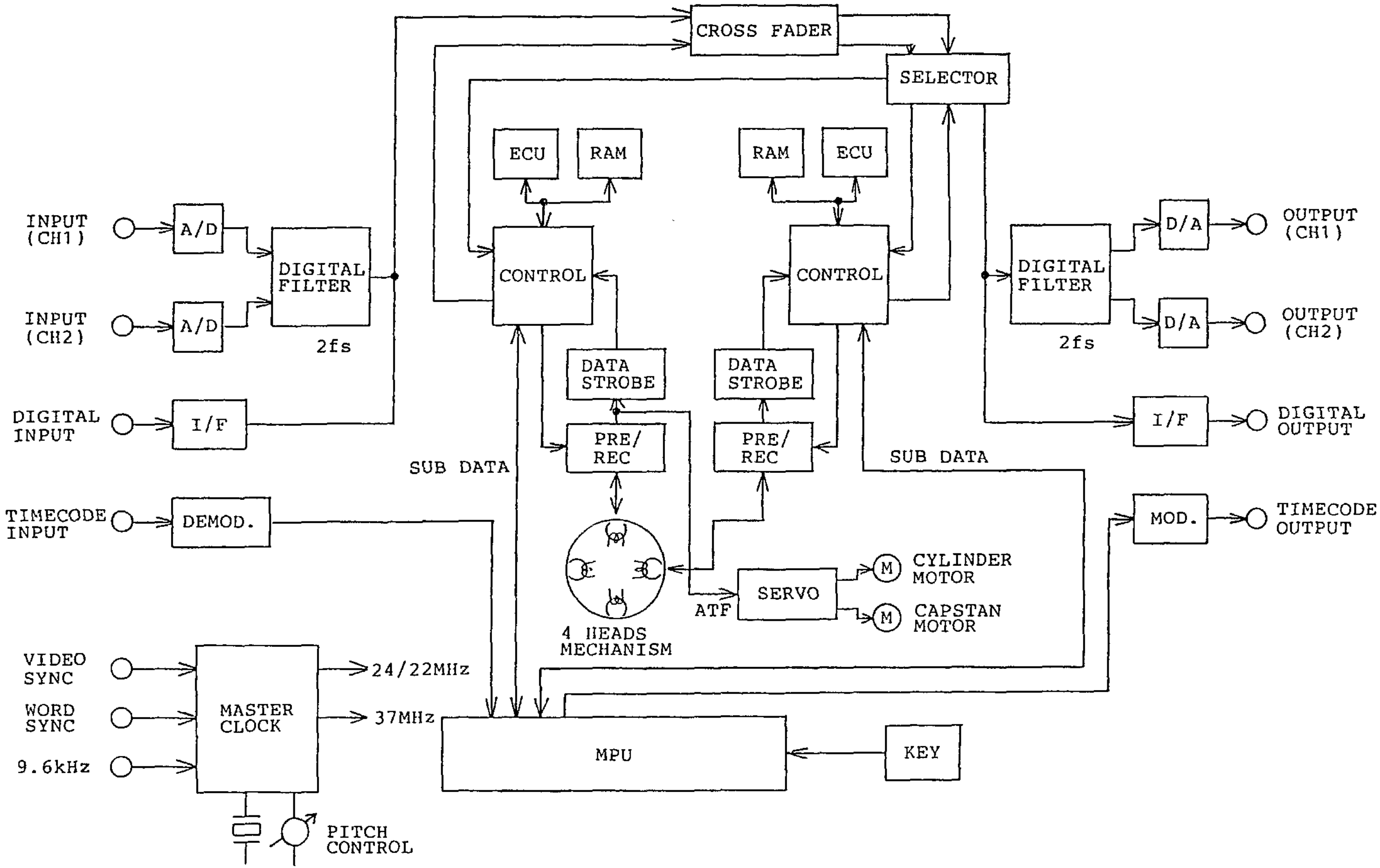


Fig.11 Block diagram of Fostex's Digital Master Recorder

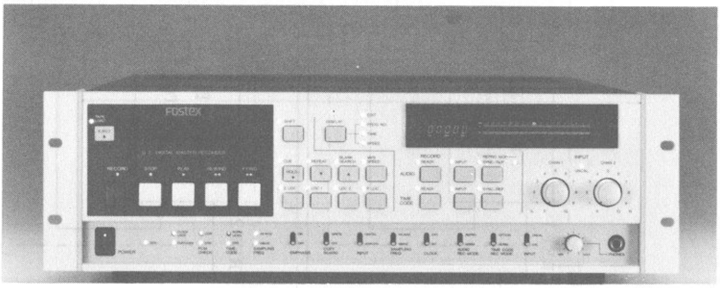


Fig.12 Physical appearance