Real-Time Recording Results for a Trellis-Coded Partial Response (TCPR) System

Hemant K. Thapar
Advanced Magnetic Recording Laboratory, IBM AdStaR, San Jose, CA 95193

C. Bernard Shung
Department of Electronics Engineering, National Chiao Tung University, Hsinchu, Taiwan R.O.C.

James W. Rae
Advanced Magnetic Recording Laboratory, IBM AdStaR, Rochester, MN 55901

Razmik Karabed and Paul H. Siegel
Almaden Research Center, IBM Research Division, San Jose, CA 95120

Abstract— **This paper describes the results of an experimental performance comparison between a Trellis-Coded Partial Response (TCPR) system and a Partial Response Maximum Likelihood (PRML) channel, using magneto-resistive (MR) recording heads and metal film disks. Measured data confirms that the TCPR method provides substantial performance advantage in terms of ontrack error rate, offtrack capability, and areal density.**

I. INTRODUCTION

The Partial Response Maximum Likelihood (PRML) method has been used in a variety of disk drive and tape applications (see, for example [1]), as well as in the experimental demonstration of one gigabit per square inch areal density [2]. It has also been demonstrated to provide substantial performance advantages in terms of signal-to-noise ratio, offtrack performance, and areal density

The advantages of PRML may be further enhanced by coding methods that invoke additional structure in the equalized waveform beyond that due to Class 4 partial response signalling. The additional structure provides increased free Euclidean distance, which is a measure of the coding gain [4] as well as signal distinguishability in additive white Gaussian noise. We refer to this general approach as Trellis-Coded Partial Response (TCPR).

Hardware TCPR and PRML prototypes were built to experimentally compare the performance of the two detection methods. The PRML prototype was the same as used in the 1 Gb/sq. in. demonstration [2]. The TCPR system, based upon Matched Spectral Null (MSN) coding [4] with Class 4 partial response signaling, was the same as used previously to verify predicted performance advantages of TCPR relative to PRML in the presence of additive noise and synthesized interference [5], [6].

In this paper, we present the first real-time experimental results using actual magnetic recording components that demonstrate the performance advantages of TCPR over PRML.

II. EXPERIMENTAL RESULTS

The performance of the TCPR channel was compared with that of PRML using experimental magneto-resistive heads and metal film disk components. The TCPR channel used a rate 8/10 MSN code whereas the PRML channel used a rate 8/9 code. To factor out the code rate differences, all performance comparisons were conducted using the customer linear density as a reference. The customer data rate for both channels was set at 3 MB/s, thus requiring the PRML channel clock rate to be 27 MHz, and the TCPR clock rate to be 30 MHz. Unless otherwise noted, changes in linear density were accomplished by changing the rotational speed, thereby also affecting the flying height.

A. Ontrack Error Rate

One of the direct manifestations of the coding gain of TCPR is an improvement in ontrack error rate. The amount of improvement depends upon the operating point as well as the properties of the medium. Because of the higher free Euclidean distance, the TCPR method provides increased immunity to small ampli-

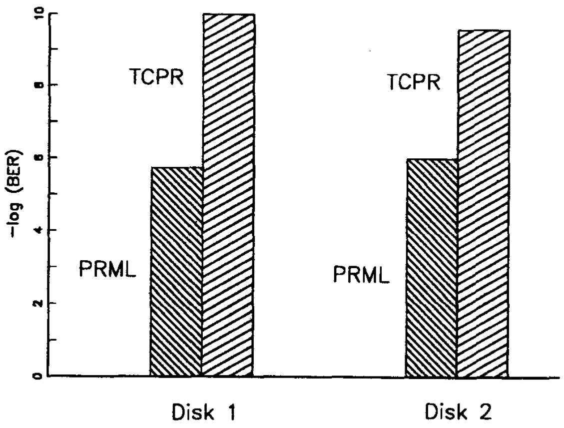

Figure 1: Measured ontrack error rate comparison

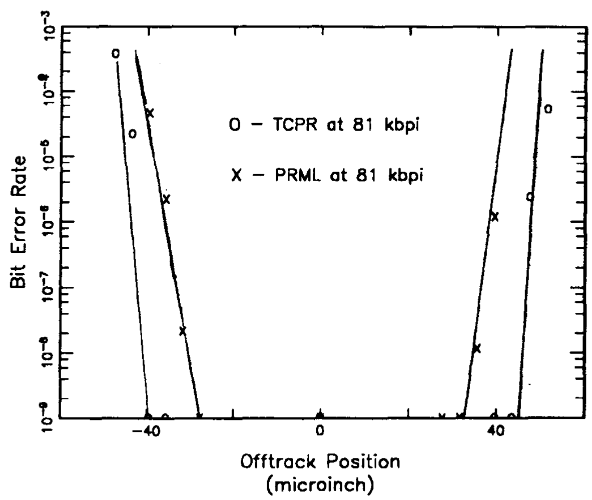

Figure 2: Measured offtrack performance comparison

tude drop-outs due to disk defects. Experimental results at relatively high linear density show that the TCPR channel reduces the ontrack error rate by at least 2 orders of magnitude. Fig. 1 shows a representative plot of the ontrack error rate for the PRML channel and the TCPR channel at 135 Kbpi for two disks with different defect densities. In both cases, the TCPR channel reduces the ontrack error rate in excess of 3 orders of magnitude.

B. Offtrack Performance

The coding gain of the TCPR method can be used towards increasing the offtrack capability. The amount of increase depends upon the head-disk combination and the operating point. Measured performance with experimental MR heads, ranging from 2-6 μm read width, showed that the TCPR channel can increase the offtrack capability by about 10-20% at a bit error rate of 10^{-6} relative to the PRML channel. Fig. 2 shows a representative plot of the offtrack advantage of TCPR for a given customer linear bit density of 81 Kbpi. At a bit error rate of 10^{-6}, TCPR provides approximately 20% increase in offtrack capability over PRML. Similar gains were measured at higher densities and with other head/disk combinations.

C. Areal Density

Instead of increasing offtrack capability and reducing ontrack error rate, the coding gain of the TCPR method may be used towards increasing the areal density. In order to assess the linear density advantage of TCPR, experiments were conducted wherein the flying height was kept constant and the linear density was varied by changing the data rate of the PRML channel. Fig. 3 shows a representative plot of the linear density gain provided by the TCPR channel for a given head-disk and flying height combination. The offtrack capability of TCPR was measured at 101.6 Kbpi. The data rate (and hence the associated linear density) for the PRML channel was reduced until the offtrack capability was comparable to that of TCPR. The net increase in linear density is in excess of 17%. Similar gains were achieved with other head-disk components.

In another experiment, the linear density was varied by changing the rotational speed of the disk while keeping the customer data rate of the two channels at 3 MB/s. Conventional squeeze tests were performed with a bit error rate criterion of 10^{-6}. Fig. 4 shows a plot of the offtrack capability versus track pitch for PRML at 122 Kbpi and TCPR at 145 Kbpi. Note that the offtrack capability of the two methods is comparable even though the linear density of TCPR is approximately 20% higher. Furthermore, the hump of the PRML curve is shifted to the right relative to that for TCPR, thus signifying a larger track pitch requirement or, equivalently, a lower track density capability for PRML.

The plot of Fig. 4 was obtained with components used to demonstrate 1 Gb/sq. in. [2]. Using the same criterion as in [2], the areal density achieved with the TCPR channel is approximately 1.3 Gb/sq. in., about 20% higher than that achieved with the PRML channel.

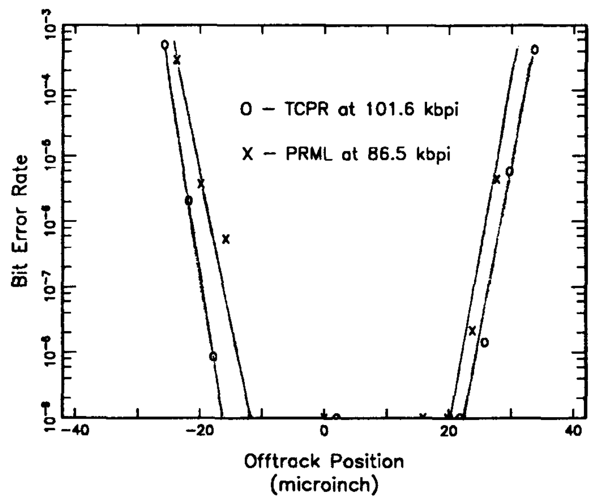

Figure 3: Measured linear density comparison

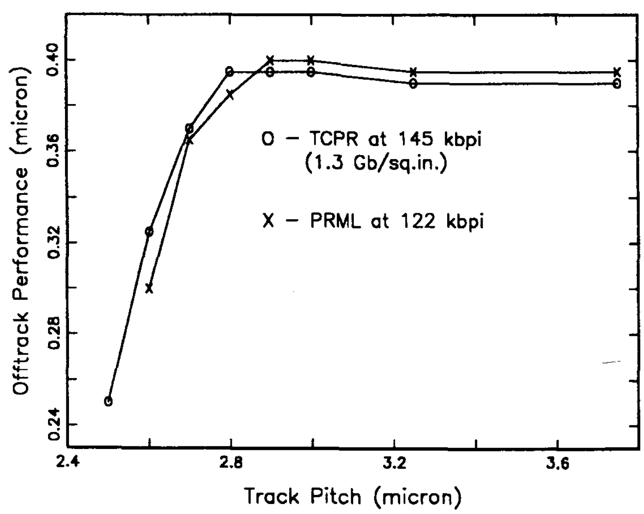

Figure 4: Measured "squeeze test" comparison

III. CONCLUSIONS

This paper has described the application and performance of a trellis-coded partial response channel for magnetic disk recording. The TCPR method uses coding in a broader role than PRML to enhance the performance of the detector. In side-by-side comparisons, we have experimentally shown that TCPR is an improved detection method over PRML. It substantially improves the commonly-used performance measures for digital magnetic recording systems, and thus provides a means to increasing the recording density or improving the performance in disk drive systems. The TCPR method requires additional hardware complexity in the encoder, detector, and decoder functions relative to the PRML method. However, as VLSI technology evolves, the incremental increase in complexity is likely to be offset by the potential benefits of TCPR, thus making it a viable recording method for magnetic disk systems.

REFERENCES

[1] R. Cideciyan, F. Dolivo, R. Hermann, W. Hirt, and W. Schott, "A PRML System for Digital Magnetic Recording," *IEEE Journal of Selected Areas in Communications.*, vol. 10, no. 1, pp. 38–56, January 1992.

[2] T. D. Howell, et. al., "Error rate performance of experimental gigabit per square inch recording components," *IEEE Trans. on Magnetics*, vol. 26, no. 5, pp. 2298–2304, September 1990.

[3] H. Thapar and T. Howell, "On the performance of partial response maximum likelihood and peak detection methods in digital magnetic recording," *Digests of the 1991 IEEE Magn. Rec. Conf.*, Hidden Valley, Pennsylvania, June 12–15, 1991, paper D1.

[4] R. Karabed and P. Siegel, "Matched-spectral-null codes for partial response channels," *IEEE Trans. Info. Th.*, vol. 37, no. 3, pt. II, pp. 818–855, May 1991.

[5] C. Shung, P. Siegel, H. Thapar, and R. Karabed, "A 30-MHz trellis codec chip for partial-response channels," *IEEE J. Solid-State Circuits, Special Issue on Analog and Signal Processing Circuits*, vol. 26, no. 12, pp. 1981–1987, December 1991.

[6] H. Thapar, J. Rae, C. Shung, R. Karabed, and P. Siegel, "On the performance of a rate 8/10 matched spectral null code for class-4 partial response," *IEEE Trans. Magn.*, vol. 28, no. 5, pp. 2883–2888, September 1992.