1533 (G-3)

IMPROVED TWO CHANNEL PCM TAPE RECORDER FOR PROFESSIONAL USE

Kunimaro Tanaka, Tetsuya Yamaguchi,
and Yasuo Sugiyama
Mitsubishi Electric Corp.
Hyogo, Japan

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

AN AUDIO ENGINEERING SOCIETY PREPRINT

IMPROVED TWO CHANNEL PCM TAPE RECORDER FOR PROFESSIONAL USE

Kunimaro Tanaka†, Tetsuya Yamaguchi††,
Yasuo Sugiyama†††

† Products Development Lab.
†† Communication Equipment Works
††† Communications R&D Dep.
Mitsubishi Electric Corp.

Abstract

Two channel PCM tape recorder employing stationary head for professional use is developed. It has function of both electronic and tape cut editing along with its digital quality. The paper describes its structure, editing system, and error-correction scheme.

1. Introduction

It is already some ten years since PCM tape recorders were developed to improve the performance characteristics of magnetic recording. PCM tape recorders hitherto developed fall generally into two categories: those using VTR-type tape-drive mechanisms and rotary heads, and those using the tape-drive mechanisms of conventional analog tape recorders and stationary heads. Each category has its own particular advantages and disadvantages, but the stationary head PCM tape recorder, in view of the similarities of its method of operation with that of conventional analog recorders, and its capabilities of read-after-write monitoring and of tape-cut editing, will probably form the main stream of master recorders.

Here we introduce our newest model of professional PCM tape recorder for broadcasting and record cutting, and for preparing PCM sources for future use using 6.3 mm (1/4") tape and 38 cm/sec (15 ips). The tape recorder is featured in small size and re-usability of spliced tapes.

2. Features of the Main Unit

In addition to the high quality of the playback signal, a PCM tape recorder for professional applications should also possess certain other features. The new Mitsubishi unit possesses the following distinctive features:

(1) Both electronic and tape cut editing is possible. In addition to it, spliced tape is reusable with this PCM tape recorder.

(2) Sophisticated circuitry design makes the recorder small in size and light in weight.

(3) As shown in Fig. 1, this tape recorder has similar appearance to the analog one. Arrangement of knobs and buttons allows you to operate the recorder in the same manner as analog one.

(4) SMPTE code track is provided for automatic location of the tape and for electronic editing.

3. Circuit Configuration

The block diagram of the circuit configuration is shown in Fig. 2. The signal applied to left- and right-hand channels first passes through the low pass filters (LPF) to eliminate aliasing noise, then passes through the sample-hold (S/H) units, where it is sampled at a frequency of 50.35 kHz and converted to a pulse-amplitude modulation (PAM) signal. The output of the S/H block is converted into a 16 bit PCM signal by successive approximation technique in the analog-digital converters (A/D). The RSC encoder then adds the check bits to the PCM signal, and the resulting combined signal is split into eight tracks and interleaved as shown in Fig. 3 and Fig. 5. This means that the data-transmission speed for each of the eight tracks can be reduced to one-eighth that of the original serial signal, enabling recording at the tape speed of 38 cm/sec (15 ips) of the PCM signal, and at the same time forming an extremely effective error-correcting code to be described below.

The PCM signal distributed between the eight tracks is subjected to modified frequency modulation (MFM) and recorded on the tape with a recording density of 797 bit/mm (20,240 bpi). This very high data density requires the appropriate compensation to be applied to the recording current during recording and to the playback signal during playback. The demodulated MFM signal is completely freed from the effects of wow and flutter in the time-base corrector (TBC)--a buffer memory--and at the same time the eight parallel tracks are recombined into one serial signal. At the output of the TBC, the RSC decoder performs deinterleave and error correction, restoring the PCM signal to its original error-free form. The error-free signal normally passes directly through the tape-cut editor circuit to the digital analog (D/A) converter. However, at the point where a tape-splicing has been made using tape-cut editing, a very large number of errors are generated. This enables the RSC decoder to detect the positions of tape-splicing, at which the tape-cut editing circuit performs the editing function described below. The signal that enters the D/A converter becomes a PAM signal, and on passing through the LPF on the playback side, the original analog signal is reconstituted.

The capstan rotation is servo controlled on the basis of the difference in phase between the PCM playback signal and the reference signal generated in the recorder. This ensures that the buffer memory responsible for eliminating the effects of wow and flutter will not be swamped with differences too great to compensate for: unless the pulses that entere the TBC are at least on average the same as the number of pulses leaving it, the buffer memory will become empty or overflow.

As revealed in Fig. 9, one auxiliary analog track and SMPTE code track are provided outside the digital tracks. The analog signal and SMPTE code are amplified and recorded by an auxiliary analog system and SMPTE system respectively.

4. The Error-Correcting Code

PCM recordings are generally of very high density, and this means that drop outs caused by dirt or defects on the tape surface, and the methods adopted to deal with them, are of the greatest importance. This is particularly so in professional tape-recording machines, where the frequency of dubbing tends to be rather high, for unless the errors were eliminated at each stage, they would rapidly accumulate with successive stage in the dubbing process. In the new Mitsubishi PCM tape recorder, error-correcting code, which we call RSC CODE, has been adopted. It is generally characteristic of errors in magnetic media that they tend to occur in bursts, with from 100 - 200 bit errors comparatively frequent. According to Reiger's boundary theorem [1], an check bits of more than twice this length would be required to eliminate every error of such a burst, or some 200 - 400 bits.

On the other hand, a consideration of the defects in magnetic media also indicates that when a number of tracks are recorded across the width of the tape, the errors (defects) in each track tend to be more or less independent of those in the other tracks, with very few occasions on which more than one track is suffering from errors at the same time. It follows that under circumstances where a block like that shown in Fig. 3 is adopted for multitrack PCM recording, with a transverse error-correcting code configuration as shown, resulting to give a highly effective error-correcting code. Each block consists of 252 bits along the tape with eight tracks across it, with each track having first an 11 bits synchronizing code a 1 bit flag, fourteen samples, and finally a 16 bits CRCC (cyclic redundancy check character). In Fig. 3, 1L refers to the first sample of the left-hand channel, and 1R to the first sample of the right-hand channel, etc. Tracks 1 to 6 carry the PCM

signal, but tracks 7 and 8 carry the check bits.
The 4 bit divisions of each track are forming a sub-block 4 bits long and eight tracks wide, constituting one code word of a Read-Solomon code.[1] These 4 bits are corresponded to elements over GF(2^4) $(0, 1, \alpha, \alpha^2, \cdots\cdots \alpha^{15})$ and where α is the primitive element, the roots of the primitive polynominal $x^4 + x + 1 = 0$.
The parity check matrix for the Read-Solomon code is

$$\bar{H} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ \alpha^{10} & \alpha^5 & \alpha^8 & \alpha^2 & \alpha^4 & \alpha & 1 & 0 \end{bmatrix}$$

and the a_7, a_8 for tracks 7 and 8 are given by

$$a_7 = \sum_{i=1}^{6} a_i \alpha_i$$

$$a_7 = \sum_{i=1}^{7} a_i$$

where a_i stands for elements in i th track. The minimum distance of the Read-Solomon code is 3, so that errors within only one track will be 100% corrected, and when errors arise in two tracks, if the tracks that are in error can be identified from other methods, 100% correction is still possible. The information as to which track contains errors can be derived, as shown in Fig. 3 from the CRC that has been added. The power of this CRC to detect burst-type errors is considerable.[1] For 16 bits, in this tape recorder, as long as the burst length is not exceeding than 16 bits, all bursts will be detected, and the rate of failure to detect burst lengths longer than this is only 2^{-16}. If errors occur in three tracks or more, correction becomes impossible, but the fact that errors are occurring can be identified, and error concealment can be perfoemd. According to the calculation based on the Gilbert model mean time between occurrance of error concealment is 11 hours and mean time between miss correction is 24 years, in the case of bit error rate of 10^{-4} and average burst length of 100. In addition to the type of the error described above there are a lot of errors which occur in every tracks at the same time, such as gaps of spliced tapes and wrinkles of folded tapes. Fig. 4 shows errors caused by spliced gap. Each line corresponds to a track. One digit corresponds to one frame. As shown in the picture, there is one frame error in every tracks at the same time. In order to overcome this situation signal is interleaved before it is recorded on the tape as shown in Fig. 5. It means that when the signal is recorded on the spliced tape, the gap destroys only two tracks of a signal block shown in Fig. 5, and error can be corrected. Consequently a spliced tape which was tape cut edited can be used again.

5. Magnetic Recording

5-1 Demodulation of MFM signal

PLL (phase lock loop) of conventional demodulating circuit takes time before it is locked again when it looses synchronization by errors caused by drop out or gap at the spliced point. Therefore demodulator using counter instead of PLL is employed in this recorder. Fig. 6 shows the circuit diagram and Fig. 7 illustrates the time chart. The crystal oscillator generates the clock signal whose frequency is about 100 times of frequency of data clock. Counter (1) which counts the output of crystal oscillator is reset by input data and selects the edge pulses according to the time interval of 1.5T and 2T. Where T represents bit interval. 1.5T pulse (4) drives t flip-flop whose output is selecting pulse (6). When selecting pulse (6) is (L), selecting gate selects edge pulse delayed from original edge pulse (2) 0.5T. When it is (H), the gate selects edge pulse (2). Resultantly signal (7) is derived. OR signal of signal (8) and (9) drives square wave generator. Output of the square wave generator is reproduced clock (10). By latching signal (3) by OR signal of signal (8) and (9), demodulated data is derived.

This demodulator has following characteristics:

Advantage

(1) Circuit is stable against temperature variation and supply voltage variation. More over circuit configuration is simple.

(2) Correct data can be obtained immediately after drop out finishes. (Fig. 4)

Disadvantage

(1) Demodulating margin is reduced when there is a big jitter.

(2) Suppose frequency of data clock is f and frequency of crystal oscillator is f_H, there is a margin loss of f/f_H.

5-2 Auxiliary analog track

There are auxiliary analog track and address track at both side of PCM tracks. Fig. 8 shows the curve of reproduced signal level vs recorded track position when 100 kHz signal is recorded. Because of poor contact at the tape edges, there is a signal loss. Spacing loss L_s is given by [2]

$$L_s = 54.6 \frac{d}{\lambda} \quad [\mathrm{dB}]$$

Consequently it is desirable to record a low frequency signal in outer tracks. Therefore analog track and address track are alocated at the edge of the tape in this recorder. From the stand point of editing, head gap for analog track should be in line with the head gap for PCM tracks. The head employed in this recorder is made of ferrite block by precise cutting and lapping process. By widening gap length of analog track, S/N ratio of more than 40 dB is gained. When analog track is reproduced with narrow gap head in slow speed, there is an interference of AC bias signal. It is also eliminated by widening the gap.

6. Editing

For editing with the PCM master recorder, there are both the tape-cut editing used with conventional analog recorders, and electronic editing. Electronic editing which is performed by copying the original tape selectively was first made possible by the introduction of the PCM recorder. The characteristics of these are listed in Table 1.

As listed in Table 1 electronic editing has the advantage of editing without physically cutting the tape. Thus electronic editing will in the future become the most used method of editing. However, since tape cut editing requires only one PCM recorder and less time is needed for editing a small number of points in a long tape, tape cut-editing is necessary while the number of PCM tape recorders is small. It will also be used along with electronic editing in the future.

6-1 Tape cut editing

However, unless special measures are taken to guard against it, the attempt to join PCM recordings--where playback is synchronized with a crystal-oscillator clock--using conventional tape-cut techniques with existing PCM stationary head decks, will cause pop noise at the join. This makes it impossible for such editing to be performed during a performance. Thus, there were several problems that had to be solved before the stationary head PCM tape recorder could be used for tape-cut editing.

(1) The synchronization of the PCM signal with the internal clock makes it impossible to locate the starting point by "rocking".

(2) Because the phase of the internally generated reference pulses is compared with the playback pulses to control capstan rotation, a sudden discontinuity in the playback pulses such as could be expected at a tape join would break the synchronization of servo-lock.

(3) If there exists discontinuous jump in analog level at the

spliced point, it will cause click noise.

The procedure of the tape-cut editing which we developed is first winding the tape at high speed to the vicinity of the place to be edited, listening to the high-speed chatter to find place, then--in the stop mode--rocking the reels slowly backwards and forwards using both hands, listening to find the precise point. Then the back of the tape is marked, and an editor and splicing tape are used to splice the tape. The procedure is virtually identical with that used for conventional tape-cut editing. There is no need to 'visualize' the tape pattern, as there is with tape-cut editing of VRT-type recordings. The followings are the methods used to overcome the various problems.

(1) Finding the place: as shown in Fig. 9, there are an auxiliary analog tracks on the side of the PCM tracks, containing precisely the same program material. During the rocking of the reels, it is only necessary to listen to the output from the analog trakcs.

(2) Coping with the discontinuity of the phase of the servo pulses: as shown in Fig. 10, the playback servo-pulses are also used to derive a number of sub-servo-pulses, (a), (b), and (c), at staggered phase--in this case at 120°. Normally, just one series of pulses from among them is selected and used as the controlling servo-pulse for comparison with the internally generated reference to control the rotation of the capstan. By selecting the sub-series closest to the servo-pulses immediately before the splice, and adopting it as the new servo-pulse series, the servo-control after the splice can continue without any disruption of the phase-locked control, for the deviation between the two pulse trains cannot, in the present design, be more than ±60° , and thus the servo-lock will not be broken. Fig. 11 shows how the selective gate circuit operates. A phase-locked loop with a long time constant is applied to the playback servo-pulses, and the oscillator output of the PLL is used to form the gate. Even when there is a large discontinuity between the phase before and after the splice, it continues briefly with the same phase as before the splice, the picking up the sub-series of servo-pulses closest to it.

(3) Level discontinuity at the edited position: Fade-in/Fade-out technique is employed for smooth join of the signal before the splice and after the splice. In oder to initiate Fade-in/Fade-out at the edited portion, the spliced gap has to be detected. The gap is detected by watching CRC of each track. When CRC indicates error on every tracks at the same moment, magnetic head is reproducing gap portion. After gap is detected the errors generated at the gap are corrected in the case of reuse of

spliced tape, and signal before the splice is smoothly joined to the signal after the splice with Fade-in/Fade-out technique in the case of editing. Fig. 12 shows the wave form of the signal at the spliced portion. Fig. 12 (a) corresponds to zero order extrapolation and Fig. 12 (b) indicates Fade-in/Fade-out case.

6-2 Electronic editing

As described above, one of the outer most tracks is used for recording address information in this recorder. SMPTE code generated with micro computer which is mainly used for sequential control of the tape deck, is recorded in the address track and is used for identification of electronic editing point. Fig. 13 shows appearance of electronic editor. Fig. 14 shows basic diagram of electronic editing.

Process of the electronic editing is as following. At first in order to point an editing point,run tape in slow speed with listening playback signal from analog track and push a button at the moment when a point at where signal should be joined is reproduced. Then select Fade-in/Fade-out time. After entering these information at beginning and end of the source should be joined into electronic editor, one can listen the edited program without doing actual editing by pushing 'preview' button. If editing point is not adequate, it can be changed by pushing 'shift' key. If recorded level of the program is not adequate, it can be readjusted during electronic editing by adjusting 'fader' knob. Finally after everything is prepared, editing is performed automatically by pushing 'edit' key.

Fig. 15 shows an example of automatic editing. Electronic editor can control three tape recorders and can memory 99 editing points. According to the information given to the editor, the editor serches the recorded materials which is needed, in order, automatically and join them.

7. Specifications

The performance specifications and structural specifications are described in Table 2.

8. Conclusions

The professional-type two-channel PCM tape recorder developed by Mitsubishi Electric and described in outline above, possesses not only the basic performance to satisfy all professional requirements, but also satisfies the demand for ease and convenience of use, although there is room for further improvement. The debut of an extremely high-performance unit like this is a stimulus to the improvement of other elements in the chain of recording and reproduction, including microphones and speakers. We would also like to see ultrahigh-quality digital mixing equipment that is nevertheless freely and conveniently usable. There may even be a need for review of certain of the accepted practices in recording techniques.

Acknowledgements

The specifications of this PCM tape recorder were decided under the guidance of the Japan Broadcasting Corporation (NHK) to whom we would like to express our grateful thanks.

Reference

[1] Shu Lin: "An Introduction to Error-Correction Code", Prentice Hall.

[2] L. G. Sebestyen: "Digital Magnetic Tape Recording for Computer Applications", Chapman and Hall.

Item	Electronic Editing	Tape Cut Editing
Method	To copy original tape selectively to slave tape.	To cut tapes physically and splice them with splicing tape.
Equipment needed	Two or three PCM recorders and editing adapter.	One PCM recorder and tape splice gigue.
Editing time required for one hour program	One hour + time required for editing procedure x number of edit.	Time required for editing procedure x number of edit.
Readjustment sound quality	Possible	Impossible
Technique needed	Editing is performed by pushing button.	Identical to the analog type.

Table 1 Comparision between tape cut editing and electronic editing.

Performance specifications	
Channel number	2X PCM 1 X Auxiliary analog 1 X SMPTE
Frequency response	10 Hz to 20 kHz ± 0.5 dB
Dynamic range	90 dB
Upper harmonic distortion	0.05 % -20 dB FLSW
Wow and flutter	Limited only by quartz-crystal clock accuracy
Structural specifications	
Sampling frequency	50.349645714 kHz
Bit number	16 bits (linear)
Recording tracks	8 X PCM 1 X Auxiliary analog 1 X SMPTE
Recording bit density	797 bit/mm (20240 bpi)
tape speed	38.1 cm/sec (15 ips)
Magnetic tape	6.3 mm high-density tape

Table 2 Specifiations

Fig.1 Appearance of the PCM tape recorder

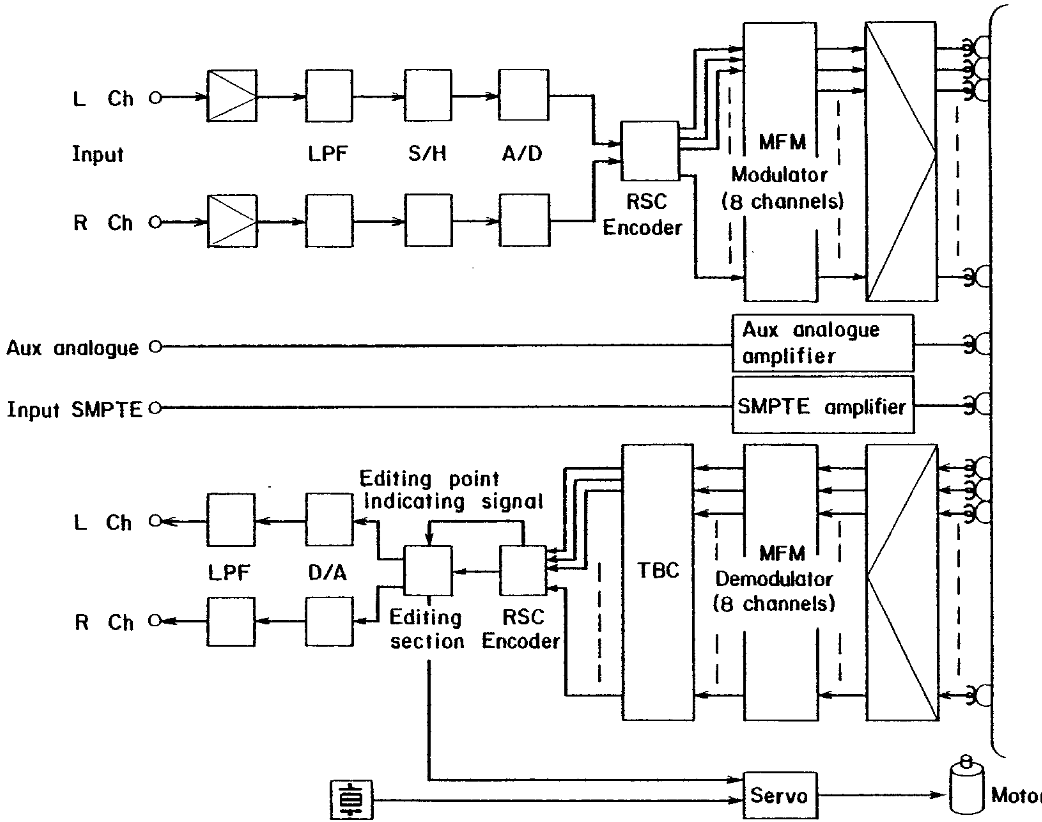


Fig.2 Block diagram of th- stationary read PCM tape recorder

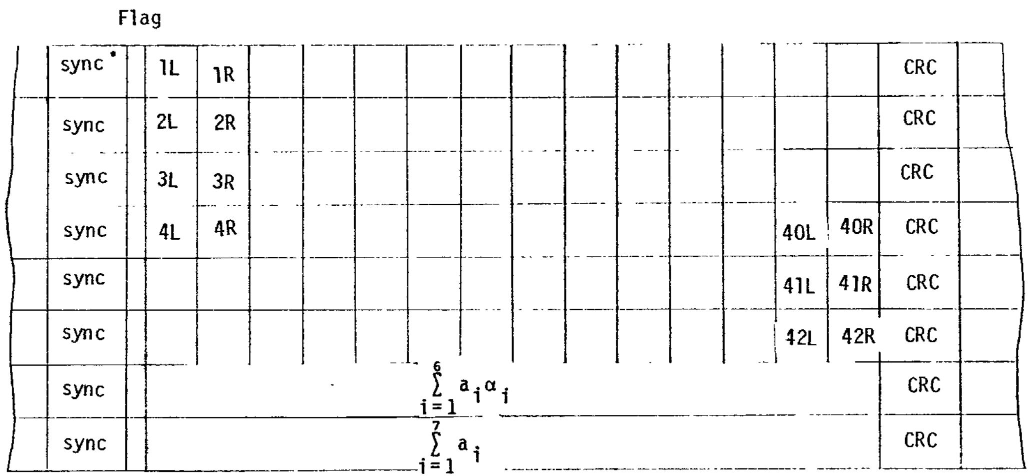


Fig.3 Signal block configuration

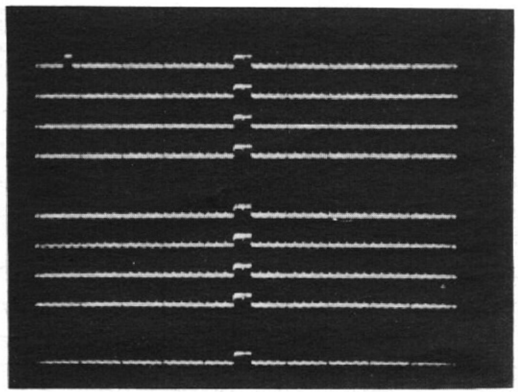


Fig.4 Block error occus in spliced portion

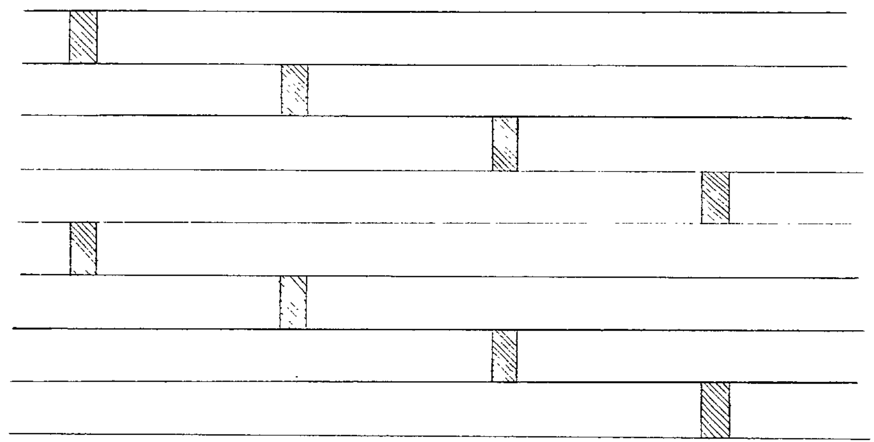


Fig.5 Interleave of the recording signal

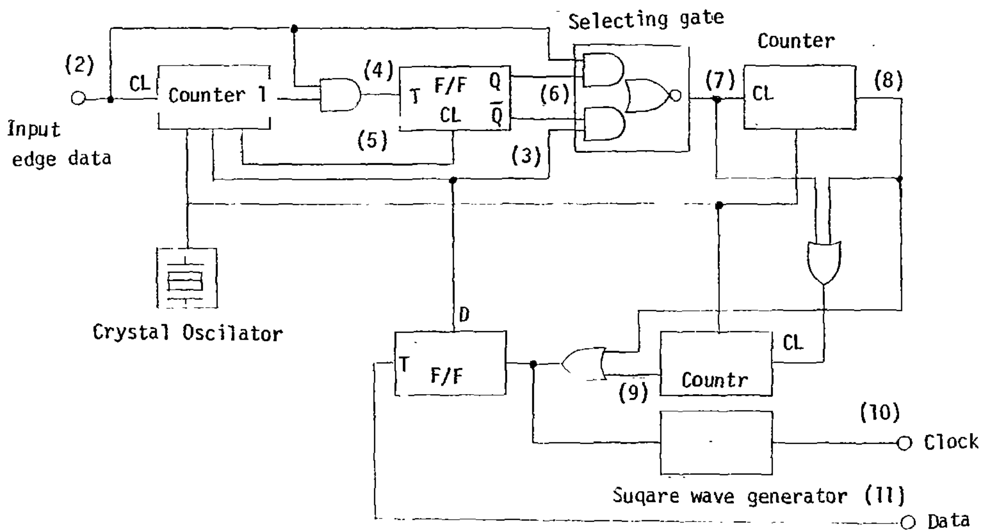


Fig.6 MFM demodulating circuit

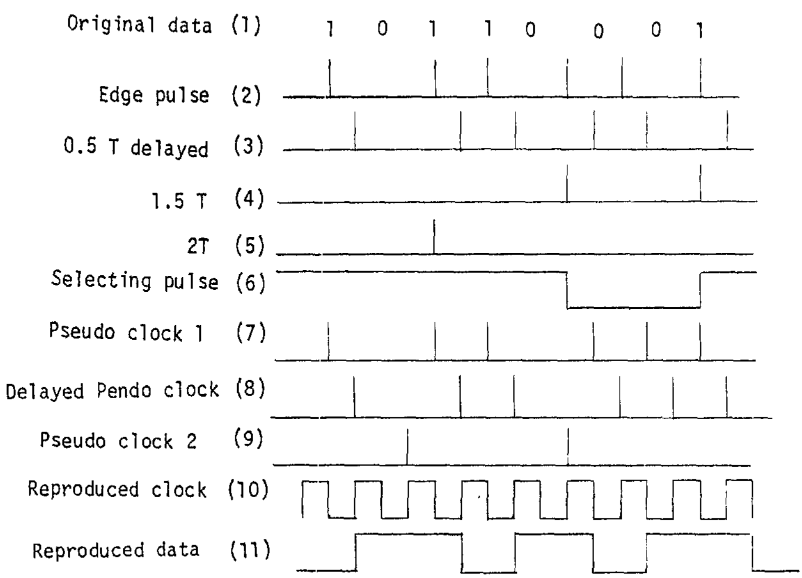
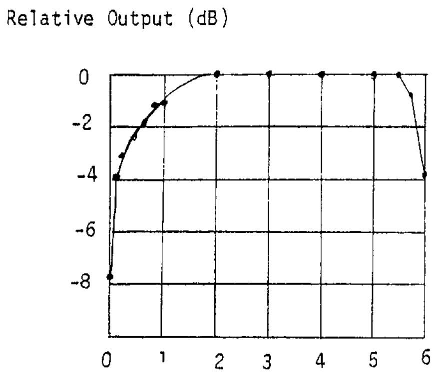
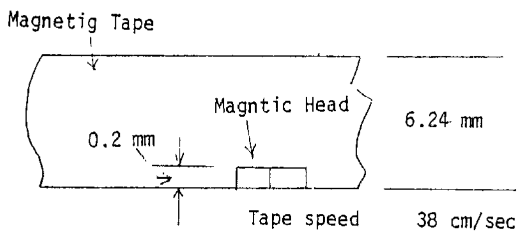


Fig.7 Time chart



(a) Output level vs Track position



(b) Measuring Condition

Tape speed	38 cm/sec
Tape tension	200 gr
Gap length	2μm
Frequency	100 kHz

Fig.8 Play back level vs track position

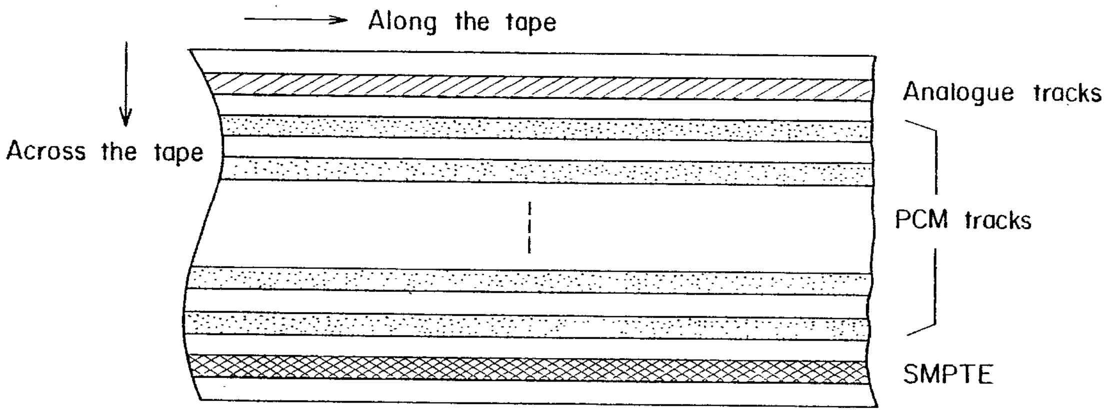


Fig.9 Recording pattern

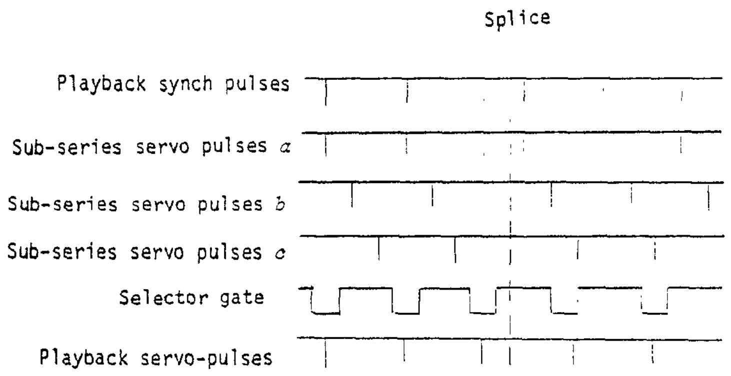


Fig.10 Selecting of sub servo pulse series

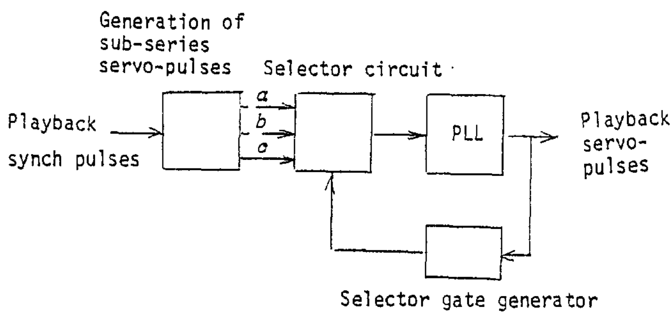
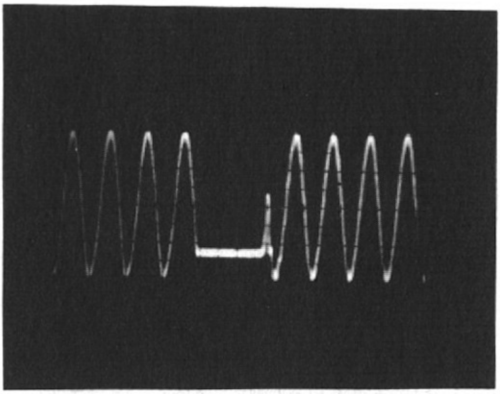
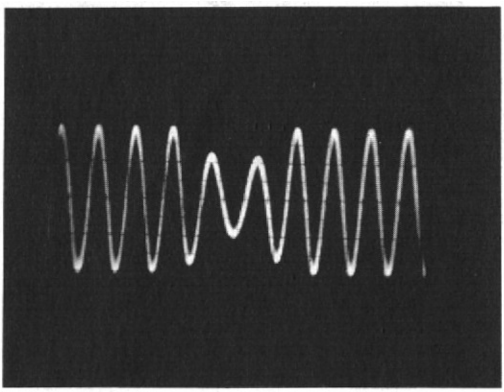


Fig.11 Block diagram of selective gate circuit



(a) Zero order extrapolation



(b) Fade-in/Fade-out

Fig.12 Joined signal

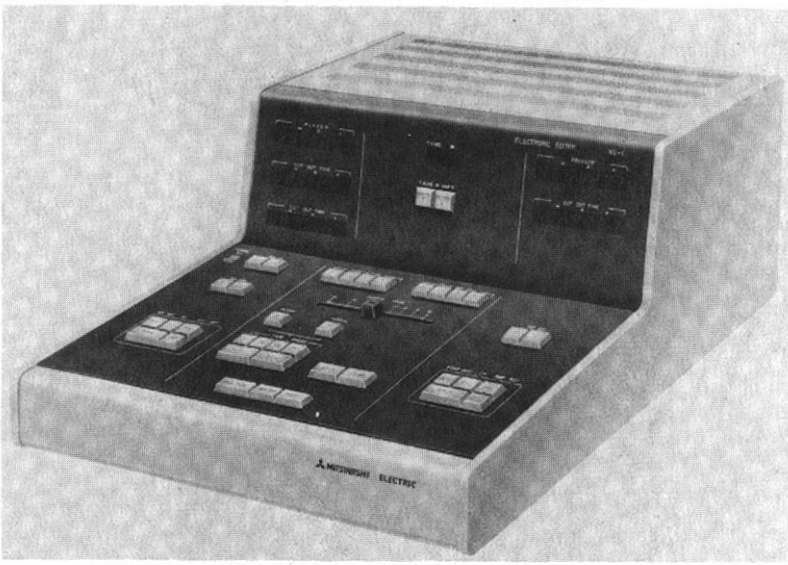


Fig.13 Appearance of Editor

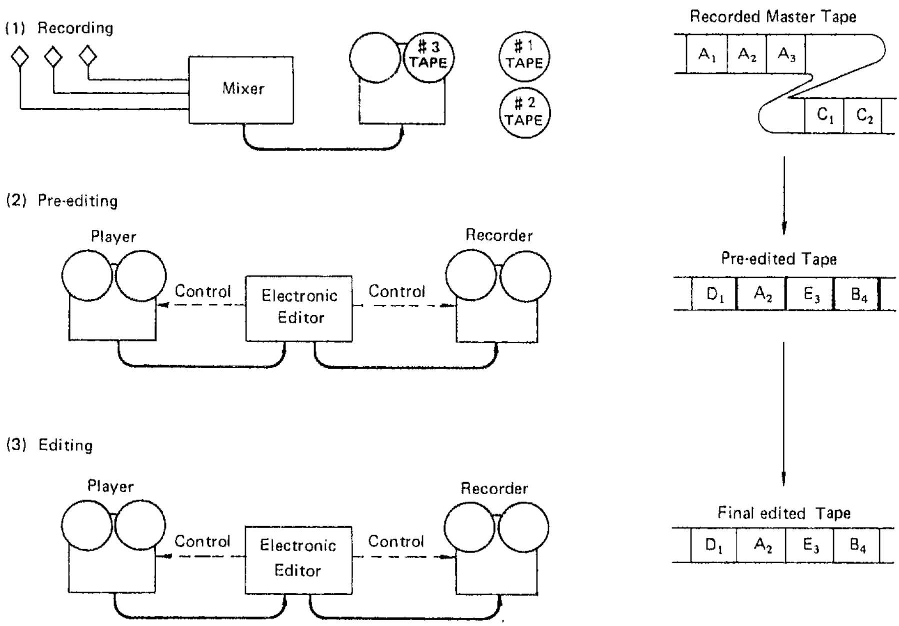


Fig.14 Basic diagram of electronic editing

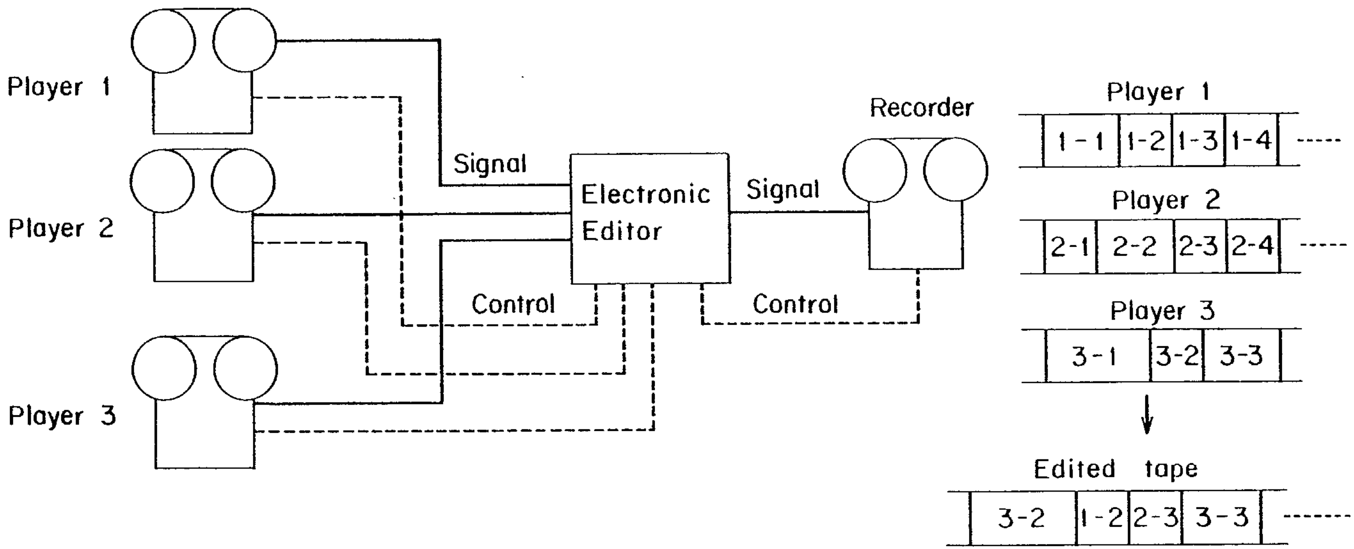


Fig.15 Block diagram of automatic editing