(1)

DATA RECORDING AND RECOVERY

Data is written on a coated disk by passing a current through the read/write coil which generates a flux field across the head gap. This magnetizes the iron oxide particles directly beneath the gap. The direction of write current controls the direction of the flux field thereby controlling the orientation of the magnetic field recorded on the disk. The strength of the flux field, which is determined by the amplitude of write current, controls the number of particles of iron oxide that are affected up to the point of saturation. Information is recorded by switching the direction of the write current to correspond with the encoding method used in the drive. In all commonly used drives, the direction of the recorded magnetic field contains no information. Information is contained exclusively in the transitions where flux reversals occur in the recorded field. However, these transitions have meaning only when their time of occurrence with respect to the data clock is known.

Data recovery involves detecting the presence of the recorded flux transitions, determining the time of their occurrence with respect to clock, and then decoding the result into a serial data stream that is forwarded to the drive controller. During readback, a flux transition passing beneath the head gap induces voltage into the coil. This voltage is proportional to $d\phi/dt$, the rate of change of flux with respect to time. The peak of the readback signal is generated where the rate of change of flux is maximum, i.e., where the flux is minimum. This peak readback signal occurs at either the cell or the half-cell boundary, which is the point where write current crossed zero during the write current reversal. Recovering the recorded data involves comparing the time at which the peak of the signal occurred to the time that the cell or half-cell boundary occurred. It is extremely difficult to determine the exact time of occurrence of a peak due to both the low rate of change at the peak and the probability of slight changes in amplitude from peak to peak. Therefore, the readback signal is generally phase-shifted by 90° through a differentiator, causing a simultaneous zero-crossing at the output and a peak at the input. This permits a more precise comparison of timing relationships and thus a more accurate decoding of the readback signal. Prior to differentiation, if any condition exists on the disk that causes the peak of the readback signal to shift abnormally from its nominal position, an error can result in the data sent to the computer.

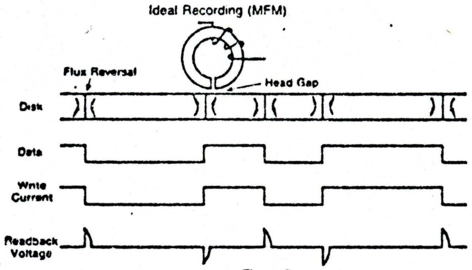
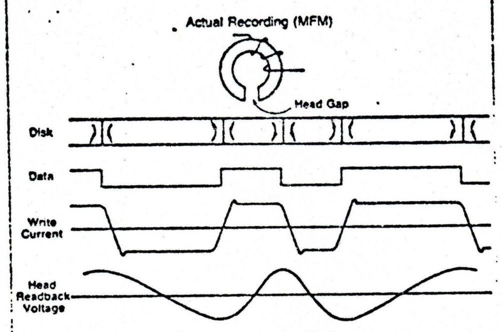


Figure 3

Peak shift is caused by departures from the ideal in the recording/readback process. Ideally, the gap in the read/write head core would be infinitesimal, the head would be an infinitesimal distance above the disk surface, and the write current reversal would be instantaneous. (Fig. 3) This would result in such discrete and narrow flux reversals on the disk that the departure of their occurring time with respect to nominal would be insignificant. The head readback voltage would consist of a train of very narrow pulses. Since the ideal gap is infinitesimal and very close to the disk, it would intercept only those flux changes due to a single flux reversal—there would be no merging at the head of the flux changes due to successive reversals. In actual recording, the flux reversals on the disk are not instantaneous. (Fig. 4) It takes time for the write current reversal to occur; the head gap is finite; and



Data recording and readback
Figure 4

due to disk imperfections, the head must fly far enough away from the disk to prevent head/disk contact. Therefore, there will, at the head, be a merging of flux changes due to successive flux reversals. The net effect is that there will always be a peak shift present in the resultant head readback voltage unless the written pattern is all 0's or all

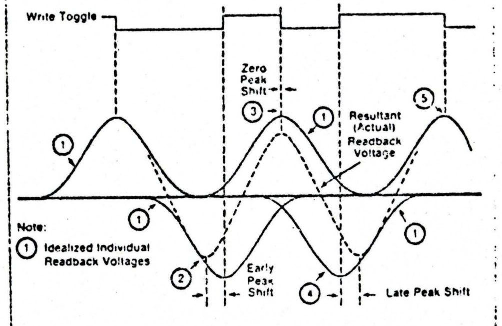


Figure 5

1's. Reference to Figure 5, PEAK SHIFT, illustrates this effect. Reversals 1 and 2 illustrate an 01 pattern. If reversal 2 were displaced from reversal 1 far enough, then readback voltage 1 would be the resultant head voltage. The dashed line represents the resultant head voltage due to the crowding and early peak shift occurs. Reversals 2, 3, and 4 are a 111 pattern and there is no peak shift on reversal 3. Reversals 4 and 5 represent a 10 pattern and late peak shift occurs. Thus peak shift is a normal occurrence in disk recording. The data recovery circuits of the drive are designed to compensate for the peak shift that occurs as a result of the data pattern. In addition, the drive data recovery circuits provide a timing margin, or data recovery window, at the output of the zero crossing detector. This window compensates for the expected production tolerances in coating uniformity, the substrate surface, and variations from drive to drive. Generally, when peak shift is mentioned, the meaning is understood to be restricted to peak shifts caused by factors other than the recording pattern itself.

NON RETURN TO ZERO INDISCRETE. A logic 1 is recorded by a reversal in write current direction. A logic 0 is recorded by *no* reversal of current. In the readback signal, only logic 1's appear as pulses and can be either positive-going or negative-going. Logic 0's are recognized by the absence of a signal. A primary *disadvantage* is that NRZI is not self-clocking and therefore requires the writing of a separate clock track. A primary *advantage* is that a maximum of one flux change (current reversal) is required per bit. NRZI was used only on IBM 1311 type drives and is now obsolete as a disk pack recording technique. (Fig. 6)

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FM:

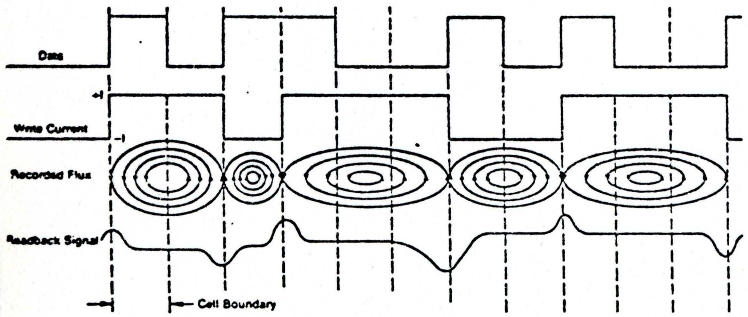
FREQUENCY MODULATION—ALSO KNOWN AS DOUBLE FREQUENCY (2F) RECORDING. A logic 1 is recorded by a write current reversal at the middle of a bit cell. A logic 0 is recorded by *no* reversal at the middle. There is always a write current reversal at the start of a bit cell. Thus in the readback signal, a logic 0 is characterized by a single pulse occurring at the start of the bit cell. A logic 1 is characterized by two pulses, one occurring at the start of the bit cell and the second occurring at the middle of the bit cell. A primary advantage to FM recording is the inherent self-clocking that occurs in the readback data. A primary disadvantage is the need for two flux reversals to record a logic 1, thereby limiting the packing density that can be achieved in a given system. FM recording was the predominant recording technique used in disk storage drives until the introduction of the 3330-type drive. (Fig. 7)

MFM:

MODIFIED FREQUENCY MODULATION ALSO KNOWN AS 3F RECORDING A logic 1 is recorded by a write current reversal at the middle of the bit cell. A logic 0 is recorded by *no* write current reversal at the middle of the bit cell. A write current reversal occurring at the beginning of the bit cell is known as "CLOCK," however "CLOCK" may be suppressed. If the cell contains a logic 1 or if the previous cell contained a logic 1, then clock is suppressed. In summary, the rules of MFM recording are as follows:

1. There is a write current reversal for each logic 1, occurring at the middle of the bit cell.
2. There is a write current reversal for each pair of logic 0 bits, occurring at the boundary between the two bits.
3. There is no write current reversal at the boundaries between a logic 01 or a logic 10 combination.

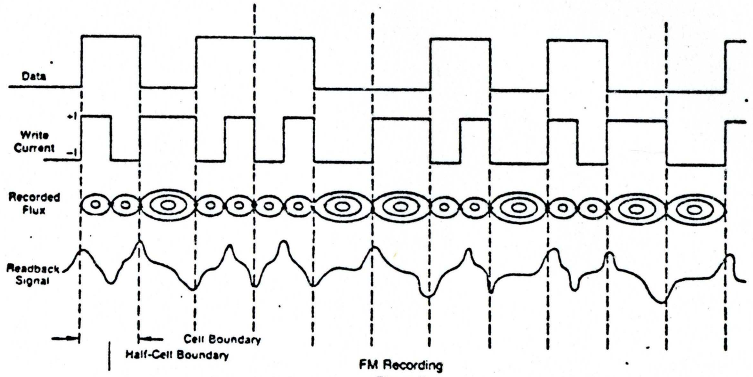
A primary advantage of MFM recording is that a maximum of one write current reversal occurs each interval. The maximum number of reversals occurs for either an all 1's or an all 0's pattern. The minimum number occurs for a pattern with alternating 1's and 0's. Therefore, it is possible to achiêve a greater packing density than would be possible with FM recording. A second advantage to MFM is that it is semi-self-clocking so that a separate clock track is not required for data recovery. (Fig. 8)



Notes:

1. Peak of readback signal will always occur at cell boundary.
2. Maximum packing density (min. spacing between flux changes) occurs with an all "I's" pattern.
3. With an all "I's" pattern, the nominal frequency of the readback signal is ½ the bit frequency.
4. Readback pulses occur only when a logic one is recorded.
5. An all "O's" pattern produces a D.C. erase.

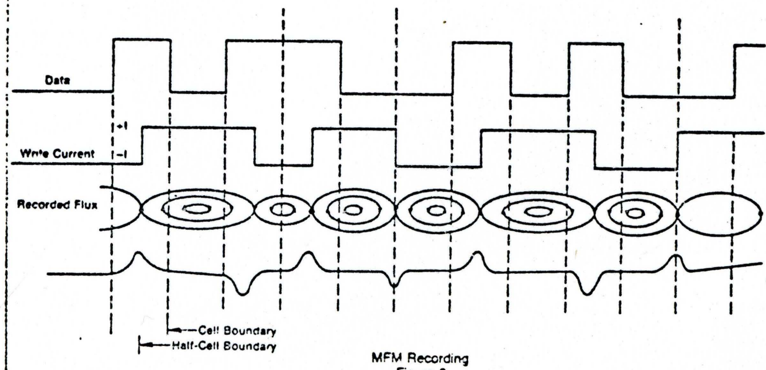
NRZI Recording
Figure 6



Notes:

1. There will always be a peak readback signal at a cell boundary.
2. There will be a peak readback signal at a half-cell boundary only if a logic one is recorded.
3. With an all "I's" pattern, the nominal frequency of the readback signal is equal to the bit frequency.
4. With an all "O's" pattern, the nominal frequency of the readback signal is equal to ½ the bit frequency.

FM Recording
Figure 7



Notes

1. If a readback pulse occurs at a half-cell boundary, a logic "I" is recorded in the cell.
2. If a readback pulse occurs at the cell boundary, a logic "O" is recorded in that cell, as well as in the previous cell.
3. If there is no readback pulse at either the cell or the half-cell boundary, there is a logic "O" recorded in the previous cell.
4. Maximum packing density occurs with either an all "I's" or an all "O's" pattern. Minimum density occurs with an alternating pattern OIOI...

MFM Recording
Figure 8

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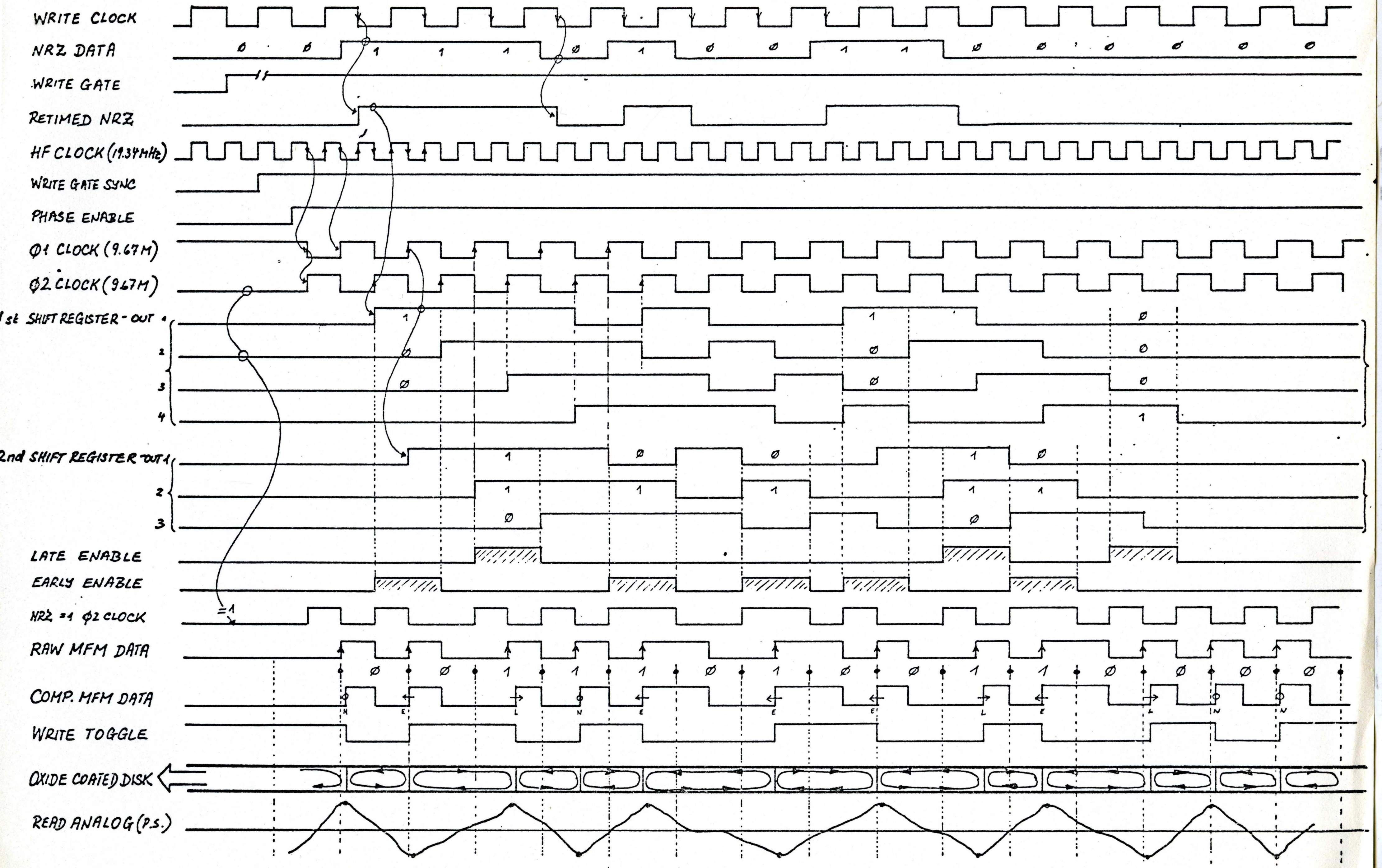
③ NRZ TO MFM CONVERSION & WRITE COMPENSATION — DETAILED TIMING CHART



WRITE DATA/200NS

(114) A01 - 8B ①
+WRITE DATA (NRZ)

(114) A01 - 11B ②
+WRITE CLOCK

(114) A01 - 9B ③
+DATA BUFFER (NRZ)

(114) A01 - 1332 -2 ④
+NRZ DATA SHIFTED

(114) A01 -2443 -6 ⑤
+UNCOMP. MFM DATA

(115) A01 -2932 -6 ⑥
- EARLY

(115) A01 -2932 -12 ⑦
- LATE

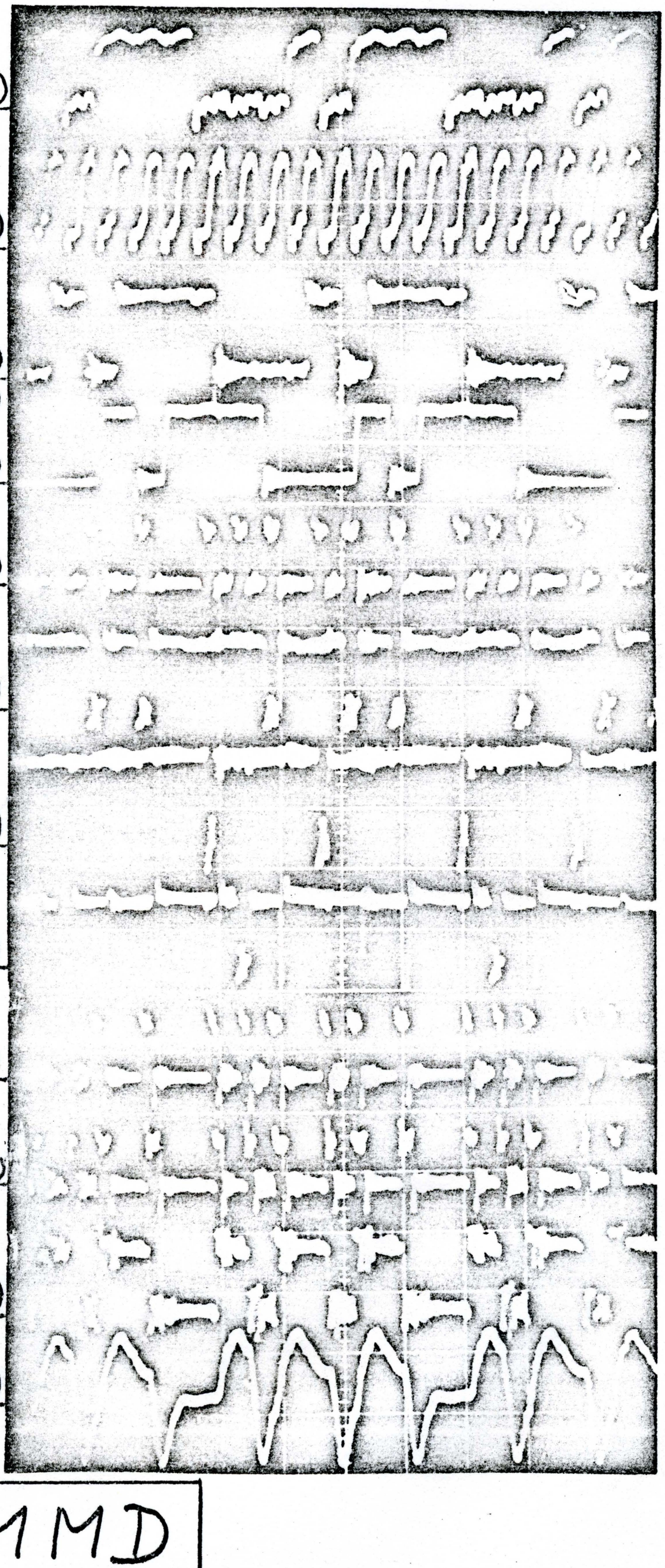
(115) A01 -2932 -8 ⑧
- NOMINAL

(114) A01 - 35B ⑨
+COMP. MFM DATA

(522) A2/B2 -5916 -2 ⑩
+COMP. MFM RECEIVED

(522) A2/B2 -5904 -15 ⑪
+ WRITE TOGGLE

⑫
WRITE CURRENT



80/160 MB MMD

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READ DATA 200NS

(533) A2/B2 TP28 (1)
+AGC'D ANALOG READ DATA

(512) A1-TP15 (2)
DIGITIZED READ DATA
(LOW RES DATA)

(512) A1-TP17 (3)
+DATA PULSES
(HIGH RES PULSES)

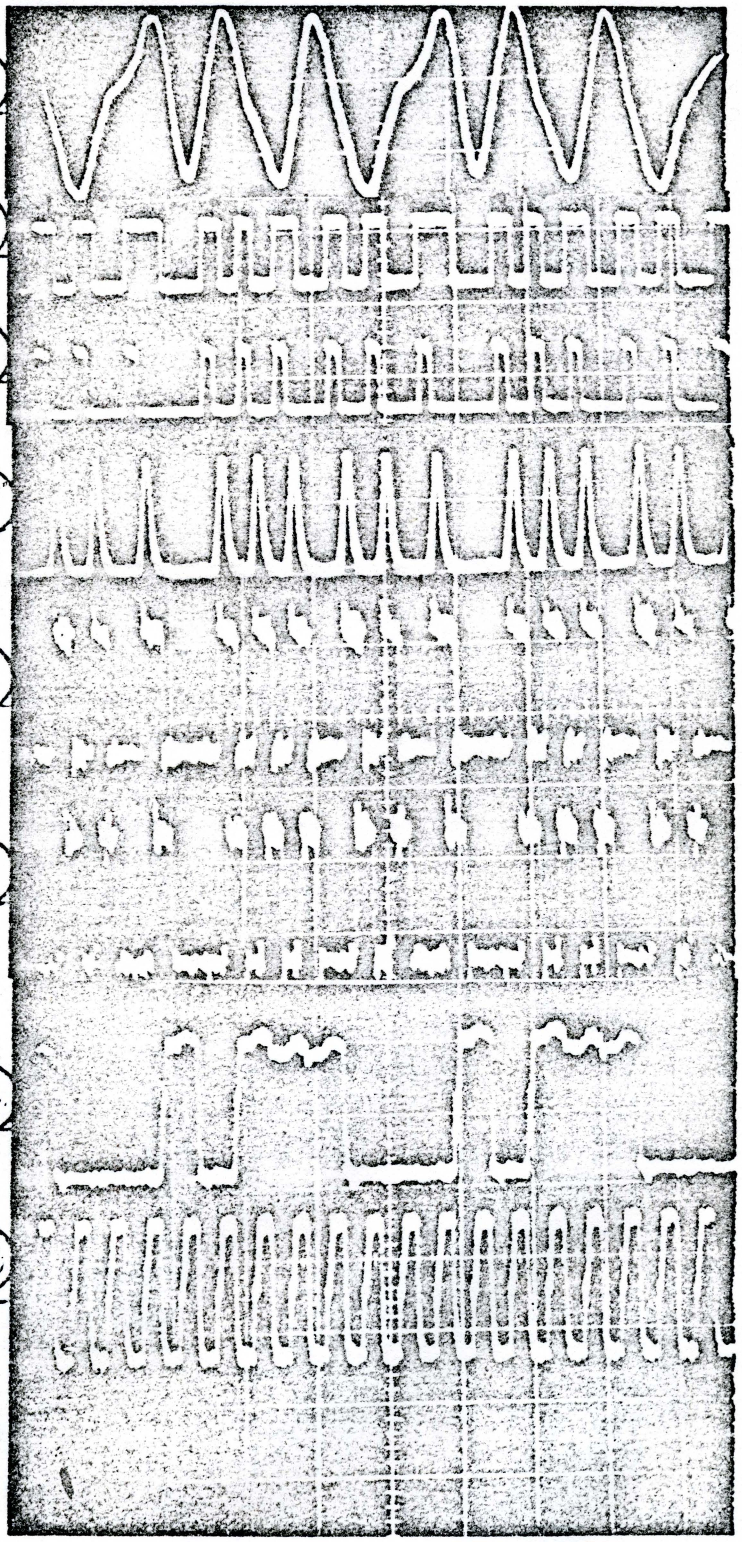
(133) A03-12B (4)
+READ DATA (STROBES)

(132) A03-0831-15 (5)
ENABLED DATA FF

(132) A03-1331-02 (6)
ENABLED CLOCK FF

(133) A03-27B (7)
+NRZ READ DATA

(133) A03-28B (8)
-READ CLOCK 9.67 MHz



NOTE: TRAILING EDGE OF LINE (8) CLOCKS LINE (6) INTO FF LINE (7)

SHEET 1 OF 2

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