Application Note for Wear Leveling of Flash Memory

Introduction

All flash memory devices suffer wear as they are erased and reprogrammed. They all have finite erase/program cycle endurance limits. The actual number of usable erase/program cycles will vary from manufacturer to manufacturer, but they all have wear out mechanisms that will eventually render the device unreliable and unusable. When using flash memory in an application, it is important to evaluate how frequently information within the flash will be updated and make sure the application does not exceed the cycle endurance specified by the manufacturer.

The wear-out mechanism occurs at the cell level and not at the chip level. It is possible to exceed the endurance specification of cells within a single sector or block of memory while the rest of the chip remains intact and fully usable. This will occur if a single sector or block is repeatedly erased and reprogrammed while the remaining sectors or blocks are either unused or programmed with static (unchanging) data.

To prevent a single sector or small group of sectors from wearing out, techniques have been developed to evenly distribute the burden of repeated erase/program cycles over a larger set of sectors/blocks. The name given to these techniques is wear leveling and they greatly enhance and extend the apparent endurance of the flash memory.

If data within a flash device only needs to be updated once per day (or less), endurance is not an issue and wear leveling would not be required. Actually, it would be an unnecessary burden of code development and overhead. The typical flash cell endurance is ~100K cycles. Doing the math, we can see that updating a sector once per day would take 100K days (100K/365days/year = 274 years) to reach the endurance limit. If the endurance were only 10K, it still would take 27 years to exceed this limit.

However, if very frequent updates are required (once per hour or less), the designer should definitely consider implementing a wear leveling scheme to ensure that sector erase/program cycles are spread evenly throughout the device and that no one sector is forced to receive all of the wear.

The following will describe three different levels of wear leveling techniques. The actual algorithms used to implement them will not be described here, so the user is encouraged to develop their own.

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Wear Leveling Techniques

Level-1: Dynamic Within A Sector

If the user's application intentionally (or unintentionally due to a coding error) reuses the same sector over and over again, there is a high probability that the sector's endurance will be exceeded and it will fail. If the data to be updated is small (256 bytes or less) and needs to be updated frequently (minutes rather than hours or days), the Level-1 wear leveling can be implemented by an application to reduce the number of erase/program cycles seen by the sector holding the data. Dedicating an entire sector to the small data set needing frequent updates does this. The location of the data set within the sector changes after each update and the sector is only erased after all empty locations within the sector have been used.

The Level-1 example described here uses a single 4KByte sector dedicated for the storage a 256-byte data set. The sector will be logically sub-divided into 16 sub-sectors (256-byte pages). The first page is overhead used for keeping track of active pages, but the remaining 15 pages are available for storing data. When the data set needs to be updated, the current currently active page will be marked obsolete and the next available empty or blank page within the sector will be used. Only after the last remaining page is marked obsolete will the sector need to be erased and recycled. This will reduce the program/erase wear on the sector by a factor of 15 because the sector will only need to be erased after the data set has used all 15 pages. This is a relatively simple wear-leveling algorithm to implement.

Level-2: Dynamic Using Multiple Sectors

If the data to be frequently updated is large (a sector or more), a large pool of free sectors should be reserved for this data. As new data needs to be written, blank sectors in the pool with the lowest number of cycles will be used. Sectors holding obsolete data will be erased and returned to the pool. This will allow the program/erase wear cycles to be spread over a number of sectors and not wear out a small set of sectors. A scheme must be employed to keep track of individual sector erase/program cycles and which sectors are currently active and which ones remain in the free sector pool. A scheme of sector mapping must also be employed to map logical sectors to physical sectors. The application should always reference sectors by their logical assignments and not their physical numbers. By doing this, the wear leveling activity will always remain transparent to the upper level application.

Level-3: Static Using All Sectors

This level uses the most extreme method of wear leveling available. It considers all sectors as potential members of the free sector pool—including those holding static data or code that never needs to be updated. As sectors holding dynamic data begin to approach or exceed a certain erase/program cycle threshold, sectors holding static data are examined to see of their sectors have lower erase/program cycles. Those static data sectors found to have lower cycle counts will have their data moved to sectors with higher cycle counts. The previous static data sector will be erased and added to the free sector pool once its data has been moved and verified successfully. This method, although extreme, guarantees that all sectors share the burden of frequently erase/program cycles and provides the maximum usable life for the device.

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Summary:

The concepts of three levels of wear leveling have been presented here. The user is encouraged to develop their own algorithms to implement the level of wear leveling they deem necessary to avoid flash endurance failures in their application.

While Level-1 is the easiest to implement, if the erase/program cycle burden on a single sector becomes too great (very frequent updates), Levels-1 & 2 can be combined. After the affected sector in the Level-1 approach is erased, the Level-2 algorithm can be used to return this sector to the free sector pool and assign a new sector to receive new data. And if the Level-1 & 2 combination is still not sufficient to cover the expected wear on the device, Level-1 & 3 can be combined so that the frequently updated data is spread evenly across all sectors.

There are overhead and design considerations to be considered when choosing either Level-2 or Level-3. While Level-2 & 3 must both keep track of logical versus physical sector mapping and sector cycle counts, Level-3 has the additional overhead of moving static data from sector-to-sector, verifying that the data remains intact after the move, and re-mapping the sectors holding the static data. This overhead can be performed as a background operation, but it may slow down foreground operations from time to time. Additionally, developing code to implement a Level-3 design is much more complex than a Level-2 design, so it should only be considered wear extreme wear leveling is required.

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MACRONIX INTERNATIONAL CO., LTD.

Macronix Offices : Taiwan
Headquarters, FAB2
Macronix, International Co., Ltd.
16, Li-Hsin Road, Science Park, Hsinchu,
Taiwan, R.O.C.
Tel: +886-3-5786688
Fax: +886-3-5632888

Taipei Office
Macronix, International Co., Ltd.
19F, 4, Min-Chuan E. Road, Sec. 3, Taipei,
Taiwan, R.O.C.
Tel: +886-2-2509-3300
Fax: +886-2-2509-2200

Macronix Offices : China
Macronix (Hong Kong) Co., Limited.
702-703, 7/F, Building 9, Hong Kong Science Park,
5 Science Park West Avenue, Sha Tin,
N.T.
Tel: +86-852-2607-4289
Fax: +86-852-2607-4229

Macronix (Hong Kong) Co., Limited,
SuZhou Office
No.5, XingHai Rd, SuZhou Industrial Park,
SuZhou China 215021
Tel: +86-512-62580888 Ext: 3300
Fax: +86-512-62586799

Macronix (Hong Kong) Co., Limited,
Shenzhen Office
Room 1401 & 1404, Blcok A, TianAN Hi-Tech PLAZA Tower,
Che Gong Miao, FutianDistrict, Shenzhen PRC 518040
Tel: +86-755-83433579
Fax: +86-755-83438078

Macronix Offices : Japan
Macronix Asia Limited.
NKF Bldg. 5F, 1-2 Higashida-cho,
Kawasaki-ku Kawasaki-shi,
Kanagawa Pref. 210-0005, Japan
Tel: +81-44-246-9100
Fax: +81-44-246-9105

Macronix Offices : Korea
Macronix Asia Limited.
#906, 9F, Kangnam Bldg., 1321-4, Seocho-Dong, Seocho-Ku,
135-070, Seoul, Korea
Tel: +82-02-588-6887
Fax: +82-02-588-6828

Macronix Offices : Singapore
Macronix Pte. Ltd.
1 Marine Parade Central, #11-03 Parkway Centre,
Singapore 449408
Tel: +65-6346-5505
Fax: +65-6348-8096

Macronix Offices : Europe
Macronix Europe N.V.
Koningin Astridlaan 59, Bus 1 1780
Wemmel Belgium
Tel: +32-2-456-8020
Fax: +32-2-456-8021

Macronix Offices : USA
Macronix America, Inc.
680 North McCarthy Blvd. Milpitas, CA 95035,
U.S.A.
Tel: +1-408-262-8887
Fax: +1-408-262-8810

http : //www.macronix.com