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Bi-Modal Flash Code using Index-less Indexed Flash Code and Layered Index-less Indexed Flash Code

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Abstract. Flash technology uses flash codes to efficiently manage the storage of data. Flash codes that have lower write deficiencies translate to better performance and leads to a longer lifespan of flash devices. One way to lower the write deficiency is to reduce the size of slices. This paper presents a flash code that extends the ILIFC and the LILIFC. By combining them into a bi-modal flash code, smaller slices can be used. The write deficiency is measured through numerical analysis as well as computer simulation. The flash code presented has an asymptotic worst case write deficiency of $O(k^2q + n/k)$ and produces an improved average write deficiency to ILIFC and LILIFC.

Keywords: block erasure, block write, flash code, flash memory

1 Introduction

Flash technology is now a ubiquitous technology. It is used in memory cards, flash drives and solid-state drives. As demand increases, so does the need for increased capacity and reliability. Flash technology as it stands today, however, has a limit because the cells used to store information have a limited number of erase cycles.

Flash technology consists of a many blocks of cells that store charges. A charge in a cell is increased through a process called electron injection. Flash memory, however, is write-asymmetric. This means that while increasing a cell charge is easily done, decreasing it is difficult. In fact, to erase a single cell or lower its level is not allowed. Only an entire block can be erased and rewritten [1]. In order to do so, a process called *block erasure is* employed. A block erasure removes all the charges in a block. This all-or-nothing approach is further exacerbated by the fact that block erasures are a strain on the cells, and continued erasures will eventually render the whole device unfit for use.

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Flash codes are used to efficiently manage the storage of data in a flash device. One way to measure the performance of a flash code is by determining its *write deficiency*, which refers to the gap between the theoretical maximum and actual bit writes. It is computed using the equation $\delta(F) = n(q - 1) - t$, where $n(q - 1)$ is the theoretical maximum number of write operations allowed for a block of n cells with q levels each, while t is the actual number of write operations that a flash code F is able to perform before calling a block erasure [2]. The lower the write deficiency value, the better is the performance of the flash code.

2 Related Literature

Two well-studied flash codes in literature are the Index-less Indexed Flash Code (ILIFC) [2] and the Layered Index-less Indexed Flash Code (LILIFC) [3]. Each of these two flash codes partitions a block of n cells into slices with k cells each, where k is the size of the bit information to be stored in the block. Both flash codes use an elegant scheme that enables both the bit index and the bit value to be easily inferred from the contents of a slice. The main difference is that LILFC uses a layer-based index coding, where a slice is filled up from left to right as opposed to ILIFC that fills up the level in one cell first before proceeding to the next cell.

Kaji proposed an improvement to the expected write deficiency of the ILIFC by introducing left-oriented and right-oriented slices [4]. This reduced the slice size to $k/2$ cells and decreased the likelihood of having unused cell levels when a block erasure occurs. Nagahara and Kaji were able to reduce the size of a slice further to k/p where p is an arbitrary chosen positive integer, with $p \leq k/3$ [5]. This was achieved by partitioning a block into p sub-blocks, and assigning k/p bits per sub-block, and an ILIFC-like code is also implemented.

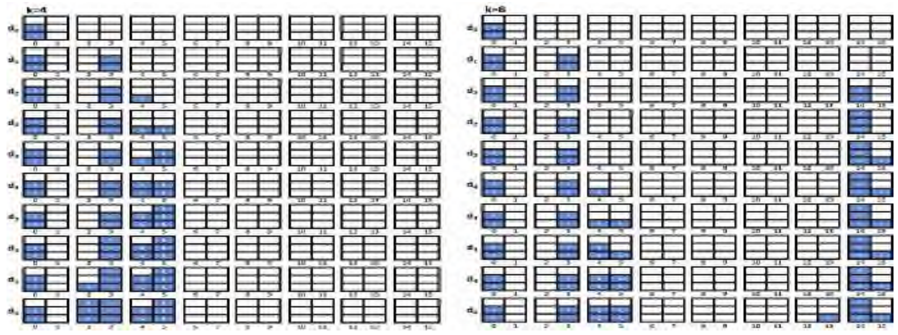
There are several other proposed flash codes in literature, including the Binary Index Flash Code (BIFC) [6], BIFC with Resizable Cluster Method (BIFC-RCM) [7], and Multi-mode Flash Code (MMFC) [8]. In this study, we focus on the ILIFC and LILIFC in order to come up with a scheme that takes advantage of the high similarity between these 2 flash codes, and develop a flash code with a lower average write deficiency.

3 Combining the ILIFC and Layered ILIFC

In this paper, we propose two flash codes, Bi-Modal Flash Code (BMFC) and Two-Split Bi-Modal Flash Code (BMFC2). Both flash codes combine the IL-IFC and the LILIFC in order to reduce the slice size and achieve better write deficiencies.

3.1 Bi-Modal Flash Code (BMFC)

In the Bi-Modal Flash Code, we partition the k data bits into 2 groups and apply a different coding scheme for each group. The first $_2$ bits, with indices 0 to $_2 - 1$, use an ILIFC-like scheme for encoding and decoding. The remaining bits, with indices$_2$ to k−1, use an LILIFC-like scheme. An active slice is accordingly referred to as *ILIFC-based* or *LILIFC-based* depending on the mode that the slice uses. Because there are just $_2$ bit indices to distinguish within a mode, the size of a slice is reduced to $_2$. The BMFC is clarified further with an illustration of a sample write sequence in Fig. 1a.



(a) Bi-Modal Flash Code (b) Two-Split Bi-Modal Flash Code

Fig. 1: BMFC and BMFC2 block state sequence

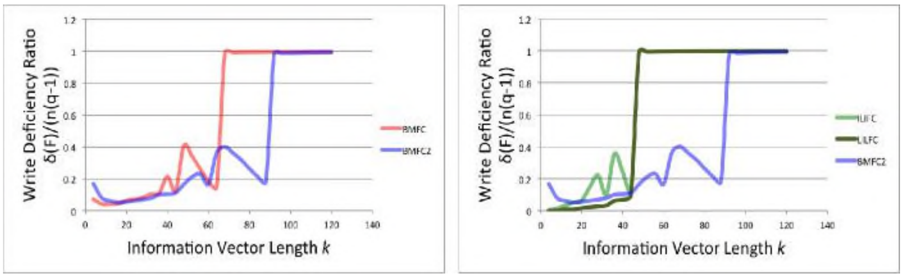
3.2 Two-Split Bi-Modal Flash Code (BMFC2)

The Two-Split Bi-Modal Flash Code (BMFC2), uses slices of size $_4$. It is an improvement of BMFC by treating a block as a two-sided storage that contains slices on the left and right ends, which grow towards the opposite ends whenever new slices are activated. The two modes are distributed among each side in order to differentiate the bit position; the two modes with the two sides allow up to four combinations. A sample write sequence for BMFC2 is shown in Fig. 1b.

4 Simulation Results

To estimate the average case write deficiencies, computer simulations on each of the flash codes were performed. The simulation used uniform distribution, where all data bits have an equal chance of being updated. The simulation results of BMFC and BMFC2 are shown in Fig. 2a. As shown in the graph, BMFC2 outperformed BMFC.

BMFC2 is then compared with ILIFC and LILIFC, and the simulation results are shown in Fig. 2b. For sufficiently small values of k, ILIFC and LILIFC performed better due to the overhead required by BMFC2 to differentiate its two modes. But for a significant majority of k values, the proposed flash code is superior.



(a) BFMC and BMFC2 (b) BMFC2, ILIFC and LILIFC

Fig. 2: Average Write Deficiency Ratios of BMFC, BMFC2, ILIFC and LILIFC in Uniform Frequency Distribution

5 Conclusion

In this paper, the BMFC and its simple variant BMFC2 used two modes of coding, ILIFC and LILIFC, to utilize slices of smaller length. Simulation has shown that the proposed codes, while underperforming at small k-bit sizes, have better average write deficiencies than both ILIFC and LILIFC at greater values of k. Further studies can be made to check the advantages of flash codes with arbitrarily smaller slices.

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