A Simplified FDTS/DF for Partial Erasure Channel

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I. Introduction

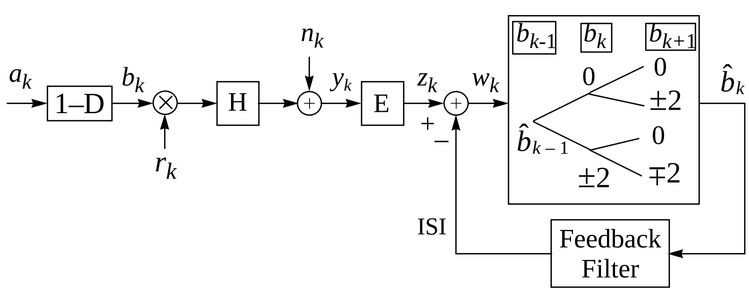
Partial erasure and transition shift are two major nonlinear distortions at high magnetic recording densities. Transition shift can be precompensated during the write process, but partial erasure causes an irreversible reduction in noise margin. Based on the fixed delay tree search with decision feedback (FDTS/DF) approach of [1], this digest transforms the metric computations in FDTS into a simple data-dependent threshold device to combat partial erasure. While retaining the exact performance of the FDTS/DF, the resulting detector requires no multiplications.

II. Partial Erasure Channel

The inductive readback process modulates a binary sequence $a_k \in \{1, -1\}$ into a ternary transition sequence $b_k \in \{-2, 0, 2\}$, where $b_k = a_k - a_{k-1}$. At high densities, the effective readback amplitude of b_k is partially erased if there are adjacent transitions. A simple and effective partial erasure model proposed in [1] introduces an erasure factor $\gamma \in (0, 1)$ to characterize the partial erasure phenomenon. In this model, only neighboring transitions can cause partial erasure effect so that b_k becomes $r_k b_k$, where $r_k = \gamma^{W(b_{k-1}, b_{k+1})}$ and $W(\cdot)$ represents Hamming weight.

III. Simplified FDTS/DF

At high densities where both linear ISI and partial erasure are severe, suboptimal detection algorithms such as FDTS/DF are of great interest [2]. Figure 1 illustrates the partial erasure channel and the FDTS/DF receiver of [1]. A transition b_k is first modulated by r_k before the linear ISI channel and additive noise. The filter E shapes the ISI channel into a causal channel so that its output is $z_k = r_k b_k + c_1 r_{k-1} b_{k-1} + \text{ ISI} + \bar{n}_k$. At time k, the FDTS/DF subtracts all ISI terms prior to $\hat{b}_{k-1}$ and calculates four branch metrics to select $\hat{b}_k$ of the smallest-metric branch. Due to the input constraint, each node branches out to only two states (e.g. if the most recent transition is –2, b_k can either be 0 or +2).



Noiseless w_k for branch i
$w_k^{(1)} = z_k^{(1)} - \text{ISI} = c_1 r_{k-1}^{(1)} \hat{b}_{k-1}$
$w_k^{(2)} = z_k^{(2)} - \text{ISI} = c_1 r_{k-1}^{(2)} \hat{b}_{k-1}$
$w_k^{(3)} = z_k^{(3)} - \text{ISI} = r_k^{(3)} b_k + c_1 r_{k-1}^{(3)} \hat{b}_{k-1}$
$w_k^{(4)} = z_k^{(4)} - \text{ISI} = r_k^{(4)} b_k + c_1 r_{k-1}^{(4)} \hat{b}_{k-1}$

(c_1 = linear ISI coefficient of $b_{k\text{-}1}$, $c_1 > 0$)

Figure 1: Partial erasure channel + FDTS/DF

Recognizing the fact that the detector only need decide whether b_k belongs to the top two branches (i.e. $b_k = 0$) or the bottom two branches (i.e. $b_k = 2$ or -2, depending on the most recent transition), instead of computing branch metrics, the proposed detector finds and utilizes a data dependent optimal decision boundary between the top two and the bottom two branches to classify b_k. As shown in Fig. 1,

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$w_k^{(1)} = w_k^{(2)}$ since the top two branches have the same $r_{k\text{-}1}$, i.e. they share common $\hat{b}_k$. Also, $r_k^{(4)} = \gamma\, r_k^{(3)}$ because $\hat{b}_{k+1} = 0$ for the 3rd branch while $\hat{b}_{k+1} \neq 0$ for the 4th branch. In addition, $\gamma r_{k-1}^{(1)} = r_{k-1}^{(3)} = r_{k-1}^{(4)}$ since the bottom two branches correspond to $\hat{b}_k \neq 0$.

Based on the above relations, subtracting all w_k values by $w_k^{(1)}$, i.e. $\tilde{w}_k^{(i)} = w_k^{(i)} - w_k^{(1)}$, gives: $\tilde{w}_k^{(1)} = \tilde{w}_k^{(2)} = 0$, $\tilde{w}_k^{(3)} = r_k^{(3)} b_k + c_1(\gamma - 1) r_{k-1}^{(1)} \hat{b}_{k-1}$, and $\tilde{w}_k^{(4)} = \gamma r_k^{(3)} b_k + c_1(\gamma - 1) r_{k-1}^{(1)} \hat{b}_{k-1}$. Because of the alternating input constraint, $\tilde{w}_k^{(4)}$ is always closer to 0 than is $\tilde{w}_k^{(3)}$. Hence the optimal decision boundary for classifying b_k is always at midway between $\tilde{w}_k^{(4)}$ and 0. In addition, an internal flag storing the most recent transition is incorporated into the threshold device to satisfy the NRZI input constraint and to limit the slicing operation to two values. For example, if the most recent transition is –2, then $\hat{b}_k$ should be either 0 or +2, and the optimal decision boundary is at $\frac{1}{2}[\gamma\, r_k^{(3)} 2 + c_1(\gamma - 1) r_{k-1}^{(1)} \hat{b}_{k-1}]$.

The data dependent threshold levels can be precomputed and stored in a table. There are six distinct threshold levels, half of which are negatives of the others. Therefore, the threshold look-up table consists of only three values and can be adapted easily for a time-varying channel. The resulting simplified FDTS/DF is illustrated in Figure 2.

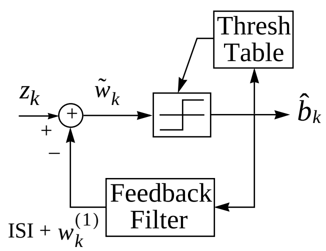

Figure 2: Simplified FDTS/DF

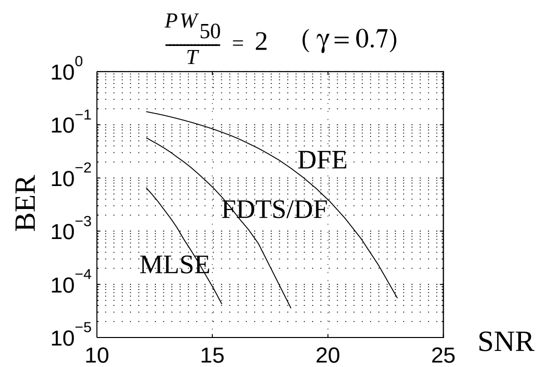

Figure 3: Simulation results of MLSE, FDTS/DF, and DFE

IV. Complexity and Conclusion

For a simple PR4 channel with partial erasure, with $z_k = r_k b_k + r_{k-1} b_{k-1} + \bar{n}_k$, a Viterbi receiver with nonlinear branch metrics requires 11 states, and a FDTS/DF requires at least two multiplications for each symbol. While retaining the same performance as FDTS/DF, its simplified version requires no multiplication but a small look-up table to store the precomputed data dependent thresholds.

For both the conventional FDTS/DF and the simplified version proposed here, the feedback filter can be replaced by a RAM look-up table to eliminate multiplications in the feedback. For a non-adaptive channel, a FDTS/DF requires 3 additions, 1 table look-up, 2 multiplications, and 1 comparison while the simplified FDTS/DF requires only 1 addition, 2 table look-ups, and 1 comparison. Also, the simplified FDTS/DF achieves a superior performance gain over a RAM DFE as shown in Figure 3, with only one additional table look-up.

V. References

[1] I. Lee, T. Yamauchi, and J. Cioffi, " Performance Comparison of Receivers in a Simple Partial Erasure Model," *IEEE Trans. Magn.*, vol MAG-30, pp. 1465-1469, July 1994.

[2] R. Wood, J. Kenney, and N. Sands, Tutorial on DFE for Magnetic Recording, *ICC 95*, Seattle, WA.