An Implementation of Limited Multi-Level Optical Recording

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Abstract:

Multi-level pits and lands are mastered in CD-resolution in a sub-channel on top of the original EFM-data, which remains unaffected. In addition, for retrieving these bits a slicer is realised which is optimised for maintaining a maximum capacity in the multi-level channel.

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1 Introduction

With most optical recording techniques, only two states are stored in the medium, being pits and lands. However, since the amplitude resolution of the detecting electronics can handle more levels in general, it might be interesting to study the feasibility of retrieving data from a multi-level optical disc [1].
Limited Multi-Level (LML) pits and lands are mastered and read out in CD format. The yielded extra capacity is optimised to approximately 24%. In addition, a slicer is proposed which can retrieve these bits without requiring a special DC-free LML-channel code. Therefore, the complete number of LML channel bits is available as user bits.

2 The LML sub-channel

We consider Limited Multi-Level (LML) recording for the CD-format. In LML-coding, multi-level modulation is reserved exclusively for the longer runlengths of an RLL encoded channel bitstream. A 2-level modulation for pits and lands is applied, accommodating a single LML-bit for each long runlength (LML-bit = 0 for non-modified amplitude, LML-bit = 1 for a reduced amplitude). The LML-channel is generated on top of the standard RLL channel, and its capacity is dependent on the occurrence of long runlengths in the RLL channel.
The minimum runlength that can be used in LML coding is determined by three conditions:

- the equalised waveform amplitude should reach the saturation level in the eye-pattern for the case of the non-modified runlength (in view of a single slicing mechanism for all LML runlengths involved);
- for the modified runlength (LML-bit = 1), the reduction in the amplitude of the centre part of the runlength should be large enough to create enough opening of the additional LML-eye, yet small enough in order to remain at respective distance from the standard slicer level of the main RLL channel;
- for the modified runlength (LML-bit = 1), the outer edges of the runlength should not move too much away from their nominal conditions, because otherwise this leads to an increase in jitter of the main RLL channel.

For the CD-format, the minimum runlength that satisfies the above conditions, is determined to be 5T (hence the word “limited”).

3 Mastering

Some LML discs were mastered at CD capacity without affecting the jitter in the original EFM signal. Reduced pits are created by instantaneously lowering the LBR current in the middle of a pit, reduced lands are realised by shortly switching the LBR current on in the middle of a land. For the shortest LML pit-runs (5T), a write strategy is applied in view of optimum jitter performance. Figure 1 shows a SEM picture of the disc surface with LML-effects in the 5T pits and lands.
As can be seen in Figure 2, the mastering is optimised for having a 30% reduction in the resulting equalised eye pattern. The resulting data to clock jitter measured on a CD-ROM disc with LML effects in both pits and lands of length 5T up to 11T is equal to 13.8 ns and 11.6 ns for the leading and trailing edge respectively (13.8 ns and 11.2 ns on the same disc on a bare EFM track as a reference).

4 A slicer for retrieving LML bits

The slicer circuitry can be separated into a sample selector circuitry and two slicer instances, one for the pit LML bits and one for the land LML bits. The sample selector circuitry supplies the proper slicer instance with the amplitude measure of a runlength when this runlength appears to have a valid LML length (5T or larger).
The LML-bit decisions are made based on these amplitude measures. There is no reason to apply (d, k) constraints or a DC-control to the LML channel data since the clock can be withdrawn from the EFM channel and no additional servo signals have to be retrieved. Therefore, loss of capacity can be minimised by creating a slicer which does not need a DC-free code as well.

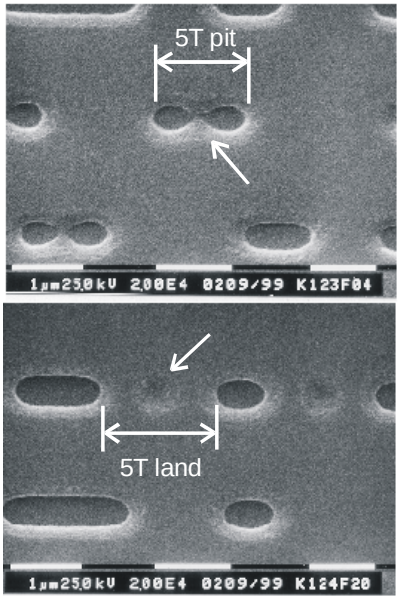

Figure 1: SEM Pictures of a disc surface with LML-effects inserted in the 5T pits (upper picture) and 5T lands (lower picture)

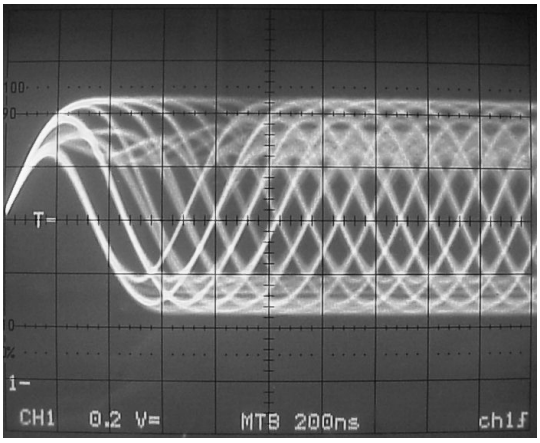

Figure 2: Eye-pattern of an LML-modulated track

Figure 3 shows the implementation of the used slicer. Based on the previously determined slicer level, the incoming samples are qualified as "high" or "low". From the collected high and low samples, the corresponding high and low levels are determined. This can be done by either a moving average or a registered average. The middle value between the high and low level gives the new slicer level. As a consequence, both levels must occur, not necessarily with the same probability. The channel code does not have to guarantee the existence of two levels in practical applications since at a higher level this condition will be met, for example by a scrambler. Only in some special cases, like heavy fingerprints or erasures, the assumed slicer level might not be the middle between high and low samples anymore. To anticipate to such cases an additional circuitry is added to search for the correct level after the level is lost.

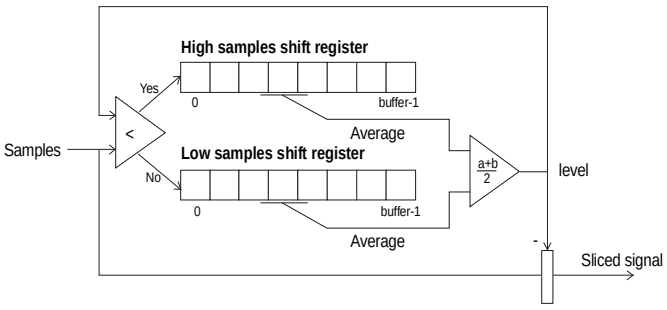

Figure 3: The slicer which does not need a DC-free constraint

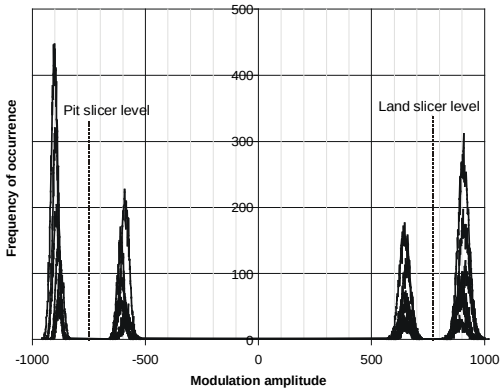

Figure 4: Measured amplitude distribution of the hf signal

The amplitude distribution for the various LML-runlengths (pit and land, reduced and normal amplitude) is shown in Figure 4. The well-defined separation between levels ensures correct slicing.

5 Conclusion

A complete system for mastering and retrieving a limited multi-level channel is developed based on the CD-ROM standard. A capacity increase of 24% can be obtained. Special attention is being paid to slicing the LML-pit and LML-land channels without the requirement of applying a DC-free coding technique.

6 References

[1] S. Spielman et.al., Using pit-depth modulation to increase capacity and data transfer rate in optical discs, Proceedings of the SPIE, Optical Data Storage Conference '97, Vol. 3109, p. 98-104