Extremely Efficient Dc-free RLL codes for Optical Recording

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Summary - *We report on runlength-limited codes (RLL) intended for the next generation of DVD, whose efficiency is extremely close to the theoretical maximum. As a result, significant density gains can be obtained with respect to prior art coding methods.*

Key words: optical recording, capacity, constrained code, runlength-limited, RLL sequence, (d, k) sequence.

1. INTRODUCTION

Runlength-limited (RLL) codes, generically designated as (d, k) RLL codes, have been widely and successfully applied in modern magnetic and optical recording systems [1]. The design of codes for optical recording is essentially the design of combined *dc-free* and *runlength limited* (DCRLL) codes. We will discuss the development of very efficient DCRLL codes, which can be used in upcoming generations of high-density optical recording products.

2. NEW RUNLENGTH-LIMITED CODES

With a new construction method,[2] we succeeded in designing very efficient RLL codes. Table 1 summarizes the new RLL codes. The efficiency, $\eta = R/C(d, k)$, where $C(d, k)$ denotes the capacity of the d, k-constrained channel, of the majority of the new codes is just a few tenths of a percent below capacity. During the presentation, details of the new codes will be presented. In the next section, it will be shown how to efficiently turn the RLL codes into DCRLL codes.

Table 1. Survey of newly developed codes.

m	n	d	k	states	$\eta = R/C(d, k)$
11	20	2	23	9	0.9975
7	13	2	11	9	0.9880
6	11	2	15	9	0.9915
9	13	1	14	13	0.9979
9	13	1	18	5	0.9973
11	16	1	10	13	0.9951

3. GUIDED SCRAMBLING

A promising method for adapting an RLL code is *Guided Scrambling (GS)*. In GS, each information word can be represented by a member of a selection set consisting of $L = 2^p$, $p \geq 1$, codewords. The encoder generates the selection set, and the "best" (according to a predefined penalty function) codeword in the selection set is selected for transmission. The penalty function weighs each element of the selection set according to its spectral and other properties such as maximum runlength and so on.

The RLL codes, listed in Table 1, will be employed in conjunction with GS for achieving four goals:

- spectral shaping;
- rejection of long runs of '0's: k constraint;

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- rejection of long transition runs of '01's (d=1) or '001's (d=2): MTR constraint;
- rejection of predefined sync(hronization) patterns, sync constraint.

The tandem of an RLL code in conjunction with GS is very flexible in trading the overall coding rate and various channel constraints. For example, the maximum runlength constraint, k, imposed by the GS penalty function can be made smaller than that of the inner RLL code.

3.1. Results and comparison with prior art methods

We will show results obtained with the rate 9/13, (1,14) RLL code. In the runlength penalty function, we set the maximum 'zero' runlength to $k = 10$, which means that the code essentially behaves as a $(d = 1, k = 10)$ code. Figure 1 shows $H(10^{-4})$ as a function of the overall rate R_o for $p = 5$ and $p = 8$. For $p = 5$ the implemented codes

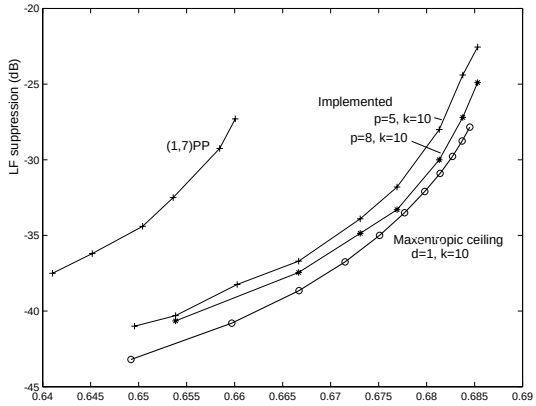

Figure 1. The two upper curves show the lf suppression, $H(10^{-4})$, as a function of the overall code rate R_o. The upper curve shows results for $p = 5$, and the lower curve for $p = 8$. The maximum imposed runlength for both cases is $k = 10$. As a comparison we plotted the theoretical ceiling, $H_{\min}(10^{-4})$, of maxentropic $(d = 1, k = 10)$ sequences.[1] The curve denoted by (1,7)PP gives results of a prior art code.[3]

are 2-3 dB, (for $p = 8$, 1-2 dB) below the theoretical ceiling. As a further comparison we plotted the performance of a prior art rate 2/3, (1,7) code,[4] which is extended with dc-control bits on data sequence level.

4. CONCLUSIONS

We have reported on RLL codes used in conjunction with Guided Scrambling (GS). With the newly developed rate 9/13, $d = 1$ code, we have achieved a 4.5% better overall rate than possible with the prior art (1,7)PP code, and with the new $d = 2$ codes we achieved a 9.3% higher overall rate than that of EFMPlus. The new DCRLL codes perform quite well in absolute terms as we have shown that only a few dB in spectral performance can be gained with respect to the best theoretical performance.

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