# BEYOND PRML: LINEAR-COMPLEXITY TURBO EQUALIZATION USING THE SOFT-FEEDBACK EQUALIZER

Elizabeth Chesnutt[1], Renato R. Lopes[2], and John R. Barry[1]
(1) Georgia Institute of Technology, Atlanta, GA, USA (2) University of Campinas, Campinas, Brazil

## Introduction

The combination of partial response and trellis-based maximum-likelihood sequence detection that dominates magnetic recording is known as PRML. The receiver front-end includes an analog filter whose role is to essentially shorten the impulse response of the underlying channel; this filter transforms the channel response into a target partial response that has very little memory, so that a trellis-based equalizer will have a manageable number of states. There are several drawbacks of the PRML approach that only grow worse as areal densities increase which includes penalties arising from noise enhancement and correlation in the noise. We propose an alternative equalization architecture for magnetic recording that addresses all of the shortcomings of the PRML approach. Specifically, we propose to abandon the PR strategy altogether; we abandon trellis-based equalizers in favor of simple equalization strategies based on nonlinear filters whose complexity grows only linearly in their length; and we propose an integration of the proposed structure into a turbo equalization framework.

## Linear-Complexity Equalization for Magnetic Recording

The main problem with the PRML approach is that it relies on a grossly sub-optimal PR equalizer at the front end, which ultimately undermines any performance gains that might arise from the trellis-based equalizer. In contrast, by leaving the channel in its natural form, we can avoid the noise enhancement and noise coloring penalties of the PR equalizer. To get around the complexity problem, we propose to use a non-trellis-based equalizer called the soft-feedback equalizer (SFE) that is easy to implement, even for very long impulse responses [1]. The SFE is a low-complexity alternative to the BCJR algorithm that is based on filtering and cancellation of residual ISI. One important difference between the SFE and previously reported interference cancellers [2] is that the SFE combines the equalizer outputs and *a priori* information to form more reliable estimates of the residual postcursor ISI.

When employing the SFE as a turbo equalizer in magnetic recording, there are some important points that can reduce the complexity further. In the first turbo equalization iteration, the SFE requires 3 inner iterations, each of which includes a $O(N^3)$ matrix inverse, where $N$ is the length of the feed-forward filter $\boldsymbol{f}$. With long filters, this overhead complexity can start to overtake the SFE's computational savings. However, with knowledge of the channel characteristics ahead of time, the feed-forward filter for the first turbo iteration can be found offline and the SFE's overhead is minimal at this stage. All other turbo iterations still require one matrix inverse in the SFE, but these can be substituted by a few steps of the conjugate gradient algorithm.

## Results

Experiments were performed to compare the differences in performance of the PR-equalized channel and the SFE system. The data is protected by a rate-8/9 (4095,3640) regular LDPC code, and it is decoded using message passing and turbo equalization. Fig. 1 plots complexity versus the SNR required to achieve BER=$10^{-5}$ at channel density 2.0. Each curve has five points, one for each of five iterations of the turbo equalizer. Here we see that the SFE has a gain of 2 dB over the EPR4-equalized channel without increasing complexity. In Fig. 2, each point represents the amount of SNR required at a given density to achieve BER=$10^{-5}$. At 14 dB, the SFE can operate on a channel with about a 0.5 higher density value than the EPR4-equalized channel while still providing the same BER performance, a significant increase in storage density.

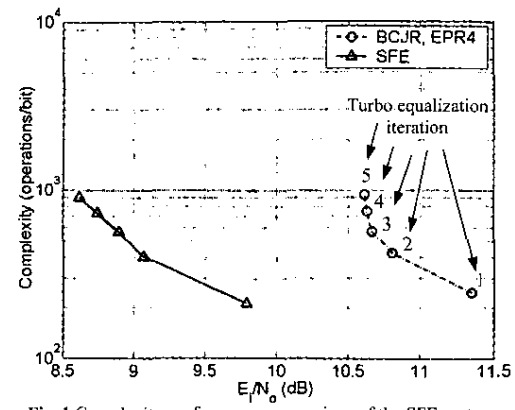


**Fig. 1** Complexity-performance comparison of the SFE system and the EPR4-equalized channel with colored noise and channel density 2.0 at BER=$10^{-5}$

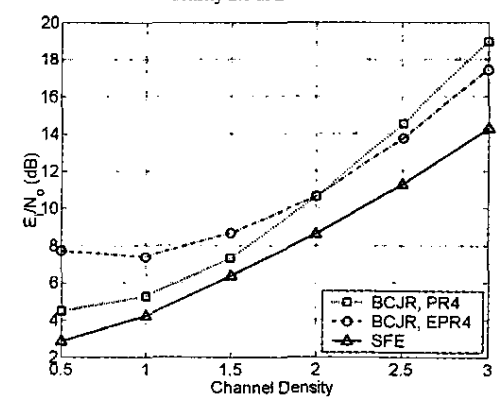


**Fig. 2** Comparison of the required SNR for BER=$10^{-5}$ for the SFE system and the PR-equalized channels with colored noise and varying channel densities with 5 turbo iterations

## Summary

This paper has proposed the use of a linear-complexity algorithm as a promising alternative to partial-response for magnetic recording. The SFE algorithm can provide up to 20% more capacity than EPR4-based detectors while maintaining low complexity costs.

[1] R.R. Lopes, J.R. Barry, "Soft-Output Decision-Feedback Equalization with a Priori Information," *GLOBECOM*, vol. 3, pp. 1705-1709, Dec. 2003.
[2] D. Raphaeli, A. Saguy, "Reduced Complexity APP for Turbo Equalization," *ICC*, vol. 3, pp. 1940-1943, April 2002.



0-7803-9009-1/05/$20.00 ©2005 IEEE