 

# Image Storage Technologies and System Implications for Digital Cameras

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## Abstract

The storage of digital image, both for short and long term, is becoming a hot topic of discussion amongst digital photography enthusiasts. With the introduction of a variety of affordable mega-pixel cameras, OEM's and consumers alike are quickly realizing that the storage solution can be both an enabler and an impediment to adoption of digital cameras by the masses.

This paper investigates the current and future removable storage technologies that could be the solution for both in-camera usage and long term archival. The technologies range from flash memory, magnetic, magneto-optical and optical. Each technology is characterized and compared in terms of technical attributes such as storage capacity, absolute and relative cost, read and write performance, power consumption, form factor and reliability. Other factors such as broader application appeal, market support, retail presence and standardization will also be explored since these factors can dramatically influence adoption. Our investigation will include system level considerations, such as added firmware or PC software and the compatibility with multimedia data types, such as video, still image and audio.

**Keywords:** image storage, digital camera, system issues, storage media

## Introduction

Currently the cost of digital cameras is considerably greater than its silver halide (film) counterpart. However the trend is toward an affordable mega-pixel camera with image quality and ease of use that rivals or exceeds that of film cameras. One critical component that could accelerate or impede the acceptance of digital camera is a storage technology that could support the usage model compelling for mass consumers. Currently solid state flash memory is the most popular storage media being designed into digital cameras. However even with the recent drastic price decrease, it is uncertain whether the cost of flash component will reach a sufficiently low price point to be considered by the consumers both for temporary and long term imaging storage. Furthermore, rotating storage media such as magnetic and magneto-optical disks have been miniaturized sufficiently to be a viable alternative to flash. The cost-density ratio of the rotating media are substantially lower compared to solid-state media. The issues however are power, reliability and cost for the disk drives needed to read/write the rotating disk media.

Typical size of an uncompressed image data captured by mega-pixel image sensor after color interpolation is greater than three megabytes (MB). To capture a set of 24 pictures with an image size of 3 MB each and an average lossless compression ratio of 2:1, it would require 36 MB of storage. At $4 per MB, the cost for that amount of flash memory is around $144. According to a survey conducted by Photo Marketing Association[1] (PMA), an average of 7.6 rolls of color film per household was used by US households in 1996. If the same images were stored on flash memory, it would cost in the range of $1092 per year in flash memory alone for 182 images, assuming 1.5MB per picture. Even before factoring in OEM mark ups and retail margins, we can arrive at the conclusion that the cost of flash is not consistent with driving the adoption of digital cameras into mass market in the short term.

Presently almost all consumer class cameras use lossy compression such as JPEG to reduce the memory required per image. The image data, after color interpolation and image enhancement, is compressed to a finished file and written to the storage media. The compression process is a necessary compromise to control the cost of storage from becoming excessive for consumer cameras. However compression adds complexity and implementation cost to the camera, and compromises image quality which detracts from the original intent of moving to mega-pixel sensors. If the cost of storage is sufficiently low, and if the storage media can also freely interoperate between cameras, PCs and peripherals, there is no need for compression (or at least lossy compression), for cameras!

Intel has proposed an alternative partitioning where the image data is lossless compressed in raw format for in-camera storage. The host PC is responsible to decompress and finish the processing to complete the file. Albeit this architecture effectively reduces the amount of storage needed per image, it is not a direct solution for the storage problem.

## In-camera storage options

The removable storage media being designed into digital cameras fall into one of the following categories – solid-state miniature flash memory cards, magnetic disks and magneto-optical disks. The different types of flash memory cards include CompactFlash card, SmartMedia card and Miniature card. For the purpose of comparison we will also evaluate two alternatives to flash cards – Click™ and Minidisc.

Facing with many available and viable storage media technologies, and without one with a clear overwhelming advantage in all of the important attributes for digital cameras, an OEM is faced with a difficult choice. Yes, there is a market share leader at the moment but could that position be sustained over long term? Are we facing with the Beta/VHS scenario all over again where the Beta format also had an early market share lead. Furthermore, what will be the usage model for such storage media when digital camera goes into mass adoption? Are we looking at a video tape model where the consumers will use the removable media for both temporary and long term storage? Or alternatively will this be more analogous to a camcorder battery model where a consumer might have a single spare to increase the usage duration? Finally could there even be the possibility of an electronic film model where the removable storage is actually a consumable item?

## Solid state versus rotating media

Flash memory is one of the fastest growing segments of the semiconductor market. With the steep drop in the price of DRAM in the last two years, many manufacturers have shifted production over to flash in the hope to participate in a more lucrative market. This additional influx of capacity has instead triggered a precipitous drop in the price of flash memories. Nonetheless the storage density of flash on a per chip basis is catching up with DRAM, with improvements in write time, write cycle, and single supply operation. All of this translates to lower cost and increased capacity of miniature flash cards for markets such as mobile computing, portable communication devices, and digital camera.

Rotating magnetic disk for data storage has been in use for decades. With the advent of personal computing the cost-density curve of both fixed-disk and removable disk drives has been improving at a rate even more aggressive than semiconductors' Moore's law. On a dollar per Mbyte basis the trend for the last eight years has been averaging at over 60% year to year improvement. Comparatively during the same eight year period, dollar per Mbyte for flash memories has been averaging around 40% year to year improvement. If it were determined only on the basis of the cost per Mbyte the decision would have been simple. Obviously other factors such as size, weight and power are equally if not considered more important for digital camera use than absolute lowest cost per Mbyte. However with the need for higher and higher capacities, it is a battle to see if flash memory could accelerate the downward cost trend even more, or if the rotating magnetic storage systems could be significantly miniaturized and reduce the power needed to operate.

## Removable miniature flash cards

The three miniature flash cards are similar in size and offers adapter cards for the PC using the PC-Card slots. The major differences are in the type of flash component used in the card, and in the partitioning of control functions between hardware and software necessary to support the cards. A snap shot cost for the three cards in different commercially available capacities are listed in Figures 1 to 3.

CompactFlash is the only flash card that contains an on-board microcontroller. This on-board 32-bit controller handles all management of the flash components and provides a standard ATA interface to the host of the card. The advantage of this partitioning is that the card will appear as an ATA disk drive for the camera as well as the PC host. The on-board microcontroller isolates the flash component from the interface so the card can use different type of flash memories. In practice NAND and AND are the two types that have been implemented. The two main disadvantages are cost of the microcontroller (and supporting devices), and not being able to manage in-camera flash memory and the CompactFlash card as an unified memory resource. The card uses a 50 pins male/female connector system for connection.

The Miniature card contains memory only. The interface, which consist of a 16-bit data bus, 25-bit address bus and control signals, will support a variety of different memories including flash, ROM, and DRAM. It requires NOR type flash when used as flash cards. The card also relies on an elastomeric connector system to mate 60 pins which has been the source of much debate about its reliability. The main advantage of the Miniature card is the direct memory bus interface which allows any in-camera memory and the flash card to be treated as an unified memory resource, including executing code from the card. However this interface becomes a disadvantage when interfacing with the PC since an additional layer of software is needed on the PC to read/write the card.

SmartMedia also contains memory only. It is essentially an NAND flash die in a plastic package with 22 leads brought out to two rows of contact pads. Originally each SmartMedia card can only accommodate a single flash die which limits the capacity of the card. However recently two dies has been packaged into a single card to increase the capacity of the card. The main advantage of SmartMedia is that it should be the lowest cost card amongst the three formats. The disadvantages are the limited capacity of the card, and the interface issue similar to the Miniature card.

## Software ease of use

CompactFlash card is the easiest to interface from a software perspective. It is a basic ATA/IDE interface of Ports and Read/Write Registers. The flash media is completely managed by the microcontroller inside the flash card, including error detection and correction. The interface is readily compatible to the PC-Card systems and will operate as a PC hard drive through card and socket services.

In contrast, Minicard requires the most complex software amongst the flash cards. A software layer referred to as the Flash Translation Layer (FTL) running in-camera or on the PC host does the management of the flash memories. Simplistically speaking, the FTL converts the linear array of 64KB blocks of the NOR flash memory into a series of 512 byte sectors of a PC hard drive, converts the ATA track, sector and head references, and management of the flash memory such as device leveling and garbage collection. Minicard has no explicit support of error detection and correction.

Since SmartMedia is little more than NAND flash dies packaged in a plastic wrapper, the software/hardware partitioning can be more flexibly defined. The NAND flash device has a serial architecture with register level interfaces, a file storage specification with configuration registers and data read/write registers. The support of error detection and correction is optional. Dedicated controllers can be used inside the camera and inside the PC-Card adapter to provide an ATA interface. Alternatively the in-camera software similar to FTL can manage the NAND flash memory while the controller inside the PC-Card provide the ATA interface to the host. Toshiba is also offering a floppy disk adapter and PC driver software to provide PC connectivity.

## Comparisons

Factors that differentiate the various storage media for camera use are size, weight, capacity, power consumption, interoperability with PC, cost of media, cost of integration, data transfer speed, usability for long term storage, and lifetime reliability. Not all of these factors are of equal importance for OEMs deciding on which media type to use. Typically it is the capacity, cost of integration, cost of media and PC interoperability that are weighted more heavily than other factors when deciding within formats of the same technology (e.g. which flash card to use?). When deciding between technology categories (e.g. rotating magnetic disk versus solid state flash memory) all of the factors comes into play and are weighted depending on the design focus of the camera.

The SmartMedia cards are the thinnest and lightest of the three flash formats. It also has the potential for being the lowest cost due to its simplicity of packaging and contact design. However the mechanical design of the card also has several negative aspects. The 3V and 5V versions of SmartMedia cards by design are not physically compatible and cannot be used interchangeably. Then there is the electrical contact design of the card requiring a protection mechanism during card insertion and removal to prevent the shorting of the contacts from damaging the card. The major disadvantage of SmartMedia is that its maximum capacity is limited to what can be provided by one or two NAND flash dies. In comparison the other two formats can accommodate many more dies and therefore can have higher capacity cards than SmartMedia.

The CompactFlash cards are the easiest to integrate into cameras and interface with PCs. It also has the potential for supporting the highest write speed. Several CompactFlash cards on the market today already integrate buffers to increase the effective write speed of the card. The 528 MByte maximum address space supported by the CompactFlash card is also higher than the other two formats. The major disadvantage of CompactFlash is the additional internal components besides the flash memories that add cost to the card. This "overhead" cost as a percentage of the overall cost of the card will diminish as capacity increases. However the additional cost factor for CompactFlash will likely prevent it from being the lowest cards compared to the other two formats, even at a limited capacity.

The Miniature card has the benefit of being able to be integrated with other in-camera memories, including additional flash memories. This mean it is easier to design a digital camera with Miniature card that could be used without a flash card installed relying on in-camera flash for storage. The ability to be able to execute code directly from the card opens the possibilities of using the card to distribute additional application software for in-camera use. The design of the Miniature card should be very cost competitive against the SmartMedia cards. However there are two major inconvenient factors in using the Miniature card. First is the additional FTL software that must be integrated into the firmware of the camera to manage the flash memories and to write to the card using PC format. The second is the mechanical impact of the card to design of the camera. The elastomeric connector system requires a more complex design to insert the card compared to the other two formats.

Referring to the information summarized in Table 1, we can conclude that no one format is advantaged in all of the important attributes. If we rank the three card formats both objectively and subjectively, tables similar to Table 2 can be filled out. In most areas the advantage is actually quite marginal, except for the cost of the card, and the highest capacity of current products. We have observed these are the two areas that frequently become the decision factor in deciding between these three formats.

## Alternative to removable flash cards

Click™ is a magnetic disk and drive system introduced by Iomega. The disk is approximately 2 inches in diameter and has the capacity of 40MB. The major benefit of the Click™ system is the price of the media. Iomega and their partners will be selling the Click™ disks at less than $10 retail. The drive is available in two versions, a version that can be integrated into portable handheld devices such as a digital camera, and an external version for use as an accessory. The Click™ drive uses an IDE/ATAPI interface, which allows the drive to be easily integrated into products. The IDE/ATAPI interface also allows the drive to be used to "boot" or execute code directly from the disk in-cameras, or used as spool or swap space by the in-camera software. This is an unique capability of the Click™ system and makes it most versatile in terms of the type of applications it can enable. However there is no getting around that a disk drive requires more power to operate and takes up real estate inside the camera when compared to flash cards. The size of the Click™ drive is about the size of a PC-Card (3.37in x 2.13in x .26in) and weighs 2 ounces. The drive operates at 3.3V and supports several power management modes when not in use. The Click™ disks are rated at over 10 years of data retention without degradation.

Minidisc (MD) was introduced by Sony in 1992 as a consumer recordable music medium to replace cassettes or CDs. Sony introduced another version of the Minidisc in 1993 for data storage. The MD disk is 64mm (2½ inch) in diameter housed in a protective cartridge measuring 70mm x 67.5mm x 5mm, has data capacity of 140 MB, and uses a magneto-optical process call Magnetic Field Modulation Direct Overwrite to record data. Physically the MD disk is made of a magnetic layer, a dielectric layer and a reflective layer sandwiched between a plastic substrate material and a protective layer. A laser is used to heat up a small area of the magnetic layer to its Curie temperature (about 400 degrees Fahrenheit). A magnetic head on the opposite side of the disk is used to write data into the heated area. During read time the laser beam, used in a lower power mode, is reflected off the disk surface. The polarization of the laser light due to the Kerr effect will change depending on the magnetized state of the particles in the magnetic layer. The advantages of the MD system are relative low cost of the media (between $5 and $10), higher storage capacity compared to flash cards and Click™ disks, and the robustness of the MD disks against handling, exposure to magnetic field, and can retain data for over 30 years without degradation. The disadvantages of MD are the size, weight and power consumption of the drive and read/write system. Minidisc does not use or have an adapter for IDE/ATA/PC-Card interface, which means connectivity with PC desktop or laptop will be extremely difficult.

IBM recently announced a miniature hard drive technology call Microfile that could have significant application for digital cameras, provided IBM decides to develop it into a commercial product. Microfile is a complete hard drive packaged into the type 2 Compact Flash Association (CFA-2) format (36.4mmx42.8mmx5mm). IBM has reported two available capacities: 340MB and 170MB. The drive will be electrically and logically compatible with the CFA-2 standard, and will be powered through the CFA-2 connector. According to IBM, Microfile is the result of 5 years of research which produced special motors, special lubricant and miniatures designs. IBM is careful to mention that Microfile is still a technology and not yet an announced product. An attractive aspect of the IBM technology is that it is a complete self- contained system, with no mechanism that has to be integrated into the camera.

## Long term storage options

If the cost of media is low enough, the same removable in-camera storage devices could also be used for long term storage. This is much like the usage model of the camcorder video tape, or even the silver halide film. A consumer could transfer the images from the in-camera memory to an external storage medium for long term archival. In the current usage model and mostly by default, the hard drive on the PC serves as this long term storage archival. However as the number of digital images increases, we believe consumers will look for an alternative long term archival medium. The reason for this is quite simple and analogous to the traditional photography – we place a great deal of value on the images and demands safe keeping for our treasured memories. Many of us are used to the need to backup our computer data in case of an unexpected demise of the hard drive on our PC or laptop. We expect the same will be the case for digital images.

Could any of the previously discussed storage media be suitable for long term storage? The initial answer, unsurprisingly, is it depends on the cost of the media. For long term archival and unlike in-camera storage, the media is the main concern. The cost of the media has to be sufficiently cheap for consumers to be willing to treat it as a consumable item, much like the video tapes, silver-halide films and floppy disks. It is for this application the rotating media system such as Click™ and Minidisc has an advantage over flash memory cards. From a cost per bit basis the rotating media are currently 10X to 40X cheaper than solid state flash. The cost and density improvement curve is also in favor of the rotating media.

Several other storage systems are worth mentioning in the usage model where the consumers will transfer the images from in-camera storage to a dedicated long term archival system. These systems were originally conceived for entertainment and computer applications but could also be deployed for long term storage of digital images:

- CD-ROM (write-once)
- CD-R (recordable)
- DVD-ROM (write-once)
- DVD-R (recordable)
- DVD-RAM (read/write)
- Digital video cassette
- Magnetic removable disk drives
- Magneto-optical removable disk drives
- Magnetic fixed disk hard drives
- Magnetic tape drives

The tape drive systems are disadvantaged compared to disk-based systems due to the sequential access nature of the tape. From a shelf life and robustness perspective, the magneto-optical media should have an advantage over magnetic disk or tape media. The relatively low data transfer rate of the magneto-optical system compared to the magnetic fixed or removable disk system is not a serious draw back for archival use.

A long lasting and broadly supported standard "format" is also necessary for archival of digital images. After all, it would be difficult to read a file from a 5.25" CPM formatted diskette today even if the floppy disk retained the original data without degradation. This is a cause for concern for some of the storage technology where a "format" is also defined as part of the storage system. We expect that for long term archival of images, the standardization of a "format" is a more critical consideration than the type of media that holds the image data.

## Going into the future

The cost of storage media will become even more critical as the price of the digital camera drops below $300 for a high quality mega-pixel model within the next 2 years. We expect, as consumers become more educated, the cost of media will be factored into the buying decision along with the price of the camera. The market share lead for in-camera removable storage will be transition to, or be held by a storage system that can enable rather than being an obstacle to lowering the price of adoption for the cameras.

It is likely that both magnetic and magneto-optic storage systems will play a more significant role for digital cameras in the future. This will happen for both in-camera removable storage and for long term archival storage. The initial adoption will be in very high-resolution digital cameras and cameras with substantial video capture and multimedia capability. The flash cards will continue to be in wide use as magnetic and magneto-optical media gains in popularity. The usage of these different storage media will be clearly differentiated depending on the feature and function of the camera. There is no need to standardize the media if the interface and an imaging format can be standardized instead.

## Interface and infrastructure

Today the digital photography segment of the industry is still too immature for a single storage media to emerge as a standard. There are logical arguments to support more than a single storage media standard going into the future. We expect that all of the current media technologies will continue to experience major advancements within the next two to three years. The important factor for the industry is a standard interface from which all of these advancements can be accommodated, and for that standard to be widely adopted by the supporting infrastructures. Today we have many storage solutions available to us on the PC because the innovators can design to a known standard set of interfaces available on the PC (e.g. IDE, ATA, SCSI). We propose this is similarly needed for digital cameras as well as other handheld computing devices that could benefit from cheap and high performance electronic storage.

The interface proposed by the CompactFlash Association (CFA) has an early lead because it has value beyond being an interface to flash card. With the release of the type II CFA specification, which remains compatible with the original CFA interface, this is the only available miniature interface that could also be used as an expansion connector for digital cameras. The memory-bus interface of the Miniature card has the potential but lacks the physical attribute to be convenient as an expansion interface. For SmartMedia the NAND memory interface and the extreme thinness of the card makes it all but impossible to use as an expansion interface. Other interfaces on digital cameras are either size disadvantaged, or can only be suitably used as a communication channel.

 

## Conclusion

If a standard interface is broadly accepted within the developing digital photography infrastructure, the question of which storage media to use becomes much less significant. A standard interface rather than a standard media type will also have the benefit of concentrating the development spending of the industry. Unlike traditional photography, the digital photography infrastructure includes interoperability issues with the computing and entertainment. It is important to note that as the photographic industry transitions to digital, the innovation and leadership could also be coming from the computing and entertainment companies. Looking towards the future of digital camera storage technology we can predict one trend with certainty – there are much more interesting developments to come.

## References

1. *1996-1997 Digital Imaging Industry trends report*, Photo Marketing Association International, November 1997.

2. ISO/TC42-DIS 12234-1, Photography – Electronic still picture cameras, "*Removable memory, part 1: Basic removable memory reference model*", May 1997.

| Attributes | Advantaged |
|---|---|
| Size | SmartMedia |
| Weight | SmartMedia |
| Capacity of current products | CompactFlash |
| Power consumption | SmartMedia |
| Ease of use | CompactFlash |
| Media cost | SmartMedia |
| Integration cost (in-camera) | CompactFlash |
| Integration with in-camera memory | Miniature Card |
| Data transfer speed | CompactFlash |
| Reliability | CompactFlash |
| 3V/5V interoperability | Miniature Card |

**Table 1**

| | Compact Flash | Miniature Card | SmartMedia | MiniDisc | clik! |
|---|---|---|---|---|---|
| Size | 36.4mmx42.8mm x3.3mm | 38mmx33mm x3.5mm | 45mmx37mm x0.76mm | 68mmx72mmx5 mm | 3.37inx2.126in x0.256in |
| Weight (g) | 11.4 | 9 | 1.8 | | 10 |
| Capacity (MB) | 2 to 48 | 2 to 64 | 1 to 8 | 140 | 40 |
| Component type | NOR,D.NOR,AND | NOR | NAND | Magneto-optical | Magnetic |
| Practical Write Speed Min.(KB/sec) | 130 | 97 | 470 | 150 | 500 |
| Practical Write Speed Max.(KB/sec) | 400 | 220 | 730 | | 1000 |
| Read power (watts) | 0.135/0.375 | 0.033/0.2 | 0.075 | | |
| Write power (watts) | 0.225/0.45 | 0.1056/0.2 | 0.2 | | |
| Controller | built-in | in-host | in-reader | | |

**Table 2**

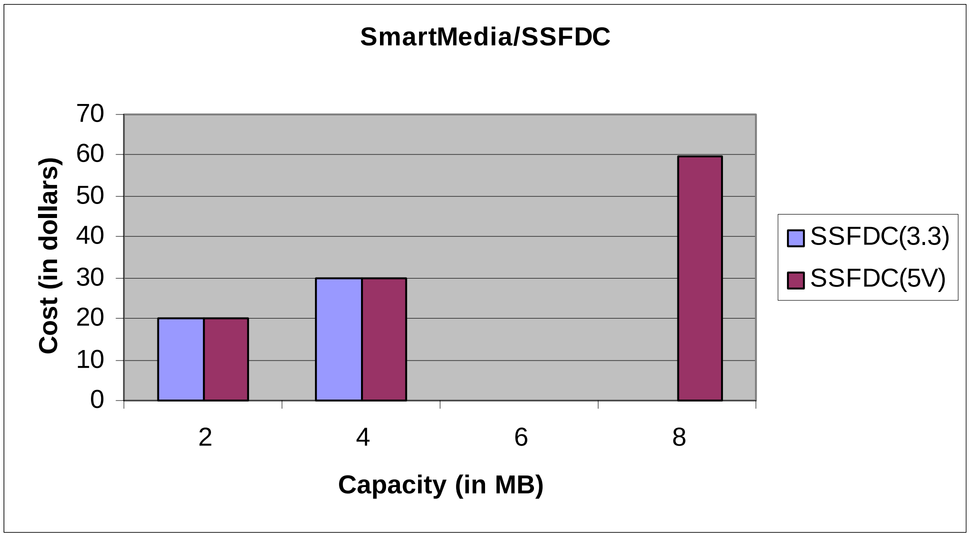


**Figure 1**

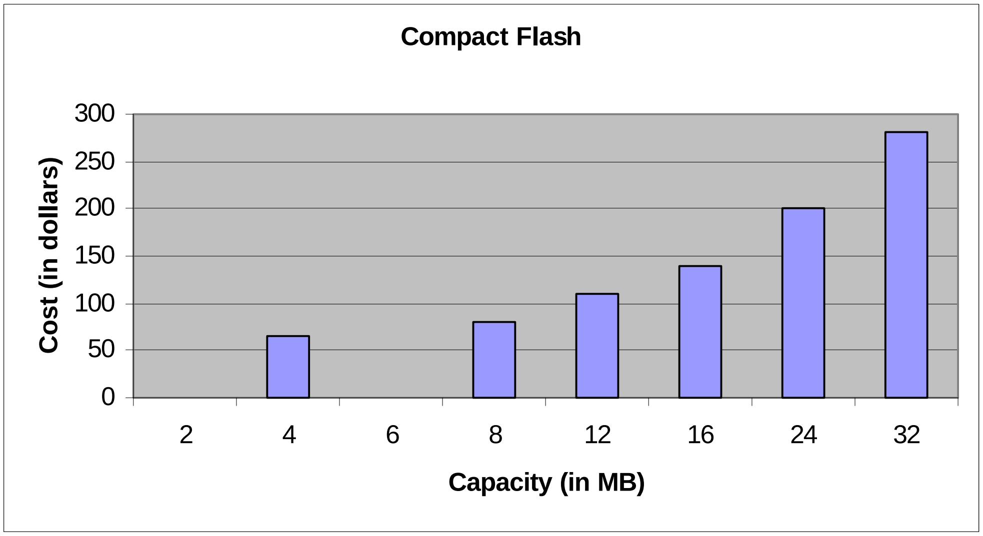


**Figure 2**

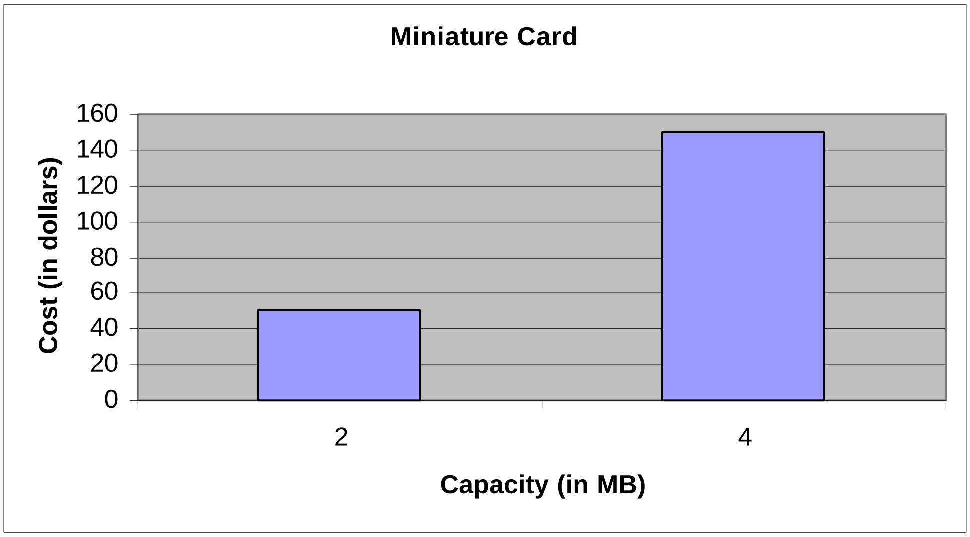


**Figure 3**