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TECHNICAL REPORT

COMPARISON OF METHODS OF MAGNETIC RECORDING

by

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ABSTRACT

Ten different methods of magnetic recording are briefly reviewed. The potential increases in bit density over the discrete pulse system are given for some systems. Experimentally reported bit densities are given together with conditions for comparison.

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Introduction

Ten different systems of magnetic recording are illustrated by sample waveforms for the word "001110100111". The primary objective of this report is to provide reference to these different systems in one place. Following the series of sample waveforms are brief descriptions of the Systems, sample data, and references. Since it is difficult to compare the experimental performance of different systems where other conditions are not kept constant, a table of significant data is given for comparison.

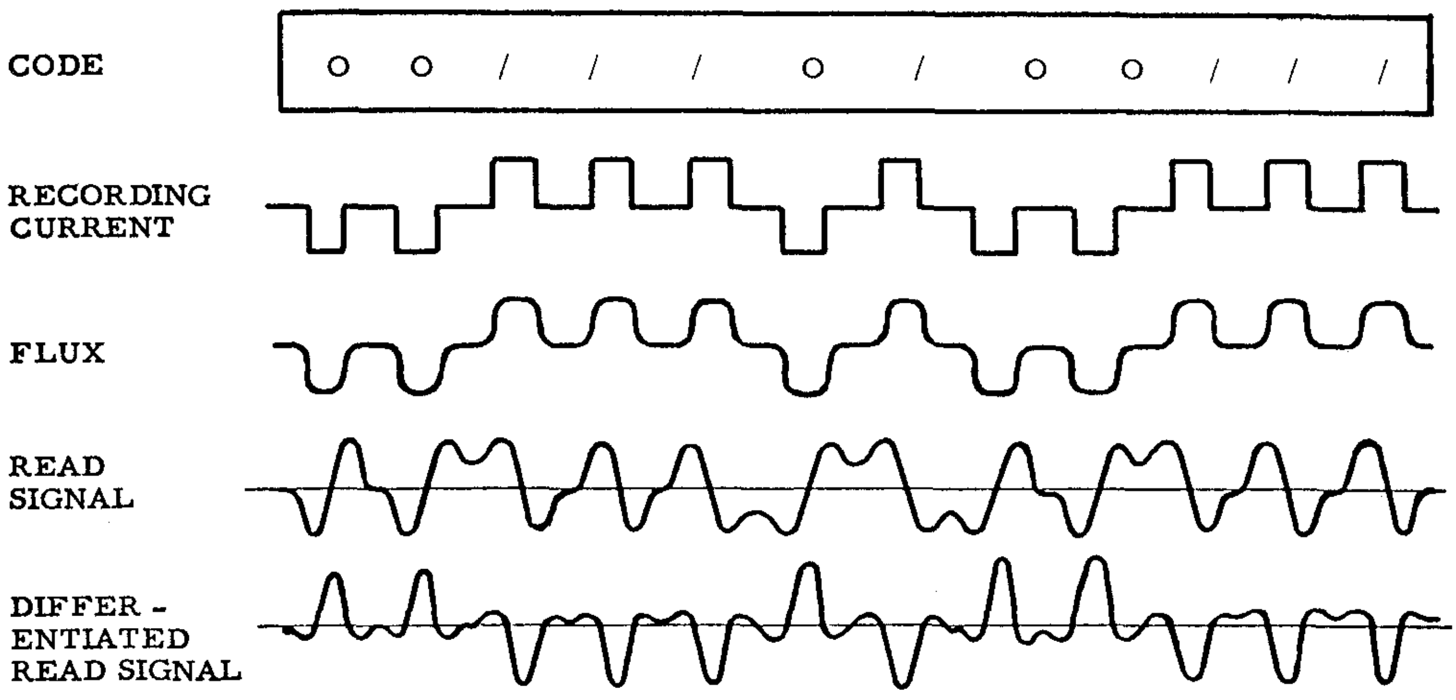

Figure 1 Discrete Pulse Method

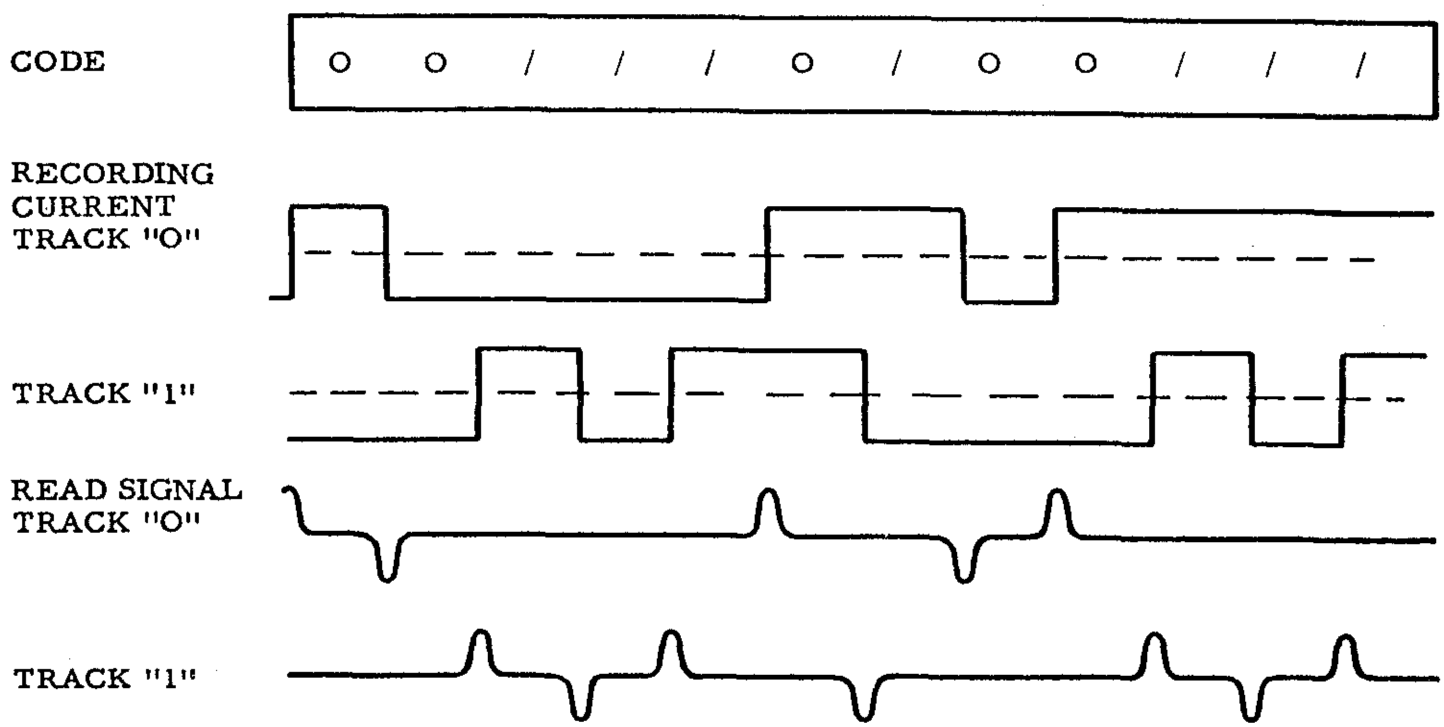

Figure 2 Two Channel Discrete Pulse

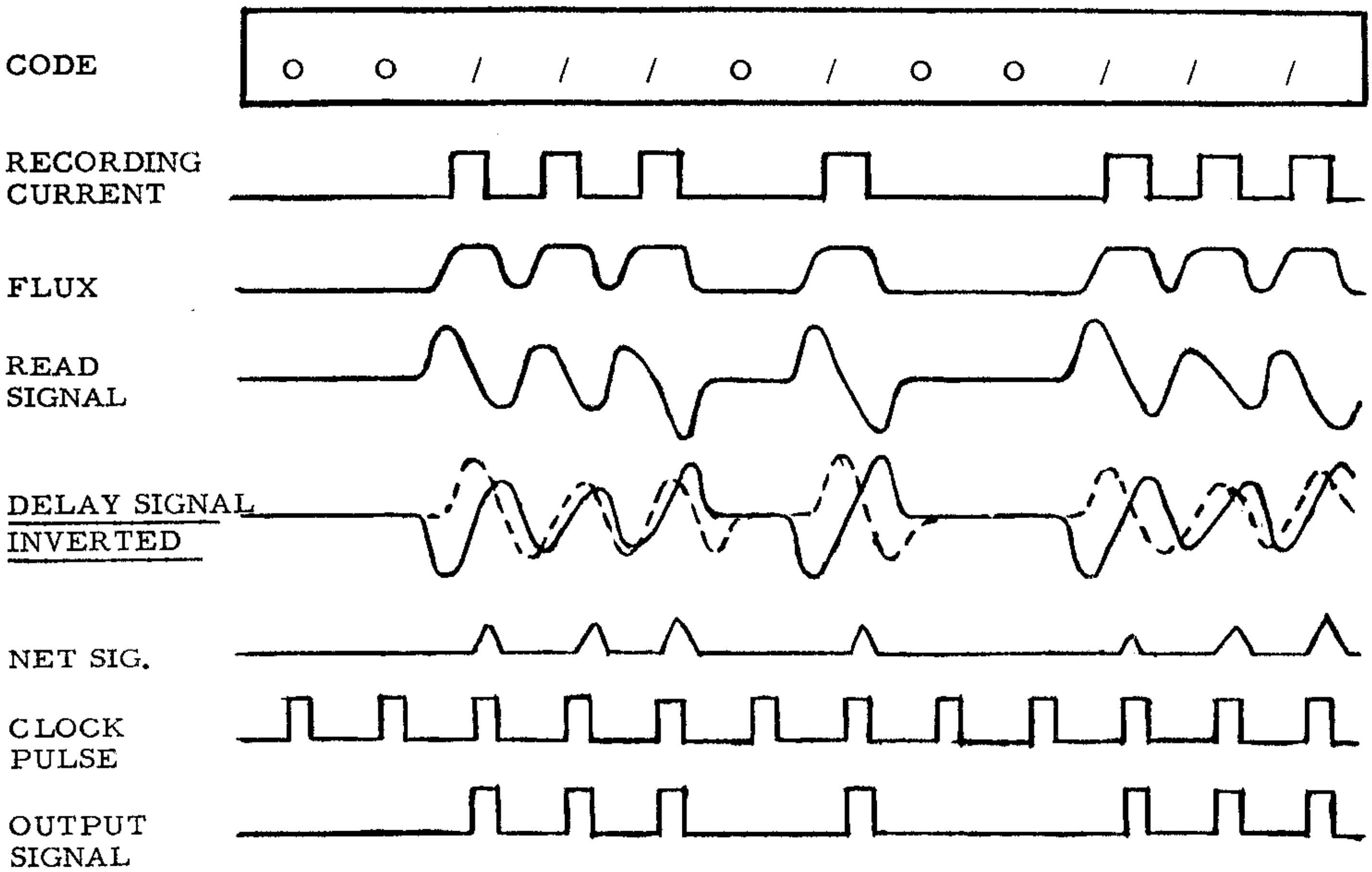

Figure 3A Dual Correlation Waveform

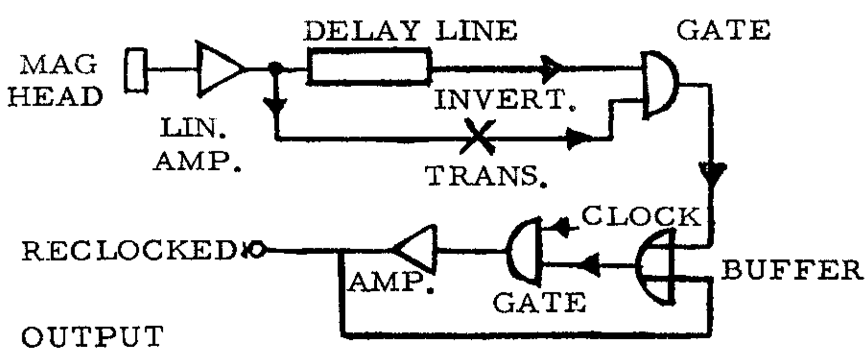

Figure 3B Dual Correlation Circuit

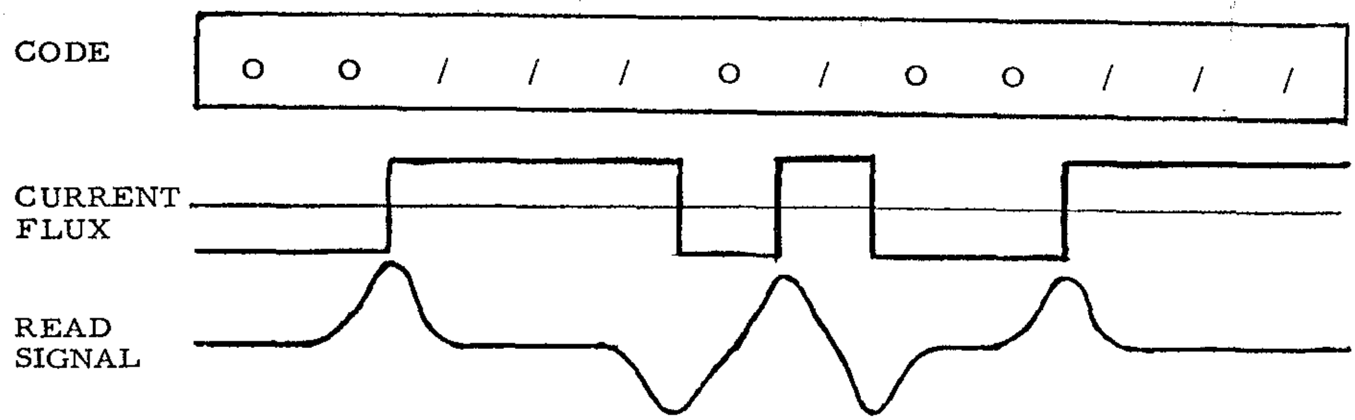

Figure 4 NRZ System

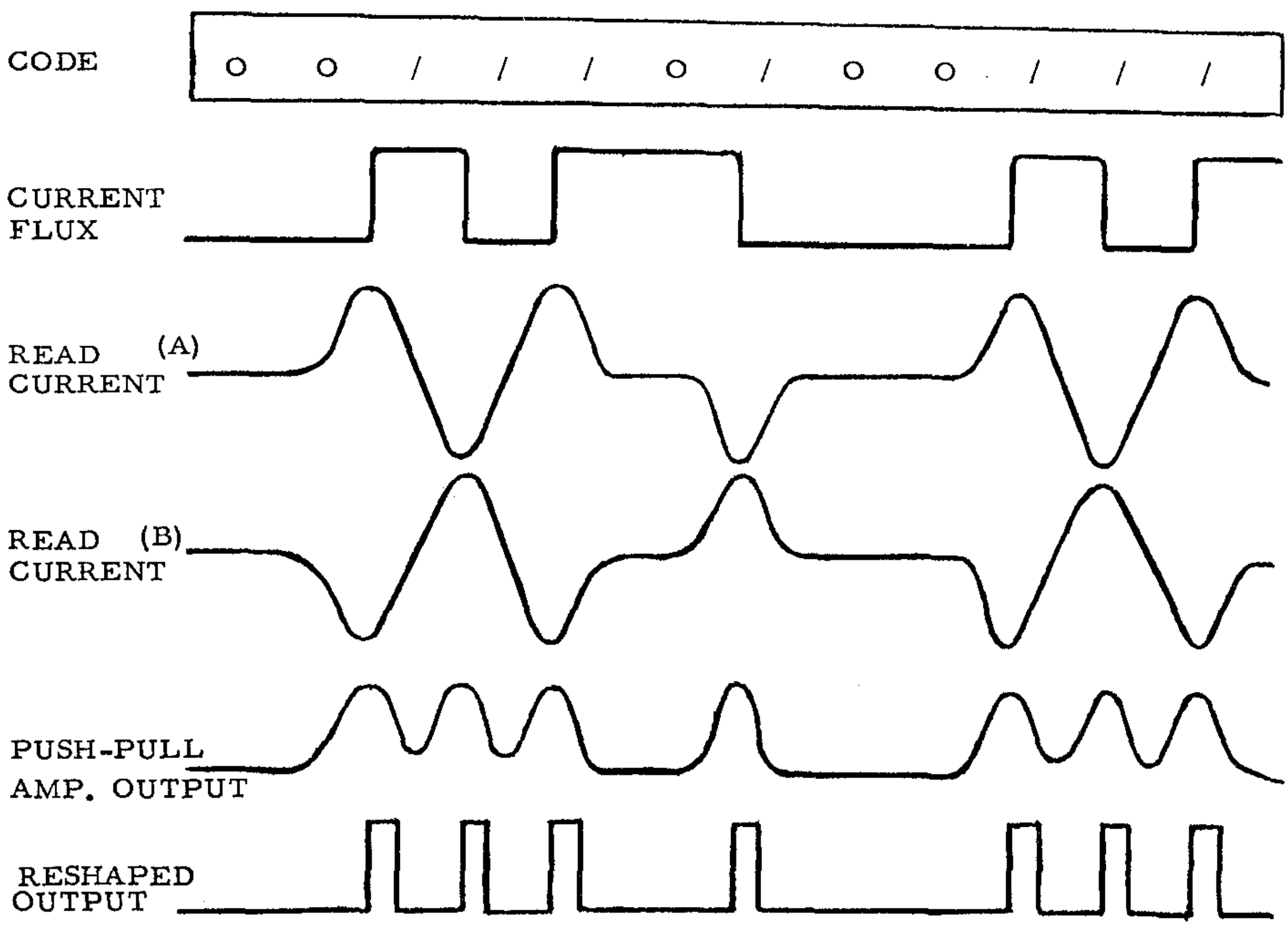

Figure 5 NRZI System

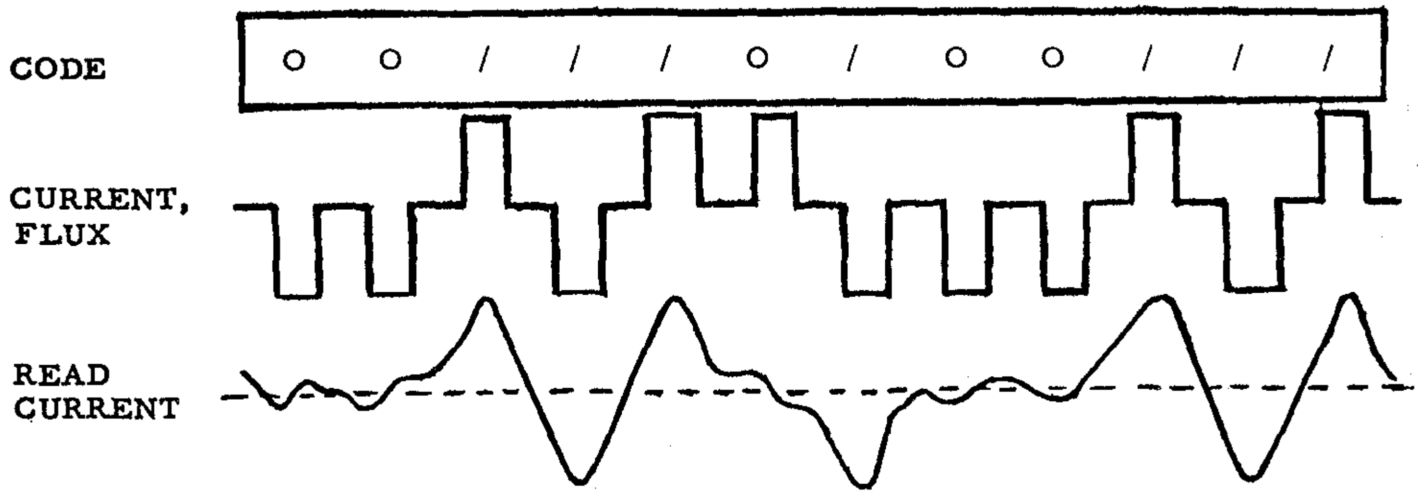

Figure 6 NRZ Pulse Method

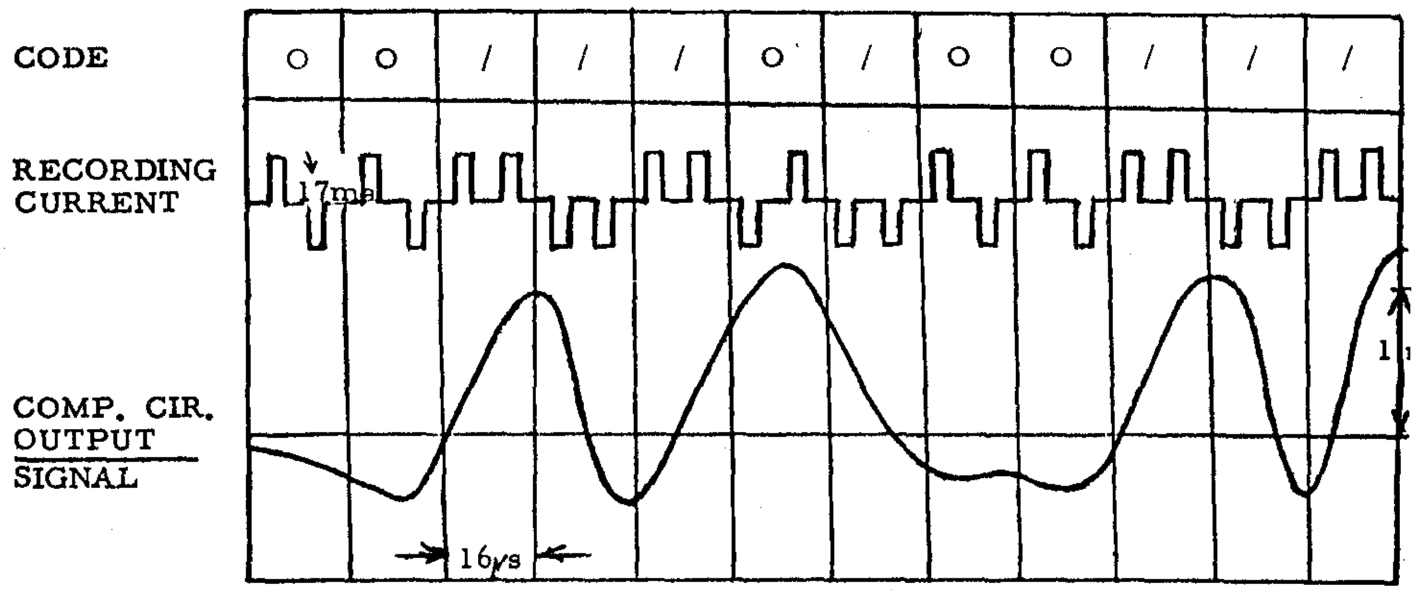

Figure 7A Frequency Doubling Method

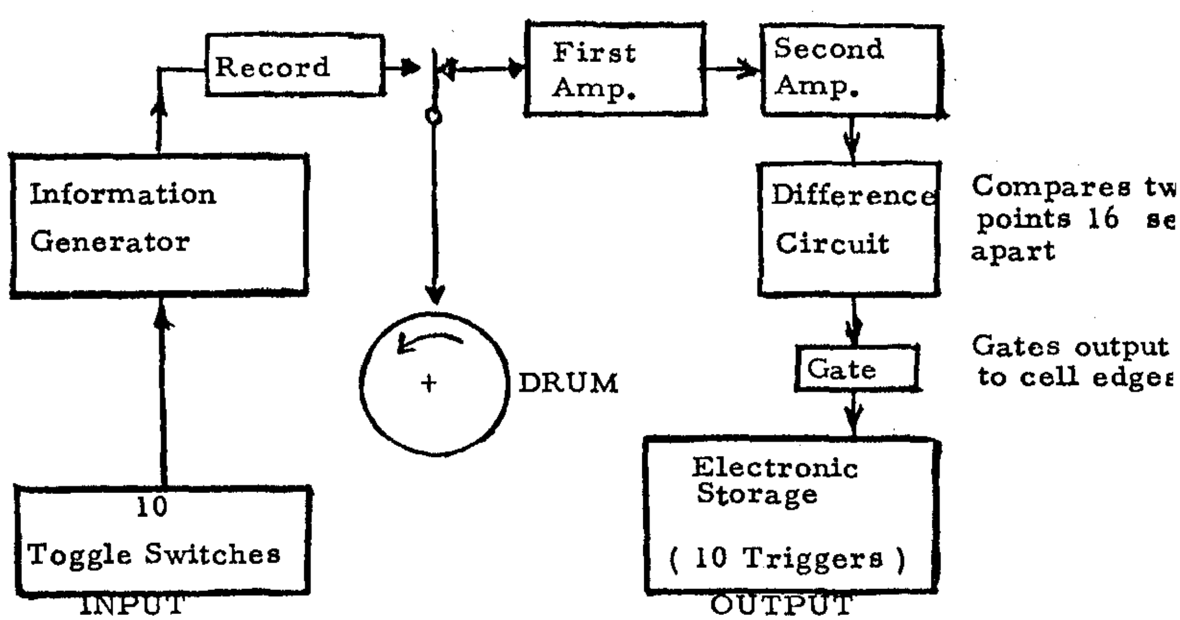

Figure 7B Havard Frequency Doubling System

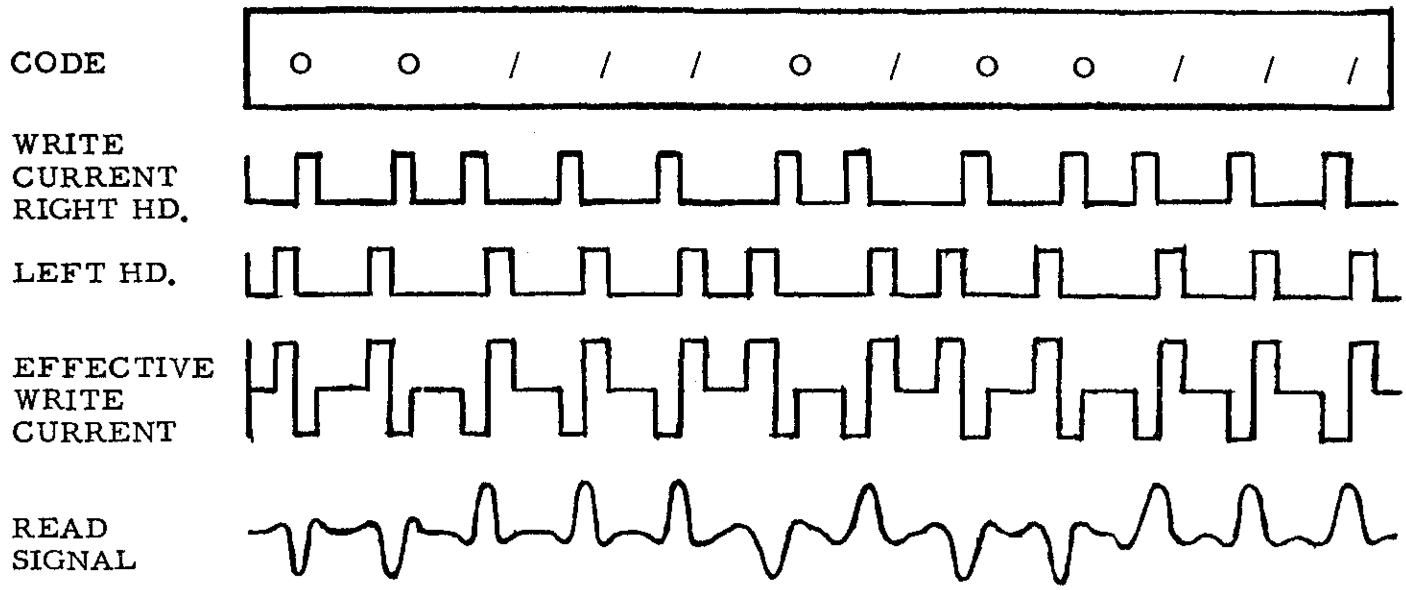

Figure 8 Current Pulse Displacement Method

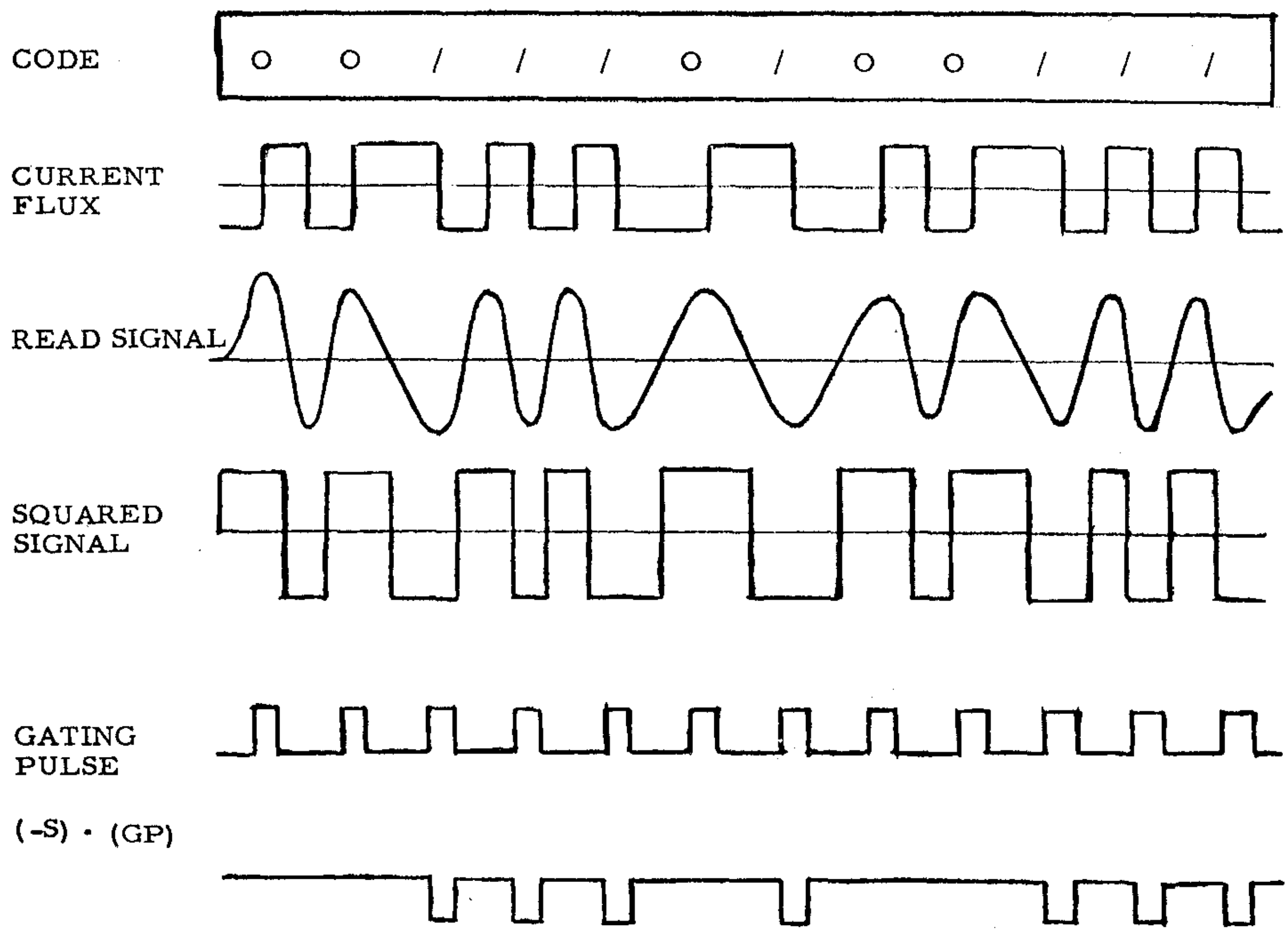

Figure 9 Phase Modulation (Ferranti) Method

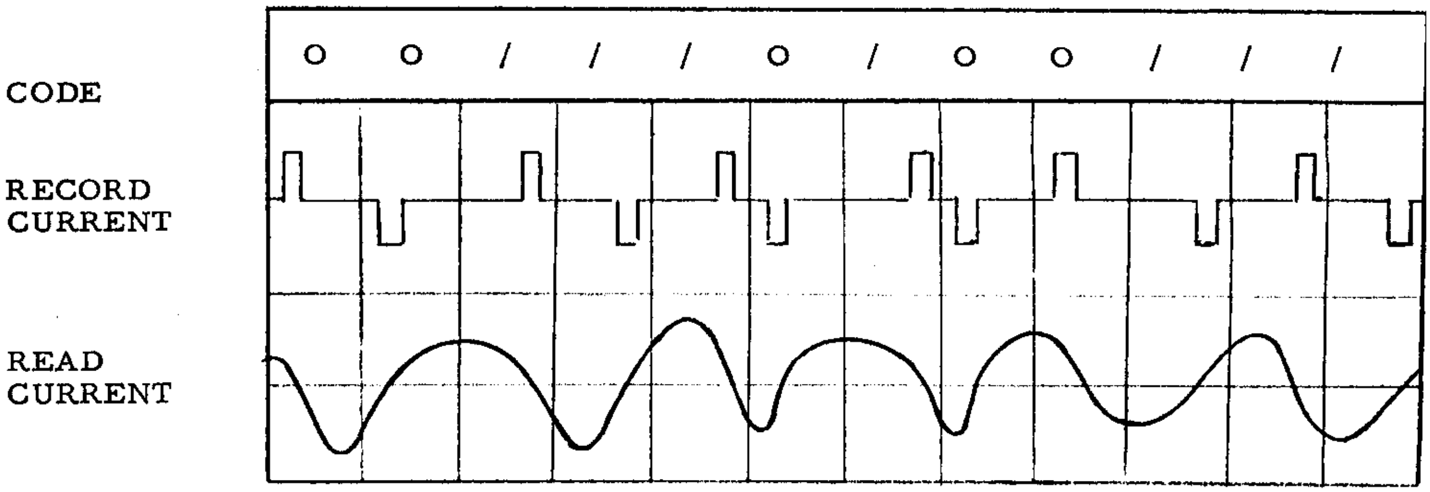

Figure 10 Phase Shifting Mehtod

1. Discrete Pulse Method

The read signal has one cycle per digit as is shown in Figure 1. The double signal can be reduced to a single signal by differentiating.
An alternative is to integrate the read signal. See Figure 9 of Reference 2.

Typical density is less than 75 bits per inch. Overlapping at 100 bits per inch shown in Report 003.042.521 (29). Disk and drum surface speeds run in the range of 750 to 1500 inches per second. At speeds of 100 inches per second, 200 bits per inch is readable.

References:

1. J. A. Hadad and H. W. Nordyke, "Factors Affecting Spot Density in Magnetic Tape Recording", January 1, 1950. IBM Code: 02.043.42.

2. L. D. Stevens and H. A. Mussell, "Magnetic Tape Reading and Writing Methods", February 9, 1951. IBM Code: 02.043.61.

3. J. R. Brown, "An Improved Magnetic Drum Recording System", February 1, 1954. IBM Code: 003.042.521. See also reference 8.

2. Two Channel Discrete Pulse System (Continuous Current)

A system using two tracks, one for "1's" and the second for "0's" is described in Reference 2. The current is reversed in the corresponding track each time a "1" or "0" occurs.

Reliable operation up to 330 bits per inch on tape. Effective bit density is one-half of above due to using two tracks.

3. Dual Correlation Method

This system is based on sharpening the reading signal by sending an inverted signal and a delayed signal to a gate or described in Reference 4. This system gives a blank output voltage for zeros and has positive magnetization for ones. The gain in density is 2 based on discrete pulse width = 1/3 cell width and increase of pulse width up to 2/3 cell width by correlation method.

Reference:

4. Samuel Lubkin, "An Improved Reading System for Magnetically Recorded Digital Data", IRE Trans -EC - 3, September 54, pp. 22 -25.

4. Non-Return-to Zero (NRZ) or Pulse Envelope Method

The current is positive for "ones" and negative for "zeros", and the current is maintained throughout the full bit period. The highest frequency read cycle has a half cycle per digit or twice the bit density of discrete pulses.

Typical operating characteristics:

200 bits per inch, 600" per sec. = 120 KC 5 mv.

.0002" spacing for reading (contact writing)

30 mv at 700 inch per sec.

80 mv at 2000 inches per sec.

References:

5. J. R. Brown, Jr., "An Improved Magnetic Drum Recording System", IBM Code: 003.042.521, February 1, 1954.

6. Librascope Bulletin, Head MH 15 A
100 bits per inch, 1880" per second, 70 ma write current head to drum spacing .001" drum coated .001" red oxide, 1 volt output.
7. G. L. Clapper, "Non-return-to-zero Recording and Reading Circuits", IBM Code: TR 103.045.290, November 11, 1955
3000 bits per square inch on drum, 22 tracks per inch for NRZ with bit frequency of 240 kc, maximum spot frequency is 120 kc/s average spot frequency is 60 kc, 134 bits per inch, representing 67 magnetized spots per inch.

5. NRZI - Non-Return-to-Zero-IBM Method The writing is reversed each time a "one" occurs, and is kept constant at the level of the previous digit each time a "zero" occurs. This system uses a maximum of one-half cycle per digit on twice the bit density of discrete pulses. The magnetization changes each time there is a "one", but does not change for "zeros".

A sample performance is as follows:

RAMAC 305-A 50 to 100 bits per inch air head: 800 bits per second x 5 records x 20 rps = 80 KC   815 - 1440 inches per second. 20 mv.

References:

8A. H. W. Nordyke, Jr. and W. Winger, "Magnetic Recording Techniques", IBM Code: 02.042.90, April 10, 1950.
8B. H. W. Nordyke, Jr., "Magnetic Tape Recording Techniques and Performance", IBM Code 02.041.420, 10/15/52.

9. H. William Nordyke, Jr., "Magnetic Tape Recording Techniques and Performance", AIEE Publication S-53, Joint AIEE-IRE-ACM Computer Conference, N. Y., Dec. 10-12, pp. 90-95.

6. NRZ Pulse Method (NBS System Similar to NRZI)

This system uses pulses with the same polarity of preceding pulse for zeros and pulse of reversed polarity for ones. When the pulse length is increased to be equal to the bit space, it becomes the same as the NRZI system.

NBS, using 2 usec. pulses, 60 ma writing current, obtained up to 735 bits per inch on tape.

Reference:

10. "High-Density Tape Recording for Digital Computers", National Bureau of Standards - Technical News Bulletin, 390, 121-124 (Sept. 1955)

7. Harvard Frequency Doubling Method - Each digit consits of two separate pulses. The two pulses, one of opposite polarity for a "zero" and of the same polarity for a "one". The polarity of pulses changes between each digit. This system has one-half cycle per "one" digit and the "zero" bits represent a full cycle per bit at twice the frequency. This puts the frequency of "Zero" bits above the upper pass band of the circuits. This utilization of the filtering property of the circuits under best conditions can double the bit density to four times that for discrete pulses (*Reference 13)

With head in contact:

Bit density of 1150 bits per inch x 54 inches per second = 62 kc.

(compare with 200 bits per inch contact discrete pulse)

One to zero ratio of 2 with Raytheon head at 1150 bpi.

The one frequency signal can be increased by dropping to 800 bpi. Self-clocking can be developed using either the zero or one frequencies in the signal.

References:

11-13: The Computation Laboratory, Harvard University, "Design and Operation of Digital Calculating Machinery".

11. Progress Report No. 30 (AD-35681) 10 Feb '54 "Frequency Doubling" System described in Section VII and Figure 1 (page VII-9). Using a Mark IV pole piece .001" away from a coated magnetic drum gave a density of 280 bits per inch. Using the same equipment gave 80 bits per inch for return to zero recording. The recording was done at 50" per sec. or 10 KC. The reading was done at 80 kc or 400" per sec. (p VII-2).

12. Progress Report No. 32 (AD-32200) 10 May '54, Experimental equipment to test frequency doubling method described on page IX-1.

13. Progress Report No. 34, August 1954, Further test data on frequency-doubling system in Section II pp 1 - 11.

14. F. Boxall (unpublished memorandum) IBM, San Jose, October 24, 1955, "Magnetic Bit Density -- Comparison of NRZI and Harvard System".

8. Current Pulse Displacement Writing

This system is described in Reference 2. Pulses displaced ahead of the center of the timing interval goes through one-half coil, while a pulse displaced behind the same point goes through the other half coil.

In the example in Figure 8, for a "zero" the pulse is ahead in the left coil and delayed in the right coil. For a "one" the timing is reversed. The left and right coils are parts of a center-tapped coil, such that the effective read signal is a negative pulse for "zeros" and a positive pusitive pulse for "ones".

John Beck has pointed out that when the bit spacing is decreased so that the effective write current fills the whole bit space, this current pulse displacedment writing becomes equivalent to the phase modulation system (Ferranti).

9. Phase Modulation (Ferranti)

In the pase modulation system, the magnetization is reversed in the center of each bit space, always up for "zeros" and down for "ones". This puts in an extra flux reversal between bits of the same value which is cut out on reading by the gating pulse. The read cycle is one-half cycle per digit for 1010101 to one cycle per digit for 1111111 or 000000. Thus the ratio of the bit density with the Ferranti system to that for other systems varies with the pattern of digits. A ratio of twice the bit density as is obtainable with the NRZ system has been estimated as potentially realizable. Experimental waves shapes obtained so far indicate a ratio of between 1.3 to 1.7 over NRZI recording under comparable conditions.

The limiting point with increase of bit density in NRZ or NRZI systems is the point where an isolated "one" spreads out to overlap with the adjacent zeros. The phase modulation system by reversing the magnetization in each bit space, sharpens the isolated one pulse so that it can be pushed to higher bit densities.

References:

15. F. C. Williams and others, "Universal high speed digital computer: a magnetic store", IEE Proc. vol. 19, pt. 2, pp. 94-106, April 1952.

16. Ferranti Electric, Inc., 30 Rockefeller Plaza, N. Y. C., "Ferranti Magnetic Storage Drum Type 200 B", 3 pages, ". . . Phase-reversing, return-to-zero recording system. . . " 170 bits per inch compared to 100 bits per inch NRZ.

10. Phase Shifting Method

The recording pulses have alternating polarity with the ones delayed one-third of a bit space. The position of the maximum read voltage indicates a zero if in the last half of the bit space (or on boundary) and a one if in the first half or the next bit space.

The Harvard Laboratory reports 200 bits per inch, but reports this system is not sufficiently promising to warrant the construction of such circuit

Cell boundaries of 100 usec. with pulse delays of 33 usec. were used.

Reference:

18. The Computation Laboratory, Harvard University, Program Report No. 30, February 10, 1954. Section VII, Figure 2. (page VII-9)

11. Comparison of the Different Systems

The different systems are compared in the following table:

	METHOD		Drum or Disc	TAPE	Air Gap	Contact	in/sec. Surface Speed	bits/inch Bit Density	NOTES	(Year)	REF.
1.	DiscretePulse										
		A	X					75		(1954)	6
		B	X		X		400	80	Conditions of 7(b)		11
		C		X		X		200		(1950)	8A
2.	Two Channel DiscretePulse	A		X		X		(1/2) 330=165		(1950)	2
3.	Dual Correlator								No. Data		
4.	NRZ										
		A			0.2mil		600	200	5 mv	(1954)	5
		B	X		X		1800	100	1V.	(1955)	6, 16
		C	X				1800	134		(1955)	7
5.	NRZI										
		A	X		X		815-1440	50-100	RAMAC		
		B		X			200	500			
		C		X		X		500	d-c self erasing	(1950)	8A
		D		X			72	100	701	(1952)	8B
6.	NRZ Pulse	E	X		0.5mil		700	250		(1955)	17
		A		X		X		735		(1955)	10
7.	Harvard Frequency	A				X	54	1150	S/N =2/1		13
	Doubling	B	X		X		400	280	Compare W. 1 (C)	(1954)	11
8.	Pulse Displ										
		A		X		X		70		(1950)	2
9.	Phase Mod										
		A	X				1880	170	Compare W. 4(B)	(1955)	16
		B			X		1285	80		(1952)	15
		C	X		.5 mil		700	250		(1955)	17
10.	Phase Shifting								Tested for Recording		
		A					50	200	Only	(1954)	18

The NRZ System (item 4) is theoretically able to be useable at twice the information bit density as the Discrete Pulse System (item 1). This is in approximate agreement with a comparison of 1a and 4c in the table.

The Harvard Frequency-Doubling System (item 7) is claimed to be capable of twice the bit density of the NRZ System (item 4.). This would be four times the density of the Discrete Pulse System (item 1). Rejecting comparisons between high speed and low speed, and between drum (or disk) and tape, i. e., comparing experiments for comparable conditions gives a ratio of 280/200 = 1.4 for 7b and 4a or 280/134 = 2.1 for 7b and 4c, which are of the order of magnitude of 2.

The Ferranti Phase-Modulation System (item 9) has likewise had a gain of a factor of two in bit density over the NRZ System (item 4) claimed for it. On the basis of 7b and 4b the experimental ratio is 170/100 = 1.7 which is less than two. The more recent work of G. L. Clapper (item 4c) in which reshaping circuits are used with the NRZ System indicates a ratio of 170/134 = 1.27, which diminishes the advantage of Phase-Modulation over NRZ. Further experimental testing of the Ferranti Phase-Modulation System is being conducted by J. W. Beck.