White Paper 1.4

USB 2.0 Flash Performance

This paper will show the advantages of a USB 2.0 solution over a USB 1.1 solution as it relates to performance. A USB 1.1 solution connecting a Compact Flash Device to a Host System (PC), in many cases, is the limiting factor with regards to throughput. USB 2.0 removes the bottleneck of this connectivity solution. USB 2.0 will allow the fastest Flash Data accesses to the host.

This paper will also discuss what Flash Memory Cards are, what are the advantages and disadvantages, and how Flash cards are connected via USB to a PC host.
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Introduction

With the emergence of digital consumer products in general, and portable electronic equipment in particular, the ability to store and transfer digital information has become increasingly important in the past couple of years. Flash cards have evolved as a convenient solution to this data storage and transfer challenge.

Designed using flash memory technology, flash cards do not require a battery to retain data indefinitely. As a solid-state device, they contain no moving parts and provide users with several benefits not offered by conventional magnetic or optical disk drives. A Flash Card comprises one or more encapsulated flash memory integrated circuits accessed via a parallel data interface supporting repeated insertions. The primary method of connecting Flash Devices to PC’s has been and continues to be USB. With regards to Flash devices, among the benefits are reduced power consumption, lower cost per device (media plus drive), and increased ruggedness/reliability. A flash card should not be confused with an In-Line Memory Module, which is designed for a single insertion into a printed circuit board (PCB) level application, nor is it an ISO 7816 Smart card.

For consumers, a staggering number of incompatible flash card form factors have emerged, each aspiring to become the de facto standard but with varying physical, electrical and protocol standards. In this world of rivalry-collaboration, the multi-standard Flash market created competition and cooperation in each layer of the flash card food chain. The five most popular standards are Compact Flash, Smart Media, Memory Stick, Multimedia Card (MMC) and Secure Digital Card (SD Card). Two additional emerging standards will be available soon. The new standards are XD and Sony Memory Stick Pro.

Sony Memory Stick Pro (MS Pro) is an extension of Sony's Memory Stick. MS PRO increases the data transfer speed as well as supporting higher memory capacities. With regard to XD, here's just what the world needed: a new memory card format! Developed by Fuji and Olympus, XD cards are the smallest out there -- the size of a penny. If you have trouble keeping track of where your memory cards are (like I do), these tiny things will really give you a headache.

As mentioned, Fujifilm and Olympus have jointly developed the 'XD-Picture Card' - a new kind of memory card that offers higher storage capacity in a smaller size than any other format currently available.

The new cards measure just 20mm wide, 25mm high and 1.7mm thick, and weighs just two grams - but will be able to store a staggering 8GB of digital files.

The technology - which takes its name form 'xTreme Digital' - will help manufacturers develop smaller and smaller digital cameras, while at the same time providing users with more and more storage space.

The XD-Picture Card will be available shortly in sizes of 16MB, 32MB, 64MB, and 128MB. A 256MB card will be available later in 2003. XD cards can theoretically get as large as 8GB, but that is years away.

It will also help compatibility between digital cameras, with an adapter being developed to enable cameras designed for CompactFlash media to use the new system.

The XD 16MB and 32MB cards can record data at 1.3MB/sec, while larger cards record at 3MB/sec. All XD cards can read data at 5MB/sec. This is comparable to SmartMedia, the popular format, which it is anticipated that XD is replacing, as well as the other memory card formats.

It is anticipated that Manufacturers utilizing SmartMedia cards will start making the move to XD shortly.
Flash Product Description

A flash card is a portable, solid-state, nonvolatile peripheral device used for the storage and transfer of electronic data. In 2000, the third-party flash card market was worth approximately $1.3 billion, according to Gartner Dataquest estimates. Two flash card formats, Compact Flash and Smart Media, dominate this market, accounting for almost 70 percent of revenue. Sony's Memory Stick represented approximately 10 percent of flash card revenue in 2001 because of the company's large captive market.

Compact Flash

The Compact Flash card, introduced by SanDisk in 1994, is considered the most popular small form factor card format. The Compact Flash Association (CFA) (www.compactflash.org) has more than 190 members, ranging from data storage manufacturers to network communication vendors and card application manufacturers. The card and interface specifications are openly licensed and the standards organization enjoys broad industry participation.

The Compact Flash card comes in two form factors: Type I (43.8mm x 36.3mm x 3.3mm) and Type II (43.8mm x 36.3mm x 5.0mm). The Type I card can store up to 192MB of information while Type II can store up to 300MB. The wider thickness not only helps increase the range of available storage capacities, but also lets vendors include additional communication functions, such as including a more flexible CF+ system interface.

The ATA/IDE protocol allows Compact Flash cards to be swapped between any media devices with a compatible slot. Although it is based on a 50-pin parallel bus, it can be slipped into a passive 68-pin Type II adapter card that fully meets Personal Computer Memory Card International Association (PCMCIA) electrical and mechanical specifications. By employing the Common ATA/IDE commands and corresponding file-allocation-table (FAT) file format standardization, host designers can develop system software more quickly and easily.

A wide variety of low-cost flash technologies can be used because of the built-in controller. Some use NAND flash and others use NOR. In any case, the basic Compact Flash concept is based on reading data at a high speed.

A typical Compact Flash card can read data at bursts of up to 2MB/sec to 15MB/sec \(^1\) and write at 0.3MB/sec to 1.0MB/sec. The speed is dependant on the Card or device the card is being inserted into. Because of this flexibility, the Compact Flash card provides a low-cost flash storage solution. The built-in controller becomes a cost-effective option (for both system OEMs and Semiconductor vendors) because it reduces overhead in the host device and increases flash chip yield by allowing defective chip cells to be mapped out. The Compact Flash card also can operate at either 3.3 volts (V) or 5V. Unlike other standards, the Compact Flash card can be interchanged between the two systems such as card readers, Camera's, etc.

Smart Media Card

Toshiba, in alliance with Fuji Photo Film, Sega, Olympus and Tokyo Electron, created the solid-state floppy disk card (SSFDC) Forum (www.ssfdc.or.jp) in 1996. To provide a presence outside of Japan, several other companies, including Samsung Semiconductor, also joined the forum. While the consortium name remains, the cards have since become known as Smart Media cards. Toshiba and Samsung provide the flash memory chips and the card specification. Gartner Dataquest forecasts that the Smart Media cards will remain essentially flat in 2001 at about $400 million and then will gradually decline through 2004.

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\(^1\) Even though Compact Flash can transfer data at a data rate of up to 15MB/Sec, the average throughput is much less. This is due to system and interrupt latencies inherent to all Flash Media Drives.
Smart Media, with a dimension of 37.0 mm x 45.0 mm x 0.76 mm and a weight of 1.8g, is the lightest and thinnest small form factor card format in the industry available today.

Smart Media’s biggest advantage and most probable reason for success thus far is low cost. Because of its small and simplified design (that is, no on-board controller and primitive packaging), Smart Media cards are typically the lowest-cost cards compared with other form factors at equivalent capacity.

Similar to Compact Flash technology, the Smart Media data format is based on ATA standard. By adopting ATA, users can receive a host/system that can be independent of the flash memory technology and the flash memory supplier. Furthermore, host designers can develop system software more readily, as has been mentioned with Compact Flash. Smart Media embedded unique identification numbers that will be essential for the compliance of the SDMI portable device requirement. SDMI is the Secure Digital Music Initiative, a group whose goal is to "protect the playing, storing, and distributing of digital music" (from their website at www.sdmi.org). With a unique ID, the ability to make the Digital Data secure can be achieved.

Smart Media cards contain no memory on-board controller. They require the controller functions to reside on the host device or USB Slave Device rather than on the storage media. Lacking an on-board controller definitely has its cost benefits.

Like Compact Flash technology, Smart Media plays an important role in the digital camera market. Most of the digital cameras are shipping with 8MB, shifting to 16MB. Next year more cameras will use 16MB and 32MB.

**Memory Stick**

Sony's Memory Stick is a flash card the size of a stick of gum and is aimed at enabling personal area networks (PANs). It weighs 1.8g, with a dimension of 37 mm x 45 mm x 0.76 mm. Sony commercialized Memory Stick Duo in 2001. The smaller 20-mm x 21-mm x 1.6-mm media block comes along with a cartridge block of a regular Memory Stick size. The company has been shipping the Memory Stick since 1999 and has chosen to leverage its large captive market in consumer electronics by retaining sole control of the card's specification and charging royalties to licensees who wish to sell Memory Stick media or manufacture Memory Stick-compliant products. Sony has recognized the need to be more open if it is to garner support from other device manufacturers. The Memory Stick Web site (www.memorystick.org) allows Sony to promote development of Memory Stick-compliant applications and products by third parties.

Some versions of Memory Stick have included a special secure media protocol called Magic Gate. It is SDMI-compliant. Incorporating such security standards will be not only essential for copyright protection, but also essential for audio/video applications.

Sony's vision is that Memory Stick will enable the PAN, allowing users to transfer all types of digital information, images, audio files, electronic documents and presentations and so forth, between a multitude of devices.

While Memory Stick had a time-to-market lead over MMC (Multi Media Card) or Secure Digital Card, Sony's current development of the smaller Memory Stick Duo acknowledges that the regular Memory Stick was too large to be designed into cellular handsets.

**Multimedia Card**

Siemens (now Infineon Technologies) and SanDisk originally developed the MMC (Multi Media Card) to address mobile applications that demand a smaller form factor and reduced power consumption compared
with Compact Flash. The card is just slightly thicker (1.4 mm) than a Smart Media card and accommodates an on-board I/O controller and provisions for greater security. The Multimedia Card Association (MMCA) (www.mmca.org) has 90 member companies, including cellular handset heavyweights Nokia, Ericsson, Motorola and Siemens. Gartner Dataquest estimates that MMC-generated revenue was approximately $60 million in 2000 and will likely grow 60 percent to 65 percent annually over the next five years.

Similar to Compact Flash, but unlike Sony's Memory Stick, MMC (Multi Media Card) is governed by a truly open-standard association. This promotes greater global adoption of the standard by encouraging more companies to design compatible slots into their products. It also ensures members voting privileges and hence, more influence over the evolution of the card's specifications.

The MMC is supported by several cellular handset manufacturers whose volumes represent the single largest application for potential flash card consumption. One key reason (in addition to its small size) is the secure MMC's focus on enabling financial transactions in addition to copyright protection. The secure MMC has an on-board encryption engine and uses a longer, 128-bit key that other secure flash cards do not have.

Furthermore, cards supporting financial transactions require significantly less memory (for example, 4MB to 8MB of flash) than do cards used for audio, digital images or other data-intensive applications. This will directly translate too less expensive cards.

A near-term disadvantage is similarity to, yet lack of full compliance with, the Secure Digital Card. Currently, an MMC host device cannot accept the slightly wider Secure Digital Cards, though a Secure Digital host device can accept either an MMC or Secure Digital Card.

**Secure Digital Card**

Matsushita/Panasonic, Toshiba and SanDisk jointly developed the 32-mm x 24-mm x 2.1-mm Secure Digital Card. The Secure Digital Card Association (www.sdcard.org) was formed in January 2000 and has quickly gained an impressive following of 165 member companies from various industries, including computing, consumer electronics and automotive.

Gartner Dataquest views the potential annual revenue for Secure Digital Card sales to be as high as $800 million to $1 billion by 2004. This assumes that third-party support (i.e. support from parities other than Matsushita, Toshiba or SanDisk) will be greater for the Secure Digital format than for Sony's Memory Stick because of Secure Digital's more open nature and its focus on copyright protection from the beginning.

The Secure Digital Card Association has grown its membership faster than any other flash card standards body (the association has acquired 165 member companies in less than one year). The Secure Digital Card is backed by Matsushita/Panasonic, SanDisk and Toshiba, which should guarantee a substantial consumer market. The Secure Digital Card has a copyright-protection scheme that will enable content to be unbound to a given piece of media or device, as many other schemes require. Of course this presumes the devices are capable of detecting the Secure Digital Card's "watermark" (analogous to DVD-audio) that provides proof of origination. However, security implementations that offer consumers the most freedom to move their legitimate digital content around will have the greatest likelihood for acceptance. Additionally, the Secure Digital Card employs the content protection for recordable and prerecorded media (Content Protection for Recordable Media [CPRM] and Content Protection for Prerecorded Media [CPPM], respectively) standards supported by the DVD-video specification. The Secure Digital Card is highly influenced by the MMC specification. With the same length and width as MMC, Secure Digital's greater height allows the card to have more memory for higher data capacity. Host systems designed for the Secure Digital Card will also be able to read from or write to MMC. This is quite important, as MMC users can easily transfer their data to and use it in the new-generation Secure Digital systems.

Unlike Compact Flash or MMC, which operate as open industry standards without royalties, the Secure Digital Card was originally set up similar to the way Sony controls Memory Stick. That is, a closed, proprietary standard that would demand royalties from companies selling Secure
Digital Cards or Secure Digital-compliant devices. Since Secure Digital's inception, the Secure Digital Card Association was formed to make the Secure Digital specification more open with easier access to potential developers. The challenge for Secure Digital is that it is difficult to do a clean switch (from a closed, proprietary standard to an open, consortium-controlled standard) midstream. Matsushita, Toshiba and SanDisk developed and own the intellectual property for the Secure Digital Card, and other board members may be at a disadvantage when it comes to having an equal vote to determine the card's evolution.

The Secure Digital Card is primarily targeted at secure digital audio, video and other protected content. The current focus is on audio and compliance with the SDMI standard. However, backers of the Secure Digital Card format include manufacturers of cellular handsets, PDAs and automotive electronics. Future applications could include digital video storage and playback because of Secure Digital's support of DVD's copyright protection schemes and the greater compression available from MPEG-4.

USB Flash Media Controller

The USB2224 is a USB2.0 Bulk Only Mass Storage Class Peripheral Controller intended for supporting Compact Flash (CF) in True IDE Mode only, Smart Media (SM), Memory Stick (MS) and Secure Digital/Multimedia Card (SD/MMC) flash memory devices. It provides a single chip solution for the most popular flash memory cards in the market.

Figure 1 – USB2224 Block Diagram, shown following, describes the internal Architecture of the USB Flash Media Device.

Employing an enhanced architecture that utilizes an internal 8051 8-bit microprocessor running at 30Mhz and 12Kbytes of internal SRAM and multiple Double Buffered Bulk 512Byte Endpoint FIFO's, superior performance can be achieved.
Figure 1 – USB2224 Block Diagram
Enhanced Performance

The USB2224 is a USB2.0 Bulk Only Mass Storage Class Peripheral Controller. This device is able to transfer data to the host at rates that exceed all of the supported Flash Media maximum data rates. This is done by utilizing dedicated hardware that interfaces to each Flash Media interface. Additionally, SMSC has written firmware for each Flash Media Interface allowing a highly optimized algorithm transferring and moving data to and from the Host via USB.

The graph shown in Figure 2 - Percent increase in Speed from USB 1.1 to 2.0, below, summarizes the average Read/Write percentage increase in speed from standard USB 1.1 solutions available on the market when SMSC’s USB 2.0 solution is used. This increase in speed is derived from the USB Flash Controller being able to transfer data at high-speed\(^2\) (rather than the full speed transfer rate of USB 1.1 Controllers) over the USB bus as well as SMSC’s optimization of its internal logic and fast CPU.

This increase is substantial, and would have a dramatic effect on the “end user” experience. In the case of utilizing a “Compact Flash” device, an increase of 500 percent is achievable, allowing faster Read/Write times to and from the device.

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\(^2\) High Speed is defined to be up to 480Mbits per second This data rate is only available when the Host, Hub (Optional) and the device conform to the USB 2.0 “High Speed” specification. Full Speed is defined as data transfer rates of up to 10Mbits per second.
Flash Media controller as compared to a standard USB 1.1 Controller solution. As shown, for all of the media types discussed, SMSC’s High-speed solution increases performance. This is especially true for Read Accesses to the flash. The write and read transfer data rates of the USB 2.0 solution are up to three times faster than the fastest USB 1.1 solution. The graph also shows the maximum possible data throughput rate of USB 1.1. This indicates that given the data rates of Flash Devices today, USB 1.1 would unquestionably be the performance-limiting factor. This performance-limiting factor will continue as it relates to access times of the device. Additionally, as Flash devices become larger in memory size, and the Access times of these devices decrease, the USB 1.1 performance bottleneck will broaden.

Figure 3 - USB 1.1 to USB 2.0 Read/Write Media Performance Comparisons
Summary

The SMSC USB2224 is a USB2.0 Bulk Only Mass Storage Class Peripheral Controller intended for supporting Compact Flash (CF); Smart Media (SM); Memory Stick (MS) and Secure Digital/Multimedia Card (SD/MMC) flash memory devices. This single chip solution is a high performance (utilizing fast data transfer rates of USB 2.0) and cost effective device supporting the most popular flash memory cards in the market.

A USB 1.1 solution connecting a Compact Flash Device to a Host System (PC), in many cases, is the limiting factor with regards to throughput. A USB 2.0 solution removes the bottleneck thus achieving higher performance. A solution supporting USB 2.0 will allow the fastest Flash Data access to the host.

The advantage of a USB 2.0 solution over a USB 1.1 solution, as it relates to performance, is quite clear. As discussed, up to a %500 increase in performance can be achieved. This noticeable increase in performance would have an impact on the marketability of any Flash Reader product.