Putting Portable Storage in Perspective

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Introduction

After months of rumors, Apple recently confirmed that the next generation of their small music players would be based on high capacity flash memory rather than 1-inch hard disk drives. Samsung, which will supply most of the flash memory for the new nano iPod has been declaring that the days of small form factor hard disk drives in mobile consumer devices is numbered.

Are the days of rotating magnetic memories numbered? Can flash technology development really outpace hard disk drives? What will be the demand and requirements for future generations of digital music and video players? What will be the role of various storage technologies in the development of personal media players? This article will address these issues.

Apple Created a Music Utility Service

Thomas Edison is famous for creating the light bulb and other early electrical consumer devices (see **Figure 1**). But the real genius of Edison and his collaborators was creating an electric power distribution system, without which all these consumer devices would have been useless. Creating a distribution and use network such as the electrical power system created by General Electric resulted in a vast and powerful economic feed-forward system as the power grid expanded and sales of consumer electrical products spread throughout the USA and the world.

Figure 1. Thomas Edison Created an Electrical Distribution and Use Network

The drivers behind the iPod phenomena are not just the attractive design and progressive advertising images but more importantly the creation of a viable distribution and use entertainment network. The iTunes service makes recorded tracks, podcasts, and other content available to download over the Internet to computers and iPods without having to go to the trouble of buying and ripping CD collections. You only have to buy the musical tracks that you want rather than an entire CD. Cutting a deal with the music suppliers and making a vast range of recorded material available to iPod customers propelled iPod sales, making it the most popular music player in the industry and making Apple considerable profit.

The new iPod nano continues the Apple tradition of sleek and well designed portable consumer products and will undoubtedly do well in the market. The first generation iPod nano uses 2 and 4 GB flash memory rather than the 1-inch hard disks drives that were used in the mini iPods. The iPod nano comes with 2 cables, one for headphones and the other a cleverly combined USB 2.0 cable that supplies power to charge the iPod while it is downloading. Samsung, the worlds largest flash memory manufacturer, is supplying most of the flash memory chips that Apple will use in the iPod nano.

Current and Projected Price and Capacity of Portable Storage

The 2 GB iPod nano (see **Figure 2**) is selling for just under $200 while the 4 GB version is selling for just under $250. A quick search of the Internet shows that discount retail prices for 4 GB flash memory only devices was no cheaper than about $250 (as of 9/19/05). According to Semico Research, 2 GB flash memory chips sell OEM for about $60 while 4 GB run about $120. I estimate that a 4 GB 1-inch disk drive OEM price is about $55. The 4 GB mini sells for about $200 while the 4 GB nano sells for about $250 so the difference in produce sales price vs. digital storage component cost is about $145 for the mini and $130 for the nano. Either Apple is making considerably less profit on the 4 GB iPod nanos using flash memory or Samsung is subsidizing much of the cost of the flash memory chips. Probably both sides are taking less profit on the 4 GB product in order to promote sales for the 2005 holiday season.

Figure 2. Apple Flash Memory-Based iPod nano

Apple is taking a bold move in eliminating the higher capacity mini iPods that use 1-inch hard disk drives. These have had capacities of 4 and 6 GB for most of 2005 although both Seagate and Hitachi Global Storage Technologies have announced that they will ship up to 8 GB 1-inch HDDs in the second half of 2005. Apple is betting that for most music users 2 or 4 GB will be large enough capacity today and that flash memory will have sufficient storage capacity to supply the needs of consumers. Earlier this year there were reports that 4 GB mini iPods sold much better than the 6 GB versions even though the 6 GB products with 50% more storage capacity only sold for $50 more.

We suspect that Apple deduced from this that 4 GB may be sufficient storage capacity for many portable music listeners and when Samsung offered them a very good deal on up to 4 GB flash memory they decided to make the transition. But this difference in sales volume may also represent the antipathy of consumer to pay an extra $50 for a portable music player (note that there are many lower capacity flash music players that sell for less than $50!). Presumably Apple did adequate market analysis to understand whether it was price or capacity use saturation that caused the 4 GB music player sweet spot for the minis.

Table 1 shows Apple's suggested music track capacity for various iPod storage capacities whether they be the nano, the mini, or the original iPod products (Track capacities are from Apple promotional materials).

Table 1. Number of Music Tracks for Various iPod Digital Storage Capacities (From Apple Specifications)

Storage Capacity	2 GB	4 GB	6 GB	8 GB	20 GB	40 GB
Number of iPod Music Tracks	500	1,000	1,500	2,000	5,000	10,000

The price points for a given storage capacity as well as the overall storage capacity will develop with time for both flash memory and small form factor hard disk drives. At any given point in time the amount of storage capacity of flash and hard disk drives will be different.

Both HDDs and flash memory show significant technical advances in storage capacity as well as performance and reliability with time. With magnetic recording, the amount of digital storage in giga-bits (Gb) that can be stored in a square inch of disk surface is called the areal density (in Gbpsi). **Figure 3** shows quarter by quarter disk drive public technology demonstration announcements on hard disk drive areal density as well as quarter by quarter hard disk drive product announcements since Q1 2000. Also in the Figure are shown multi-level flash memory (MLC) projections of areal density from a major flash memory supplier (Toshiba).

Flash memory product development is certainly aggressive (driven by both reduced line-width as well as multi-level flash memory development) but hard disk drive areal density is expected to grow significantly as well due to the recent introduction of perpendicular recording and tunneling magnetoresistive read (TMR) heads. Note also that the most recently announced high areal density disk drive products are smaller form factor disk drives in order to offer direct competition with flash memory. Also note that although disk drive technology announcements appear to be slowing that is likely due to less public technology development than occurred during the past, although the rate of technology development is probably picking up. It will be a considerable period of time, if ever, before flash memory areal density meets or exceeds that of hard disk drives.

Figure 4 shows an analysis of how much flash memory and 1-inch disk drive digital storage capacity can be bought by an OEM for $55. A $55 flash memory and 1-inch hard drive represent relatively mature products. Hard disk drives are expected to offer a significantly higher storage capacity (~3X higher) than flash memory for this price range.

Figure 5 shows a late Spring 2005 retail price comparison of Compact Flash memory vs. 1-inch hard disk drives (we choose Compact Flash since it is close to the same dimensions as 1-inch hard disk drives). This graph illustrates that at any point in time there is a cross-over point in the price of a small form factor HDD and flash memory. At the time of this analysis that cross-over point was somewhat less than 3 GB. Thus HDDs offer cheaper storage for greater than 3 GB storage capacity while for less than 3 GB flash memory is a better buy. This difference in the price of flash memory vs. HDDs is a reflection of a higher fixed cost for a HDD vs. a lower fixed cost for flash memory. The fixed cost mentioned here is the lowest possible cost of the material used to build the product at a point in time and with then current technology and yield.

Figure 3. HDD Quarter by Quarter Public Technology Demonstrations and Product Announcements Compared to Toshiba MLC Flash Numbers

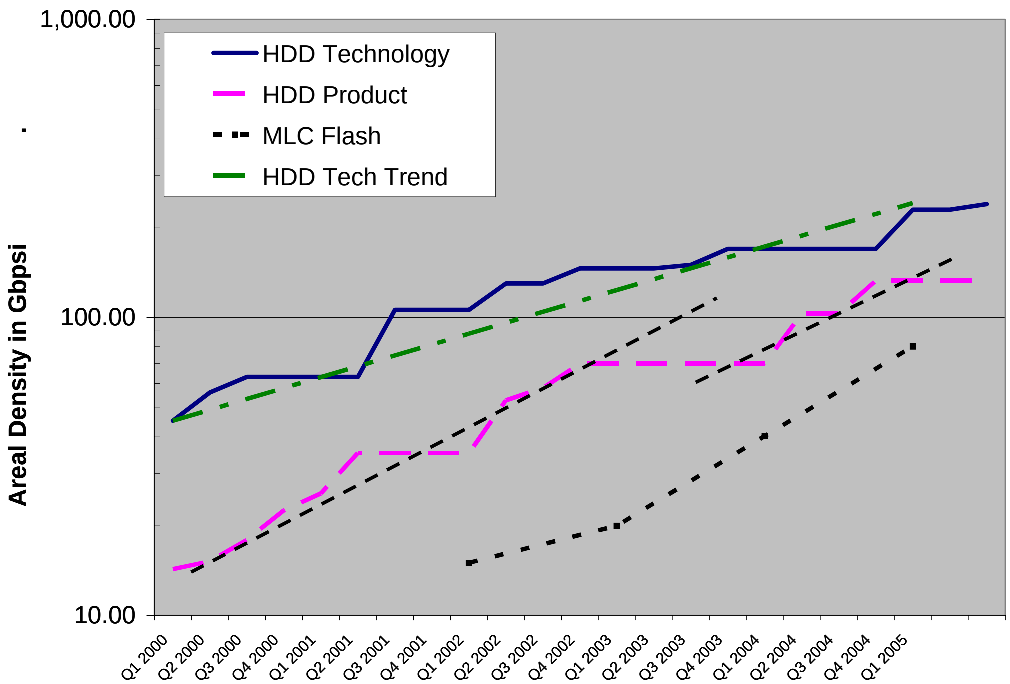


Figure 6 shows a projection for the compact flash vs. 1-inch HDD OEM price cross-over point as a function of time. Starting in 2005 the flash memory manufacturers have announced considerably more aggressive cost reductions vs. capacity, which reflects a change in slope of the cross-over curve starting in 2005. By 2006 new disk technologies such as perpendicular recording and TMR heads will accelerate the rate of HDD capacity growth for small form factor disk drives and thus slow the rate of increase in the cross-over capacity.

Figure 4. Capacity of Embedded Flash and 1-Inch HDD for About $55 OEM vs. Time (Coughlin Associates)[1]

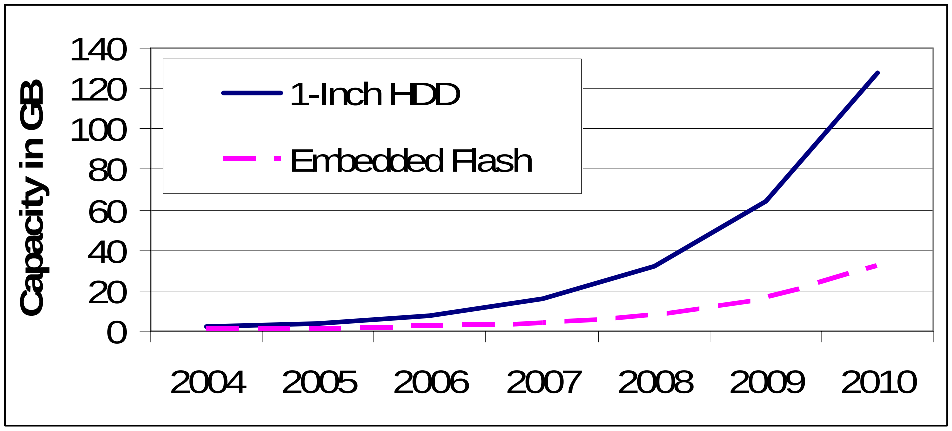
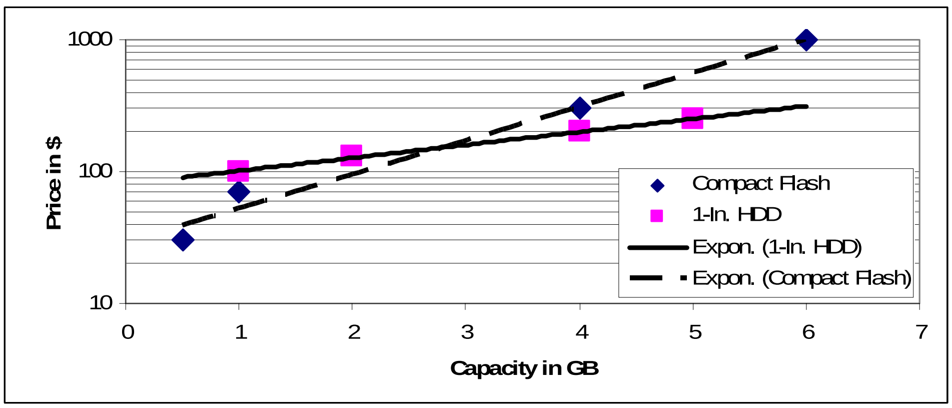


Figure 5. Retail Compact Flash vs. 1-Inch Hard Disk Drive Prices for Various Storage Capacities [1]



While economics alone will not determine how digital storage will be incorporated into consumer electronics it is nevertheless an important one in the price sensitive consumer electronics market

A Mobile Digital Storage Hierarchy

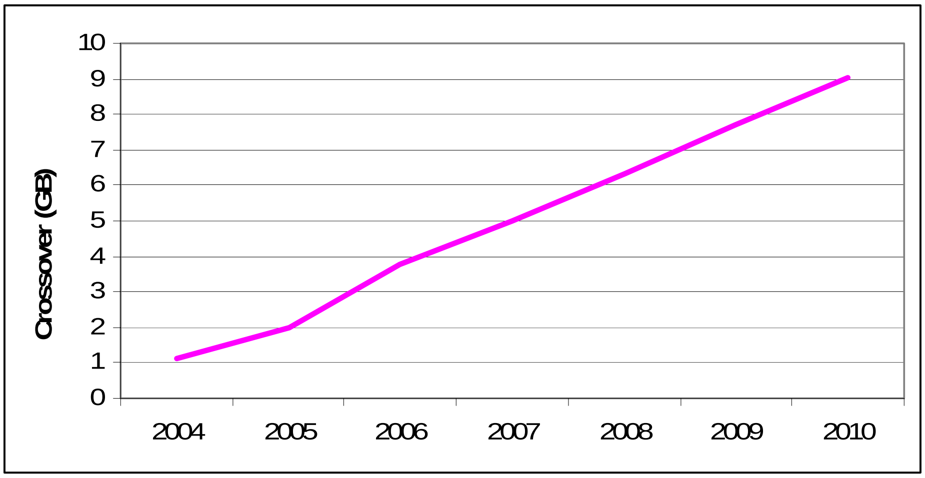
Computer scientists often refer to the characteristics of various memory devices as constituting a "storage hierarchy." The concept of a storage hierarchy allows sorting various memory products based on important characteristics for the applications for which they are to be used. Below is a list of important characteristics for consumer

[1] Thomas M. Coughlin, ***2005 Integration of Digital Storage into Consumer Electronics Report***, Coughlin Associates, 2005, www.tomcoughlin.com

electronics storage devices that we will use to construct a Mobile Consumer Electronics Storage Hierarchy.

- Price
- Size
- Power
- Capacity
- Data rate
- Reliability and environment

Figure 6. Compact Flash vs. 1-Inch HDD Capacity OEM Price Cross Over Point with Time (Point above which HDDs become less expensive than Flash Memory) [1]



In addition to cost advantages at high storage capacity, HDDs have some performance advantages over flash memory:

- They are suitable for Streaming and Multitasking, especially if multiple writes are required
  - Interactivity e.g. recording programs while listening to music
  - Mobile PVR / Time Shifting–Multiple streams
- HDDs are better for applications demanding a large number of overwrites
  - Write performance –HDD access time = 18ms vs Flash Erase = 30 ms/page
  - Rewrites unlimited for HDDs while 10,000 to 1,000,000 write limit for Flash
- Higher write bandwidth for transfer and synchronization of contents
  - Faster time to sync with wireless

HDDs are however intolerant of going through a clothes wash cycle and they won't operate well if the ambient temperature is very low or very high (but neither will humans). HDDs are somewhat more sensitive to shock such as from a significant drop but they are rapidly developing zero-g sensors and other technology to pull the head from the disk before shock can occur which should reduce this sensitivity. If a hard disk drive is embedded into a portable device the portable device protects the hard disk drive from shock. Thus small form factor hard disk drives are most likely to be used for embedded mass storage.

The biggest difference between a HDD and flash memory is the power usage, although because of the much higher data rate of the HDD they need not be continuously powered up. In actual practice the power usage of a HDD and flash based MP3 music player is just about the same using common power saving modes for the HDD player. **Table 2** compares important characteristics of a 1-inch HDD vs. 2-level per cell SD flash (MLC) such as would be used in a music player. Note that write and read speeds are sustained.

Although hard disk drives use more power when on, in practice they are not kept on at all times. For MP3 and other highly compressed musical digital content a hard disk drive may only be on 5% of the time. When on the drive fills a semiconductor buffer with content and then turns off. The content is then streamed from the buffer and the hard drive turned on again only when the buffer needs to be refilled.

Table 2. Comparison of Mobile Storage Product Important Characteristics

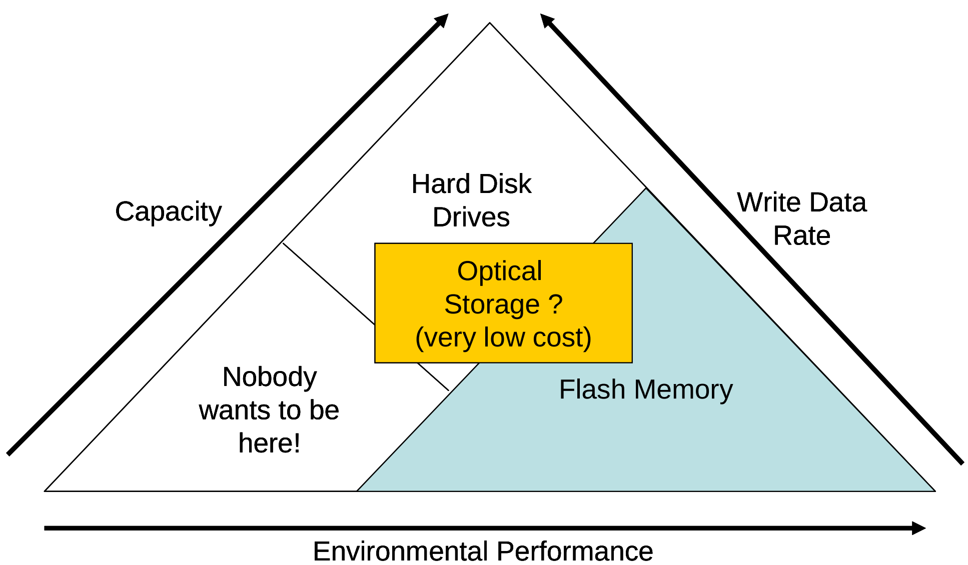
	SFF HDD (1-inch)	**MLC SD Flash**
Height	3.3 - 5.0 mm	1.4 mm
Width	24 - 36.4 mm	24 mm
Length	32 - 42.8 mm	32 mm
$/GB	~8 $/GB	~23 $/GB
Write Data Rate	7.2 MB/s	2.5 MB/s
Read Data Rate	7.2 MB/s	13.5 MB/s
Active Power	660 mW	36 mW
Standby Power	33 mW	0.2 mW
Temperature Range	0 – 70 C	-20 – 65 C
Operating Shock	1500 G	>1500 G
Non-Operating Shock	2500 G	>2000 G
Noise	Some	None

All of these factors and the needs of the application that the product is to be used in must be taken into account in order to choose the right storage solution. **Figure 7** is a graphical representation of an embedded mobile digital storage hierarchy showing the proper choice of digital storage as a function of storage capacity, price, data rate, and environmental performance. We have included possible optical storage products to be complete since they could offer very low cost content distribution. Note that for a particular device, application, and price point one or more storage devices can be used. For instance a consumer electronics device could have an embedded 1-inch hard disk drive for mass storage and a removable flash memory device for data sharing. In general we believe that HDDs will grow most in embedded applications requiring large amounts of digital storage. Flash memory can also be incorporated into HDD circuitry creating what is called a **hybrid drive**.

Hybrid drives have been announced for 2.5 inch notebook computer markets by **Samsung** and **Hitachi** to utilize hybrid drive support in the **Microsoft** Vista operating system (due out in late 2006). Such combinations of storage components in a single application takes advantage of the strengths of both types of storage.

Microsoft and **Samsung** demonstrated a prototype Hybrid Hard Drive (HHD) at the Windows Hardware Engineering Conference in April 2005. The hybrid hard drive architecture incorporates a small OneNAND device from Samsung that works within the hard disk's architecture. The ultra-high-density benefits of magnetic storage technology are preserved, while the ultra-low-power, ultra-high-reliability and fast read/write access of advanced NAND technology such as OneNAND enhances the overall value of the hybrid drive at little additional cost. The hybrid hard drive will eliminate costly inefficiencies caused by the need for the hard disk drive to continue to spin whenever the computer is on. Additionally, the hybrid drive design also can provide significantly faster boot times when a computer running "Visa" starts up.

Figure 7. An Embedded Mobile Storage Hierarchy[1]



Microsoft reports that the hybrid hard drive prototype uses 1 Gigabit OneNAND™ Flash as both the write buffer and as a boot buffer. In the hybrid write mode, the mechanical drive is spun down for the majority of the time, while data is written to the Flash write buffer. When the write buffer is filled, the rotating drive spins and the data from the write buffer is written to the hard drive. The hybrid drive saves power by keeping the spindle motor in idle mode almost all the time, while the operating system writes to the OneNAND write buffer.

While the cost of hybrid disk drives will increase with the addition of OneNAND, Microsoft believes any increase will be mitigated by several factors, including lower maintenance costs, 95 percent power savings when the disk is not spinning, faster boot time and substantially increased reliability.

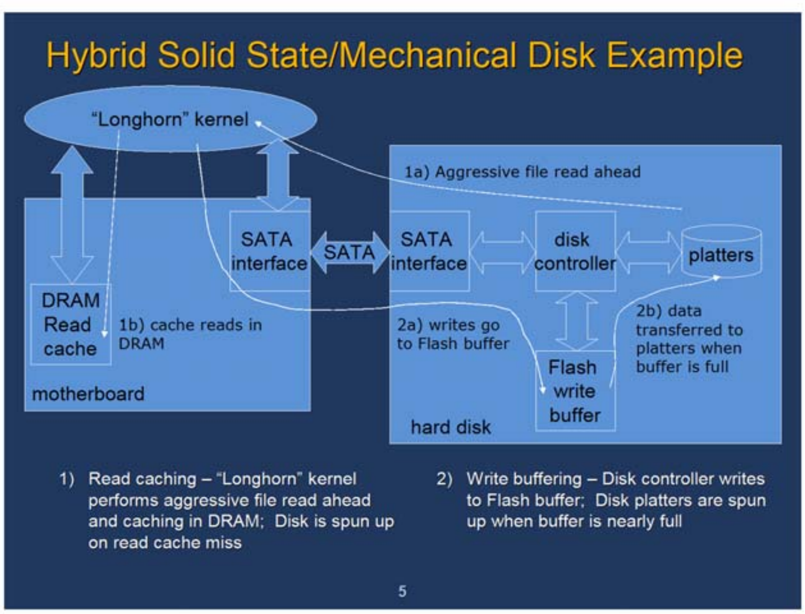
Figure 8 shows how a flash memory can be implemented on a drive resulting in a hybrid storage device.

Mobile and Fixed CE Storage Requirements and Trends

Consumer storage applications will become richer and the expectations of the consumer will become greater with time. Furthermore, the growth of new ways to interact with consumer devices as well as technology improvements in making the experience of high resolution content in mobile and fixed applications available to mobile consumers will increase resolution demands. This will drive demand for higher capacity storage. The net results is various market levels for economy and premium consumer devices with various storage requirements in the years to come. Examples of high resolution devices include personal media players and hard disk drive cell phones.

We argue that the **Apple** iPod nano may represent the last major development in what we will call the **low end media player market**. This market is characterized by lossy music formats for mobile applications that economize on scarce and relatively expensive digital storage. This has characterized the history of portable music players until now. Lower capacity flash memory that is cheaper than a comparable HDD dominates this market and we see the iPod nano representing what may be the last major innovations for this type of product. It should be understood however, that lossy compressed format music players will represent the highest volume market for some time in the future since compressed music formats such as MP3 and AAC allow a lot of music to be stored on a "smaller" storage capacity than is the case for a loss-less music format and thus can provide lower capacity, lower cost products for less discerning and price conscious listeners.

Figure 8. Microsoft Vision of a Hybrid Hard Disk Drive (note that Longhorn is now called Vista)



Lossy music compression technologies include MP3, AAC (used by the Apple iPod iTunes service) and Ogg Vorbis (an open source compressed music format). These lossy compression technologies remove some of the music "information" in the compressed music file. Once this music information is removed it cannot be recovered—hence the term lossy. Lossy compression takes advantage of the fact that the human auditory system doesn't notice certain types of signal degradation. However depending upon the compression algorithm used and the compression ratio chosen, lossy compression can introduce artifacts that can be noticed by a keen ear, particularly in a quiet background. These popular lossy compression technologies can reduce the file size by 80-90%.

On the other hand loss-less compression compresses the audio without losing the original audio signal's integrity. Thus an audio track compressed with loss-less compression can be decoded to its original uncompressed form without artifacts. Loss-less compression technologies reduce the file size by about 50%.

We believe that with the very large digital storage capacity that is available with small form factor hard disk drives there will develop a new class of portable media player. This player would provide significantly higher resolution audio and video content on an appropriately sized screen or some external viewing device. Just as in the days when greater memory became available on personal computers, leading to new features and higher performance on these products, so too these new consumer electronic products will provide higher resolution and loss-less content storage, providing a more refined user experience.

The end result is to provide a portable device offering a home stereo quality music and video experience. Perhaps these loss-less portable media players will be introduced by traditional high end audio providers such as **Panasonic**, **Sony**, and many others rather than by the traditional mobile consumer companies and company divisions. These sophisticated media player products would likely provide ready access to photographs, music files, as well as video files.

Table 4 shows projections for the number of digital photographs, music files, and video files for different resolutions and device capacity. The gray areas for each media format show an estimate of the desired unit content capacity ranges. These are based on an estimate of how much content an individual would like to have available on-demand from a local (e.g. portable device).

- Up to 20,000 photo images
- Up to 10,000 songs
- Up to 100 movies

This chart can give us an estimate of the acceptable size of storage for various applications at various resolutions, following are some examples:

- A pure 4-MPixel photo viewer with 20,000 maximum images has 20 GB
- A combination camera and photo viewer with 8 MPixel Resolution and 20,000 images has 40 GB
- A 10,000 song MP3 player has 40 GB

- A 10,000 song loss-less compression player has 140 GB
- A 10,000 CD quality song player has 280 GB
- A 100 movie player at VGA resolution has 70 GB
- A 100 movie player at DVD resolution has 417 GB
- A combination 20k 4-Mpixel photo, 10k MP3 song, 100 VGA movie player has 130 GB
- A combination 20k 8-Mpixel photo, 10k loss-less compressed song, 100 DVD movie player has 597 GB

Based on this table and **Figure 4** the storage device for a 20k 4-Mpixel photo, 10k MP3 song, 100 VGA Personal Video Player (PVP) (130 GB) using a 1-inch HDD would have a storage cost of less than $55 by 2010 enabling a consumer product with these characteristics selling for well under $200.

Figure 9 shows some examples of Personal Video Player products including the Intel reference design from late 2003. These all incorporate hard disk drives for their mass storage.

Table 3. Media Units vs. Storage Capacity for Various Resolution Photos, Music, and Video Files (Coughlin Associates)

Object Size (MB)	1	2	4	14	28	667	4,160
Capacity (GB)	**4 MP Photos**	**8 MP Photos**	**MP3 Songs**	**LossLess**	**CD File**	**VGA Video**	**DVD Video**
5	5,000	2,500	1,250	357	179	7	1
10	10,000	5,000	2,500	714	357	15	2
15	15,000	7,500	3,750	1,071	536	22	4
20	20,000	10,000	5,000	1,429	714	30	5
25	25,000	12,500	6,250	1,786	893	37	6
30	30,000	15,000	7,500	2,143	1,071	45	7
35	35,000	17,500	8,750	2,500	1,250	52	8
40	40,000	20,000	10,000	2,857	1,429	60	10
45	45,000	22,500	11,250	3,214	1,607	67	11
50	50,000	25,000	12,500	3,571	1,786	75	12
55	55,000	27,500	13,750	3,929	1,964	82	13
60	60,000	30,000	15,000	4,286	2,143	90	14
65	65,000	32,500	16,250	4,643	2,321	97	16
70	70,000	35,000	17,500	5,000	2,500	105	17
75	75,000	37,500	18,750	5,357	2,679	112	18
80	80,000	40,000	20,000	5,714	2,857	120	19
85	85,000	42,500	21,250	6,071	3,036	127	20
90	90,000	45,000	22,500	6,429	3,214	135	22
95	95,000	47,500	23,750	6,786	3,393	142	23
100	100,000	50,000	25,000	7,143	3,571	150	24
105	105,000	52,500	26,250	7,500	3,750	157	25
110	110,000	55,000	27,500	7,857	3,929	165	26
115	115,000	57,500	28,750	8,214	4,107	172	28
120	120,000	60,000	30,000	8,571	4,286	180	29
125	125,000	62,500	31,250	8,929	4,464	187	30

Audio and video player technology built into a cell phone may be another device demanding significant amounts of digital storage. Several of these products have been introduced in 2005 by Nokia, Samsung, and others. **Figure 10** shows some examples of cell phones with hard disk drives that have been announced during 2005.

Figure 9. Examples of Personal Video Players

Intel Personal Video Player Reference Design (late 2003)

Archos Personal Video Player

iRiver Personal Video Player

Mustek Personal Media Center

Figure 10. Examples of Cell Phones with HDDs

Nokia N91 with 4 GB 0.85-inch HDD

Samsung SPH-V5400 1.5 GB HDD Phone (also 3 GB now available)

Storage Demands for Advanced Portable Device Features

The use of mobile consumer products would be easier to grow with better man/machine interfaces. In particular, viable voice recognition technology would make mobile products much more flexible. Also voice recognition technology would itself require additional digital storage. Another important interface change would be the popularization of personal high resolution content viewing devices (such as high resolution projection built into glasses). With personal high resolution viewing devices the storage demands for mobile video players could be much higher than that required for typical small device viewing screens, such as those currently in a cell phone. An interesting observation is that a move to voice activation could eliminate the need for buttons and key pads and hence provide room for a larger screen and allow the use of higher resolution content.

Today you can buy “dictation” software for your PC from multiple vendors that will recognize thousands of words, and which will capture, edit, and print a document by voice. You can call a voice activated assistant on the phone for banking, travel, ordering, and many other activities. The speech recognition algorithms used in these applications are quite large, consuming thousands of MIPs and hundreds of Mbytes of memory. Note that Dragon Naturally Speaking Professional Version 8 can take as much as 2.5 GB of storage capacity depending upon the number of speech files installed.

With greater processing speed in mobile devices and higher storage capacity (combined with noise cancellation technologies) we will have the critical requirements for implanting usable voice recognition into mobile consumer devices. In recent years, algorithms based on modern embedded speech recognition have become available on many cell phones. They allow phone dialing by name or by number using your voice, and often allow voice activation of other cell phone functions. The application understands how names, numbers, and other words sound in a particular language, and can match your utterance to a name, number or command in the phone. Users have found this new functionality straightforward to use and easy to remember.

Worldwide there are more than 10 million phones that include these modern embedded speech applications. They work very well at calling the numbers listed by name from your phone book, at allowing you to dial your phone by saying the phone number, and at letting you look up a contact entry, launch a browser, start a game, and more. Many of these phones use low power ARM processors. A few companies, such as Voice-Signal and ART (Advanced Recognition Technologies) are working on low power voice recognition solutions. The speech recognition software is running on hardware similar to that of a decade ago (except that is very power efficient and small), but the speech algorithms are almost state-of-the-art[2]. It is an easy step to see voice recognition technology becoming ubiquitous on mobile consumer devices.

Creating inexpensive and easy to use personal high resolution display technologies will be more difficult than incorporating voice recognition into mobile devices since there are implications in power use, physio-psychological effects, as well as weigh, convenience, and price. Nevertheless we expect that there will be considerable effort expended to make higher resolution content memory available to mobile users. This will make the likelihood of high end video devices with high resolution content likely within the next 5 years.

Bandwidth Constraints on High Resolution Content Players

The biggest issue with the widespread implementation of high resolution content in the portable world is the bandwidth required to download this material to the player device. The high end of today's Internet download speeds are typically 4 Mbps (mega bits per second) or 0.5 MBps (mega bytes per second) since there are 8 bits per byte, so a 4 MB (mega byte) MP3 track (see Table 3) will take about 8 seconds to download. A loss-less compressed format music file of 14 MB (again see Table 3) will take 28 seconds or 3.5 times longer. An uncompressed CD version of a track at 28 MB will take 56 seconds or 7 times longer than the MP3 file. A VGA version of a 2 hour video at 667 MB will take over 22 minutes to download. Most "high speed" Internet users have less than 2 Mbps connection speeds so their download times would be even longer. Telephone or WiFi Internet rates are much lower and thus take even more time to download. The extra time required to download richer content over the Internet makes a iTunes-like model more difficult until much higher Internet connection speeds are available. However, due to the smaller size of music files compared to video files in general a high resolution music system with loss-less CD quality music will only increase download speeds by 3.5 times. This may be acceptable to many people, particularly those with existing "high speed" Internet connections.

If the rich content exists in the home in a device connected to a home network the available bandwidth is usually higher. **Table 4** gives some common home networking data rates using several technologies. Using conventional wired or wireless home networking at least 5 MBps can be available. This allows significantly faster download times for richer content depending upon how much other traffic is going across the home network. Thus a rip and download approach could be used for richer content just as it was for earlier MP3 players (and is still used by many people).

Table 4 Common home network technologies showing data rates available

Network Technology	Infrastructure Installations (Homes, US)	Reliability	Data Rate	Comments
T-100 Ethernet	~22 million	Excellent	~10 MB/s	Common Network Technology
Gigabit Ethernet	<500k	Excellent	~100 MB/s	Expensive today
Wireless [802.11x]	~4 million	Poor	< 6 MB/s	Unlicensed Band, Interference
Powerline (HomePlug)	>100 million	Good	~ 2 MB/s (v. 1.0) ~25 MB/s (v. AV)	Network connection when plug into power. AV version available in Oct. 2005
Phoneline (HomePNA)	>100 million	Excellent	~ 16 MB/s (v. 3.0)	Said to be ~30 MB/s with optional extensions
Coax	> 100 million	Excellent	34 MB/s (at least)	Possible using out of band transmission, MOCA Standards

Another approach to getting higher resolution content on the players is to make higher resolution digital content available on a device that can be directly plugged into the device. A simple way to do this is with a transfer media. Very small optical media with a built-in player could be used for this or flash memory devices could do it. In either case several hundred MB or even a few GB of content could be provided at little cost. In the case of the flash memory the transfer storage device could even be refreshed with new content for additional transfers. This would again create a hybrid device using characteristics of the portable storage hierarchy to mix different storage technologies where appropriate. Note that adding extra hardware such as a transfer media reader will increase the cost of the player, again making this initially a higher end consumer product.

Mobile consumer devices can utilize one or more storage technologies to provide ranges of product costs as well as product features. **Figure 11** shows how flash could fill a low end product, small form factor hard disk drives a medium range product and a combination product with e.g. an embedded hard disk drive and a removable flash storage could provide a product with the most features and options.

Figure 11. Range of Features and Capacities with Different Mobile Digital Storage Architectures

Apple's Video iPod and Hard Disk Drives for Rich Content Devices

While much attention has been given to the replacement of the mini-iPod using a 1-inch hard disk drive by the sleek memory nano-iPod Apple continues to support and augment the traditional iPod that uses a 1.8-inch hard disk drive. In October 2005 Apple introduced the long rumored video iPod. The video iPod also uses a 1.8-inch disk drive but it has a 2.5 inch color screen (320X240 pixel) and can hold up to 150 hours of H.264 video on a 60 GB model. The video iPod also can hold 20,000 photos and 15,000 lossy compressed music tracks. Note that these capabilities are close to those defined in the desirable multimedia player defined in an earlier section. The video iPod also has a TV port for composite video using an AV cable which will allow consumers to connect their video iPods to most televisions. The battery used supports 3 hours of video for the 60 GB model. The unit is offered for $399.

In addition to the introduction of the video iPod Apple is also offering some television content and music videos for download on its iTunes download service for $1.99 each. Thus Apple has again begun a distribution and use network for video content similar to that created for music content in the iTunes service. **Figure 12** is an image of the video iPod.

Apple's use of small form factor (1.8-inch) hard disk drives in the video iPod demonstrates that there is a need for these storage products to support the rich media market. As small form factor hard disk drives increase in capacity and as means are made available to enjoy rich content in a portable device we shall continue to see hard disk drives used for many years to come, including 1-inch drives where space is of increasing importance. This is not to say that HDDs will replace flash for many portable entertainment applications but they will have their market niche due to their greater cost effectiveness for high capacity digital storage.

Figure 12. Apple's Video iPod

Projections for High Resolution Content Downloads

Following are some projections for legal music and video downloads. These projections have been pieced together out of several public sources as well as best estimates for the growth in a new media format. Besides ripping and moving files to audio/video players or adding content to a player from a removable media, downloads over the Internet will be a big driver of the growth of a distribution and use network for high resolution content.

Figure 13 shows projections for the growth of legal MP3 as well as loss-less compressed audio content. Illegal file-swapping content downloads would add significantly to this projection. This data shows annualized MP3 downloads growing at a steady rate until 2008 when loss-less content downloads begin to grow to a sizeable market and start taking some of the growth away from the MP3 downloads. This growth in loss-less content is expected to be driven by faster download speeds being available and strong market networks developing for this richer content not unlike the iTunes and iPod markets of the early 2000s.

Likewise **Figure 14** projects the rate of growth of legal video downloads (in this case full movie length videos) although shorter clips and music videos will likely grow at an even faster rate since they don't take as long with currently available Internet bandwidth.

Figure 13. Audio download projections for MP3 and loss-less formats.

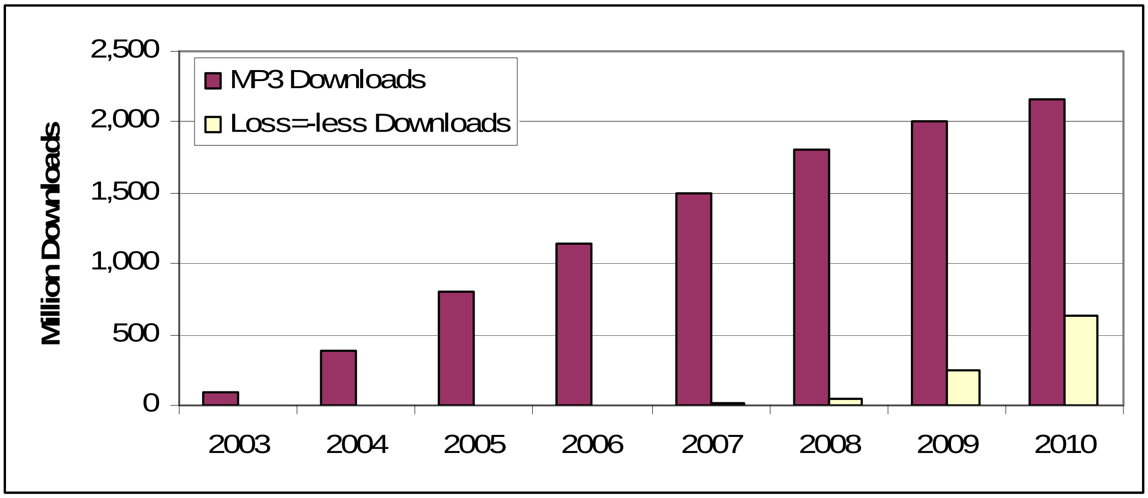
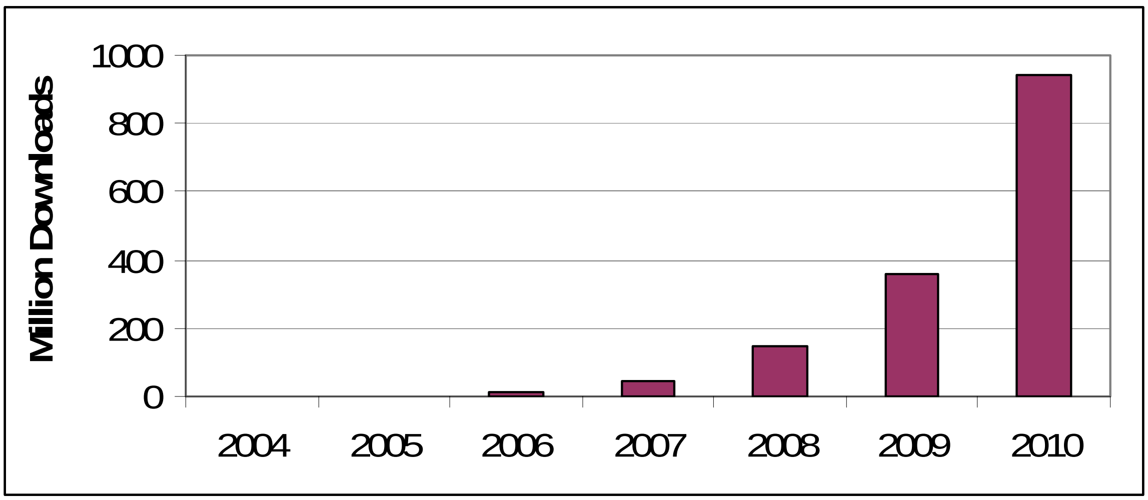


Figure 14. Legal movie download projections.



Summary and Conclusions

We can draw the following conclusions from this analysis:

- Different storage devices compete for portable applications depending upon trade-offs of various specifications and characteristics. These specifications and characteristics can be organized as a portable digital storage hierarchy.
- Hard disk drives enable richer media applications much more cost effectively than flash memory. Flash memory will dominate for commodity player products while hard disk drives will define the high end products.

- Both hard disk drives and flash memory will increase in capacity in the coming years although disk drives will maintain their advantage in $/GB for some time to come.
- Small form factor hard disk drives are most likely to be embedded mass storage in most mobile applications where they are used with removable storage being either flash memory or even small form factor optical disks.
- Higher capacity hard drives and suitable human interfaces will allow portable products with very high resolution audio and video appealing initially to a high end audience.
- Apple created a music distribution and use network with the iPod and iTunes network. This created a positive feedback system where iTunes sold more iPods which led to more iTunes downloads.
- The new video iPod as well as other multimedia player devices combined with content download services such as iTunes may enable a video distribution and use network with a consequent positive feedback system driving more hardware and content sales.
- Bandwidth constraints and the time to download richer media may initially inhibit growth of video content downloads. Demand for such downloads may eventually drive higher bandwidth Internet connections.
- Another option to transfer rich content into mobile devices may be readers for content distributed on small form factor optical disks or flash memory used for content distribution and transfer of this content to the mobile device mass storage.
- A home with a high speed network may be more likely to use a rip and transfer model for mobile video if the content owners make this model possible. Trusted mobile data storage devices will be a key technology in making this happen.
- We expect loss-less compressed music as well as video downloads to reach appreciable levels by 2010.