M-Systems
Flash Disk Pioneers

MobileDiskOnChip

Embedded Flash Drives: Standardizing NAND Flash for Use in Mobile Handsets

White Paper

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INTRODUCTION

This white paper traces the evolution of NAND flash-based products from 2001, when they were first introduced to the mobile handset market, to date. It discusses the challenges that hardware and software designers face to make NAND flash usable in handsets, the contributions of the embedded flash drive (EFD) solution to overcome these challenges, and new challenges faced by EFDs to meet the growing storage requirements of multimedia-centric mobile handsets.

FLASH TECHNOLOGY TRENDS

The convergence of voice-centric mobile handsets into multimedia-enabled handsets has had a direct and profound impact on the memory industry. Flash vendors are required to constantly provide higher densities and better performance at lower costs and in smaller packages.

From NOR to NAND

A major ongoing trend, which began in 2001 to meet these seemingly contradictory requirements, was the shift from NOR to NAND flash technology in mid and high-end handsets. Although use of NOR memory continues to be widespread in low-end handsets where high-capacity memory is not required, the number and proportion of NAND-based handsets has grown exponentially over the past two years. The deployment of 3G smartphones and high-end multimedia phones, requiring both high-capacity embedded memory and high performance, has in large part been responsible for this shift from NOR to NAND. In fact, statistics show that for the first time in Q1 2005, only three years after NAND flash was first introduced to mobile handset manufacturers in what was until then an exclusively NOR flash holding, NAND flash revenues exceeded those of NOR flash (Semico, May 2005). This dramatic success was the result both of increased memory card sales in growing capacities, and a massive penetration of NAND as an embedded nonvolatile memory (NVM) solution into a traditional NOR stronghold.

The Evolution of NAND

To accommodate the growing demand for more embedded storage and higher performance at lower costs and in smaller packages, NAND technology is constantly being improved. NAND flash is evolving more quickly than the rate established by Moore’s law, doubling in capacity every 12 months rather than every 18 months. This is being achieved both by a smaller, more precise manufacturing process (down from 130nm in 2003 to 90-70nm in 2005) and by altered physical characteristics; for instance, the page size has jumped from 512 Bytes to 2KB and the block size from 32KB to 128KB. In addition to enabling the support of higher capacities, the increase in page and block sizes also enhances performance, required to provide acceptable response rates to store more data efficiently.

A major leap forward in NAND flash technology was made with the introduction of MLC NAND flash in 2003. By storing 2 bits per cell as opposed to the standard 1 bit per cell with single level cell (SLC) NAND, MLC NAND increases capacity in a given die by up to 80%. Because of this, MLC NAND offers a superior cost structure, but this comes with a penalty: its performance and reliability are lower than SLC NAND. Despite this, the performance of MLC NAND remains both significantly superior to NOR and in excess of multimedia handset requirements.

EMBEDDED FLASH DRIVES (EFDS)

The first successful implementation of NAND flash in the mobile handset market was enabled by an EFD introduced by M-Systems (also sold by Toshiba). EFDs integrate the flash media along with a flash controller on the same chip, and sometimes even on the same die. Such an architecture isolates issues related to flash management from chipset integration.

Making NAND Usable in Handsets

The EFD architecture was originally introduced to overcome problems with the NAND flash media (widely known as "raw NAND") that had made it unusable in mobile handsets:

- NAND flash is more prone to errors than NOR flash, due to inherent manufacturing-related characteristics such as bad blocks and a higher bit-flipping tendency than NOR flash.
- NAND flash uses a different and more complicated processor interface than NOR flash, one with which designers were not familiar and required more integration efforts, potentially negatively impacting on time-to-market schedules.

Today, all existing NAND flash manufacturers offer EFD solutions, testifying to their acceptance and success in the multimedia-centric handset market to meet the data storage requirements of an ever-widening range of complex applications. Among such EFD solutions are Renesas' SuperAND and Samsung's OneNAND. Newcomers to the flash industry are also allegedly planning to introduce their own EFD solutions during 2006.

Enabling the Latest NAND Technologies

The changes in flash structure and technology are too rapid and frequent for chipsets to keep pace with. For instance, smartphone chipsets began supporting small block SLC NAND flash at the end of 2003. Earlier that year, both large block SLC and MLC NAND had already been introduced. Large block NAND will finally be supported by a few chipsets only by the end of 2005, while MLC NAND is not expected to have chipset support until the end of 2006. Despite NAND's overwhelming acceptance in the handset market, to date lower-end chipsets targeting feature phones do not offer any NAND support.

The EFD architecture enables any existing chipset to access new generations of flash products as they are introduced to the market. For example, M-Systems' new generation of DiskOnChip flash disks implements the latest MLC NAND flash technology from Toshiba, and offers a standard NOR interface, supported by all mobile chipsets.

This directly affects the memory cost structure of handsets. Designers using chipsets that include support for NAND are unable to use a commodity device, but rather must make do with a limited selection of older generation flash devices. These tend to be slower, less cost-effective and with lower capacities. Designers of feature phones, the majority of which use chipsets that have no NAND support, must make do with NOR. Those few chipsets that do offer raw NAND support must use software solutions that downgrade system performance.

Minimizing Project Risks and Time-to-Market

One of the toughest challenges for handset manufacturers is meeting time-to-market schedules. Fierce competition forces them to continuously narrow design cycles, while at the same time design complexity increases with the introduction of new applications, multimedia features and the integration of full-scale open operating systems (OSs). Delaying the introduction of a phone by as little as one or two months may result in project cancellation or lost market share.

As opposed to raw NAND, EFDs maintain a stable hardware and software interface and offer backward compatibility when a new generation is introduced with higher capacities. Usually, the same ballout, boot mechanism, software driver, and development and programming tools can be used with minimum integration efforts and project risks.

EFDs enable support of the latest advances in NAND technology – unlike chipsets and NAND software provided by OSs - while maintaining a standard NOR interface and using the same software API. This combination of “new” and “legacy” allows developers to shorten time-to-market while maintaining their cutting-edge relevancy and value add.

Improving Specifications and Feature Set

EFDs provide much more than just a standard and consistent interface for the latest flash technology. They frequently improve upon the basic specifications and offer a wider range of features than raw NAND. For instance, the power consumption of EFDs is much lower than that of the NAND media on which they are based, most significantly in standby mode. EFDs also provide major improvements over the performance offered by raw NAND flash media. To do so, they include additional page puffers, access the flash in interleaved mode, and offer DMA and burst read support. MLC NAND, for instance, though extremely cost-effective, is some four times slower than standard SLC NAND. However, M-Systems’ MLC NAND-based DiskOnChip offers performance that is nearly equivalent to that of SLC NAND, thanks to its parallel multi-plane flash design and optimized software support (compared with slower, generic NAND software support).

Most EFDs include security features to protect the content of the flash media against a growing range of intentional tampering and accidental deletion. Raw NAND generally does not. M-Systems’ DiskOnChip, for instance, includes the most comprehensive range of protection and security-enabling options with unique ID, configurable One Time Programming (OTP) areas, up to six hardware-protected partitions that users can define by size, location, and protection type (read/write), and passwords that can only be used once until the next boot, ideal for protecting OS partitions.

CONCLUSION

As the mobile market continues to offer more and increasingly sophisticated multimedia applications, the need for memory for end-users, applications and operators is exponentially increasing, justifying the move from NOR-based handsets to NAND-based handsets.

To maintain or increase their market share in a very competitive market, handset manufacturers favor complete memory solutions rather than components, which require heavier integration efforts and higher design costs.

These two considerations contributed to the emergence of the EFD category. As handset manufacturers continue to attempt to reduce their design efforts and move to platforms capable of supporting several existing handset models and also serve as the basis for new-generation handsets, the importance of EFD solutions will grow.

M-Systems' DiskOnChip, the first EFD solution introduced to the mobile handset market in 2001, offers all the components required for success: a low-cost structure (it is the only MLC NAND-based solution currently available), ease of design, a wide range of high capacities with the same design, high maturity, low power consumption and data protection and security features. Additional flash vendors have introduced their own EFD solutions, including Renesas' SuperAND in 2003 and Samsung's OneNAND in 2004.

Today, as NAND gains industry acceptance as the best technology for high-capacity data storage, its interface has begun to be supported by application processors. However, the advantages of EFDs discussed in this paper continue to give them considerable added value over raw NAND.

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