M-Systems
Flash Disk Pioneers

MobileDiskOnChip

Meeting Multimedia Requirements for Memory in Mobile Handsets

White Paper

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SCOPE

This white paper presents a brief review of the 3G network and the opportunities it presents to enable multimedia applications on mobile handsets. It discusses the handset architecture and memory system that is required to turn these opportunities into successful, multimedia implementations. It focuses on popular flash memory and micro hard disk drive offerings, comparing the characteristics of these memory technologies and their ability to support popular, memory-intensive multimedia content.

THE 3G NETWORK AND MULTIMEDIA REVOLUTION

Driving Business in the Mobile Industry

3G is here. One of the most talked-about, high-profile topics in the mobile and wireless industry – offering potential benefits to users, operators and handset manufacturers alike – 3G has finally become a reality. According to iSupply, forty-two 3G networks were operational as of June 2004. With every passing day, announcements in countries around the globe are being made, introducing yet other operational 3G networks. By 2007, both IDC and Gartner predict that approximately 25 percent of all handsets shipped will be 3G handsets. The media is being flooded with advertisements urging users to upgrade their handsets to enable the new multimedia services that 3G supports.

Providing a bandwidth of up to 384Kb/s to over 8Mb/s (using HSDPA), the 3G network is as fast as some ADSL connections. This wide bandwidth unplugs a major bottleneck, network inabilities to handle the huge amounts of data required for multimedia content. This bottleneck has, until now, prevented many applications and services from materializing.

Operators, heavily invested in 3G, are now striving to capitalize on 3G to generate new revenues, both to realize return on the huge investments they have made in the new infrastructure and to increase the Average Margin Per User (AMPU) in general and the Average Margin Per *Hooked* User, in particular.

Handset makers are also at a crossroads. The camera phone revolution was a major catalyst for the dramatic growth in handset sales in 2004 and 2005. So much so that in Japan, camera phone penetration is close to 100%. While the global average in 2004 lags far behind, with only some 30% penetration, analysts are predicting this number to rise to 60% by 2007. However, studies show that in 2005, the handset market growth rate will slow as a new killer feature is sought to replace cameras in phones to drive the handset replacement market. To overcome this slowdown, handset makers are adding more and more multimedia capabilities to their handsets, turning them into portable entertainment stations. In fact, some handsets already offer a full range of multimedia services to their owners. They can play MP3s, record video and screen-selected TV programs, run 3D games and take high-resolution still pictures. With 3G up and running, handset makers are releasing new, multimedia devices that will drive up replacement sales, while at the same time enable operators to provide band-consuming content that will boost operator revenues. A clear indicator of this win-win trend can be seen with the formation of alliances between content owners and handset makers and operators. Recent examples include the Motorola-MTV and Motorola-iTunes agreements, as well as the Sony Ericsson-Turner Broadcasting, Samsung-Virgin records (Strategic Analytics, September 2004).

Driving Changes in the Handset Architecture

To enable this trend, handset architectures are undergoing a major redefinition that is only partially noticeable to the untrained consumer eye. Leading smartphones, for example, are now running at up to 600MHz clock frequency, comparable to the processing power of laptops some 3 years ago. Simple camera phones are advancing from low-end ARM7 devices running at 40MHz to ARM9-powered devices running at over 100MHz. A third alternative uses the “old” ARM7 processor to manage communications and run the phone OS, while implementing a dedicated, powerful multimedia processor to handle the influx of multimedia content. This approach is favored by many handset vendors as a transition measure, enabling them to use the same, main processor and thereby benefit from reduced costs, shorter development cycles and more efficient inventory management.

However, one of the most dramatic effects of the multimedia revolution on handsets is in the amount of memory they carry, especially Non-Volatile Memory (NVM) for running and storing code and for storing data. In the PC market, average storage requirements grew from less than 1GB in 1996 to over 100GB in recent years, a 100-fold increase. This growth is directly related to the fact that home PCs, formerly used mainly as personal workstations, are now becoming full-blown multimedia stations that store the entire music and video libraries of households. Handsets are following suit. Providing storage capacities on the average of 4MB just three years ago, many handsets today are being sold with 64MB memory and more. In fact, just recently Samsung Electronics and Nokia announced handsets that include a mechanical hard drive featuring about 4GBytes.

Higher capacities are only part of the memory-for-multimedia story. Multimedia applications running on small, battery-powered handsets challenge memory performance, power consumption and size. Turning average users into hooked ones by ensuring that multimedia applications have adequate memory capacity and performance to run smoothly, without draining the battery, makes this challenge particularly worth winning.

Yet despite these challenges and often at odds with them, memory reliability remains a critical requirement. The same handset that runs multimedia on a daily basis must be *always on* and *always ready* in an emergency to serve as a simple phone and phone book.

MULTIMEDIA MEMORY REQUIREMENTS

Capacity and Performance

The amount of memory and its performance required by mobile handsets varies considerably, depending on the multimedia application. Among the most memory-hungry applications are music/video clip downloads and video recordings. Storing many high-resolution photos within a photo album also requires considerable memory.

The typical storage capacities and performance required to effectively run/play/store these applications are shown in the tables below. In Table 1, it is easy to see that music, although a major memory capacity consumer, requires very low read and write performance. The typical bit rate of MP3 in wireless networks will probably not exceed 128KB/sec, thus requiring only 16KB/sec read performance.

Table 1: MP3 Music Memory Requirements

Bit Rate (Bits/Sec)	KB/Sec	4-Min. Song (KB/sec)	Memory Capacity (MB) for 50 Songs
128	16	3840	188
192	23	5520	270
320	39	9360	457

As Table 2 shows, still pictures require by far the highest write performance. For example, a 2MPixel picture produces a 6MB bitmap image. After JPEG compression, its size is reduced to 450KB. NOR flash does not comply with this requirement, and resorts to SDRAM buffering to meet it. Small-block MLC NAND-based DiskOnChip G3 delivers over 1MB/sec, thus complying even with the performance requirements of 5MPixel cameras. Large-block MLC NAND-based DiskOnChip G4 delivers over 2.5MB/sec write performance, far exceeding the performance needs of still pictures on mobile handsets.

Table 2: Still Picture Memory Requirements

MPixels	Frame Size	JPEG Picture (KB)	Sub-Second Shot (KB/sec)	Memory Capacity (MB) for 50 Pictures
1.3	1280x960	300	300	15
2	1600x1200	450	450	23
3.2	2048x1536	720	700	36
4	2272x1704	900	900	45
5	2592x1944	1,125KB	1.1 MB/sec	56

Video recording requires large storage capacities, as shown in Table 3, but does not require high write performance. However, performance becomes critical when using flash memory, due to the need for garbage collection (or space reclamation). This operation is lengthy, requiring erasing and rewriting several blocks in the flash media. If such an operation occurs during video recording, frames are lost and the video is displayed as if it were "broken" or "jumpy". Overcoming this malfunction requires advanced software algorithms that are capable of suspending any space reclamation operation in real-time if a video recording is process. To date, only M-Systems' TrueFFS® flash file system can offer such multimedia awareness and the ability to adapt itself to specific multimedia content, as required. When detecting a video recording in process, TrueFFS instructs the media management layer to delay any space reclamation operations until after the recording has finished.

Table 3: Video Capture Memory Requirements

Frame Size	Frames Per Second	Raw Video Bit Rate (Mb/sec)	Motion JPEG Compressed (MB/sec)	MPEG-4 Compressed (MB/sec)	Memory Capacity (MB) for 5-Min. Video Storage
176x144 QCIF	15	4.6	0.1	N/A	30
320x240 QVGA	15	13.8	0.3	N/A	90
640x480 VGA	15	55.2	N/A	0.1	30
640x480 VGA	30	110.4	N/A	0.2	60

How Much Memory is Enough?

Based on the above data, a typical usage scenario can be drawn in order to determine average, total memory needs for multimedia mobile handsets. This scenario would assume the multimedia-intensive device configuration shown in Table 4.

Table 4: Typical Memory Capacity Requirements for Multimedia-Fit Handsets

Mobile Handset / Feature	Smartphone		Feature Phone		Music Deck Handset	
	Quantity	Memory Capacity (MB)	Quantity	Memory Capacity (MB)	Quantity	Memory Capacity (MB)
OS and Applications	1	32	1	16	1	16
PIM	1	16	1	8	1	8
Games	4	5	4	5	4	5
MP3 Songs	20	80	10	40	100	400
High-Resolution Photos (2MPixels)	50	22.5	50	22.5	100	45
Purchased Clips (2-min)	5	60	2	24	10	120
Video Recordings (30 sec)	10	30	3	9	20	60
Total Memory Capacity		**247.5MB**		**124.5MB**		**654MB**

Adding it all up, total memory capacity requirements range between ~250MB to ~700MB, depending on the type of the device and its usage.

THE MEMORY LANDSCAPE

While waiting for 3G to come of age to provide the bandwidth to meet multimedia requirements, memory manufacturers have introduced multiple flash and mechanical drive technologies to the memory landscape, marketing them in a wide range of on-board and removable memory products. Handset designers in need of increased NVM and high performance must sort through all of these offerings.

NOR and NAND-based flash are vying for market share, each backed by huge companies such as Intel and Samsung. Recently, vendors of magnetic hard disk drives have also begun targeting the music handset market in an effort to completely displace flash technology.

More Flash Memory Choices: NOR, NAND and EFDs

NOR and NAND-based flash are vying for market share, each backed by huge companies such as Intel and Samsung. Recently, vendors of magnetic hard disk drives have also begun targeting the music handset market in an effort to completely displace flash technology.

NOR technology, the older and more entrenched of the two technologies, is better known to most engineers and more reliable than NAND technology. NAND-based memory uses less silicon and is therefore more cost-effective. However, not many know that the first NAND to be implemented in a handset was not a raw NAND chip but a NAND-based Embedded Flash Drive (EFD) called DiskOnChip, from M-Systems. With a built-in controller that uses a standard NOR interface, DiskOnChip offers XIP boot capabilities so that it can run code as well as store data, implements error detection and correction (EDC/ECC), and provides protection and security-enabling features to protect data and provide the basis for digital rights management (DRM). Today, DiskOnChip is also shipped by Toshiba, while Samsung has recently announced a similar EFD-type product. EFDs make it easy to use the latest, most cost-effective NAND technology and processes to date: 90nm MLC NAND moving to 70nm by the year's end (currently scheduled only by the DiskOnChip EFD).

EFDs were critical to the successful penetration of NAND into the handset market. Today, they co-exist with raw NAND. Together, they are consistently driving NOR into the lower ends of the handset market where less memory is required, while becoming the default memory for multimedia handsets in general and in smartphones in particular.

To better understand where and how NAND, NOR or EFD is used in handsets, we must first understand the dynamics of the handset segments and its ecosystem and architectures.

Hard Disk Drives

As requirements for high memory capacities grow, mechanical spinning, hard disk drives (HDDs) – so successful in meeting high-capacity memory requirements in the PC market – are being reinvented as *micro* HDDs (or *micro drives*) for the mobile handset world. HDDs have traditionally offered read and write performance that has surpassed the rates of flash, particularly in terms of write performance. However, both NAND and MLC NAND deliver higher performance than any multimedia application requires.

Although HDD performance makes them fit for the job, their reinvention poses a number of questions:

- Can handset manufacturers overcome the challenges of integrating such big form factors into mobile handsets, where space is so limited?
- Are HDDs battery friendly?
- Are HDDs rugged enough to withstand environmental extremes?
- Is their cost structure advantageous in the capacities required for mobile handsets?

Size

HDDs are large. Even the smallest micro drives are considerably larger than flash memory. As Figure 1 shows, the 1GByte DiskOnChip H1 measures only 12x18x1.4 mm, while the smallest HDD to date is 24x32x3.3 mm. 0.85" micro drives occupy eight times the volume of a DiskOnChip H1 device, while 1" micro drives occupy up to 25 times the volume. This difference in volume does not take into account the slot into which the drive must be connected, taking up even more real estate. In addition to size constraints, HDD solutions require an additional NOR chip to store OS code, occupying even more space (and thus increasing costs). Finally, HDDs cannot be stacked in a Multi-Chip Package to save board real estate, while flash memory can. For instance, DiskOnChip H1 can be stacked in the same package with other memory devices (such as SDRAM) to provide a complete memory system in a chip that does not require additional space.

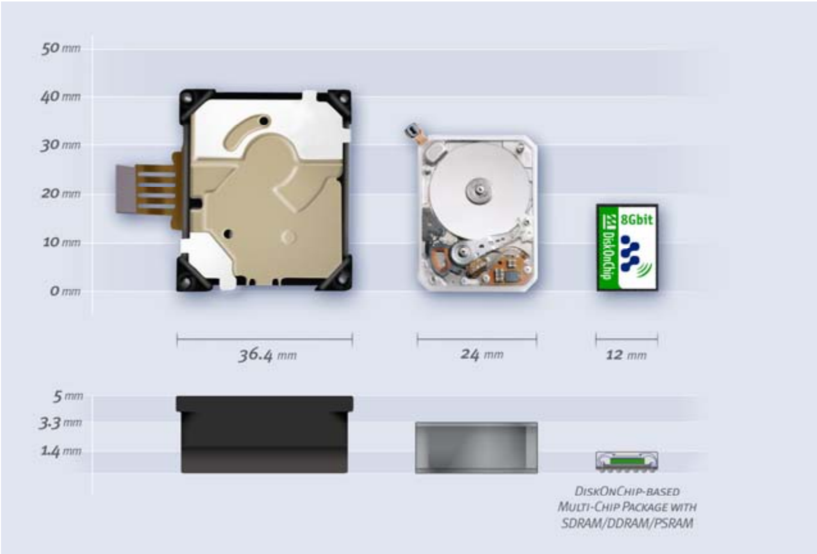


Figure 1: Popular Micro Drive vs DiskOnChip Dimensions

Power Consumption

HDDs consume an average of 1000mW when active. This is up to 50 times the power of flash memory, such as a 1GByte DiskOnChip H1 which consumes 20-50mW. This is critical in

mobile handset designs, for which studies show that the most important feature is battery life (Strategic Analytics and Gartner have both published studies).
While such power consumption levels may be acceptable in iPOD-like devices, they are unacceptable in mobile handsets. Mobile handsets are used for personal communication, data storage, as well as entertainment (MP3 files, etc.) and cannot become inoperative due to power drainage as a result of supporting multimedia applications.

Reliability

Since HDDs are made of moving (spinning) parts, they cannot withstand substantial shock or typical handset handling (frequent falls from an average height of about 1-1.5 meters). Even though HDDs have proven rugged enough for iPOD-like devices, they cannot endure the more intense handling that characterizes mobile handsets. In addition, HDDs cease operating in extreme temperatures while flash continues to operate at temperatures ranging from -40° to +85°C. (Imagine trying to use your handset after forgetting it in the car on a hot, sunny day or after getting stuck in a snow blizzard – only to discover that its HDD has overheated/frozen. On the other hand, there are stories of flash-based cards that have survived temperature and environmental extremes, including even plane crashes and washing machine cycles.)

Cost Structure

HDDs offer low cost per bit. However, they are only available at very high capacities (the minimum capacity for a micro drive today is 1GB) while the breakeven point of flash versus HDDs is at about 1.5GB – well within the foreseen storage demands of music-centric mobile handsets. This breakeven point is expected to move to 2-2.5GB in 2006.

MATCHING MEMORY TECHNOLOGIES TO MULTIMEDIA DEVICE NEEDS

Smartphones

A number of factors have joined forces to create the right echo system in smartphones to support NAND.

High-Capacity Content

Smartphones target business users, in need of devices to increase their out-of-the-office productivity. These devices are usually a combination of a handset and a PDA, with a range of additional functionality. Smartphones feature large screens (many of which are touch screens), full scale OSs such as Windows Mobile, Symbian, PalmOS and Linux, PIM applications (Pocket Outlook), and office-like software. In addition, smartphones include games, a high-resolution camera capable of still photos and video capture, and enough memory to enables users to store and play a selection of MP3 songs.
Today, a typical smartphone packs anywhere from 32MB to 256MB (and growing) of on-board memory. In this capacity range, NOR is far too costly to compete with NAND. However, the first smartphones that incorporated NAND memory used it as a disk-like solution to supplement rather than replace the on-board NOR flash. This approach was necessary since raw NAND is not eXecute In Place (XIP); i.e., it cannot directly run applications. To solve this, applications were stored and executed on the resident NOR flash, and user data was kept on the NAND media. This division of flash responsibilities changed with the integration of XIP capabilities in NAND-based devices to provide boot functionality. DiskOnChip was the first such device to provide both high-capacity data storage and run code. DiskOnChip offers memory paging capabilities to support the “code shadowing” approach of major mobile OSs.

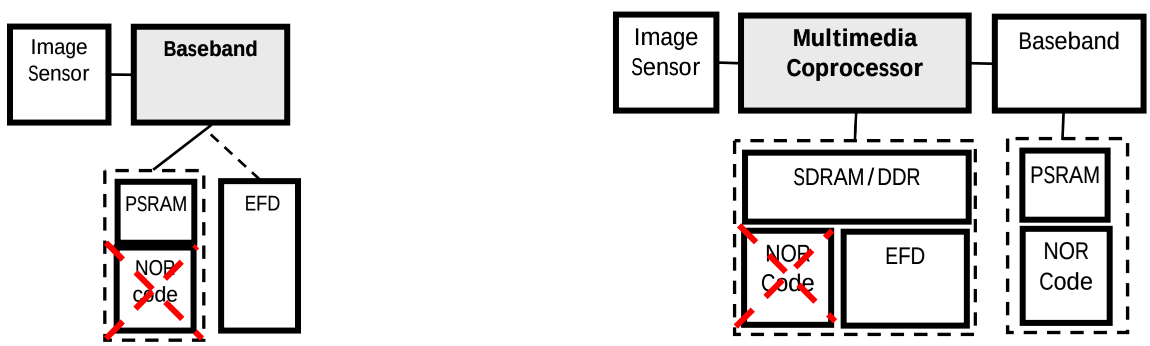
The Paging Solution to Shadowing

Devices such as DiskOnChip include a small XIP boot block. This block includes a small piece of code that initializes the system RAM and copies the OS image from the NAND flash media to the system SDRAM, where it is executed. The main drawback of this approach is that it requires additional SDRAM to store the OS image, which in turn reduces the main incentive of switching to NAND technology (cost – with the others being size and write performance). Mobile OS vendors have solved this issue by adding paging capabilities to their OSs. Thus, instead of shadowing the entire OS image to RAM, only the OS kernel is copied, while applications are paged in and out of the RAM upon demand. Microsoft, for example, called this approach "paging on demand". Paging on demand has dramatically reduced the amount of SDRAM needed in NAND-based devices to about half (from 64MB SDRAM to 32MB), and maximized its cost benefits. Today, most new smartphone projects are implementing some kind of NAND technology as an on-board NVM solution, discarding the former NOR-based architecture. Reviewing the top six handset vendors, NAND and DiskOnChip are implemented in almost all of their smartphones models, in most cases without an additional NOR flash for code.

Feature Phones

Feature phones constitute the majority of the mobile handset market. They are standard phones that are enhanced with additional sets of features to provide entertainment. The killer application of feature phones in 2004 was the camera, with 170 million camera-equipped feature phones (or camera phones) sold. Camera phones enable users not only to take pictures and video clips, but ostensibly to send them as MMS messages to other users (incompatible network standards do not fully support this extended capability).

To support this enhanced feature set, feature phones have undergone architectural changes. Today, two architectures dominate the feature phone category, as shown in Figure 2.



Enhanced Legacy   Multimedia-Centric

Figure 2: Popular Feature Phone Architectures

The enhanced legacy architecture, on the left, offers only a slight improvement over basic voice-centric handset designs. It introduces additional flash media for storage and strengthens the baseband from an ARM 7 to an ARM 9 processor. This architecture can support basic camera capabilities and simple Java games, but cannot support advanced video capabilities and 3D gaming.

A dedicated multimedia coprocessor was introduced in the multimedia-centric architecture. The baseband continues to use a relatively weak ARM processor (usually ARM 7), and is responsible for all traditional handset functionality and OS execution. The multimedia coprocessor, in contrast, is based on an ARM 9 and higher, and includes additional multimedia-targeted state machines. This processor handles all multimedia and graphic-intensive applications, and is used upon demand of the baseband processor. This architecture typically includes two memory subsystems:

- For the baseband, to store and execute the OS, communications stack and applications
- For the multimedia coprocessor, to store its code and all files managed by the file system (mainly but not exclusively multimedia).

Some coprocessors can read code from the NOR connected to the baseband, or from DiskOnChip with XIP capabilities, thus eliminating the need for NOR in the system.

Although different, these two architectures both require flash media to store pictures, video clips and games downloaded by the user, but capacity requirements differ depending on the feature phone segment.

Low to Mid-Range Feature Phones

These devices provide basic, low-resolution camera (VGA or lower) and gaming capabilities. A low-resolution still picture only occupies 40KB or less. NOR can meet this requirement. Many feature phones provide 32MB NOR, the upper limit of NOR as a competitive media, and in many cases an additional slot for a NAND-based removable card (mostly SD or MMC form factors). For these devices, NAND media offers marginal cost improvement, which many vendors do not find compelling enough to warrant a memory architecture change. As higher photo resolutions continue to be supported, a growing demand for built-in NAND media is evident. At the first stage, NAND will serve as a "disk-like" storage solution only, since paging software is not yet available in the Real Time OSs (RTOSs) used in these handsets, resulting in increased PSRAM size and reducing the NAND/MLC NAND cost advantage. However, in efforts to further reduce the BOM while increasing the storage capacity available to users, companies such as M-Systems are joining forces with feature phone OS vendors – such as ATI (Nucleus), TTPCom (ADI-based handsets), Skyworks and others – to introduce OS paging capabilities. Once ready, this capability is expected to dramatically accelerate the penetration of bootable NAND into handsets as the only NVM media on board, serving both as a code and storage media.

Mid to High-End Feature Phones

These devices offer a VGA or higher-resolution camera (the mainstream camera for these devices in 2004 was 1.3MegaPixels), and are capable of video recording, some image processing and advanced gaming capabilities (the Motorola e680, for example, comes with a range of exciting games, including a 3D NBA game). These devices are based either on the multimedia coprocessor architecture shown in Figure 2, or on a much improved baseband processor (ARM 11), such as TI OMAP 730 that is robust enough to manage multimedia. This architecture is very close to a smartphone architecture. In such handsets, NOR media is not a viable solution, as evidenced by the fact that there is massive penetration of NAND flash technology. The most basic function of NAND technology in these devices is that of a disk drive, much like the function of HDDs in PCs. However, many handset vendors are taking advantage of bootable NAND devices such as DiskOnChip to eliminate the additional NOR media storing the multimedia processor code.

Music Phones

With the camera revolution in its prime, both handset vendors and network operators are seeking new ways to boost handset sales and network usage (especially 3G networks). Strategic Analytics claims (September 2004) that the next killer application in the handset industry will be music. A brief look at TV advertising campaigns (for example, the Motorola MTV campaign focused on MP3-enabled handsets) or in daily newspapers supports this prediction.

As shown in the tables above, with 16KB/sec, music is not a performance-challenging media. In fact, such performance can easily be achieved by any flash media today. However, an average 4-minute song, sampled at near-CD quality of 128bps, occupies only slightly less than 4MB (16KB x 4min x 60sec). A music-centric handset is expected to carry at least 20 songs (80MB).

Music phones are built with music in mind. Their design is optimized for music download, playback and browsing. Their accessories revolve around music (quality speakers, docking stations to quality amplifiers, car sound systems). Although this segment is not expected to be huge – it is expected to sell close to 12 million units in 2005, and 30 million units in 2007 – its MB potential is large for flash and HDD vendors alike. Music phones are expected to offer from 512MB to 4GB (similar to the mini iPODs), as compared with the128MB to 256MB capacity predictions for smartphones.

This product segment has re-ignited an old competition between flash and HDDs. The success of the HDD-based iPOD from Apple and the introduction from Samsung of the first handset to include a built-in HDD have renewed interest in the HDD, causing handset vendors re-evaluate the possibility of using micro drives inside some of their handset models.

SUMMARY

3G is now poised to make multimedia a way of life for both low and high-end mobile handset users, promising big business opportunities to the entire value chain. High-capacity, high-performance memory is a key, multimedia enabler in mobile handsets.

Flash memory is a major contender in the multimedia-fit handset market, due to its small size and low power consumption. But not all flash memory is created equal. NOR flash is larger than NAND flash, making it less cost-effective in capacities higher than 32MB, and provides lower write performance. Even within the NAND flash camp, there are major differences that impact on silicon size and cost. MLC NAND is the most cost-effective NAND technology, storing twice the amount of data than SLC NAND in the same cell size. Because of its cost structure, MLC NAND is winning ground as the memory of choice inside multimedia-fit handsets.

As capacity requirements continue to increase, HDDs are being re-invented to meet multimedia-driven handset requirements. Micro drives are fast and cost-effective in very high capacities. However, their high power consumption and big size – even in their re-invented micro drive form format – make it difficult for them to meet the compact design, low-power requirements of mobile handsets.

Based on cost-effective MLC NAND technology, available in high capacities, offering high-performance and reliability as a result of TrueFFS flash management, and bringing the added value of XIP capabilities to replace NOR as a boot device, M-Systems' DiskOnChip is an ideal solution for multimedia-fit handsets.

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