Handling Bit Errors In Flash Memory

National Semiconductor
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INTRODUCTION

In the past, use of nonvolatile memory devices (EPROM, Flash) was predominantly confined to storing code for the microprocessor or micrcontroller (Code Storage). Now, advances in nonvolatile memory device density and design are opening up new applications where the memory is used to store data gathered by the system. National Semiconductor has focused its Flash memory offerings on these ''File Storage'' applications. In these applications the function of the memory is identical to that of the function the hard disk drive plays within the PC.

Similiar to the hard disk, National's Flash products may include regions of the memory array that are non-functional. Although working with these regions adds complexity to the system, it is overcome by the greater benefit of a lower cost.

This application note will describe the causes of these non-functional regions and how system software should work with these regions. Although this application note will concentrate on National's Serial Flash family (NM29A040/080), the majority of the concepts also apply to National's standard NAND Flash family (NM29N16/32).

BIT ERRORS

The non-functional regions in Serial Flash can be attributed to four different types of failures in the memory array. These are single bit errors, row failures, stack failures and block failures. These failure modes are shown in *Figure 1.* There is a fifth type of failure, column failures, but these are screened out at the factory so the customer will not have to deal with these.

Single or random bit failures occur due to a cell which does not program or erase properly. This cell or bit will be stuck in either the ''1'' or ''0'' state.

Row failures cause an entire chain of eight successive (by address) pages to fail. Since a page consists of 32 bytes each, 2048 bytes become non-functional. In these situations the pages will not be able to be programmed or erased correctly.

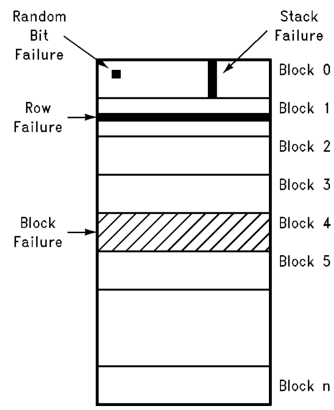

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FIGURE 1. Types of Bit Error

Stack failures are also a chain of bits that fail. This chain includes 16 bits running along a single bit line from the top of a block to the bottom. These bit errors will be located at page addresses which are multiples of 8. For example if pages 2, 10, 18, . . . 122 of block *n* all exhibit incorrect program or erase operations then this would constitute a stack failure. Further investigation can determine which specific bits are failing.

Block failures cause the entire block (128 pages or 4096 bytes) to become inoperable. These are usually due to a failure in the control logic for that block, not the array itself. Since each block is individually isolated, a failure in one block will not effect adjacent blocks.

BIT ERROR SPECIFICATION

National's Serial Flash and standard NAND Flash are specified with a maximum number of bit errors. For Serial Flash, bit errors may be specified as unusable pages or blocks. The specification calls for no more than 10 unusable blocks in a 4 Mb device (NM29A040) and 20 unusable blocks in an 8 Mb device (NM29A080). The blocks may be located anywhere within the memory array except Block 127.

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Serial Flash may also be specified by unusable pages. The advantage of going to a unusable page specification is that the memory array may be used more efficiently. For instance, with the page specification if one bit error occurs, only 32 additional bytes are disgarded. With the block specification, one bit error will cause 4KB to be disgarded. The advantage of the page specification is the higher utilization of the array at the expense of larger software to deal with the more numerous number of unusable pages. The advantage of the block specification is simpler system software but at the expense of a lower utilization of the array. The block specification also will tend to reflect a higher device ($/Mb) cost as the specification is more restrictive. Consult National Semiconductor if a system is to be designed with unusable pages.

In standard NAND Flash, bit errors are specified in unusable blocks. The specification calls for no more than 10 unusable blocks in the 16 Mb, NM29N16 device.

TABLE I. Bit Error Specification

	Part Number	Maximum Allowable	Units
Serial Flash	NM29A040	10	Blocks
	NM29A080	20	
Standard NAND Flash	NM29N16	10	
	NM29N32	TBD	

LOCATING BIT ERRORS

Bit errors locations are programmed into each memory device when they leave the factory. This is identical to a formatted hard disk drive where all bad sectors are automatically mapped out and not used by the system (HDD controller).

Serial Flash and standard NAND Flash uses similar but slightly different methods to describe the location of unusable blocks. In the Serial Flash, Block 127 is set aside as a permanent location to map the unusable blocks. This is achieved by making Block 127 a write once block. Certain locations within Block 127 are programmed at the factory with the location of the unusable blocks. This information can not be lost as Block 127 is not erasable. If a block were found to become unusable over the life of the system, this information may be added (programmed in) to Block 127. System software should refer to the unusable block map to insure that no attempt is made to write data into these locations.

The format of the unusable block map in Block 127 incorporates a direct relation between the block number and the page address in Block 127. All blocks leave the factory in the erased state. If on initial power up, data were read out of a page, the data would read ''FFH''. Block 127 also leaves the factory in an erased state except for pages corresponding to unusable blocks. Each page corresponds directly to an associated block by address. For example, page 0 in Block 127 corresponds to the block at address ''00H'' in the array. If this were an unusable block, then some portions of the page will be programmed. If all the bytes of page 0 of Block 127 are read out and some bytes are found to not equal ''FFH'', then Block 0 is an unusable block. If all the bytes read out ''FFH'', then this is a usable block. *Figure 2* shows this mapping scheme.

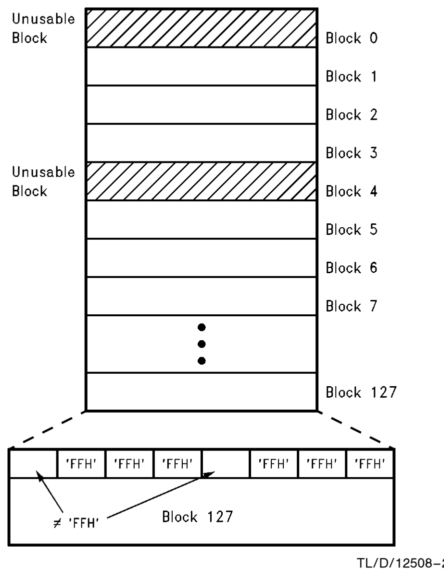

FIGURE 2. Serial Flash Unusable Block Scheme

National's standard NAND Flash also leaves the factory with the locations of the usable blocks preprogrammed in each device. Upon initial power-up, the system should read through all pages of all the blocks. All usable blocks leave the factory in the erased state, ready to be programmed. Reading these blocks will read out "FFH" for all bytes within all the pages. Unusable blocks will have some location within the block programmed with data other than "FFH". On recognizing one of these unusable blocks the system should map this block's address into an unusable block table. System software should then refer back to this table to prevent writing to these blocks.

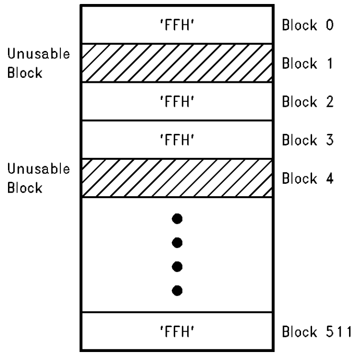

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FIGURE 3. Standard NAND Flash Block Map

WORKING AROUND BIT ERRORS

System software should make sure that data is not written to unusable blocks. Part of any filing system will include a routine which manages all write operations to the memory. An important portion of that routine should determine where to write the latest data. This may be handled a number of different ways depending on the needs of the system. One method is to use a table which may distinguish between regions which already have data, unusable regions and free space. This table is sometimes referred to as the directory. It serves the same purpose as the File Allocation Table (FAT) found in hard disk drives. Another method may set a flag in each block to distinguish if the block is free or not. With this information the system may then find the next available region into which the data should be written. Once the data has been written to the next region, the success of the write operation should be verified by using the verify commands.

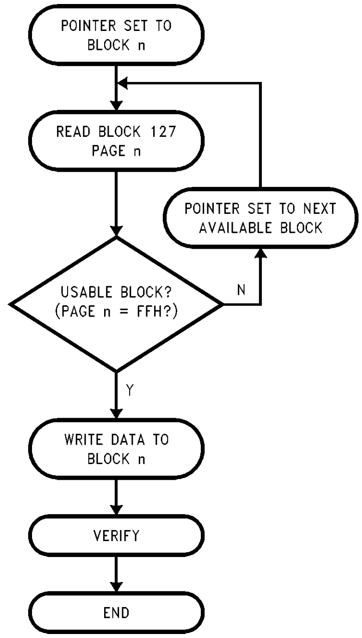

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FIGURE 4. Working Around Unusable Blocks

CONCLUSION

National's new line of Flash memories have been designed specifically for File Storage applications. In order to achieve the best price performance for these applications, these Flash memories allow certain regions of the memory array to be unusable. This is similiar to the unusable sectors in a hard disk drive. By shipping in each memory device the information pertaining to the location of these unusable regions, National has effectively formatted each Flash memory. This gives customers a simpler design-in process and allows them to get their product to market faster.

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