HIGH LINEAR DENSITY RECORDING STUDY

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ABSTRACT

A series of tests were conducted in an attempt to study the recording behavior of Enhanced Nonreturn to Zero (ENRZ) code at high linear recording densities.

Using the "eye" pattern as a criteria in the first phase, the tests clearly demonstrate the sensitivity of a tape recorder to the DM (Delayed Modulation) coding technique as compared to ENRZ. For the same linear density, ENRZ has a considerably wider margin than the DM code.

In the second phase of that study, a series of tests were conducted using high energy tape and magnetic heads with reproduce gaps in the order of 12 µin, referred to as "double bandwidth heads." Using present day technology, it was possible to demonstrate linear packing density never before achieved on magnetic recording tape.

INTRODUCTION

One of the major obstacles to increasing linear packing density in instrumentation recorders is the short wavelength required, the signal loss associated with it

$$\text{(spacing) loss} = 55 \frac{d}{\lambda})$$

due to head-to-tape interface and the decision area associated with the size, or opening, of the eye pattern. This, in digital recording, manifests itself as BER (Bit Error Rate). Another significant factor is the width of the eye, or, the time distance between the zero crossing. This distance is subject to tape and transport performance such as jitter, flutter, etc. thereby influencing BER.

Quick examination of the power spectral density of the two codes suggests that the ENRZ code would be less sensitive to high frequency or band edge disturbances than the DM code because the former has less high frequency content and therefore would be less vulnerable to high frequency dropout or spacing loss. Indeed, in separate experiments it was possible to demonstrate ENRZ recording with linear packing densities of 45 to 50 kbpi using standard instrumentation tape and heads.

PHASE I: COMPARISON OF EYE PATTERNS

In the first phase of the experiment a series of tests were made using DM and ENRZ codes at various linear densities ranging from 16.7 kbpi to 45 kbpi. To study the quality of the data a series of photographs were taken showing the “eye” pattern of both codes. The “eye” opening of each code was then measured and compared.

Finally, as an extension of ENRZ capability a test was run using 45 kbpi on 42-track per inch format.

Fig. 1A (DM)

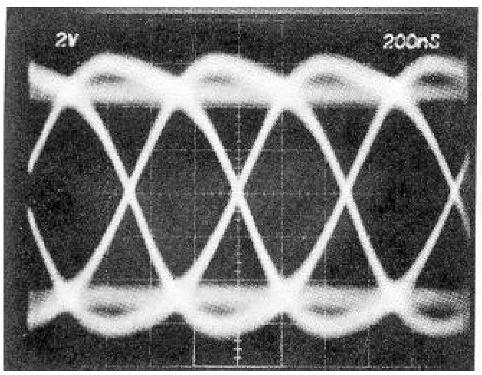
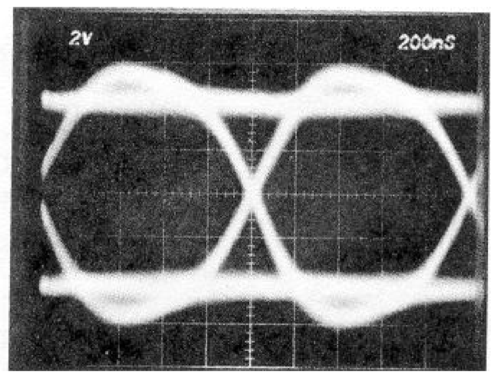


Fig. 1B (ENRZ)



Figures 1A and 1B show linear density of 16.7 kbpi of DM and ENRZ respectively. Note that the opening of the eye is essentially the same in amplitude (sensitive to dropouts) but not in distance between crossings (sensitive to jitter, flutter, etc.) where the ratio is 2:1 in favor of ENRZ.

Fig. 2A (DM)

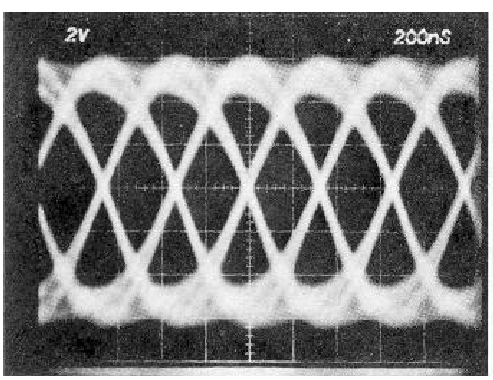
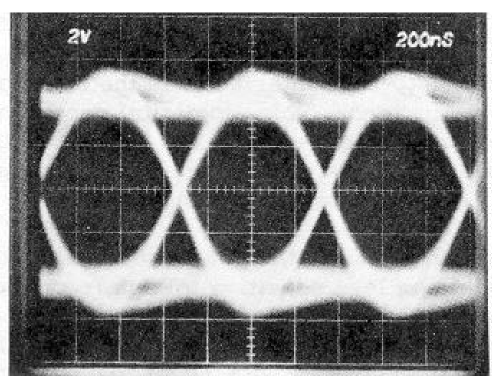


Fig. 2B (ENRZ)



Figures 2A and 2B show linear density of 24.75 kbpi of DM and ENRZ respectively. Of significane is the size of the eye pattern of the two codes as compared with 16.75 kbpi and in reference to each other with the ENRZ eye opening leading by more than 33%.

Fig. 3A (DM)

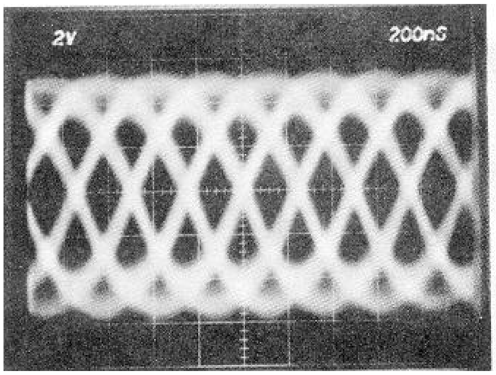
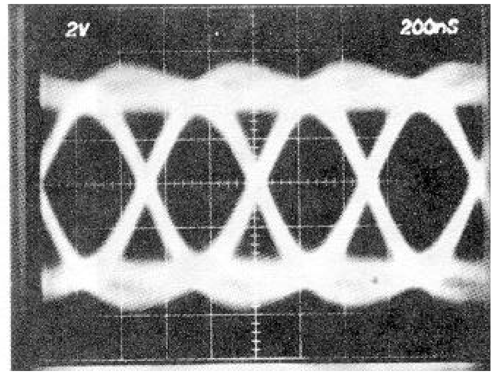


Fig. 3B (ENRZ)



Figures 3A and 3B show linear density of 33 kbpi. While there is consistent decrease in the “eye” opening, the ratio of ENRZ/DM opening increases to 3.6:2 or 1.8:1.

Fig. 4A (DM)

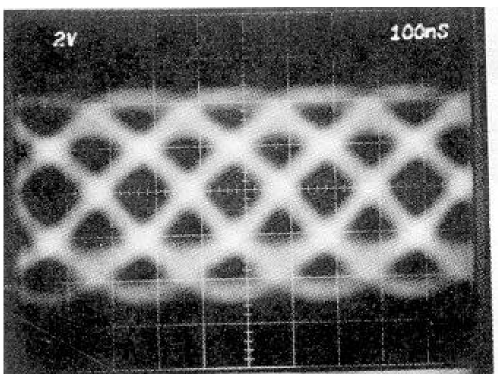
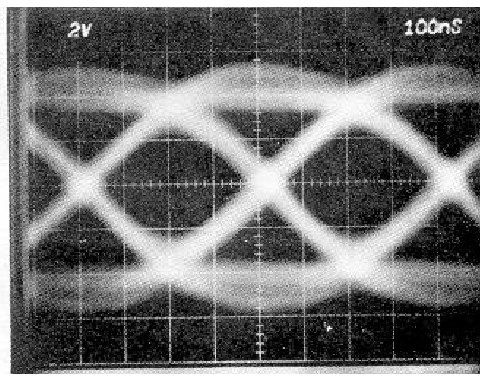


Fig. 4B (ENRZ)



Figures 4A and 4B show linear density of 40 kbpi. The ratio of the “eye” pattern is now almost 3:1 in favor of the ENRZ.

Fig. 5A (DM)

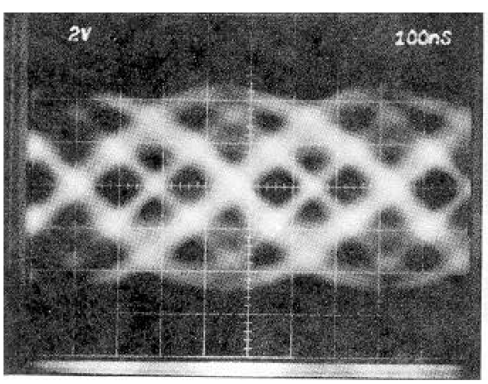
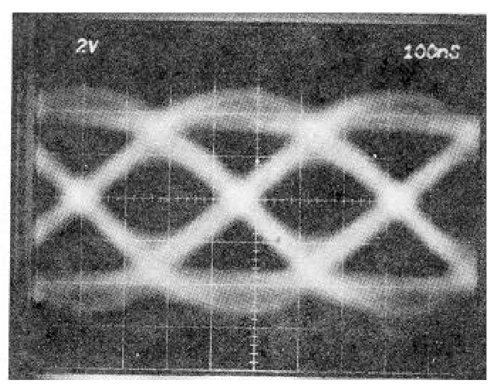


Fig. 5B (ENRZ)



Figures 5A and 5B show linear density of 45 kbpi. The ratio now between the two “eyes” is almost 4:1. While it was possible to obtain successful data with the ENRZ, the DM at this packing density was totally unusable.

Fig. 6 (DM)

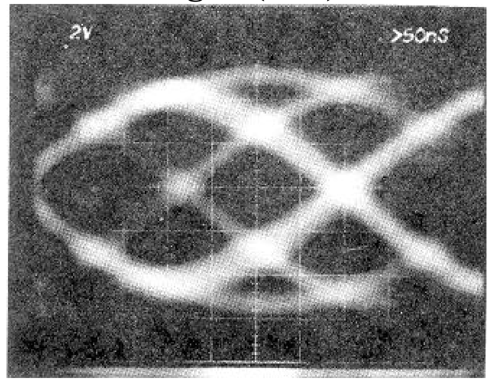


Figure 6 shows linear density of 30 kbpi using DM code. It is interesting to compare this picture with Figure 5B which shows 45 kbpi of the ENRZ. For ease of comparison the horizontal scale of the DM code was set @ 50 n_s/cm (nanoseconds per centimeter) With 50% increase in packing density, the "eye" pattern of the ENRZ @ 45 kbpi is as large as that of the DM with 30 kbpi linear density.

Finally, a test was run using 42-track per inch format recording 45 kbpi with standard tape and head. In this preliminary test a BER better than one part 10^5 was demonstrated with most, if not all, of the error traced down primarily to tape dropouts.

The above photographs show a consistent increased ratio of eye pattern with density between the two codes. Based on this ratio one can say with confidence that whatever the packing density achieved with DM an improvement of approximately 50% is possible using ENRZ code. For the same high linear density ENRZ code should provide approximately 50% margin over DM for handling errors due to jitter or dropout.

PHASE II: PUSHING THE LIMITS

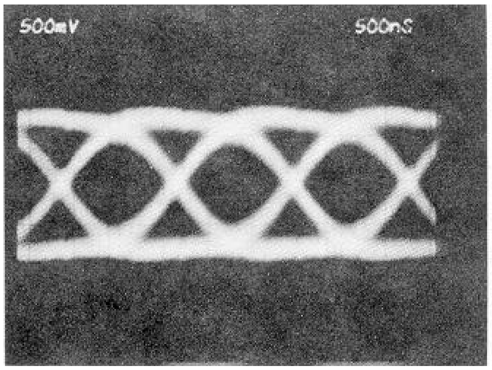
Having established in Phase I the feasibility of recording up to 45 kbpi using ENRZ code with standard tape and heads, it is only natural to investigate what further improvements could be realized by using high energy tape(1) and specially made double bandwidth(2) heads. A series of tests was scheduled in which the linear recording density was increased in steps starting from 50 kbpi.

(1) High energy tapes are commonly referred to magnetic tape with coercive force in excess of 400 oersted.

(2) Magnetic heads capable of recording and reproducing signals having wavelength in the order of 30 μ in are referred to as "double bandwidth" heads.

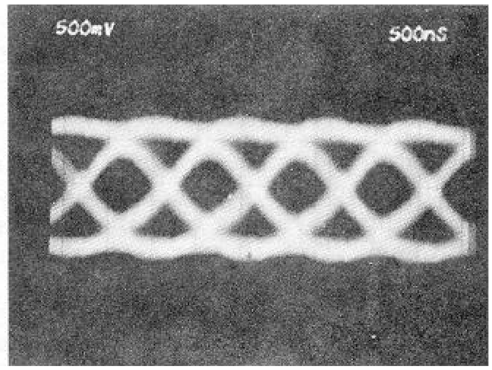
Because of the bandwidth limitations in the frequency domain, low tape speed (15 ips) was chosen for these tests. This approach allows the evaluation of the high recording packing density simply by shifting the reproduce equalizers one or two speeds down.

Fig. 1



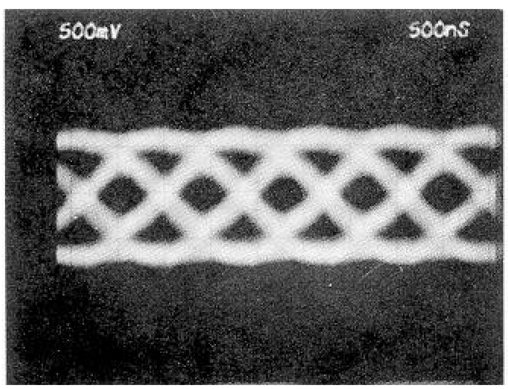
"Eye" pattern of 50 kbpi

Fig. 2



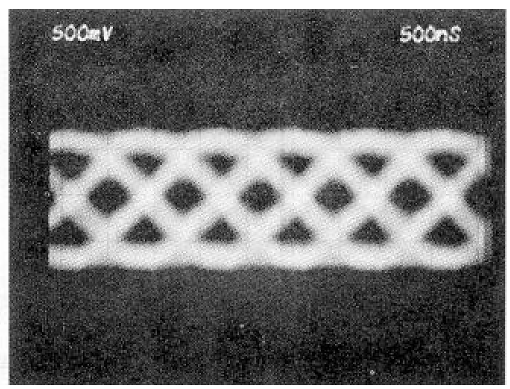
"Eye" pattern of 66 kbpi.

Fig. 3



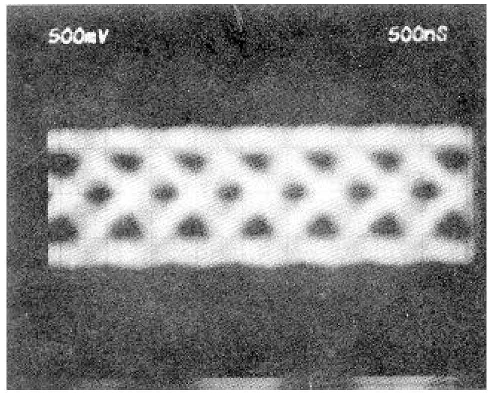
"Eye" pattern of 75 kbpi.

Fig. 4



"Eye pattern of 80 kbpi.

Fig. 5



"Eye" pattern of 90 kbpi.

As the linear density was increased the "eye pattern was getting smaller. Finally, at 90 kbpi the signal was unusable. Preliminary measurement of bit error rate of 85 kbpi shows the error to be 5 x 10^{6}.

CONCLUSION

A new horizon has finally opened in magnetic recording in terms of increased packing density. One can say with confidence that whatever the packing density achieved with DM an improvement in packing density of approximately 50% is possible with ENRZ. It is quite possible that with further improvement and optimization of electronics (head driver and reproduce equalizers), heads and tape, further improvements could be realized. It is the opening of the eye pattern both in amplitude and in time (zero crossings) of the ENRZ code which made it possible to demonstrate this increase in linear recording density. A study, which includes system performance such as over-all error rates vs. linear track density and crosstalk, is in order at this time.

APPENDIX I

Test Set-up

Tape Transport	B&H 3700B	S/N 6135
Tape Type:	3M 988	S/N 98188-15-10-04
Tape Speed:	60 ips	
Heads:	B&H 28 Track Format	
Record:	S/N Y75/Y30	
Reproduce:	7078	

Set-up was optimized for each linear packing density with no change in equalization between each individual test.

It is a pleasure to acknowledge the efforts of Messrs. D. Gish and W. Spencer in carrying out this study.