 By Brian Dipert, Senior Technical Editor

THE NUMBER OF MEMORY- AND I/O-CARD FORMATS YOUR SYSTEMS POTENTIALLY NEED TO SUPPORT IS INCREASING. INSIGHT INTO HOW THE CARDS MAY FALL WILL HELP YOU SELECT A WINNING HAND.

PICK A CARD

THE DIVERSITY OF AVAILABLE memory cards has long complicated your product-definition and -design decisions (**Reference 1**). But, even though smaller and more obscure formats have faded over the years from the scene, even more formats have replaced them, and the contenders that survived have diversified into copious permutations (**Figure 1** and **Table 1**).

Blame capitalism. At the beginning stages of the life cycle of an application, such as digital imaging, the free-market system encourages a diversity of incompatible approaches to problem-solving, with each alternative striving to get the biggest slice of the overall application pie. In the near term, the resultant confusion encourages consumers to keep their money in their wallets, constraining the size of the pie. Eventually, however, some of the problem-solvers run out of money or otherwise lose enthusiasm for the game. Others carve out a sustainable niche, often with the help of "bundling" partnerships with other companies and sibling divisions of the same company targeting the same application—digital cameras, for example. The market settles down to a few alternatives, and the pie grows. Then, a new application bursts onto the scene, and the race is on again.

Time and again, a consistent theme in the card-format industry market emerges. If several competing approaches exist, all able to meet the application needs, but one is more compact than the others, the industry will anoint it as the dominant choice. The corollary to this theorem is that, once a more svelte suitor can fully address application requirements, it'll capture the lion's share of the business that its predecessor previously owned. The driving force behind this trend is simple: Vendors are squeezing more and more functions into smaller and smaller system form factors. But the words "able to meet the application needs" are critical.

Is a given format dense enough and at a cost-effective price point? Does its system in-

Figure 1 **A multiplicity of memory cards awaits your evaluation; among them, from left to right, are SD Card, MultiMediaCard, xD-Picture Card, and TransFlash.**

terface deliver adequate burst and sustained read- and write-transfer rates (see **sidebar** "Who's write?" on the Web version of this article at www.edn.com)? Is it sufficiently rugged and power-thrifty? If removable, is it *so* small or thin that a consumer could accidentally break it or leave it in a shirt pocket that subsequently goes through the laundry? Costs may be the first 10 priorities that an engineer uses as evaluation criteria, but they aren't the only priority. Consumers intuitively realize, if not right away than assuredly after their first debacle, that the value of the information on memory cards is much higher than the price they pay for the memory cards, thereby explaining the fast-growing market for image and other file-recovery utilities for memory cards. Therefore, as a rule, they're less price-sensitive in this arena than they are in other shopping situations.

The fading fortunes of the memory-card trailblazer, PCMCIA, or PC Card, aptly exemplify the form-factor-crossover rule. I was on the team in the early 1990s that developed the ExCA (Exchangeable Card Architecture) standard at Intel, which eventually became industry-standard PCMCIA. With great fondness (and a little embarrassment), I remember how proud we all were of the first-generation Intel flash-memory cards with their then-whopping 1-Mbyte capacities. Now, of course, you can buy *8-Gbyte* PC Cards based on flash memory from Pretec and other companies, and 16-Gbyte versions are scheduled to appear this year. But few consumers will buy these products because most applications don't demand these hefty densities, and users are unwilling to pay for them. Look at Toshiba. The company offers 1.8-in. hard-disk drives in densities as large as 60 Gbytes, yet the largest PC Card it produces based on those drives stores only 5 Gbytes.

PC Card slots are also rapidly disappearing from notebook PCs, as built-in connectivity broadens its penetration and as smaller, cheaper alternative expansion connectors become mainstream (see **sidebar** "I/O devolution" on the Web version of this article at www.edn.com). For these and other reasons, CompactFlash cards, smaller derivations of the PCMCIA and follow-on CardBus hardware and software interfaces, have taken over most of the PC Card business, greatly expanding the overall card market in the process. Until recently, CompactFlash was the dominant card form factor. Yet, it too is in the process of becoming obsolete, as even smaller formats break through the good-enough barrier. 1-Gbyte CF cards based on flash memory are mainstream, larger versions are also available for niche applications, and 4-Gbyte, 1-in. hard-disk drives (with 5-Gbyte versions on the way from Seagate) squeeze into the Type II CF-format option. Cards based on magnetic media are traditionally cost-effective only at the highest densities in the available capacity range, especially when they come in nonstandard form factors (see **sidebar** "Surgical success" on the Web version of this article at www.edn.com).

AT A GLANCE

- ▷ First generation formats' fortunes fade due to integration and the emergence of enhanced alternatives.
- ▷ The SD Card has won early battles but may still lose the second generation war to its MMC foe.
- ▷ Proprietary formats acquire scant support beyond their backers' systems.
- ▷ USB ubiquity delivers current success and, likely, an even more lucrative future.

Over time, the flash-memory-versus-hard-drive decision criteria remain constant, with flash getting the nod at low densities, thanks to its superior power-consumption and ruggedness characteristics. However, the one-versus-the-other crossover point in density continues to migrate upward. To the extent that hard-disk-drive densities overshoot an application's requirement, the semiconductor-versus-magnetic-storage pendulum shifts in flash memory's favor. Dense cards are popular with "prosumer" (professional/consumer) and professional-camera users, for example, who take lots of high-pixel-count, raw, and TIFF pictures. Sooner or later, though, flash-memory capacities will adequately serve even that need, elbowing aside the hard-drive alternative. And, smaller card form factors will grow in capacity to the point at which they will push aside CompactFlash. It's survival of the fittest.

As the CompactFlash market matures, suppliers are differentiating their products in the hope of eking out continued profits. Lexar Media, for example, has added WA (write-acceleration) technology support to its cards' memory controllers; if the mating system has WA-aware firmware that employs Lexar-friendly superset algorithms, Lexar claims, a meaningful performance boost will result. Sandisk's 4-Gbyte cards neatly circumvent the 2-Gbyte-capacity limitation of the antiquated FAT (file-allocation-table)-16 file-system support that many systems include. You can operate the card at its full single-partition capacity for use with FAT32. (Microsoft doesn't recommend NTFS-formatting flash-memory-based cards due to the file system's excessive "thrashing" of the media.) Alternatively, you can appropriately toggle a mechanical switch to access two 2-Gbyte partitions. Acknowledging the growing prevalence of single-slot CompactFlash systems, Sandisk also sells CF cards that combine flash-memory storage with IEEE 802.11b connectivity. And Lexar and Sandisk, along with other companies, offer cards rated for extended-temperature storage and operation.

Reference 1 predicted SmartMedia cards' eventual demise, and this forecast has largely come to pass. SmartMedia cards, formerly known as SSFDCs (solid-state floppy-disk cards), are in effect just other packaging options for the NAND flash-memory die inside them. They don't contain a memory controller, which their advocates claimed translated to lower media cost. Although this situation may have been true in the mid-'90s, Moore's Law-driven less-than-100-nm lithographies have made it a hypothetical point, and, overall, the disadvantages of the controllerless approach outweighed the advantages. Consumers could not upgrade a system-housed memory controller for compatibility with subsequent-generation memories that had higher densities, altered program- and erase-block sizes, and the like. Other flash-memory technologies could not easily shoehorn into the NAND-centric SmartMedia interface. And people commonly viewed SmartMedia as too flimsy to withstand the kind of abuse that they would subject it to.

SECOND-GENERATION SUCCESSES

The CompactFlash card's loss of momentum has been, to a large extent, the SD (formerly, Secure Digital) card's gain. SD's success story is an example of the classic adage of being in the right place at the right time, helped along by a heaping portion of politically fueled partisanship. Ironically, few of today's applications harness the "secure" aspect of SD—specifically, its support for CPRM (content protection for recordable media, **Reference 2**). However, the SD card, which Matsushita/Panasonic and Sandisk originally championed, burst on the scene right when the point-and-shoot-digital-camera and PDA markets started to heat up. Both applications welcomed its combination of thumbnail-sized form factor and higher-speed-than-the-alternatives, 4-bit data-transfer bus (see **sidebar**, "Testing, testing" on the Web version of this article at www.edn.com).

SD cards in densities up to 512 Mbytes are now in high-volume production, and 1-Gbyte cards have recently appeared. Like its CompactFlash predecessor, the SD card comes in both conventional and enhanced variants; the enhanced versions tout such features as ultrafast read and write performance and tolerance of exposure to water and extended temperature. Sandisk is, as with CompactFlash, bundling WiFi connectivity and flash-memory storage in a common SD card for single-slot systems containing SDIO controllers. One application that SD slots *haven't* widely penetrated, however, is cell phones—aside from PDA-derived Pocket PC Phone Edition units. Part of the reason is that, until recently, with the emergence of camera-inclusive phones, no compelling reason existed for large amounts of resident storage.

The other key aspect of the SD Card's lack of success in phones centers on the phone manufacturers' intolerance for paying royalty fees. Enter the knight in shining armor: the royalty-free MMC (MultiMediaCard; association membership includes license fees). MMC's lineage goes back to then-Siemens' (now Infineon's) ROM-based card of the mid-1990s. Ironically, because the nine-contact SD card is a functional superset of the seven-contact MMC, MMCs *could* find use in any SD application. They haven't to any significant degree because of several factors, most notably, speed: MMC's single-bit data bus, running at 20 MHz, allows for only a 2.5-Mbyte/sec peak transfer rate; SD's peak transfer rate is four times higher. Other factors include that promotion of the product has to date been relatively invisible and that industry-standards bodies work at a molasses-slow pace. How slow? My four-year-old article mentions an under-development specification enhancement, security, which the MMC Association *still* hasn't finalized.

The MMC Association claims, however, that it's now charging full steam ahead. It recently finalized Version 4 of the MultiMediaCard specification, also known as MMC Plus and HS (High Speed)-MMC, which evolves the bus into backward-compatible 1-, 4-, and 8-bit-wide options. (The 4-bit option is hardware-compatible but software-incompatible with the SD card implementation.) The 8-bit option translates to a 13-contact card interface and boosts the clock rate to 52 MHz, thereby delivering a peak transfer rate as high as 52 Mbytes/sec. Dual-voltage cards run in both 1.8 and 3V systems. And MMC Association Executive Director Andy Prophet predicts that the association will by year-end finalize the Secure MMC specification, which it is developing with the OMA (Open Mobile Alliance). Then again, the MMC Association's press-release archive reveals that the organization also claimed it had in late 2001 completed the secure-card specification. Renesas has also recently unveiled its proprietary X-Mobile Card, which adds full smart-card functions, such as a Java Card operating system, hardware tamper-resistant module, and cryptographic functions, to the MMC form factor.

One other roadblock in the way of SD Card or MMC adoption in diminutive cell phones is their proportional size. In response, both associations have developed smaller card variants, respectively called the mini-SD and RS-MMS and renamed the RS-MMS as MMC Mobile in its Version 4 high-speed interface version. A removable-memory card isn't the only architectural option cell-phone manufacturers are considering for boosting lo-

TABLE 1—CARD ALTERNATIVES AND RELEVANT SPECIFICATIONS

Card format	Size (mm)	Total interface pin count	Data-interface pin count	Interface clock rate (MHz)	Maximum data rate at host interface (Mbytes/sec)	Voltage (V)	Built-in memory controller	Security
PCMCIA	85.6×53.8×3.3 (Type I) 85.6×53.8×5 (Type II) 85.6×53.8×10.4 (Type III)	68	Eight, 16, or 32	8 (PC Card variant) 33 (CardBus variant)	16 (PC Card variant) 132 (CardBus variant)	3.3 5	Yes	No
CompactFlash	42.8×36.4×3.3 (Type I) 42.8×36.4×5 (Type II)	50	Eight or 16	8	16	3.3, 5	Yes	No
SmartMedia	37×45×0.8	22	Eight	NA	20	3.3, 5	No	No
MultiMediaCard (MMC)	24×32×1.4	Seven	One	20	2.5	1.8, 3.3	Yes	Optional
MMCplus	24×32×1.4	13	Eight	52	52	1.8, 3.3	Yes	Optional
RS (Reduced Size)-MMC	24×18×1.4	Seven	One	20	2.5	1.8, 3.3	Yes	Optional
MMCmobile	24×18×1.4	13	Eight	52	52	1.8, 3.3	Yes	Optional
SD Card	24×32×2.1	Nine	Four	20	10	3.3	Yes	Yes
Mini-SD Card	20×21.5×1.4	Nine	Four	20	10	3.3	Yes	Yes
Memory Stick	21×50×2.8	10	One	24	3	3.3	Yes	No
Memory Stick Duo	20×31×1.6	10	One	24	3	3.3	Yes	No
Memory Stick Pro	21×50×2.8	10	Four	40	20	1.8, 3.3	Yes	Yes
Memory Stick Pro Duo	20×31×1.6	10	Four	40	20	1.8, 3.3	Yes	Yes
TransFlash Memory	10×15×1.1	Nine	Four	20	10	3.3	Yes	Yes
xD-Picture Card	25×20×1.7	18	Eight	NA	20	3.3	Yes	No
USB Flash Drive	Various	Four	One (differential)	12 (Full Speed) 480 (High Speed)	1.5 (Full Speed) 60 (High Speed)	5	Yes	Optional

Notes:
1. Samsung supplied most of the information in this table. 2. Confirm information with relevent vendors and standards bodies before finalizing your design.

Figure 2 Delkin's USB bridge enables tether and data transfer between mass storage devices (a), while Kanguru's HDD- (b) and CDRW-based (c) media readers enable you to offload your diminutive memory cards without a laptop PC.

cal-storage capacity. And it's not clear that the cellular carriers will be interested in offering phones with large amounts of resident storage. They may prefer that camera-phone users, for example, upload pictures to the carriers' servers for subsequent editing, e-mailing, and printing, thereby both increasing consumers' airtime usage and creating an additional service-revenue stream. Although the carriers' vision in theory sounds good, at least for the carriers' stockholders, the practical limitations of sluggish upload speeds may dash those plans.

ACHIEVING LIMITED ADOPTION

At first glance, you might think it strange to see the words "limited adoption" referring to the small-form-factor Memory Stick format. After all, several memory-card manufacturers' portfolios promote it, and a diverse collection of cell phones, PDAs, still cameras, printers, videocameras, digital-audio players and recorders, and laptop computers support it. Peer closer, though, and you'll find the name Sony on almost all of these systems. Sony doesn't discuss the terms of its licensing proposals, so it's difficult to judge to what extent monetary considerations played a role in other vendors' lack of interest in Memory Stick.

Clearly, though, Sony is a formidable competitor in numerous application areas. (For example, Panasonic originated the SD Card in response to Memory Stick.) And Sony's competitors don't want to do anything that would add to Sony's coffers. Instead, other companies generally seem content to require that consumers purchase third-party adapters if, for example, they want to transfer pictures from a Sony digital camera to a non-Sony PC. Analogous to the evolutionary steps that MMC took, Memory Stick now comes in the Memory Stick Pro version, which has higher transfer rates, supports a larger directly accessible address range, and includes MagicGate encryption, and the Memory Stick Duo and Memory Stick Pro Duo versions, which have smaller form factors.

In the past, Fujifilm's and Olympus' cameras, along with early digital-audio players from companies such as Creative Labs and Rio (now Digital Networks North America), were the predominant users of SmartMedia cards. As that format faded from the limelight, Fujifilm and Olympus switched gears and migrated to a niche format of their own creation: the xD-Picture Card. Card vendors such as Lexar Media and Sandisk support this technology, which offers the predictable benefits: compactness and high-speed data transfers. Its primary advantage to Fujifilm and Olympus appears to be revenue-related; the companies' latest cameras work only with xD-Picture Cards, and proprietary formats as a general rule sell for two to three times more than their equivalent-density industry-standard alternatives.

The latest entry in the "I'll-go-it-alone; thank-you-very-much" sweepstakes is Motorola and Sandisk's TransFlash (formerly, T-Flash) module, which the companies intend for use in cellular phones. As with Memory Stick and the xD-Picture Card, it's unclear whether other system manufacturers will adopt TransFlash support. Unlike with the other formats, users will neither regularly remove TransFlash from the system nor interchange it with other systems, although, as with a cellular-phone-SIM (subscriber-identity-module) card, they can move it from one system to another. It provides the second of three possible scenarios for increasing the local-storage capacity in cellular phones, the first of which is the removable mini-SD and RS-MMC cards. The third option, which some GSM backers advocate, involves simply boosting the capacity of the SIM card currently in the phone.

In contrast to the proprietary and semiproprietary approaches of the other sections of this article, the USB-flash drive has been the beneficiary of built-in Windows operating-system support extending back to Windows ME. USB connectors first appeared in PCs in the late 1990s, and the more recent 480-Mbps USB High Speed variant keeps pace with the ever-increasing read and write performance of latest generation flash memories. As a result, the USB-flash drive, a product category that didn't even debut until November 2000, has rapidly grown to become a leading user of data-centric AND, NAND, and equivalent flash memory. People know it by various other marketing names, too, although the USB Flash Drive Alliance, with Sandisk noticeably absent from the membership list, is trying to solve that confusing problem.

With success comes inevitable product differentiation and fragmentation, although the commonality of the USB-hardware and -software interface has constrained any consequent incompatibility. USB-flash drives come in a plethora of shapes, sizes, and color schemes. Lexar Media's devices embed LEDs that indicate in-progress writes and help prevent users from blindly yanking the flash drive from its socket. Some USB-flash drives have rugged metal cases that withstand users' dropping, sitting on, stepping on, or driving over them. Others, according to their vendors, withstand extremes of heat and cold or immersion in fluids. USB-based devices that combine digital-audio-playback functions and flash memory for generic storage, not just music, are increasingly common, and a few USB-based still cameras and videocameras offering generic flash-memory storage also exist. Forget about a USB-flash drive on your key chain; wristwatches with flash memory inside and USB dongles for connectivity are here. USB memory is in pens, and Victorinox sells a Swiss Army Knife with a built-in USB-flash drive!

The software bundles that come with USB-flash drives are as diverse as the drives themselves. Some utilities will redirect a Web browser's cache, cookies, and other "fingerprints" away from the PC's hard drive, enabling you to anonymously surf with system diversity and impunity. Others perform similar flexible-system-usage functions with Outlook, Outlook Express, and other e-mail clients. Encryption schemes protect your precious data from prying eyes. And one-touch backup with on-the-fly compression enables valuable information to survive a hard-drive crash. Although the term "flash drive" describes this product category, at least one hard-drive manufacturer, Cornice, offers magnetic-media-based USB-storage devices with retail partner Digitalway. GS Magicstor, Hitachi, Seagate, Toshiba, and others that also offer and plan to offer 1-in. and smaller drives may provide the multisourcing muscle to broaden the hard drive's penetration in this market.

Microsoft, acutely aware of the ever-increasing popularity of USB-flash drives, demonstrated two intriguing scenarios at May's WinHEC (Windows Hardware Engineering Conference). In the first, a system booted a limited-function Windows XP variant from a USB-flash drive, a capability that's useful, for example, for IT administrators doing system debugging or upgrades. In the other, first plugging the USB-flash drive into a PC and then into other LAN devices, such as access points, routers, and printers, and then back into the PC enabled straightforward setup of a WiFi network. The demo employed encrypted storage and interchange of MAC (media-access-controller) addresses, SSIDs (Service Set Identifier), WEP (Wired Equivalent Privacy) or WPA (WiFi Protected Access) keys, DHCP (Dynamic Host Configuration Protocol) or static-IP details, and other relevant configuration data.

One USB spin-off that, at least at the moment, shows little likelihood of success is the oddly named Fish Memory that the UTMA (Universal Transportable Memory Association) promotes. Technical data on the association's Web site is sparse, and the association didn't respond to e-mails requesting details. The

UTMA plans two sizes, Fish and Baby-Fish, but, without additional information, Fish Memory appears to be nothing more than a branded version of USB-flash drives that multiple suppliers already sell. After a brief flurry of promotional activity at February's PMA (Photo Marketing Association) show, the UTMA has gone quiet, and, at press time, no one had updated the Web site since Feb 10. No module or system vendors have announced backing for the format.

COMPLETING THE PUZZLE

Many digital cameras and PDAs contain built-in USB and USB-derivative connectors, but their lack of USB Host controller capability precludes their direct attachment to USB-based mass-storage devices, such as flash drives, optical burners, and hard drives. (They instead embed reduced-function USB Client logic.) Delkin's dual-AA-battery-powered, $69.99 USB Bridge aims to surmount this limitation (**Figure 2**). Its support for 12-Mbps USB Full Speed mode minimizes cost but slows transfer rates to and from otherwise-speedier media.

Want to spend a bit more money to back up and transfer data from your diminutive memory cards using a more flexible platform but not interested in buying a full-featured and expensive laptop computer for this focused function? Kanguru and others will happily sell you devices that directly burn optical discs from memory-card contents, or transfer the data to a hard drive. You can also use the Kanguru Media X-change 2.0, which supports USB High Speed mode, as a portable USB-hard drive and multiformat-card reader; it comes with a built-in LCD and in 20- to 80-Gbyte capacities. The Kanguru FC-RW works with seven card formats, supports 36× multisession write speeds over High Speed USB, and doubles as a PC's CD-RW drive and card reader.

Multiformat card readers come in ATA, USB, and IEEE-1394 variants and either fit into a PC's floppy-drive slot or externally tether to the computer. Some adapters transform MMC, SD, Memory Stick, and xD-Picture Cards to the more prevalent CompactFlash and USB interfaces, whereas others translate CompactFlash and other card formats to a PC Card-compatible connector. Kanguru even includes supplemental flash-memory storage within its USB-based Micro Drive+ (for SD and MMC) and Kanguru Micro CF (for CompactFlash) card adapters.□

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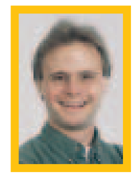

Technical editor Brian Dipert is sure he'd get a blister on his shutter finger before he could fill up his 4-Gbyte MicroDrive with pictures. Summer vacation's coming soon, though, so, just in case, he's working on building up a callus. Reach him at 1-916-454-5242, bdipert@edn.com.

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WHO'S WRITE?

In examining flash-memory module specifications, you'll frequently encounter the "×" factor, a measure of the card's claimed write performance—that is, 16, 32, or 40×, for example. The × factor derives from the transfer-rate specifications of CD drives. Initial 1× CD-ROM drives read information from the optical media at 150 kbytes/sec; 1× CD-R and CD-RW drives write to the media at this same rate. (Note that a DVD drive's 1× rating refers to a 1.425-Mbyte/sec transfer rate, 9.5 times higher than the CD equivalent.) As drive rotational speeds increased, transfer rates also increased, but only up to a point. Modern drives, employing CAV (constant-angular-velocity) accesses, achieve 52× read and CD-R-write speeds only at the disc's outer edge (**Reference A**).

Memory cards' 1× ratings match the CD drives' 150-kbyte/sec specifications. Flash-memory-card suppliers are quick to point out that, because radius-defined rotational speed and transfer-rate variances don't hamper their products, they'll deliver at minimum the rated speeds, regardless of where in memory your application is accessing. They're right about the lack of rotational variability, but be forewarned: They still may be playing fast and loose with their burst-versus-sustained-transfer-rate terminology.

Only a handful of fundamental ways exists to boost the perceived write-transfer rate of a memory card. Three of them employ RAM page buffers: in the system, in the card's memory controller, and in the memory itself. Page buffers accelerate the apparent write speed by enabling the system to begin its next task, while, in parallel, the information transfers from RAM to the much slower nonvolatile memory. This scheme works, though, only if the amount of data you need to write to the card at once is less than or equal to the available page-buffer density or densities in a multilevel-buffer approach and if the delay between burst writes is at least as long as the transfer-to-flash latency. Otherwise, the sustained speed you encounter is much less than the burst speed.

What other write-speed-boosting techniques exist? One obvious one is to select a flash-memory technology with the fastest possible program and erase times; this factor, along with comparatively smaller die and erase blocks, accounts for the fact that AND and NAND flash memory dominate over the NOR flash-memory alternative in write-intensive applications. (Smaller erase blocks simplify the necessary media-management function.) A card vendor could also widen the interface between the controller and each memory and could program and erase multiple memories in parallel.

A card manufacturer might also tweak its memory-controller design by adding enhanced proprietary commands, such as Lexar Media's WA technology; running the controller at higher clock speeds; and constructing the controller from hard-wired logic instead of using a firmware-driven microprocessor, for example. Samsung takes this idea to the next level by embedding the controller on the flash-memory die alongside the storage array in its OneNAND product line. Finally, the card vendor, working with a system partner, might widen and boost the clock rate of the interface between system and card. Note that nothing comes for free; the added performance engenders requisite trade-offs in cost and power consumption. Each situation is unique and therefore has an ideal conjunction of the fundamental three factors: performance, power, and price.

The tug of war between leading NAND vendors Samsung and Toshiba neatly illustrates the trade-off-balancing act. Samsung, for the moment at least, is doggedly clinging to its claim that MLC (multilevel-cell) NAND flash memory, which stores 2 bits of information in each cell, isn't ready for prime time. It points out the inherent read and write performance degradation of an MLC-based device, along with the incremental initial-test yield loss and long-term erase-cycling degradation versus an SLC (single-level-cell) flash-memory alternative. Samsung officials believe that the fact that the company uses a smaller lithography process than that of Toshiba negates any die-size advantage of MLC over SLC.

Toshiba predictably disputes Samsung's touted technological superiority. Toshiba also claims that its competitor vastly overstates its yield-loss estimates for MLC over SLC and points out that, with all other factors being equal, a given-sized fabrication facility can crank out twice the density-equivalent amount of MLC material as SLC. Toshiba's 130-nm SLC NAND flash memories program approximately 2.5 times faster than their MLC equivalents. Toshiba boosts MLC-page-programming speeds, at 90 nm, eightfold through a combination of twice-as-fast semiconductor technology and control-algorithm optimizations and a fourfold increase in the page-buffer size.

These enhancements will narrow but not close the write-speed gap between SLC and MLC flash memory. Toshiba's SLC chips will also contain the four-times-larger page buffer, and the company acknowledges that some niche applications will require SLC speeds, for which Toshiba will happily sell chips. However, for the broad base of audio, still-image, and video applications that constitute the bulk of NAND demand, Toshiba claims that MLC's speed and 10,000-cycle endurance are more than sufficient.

MLC's applicability is particularly of interest at the moment because, thanks to booming sales of USB-flash drives and digital still cameras, NAND-memory supply is constrained. Sandisk has, through its agreement with Toshiba, carved out a guaranteed piece of its partner's fab-network pie, but other third-party card vendors depend on an evaporating bucket of silicon. Toshiba's aggressively entering the retail channel with its own branded cards, thereby competing with its card customers, and Samsung (like Toshiba, a well-known consumer-electronics name) is likely to follow suit.

In the long term, though, memory constraints always sort themselves out. In fact, the pendulum invariably and rapidly shifts to oversupply. Renesas has added Powerchip as an AND-flash-memory foundry to supplement Renesas' own internal capacity. Hynix, Micron, and STMicroelectronics are all coming online with their own NAND-based products, and Infineon has partnered with Saifun to unveil NROM (nitride-ROM)-based, high-density devices.

Sandisk is striving to ensure, though, that the party it and its competitors are now enjoying doesn't end any time soon. As I was researching this article, an RSS (Really Simple Syndication) feed from Techbargains.com landed in my inbox quoting $109.95 (after rebate) for a 1-Gbyte Sandisk CompactFlash card. I still remember, a decade ago, when $30 for 1-Mbyte of flash memory was the price quote that turned heads! The company has also just launched a line of conventional Shoot & Store flash-memory cards that quote the number of average pictures you can expect to store on them, relegating density specifications to small print. Sandisk's aspiration, along with that of its competitors, is that consumers will tire of transferring images from their memory cards and, once they're full, instead stick them in a shoebox and buy more cards (**Reference B**).

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I/O DEVOLUTION

Most PC Cards that manufacturers shipped in the last decade have been I/O cards: analog modem, wired and wireless Ethernet, Bluetooth, and the like. CompactFlash I/O cards are also available, and a few companies even sell WiFi and Bluetooth SD cards. But, nowadays, the market for I/O cards is fading fast. Why?

The increasing integration of multiple connectivity technologies in systems is one factor. It's now difficult to find a notebook PC that contains neither an analog modem nor both wired- and wireless-Ethernet capability. Vendors are shipping all but the lowest end PDAs with built-in WiFi, Bluetooth, or both. And today's cell phones inherently include data connectivity to GPRS (General Packet Radio Service), EDGE (Enhanced Data for GSM Evolution), or one of the CDMA (code-division-multiple-access)-1x variants.

Alternative high-speed expansion buses, specifically USB High Speed and IEEE-1394, have also displaced PC Card slots as they've muscled onto computer platforms. Unfortunately, many USB implementations in cell phones and PDAs contain client controllers that can't directly manage another tethered client, such as if you attempt to use a cellular phone as a wireless modem for a PDA. Twin Paradox, in partnership with Cypress Semiconductor, sells a CompactFlash-based device with dual USB ports that adds the requisite USB Host support. TheSupplyNet also sells USB cables for PDA-to-cell-phone connectivity which contain the necessary USB Host circuitry.

Most vendors of Windows-based notebook PCs still ship them with at least one PC Card slot. But neither Apple's iBooks nor the 12-in. PowerBook offers PC Card capability. This limitation was a major downside to the 12-in. iBook I recently reviewed; lack of a PC Card slot meant I could neither use my Sprint Connection Card or Digigram VxPocket sound card with it nor connect SCSI peripherals to it. When PC Card slots inevitably disappear from the PC platform, I don't predict that ExpressCard connections will replace them to any significant degree.

Lack of requisite host-controller support has also led to both widespread consumer confusion and a dearth of consumer adoption. Though you can find SD card slots in many PDAs, few system-housed SD controllers support SDIO mode. Those that do often implement only the baseline single-bit I/O interface, which throttles WiFi performance to less-than-1-Mbps transfer rates. For all these reasons, the MultiMediaCard Association plans no addition of an I/O option to the MMC specifications.

SURGICAL SUCCESS

Hitachi's 4-Gbyte MicroDrives, in the CompactFlash Type II format, have an manufacturer's suggested retail price of $499. Poke around eBay, and you can find boatloads of them for sale for $300 or thereabouts. But, thanks to the widespread communication reach of the Internet, a much cheaper option is available. If you can find one of the rare, $199 Creative Labs MuVo^2 4-Gbyte digital-audio players and if you aren't averse to doing warranty-breaking surgery on it, you can end up with a fully functional, 4-Gbyte MicroDrive plus a MuVo^2 shell, in which you can install another CompactFlash card.

How do I know? Because I did it myself. The 4-Gbyte MicroDrive now resides in my Pentax *ist D digital SLR (single-lens-reflex) camera, and the MuVo^2 lives on, playing tunes I stored on an older, replacement 1-Gbyte MicroDrive. Many—but not all—flash-memory-based CF cards reportedly also work, as long as the MuVo^2 is running a specific firmware version. Search Google for directions. But don't try this trick with Apple's iPod mini. The firmware in the iPod mini's drive is not fully CF-complaint because it supports only one of the three possible interface modes: IDE. Most digital cameras, for example, expect cards that support memory and I/O modes. And don't assume that what works now will always work; Hitachi might in the future alter the MuVo^2-drive firmware to close this loophole, although Creative Labs, the beneficiary of much additional business due to the loophole, might be displeased.

TESTING, TESTING

I'm curious whether I'll notice any real-life read- and write-performance differences between standard and high-speed variants of the various card formats, as well as between 1-bit MMC and 4-bit SD cards. A number of vendors have provided me with product samples, and, over the next few months, I'll install them in a variety of card slot-inclusive systems, with appropriate adapters. These include:

- Kodak (DX6340 and DX6490), Kyocera (Finecam SL300R) and Pentax (*ist D) digital cameras;
- Notebook (Fujitsu Lifebook-P2040 and -P5020, and Apple 12in., 867-MHz Powerbook) and desktop (Dell OptiPlex GX260 and hand-built) PCs, both with USB Full Speed and High Speed interfaces;
- Dell Axim X5 and HP iPaq 3835 Pocket PCs; and
- Epson Stylus Photo 925 ink-jet printer.

Come back here for a regularly updated addendum, which will contain my results and analysis of these and other issues. Rob Galbraith's Digital Photography Insights Web site (www.robgalbraith.com) also contains a regularly updated CompactFlash performance database, which I encourage you to visit for another perspective on the topic.

FOR MORE INFORMATION...

For more information on the products discussed in this article, contact any of the following manufacturers directly, and please let them know you read about their products in *EDN*.

Apple Computer
www.apple.com

CompactFlash Association
www.compactflash.org

Cornice
www.corniceco.com

Creative Labs
www.creative.com

Delkin Devices
www.delkin.com

Dell
www.dell.com

Digigram
www.digigram.com

Digital Networks North America
www.digitalnetworksna.com

Digitalway
www.mpio.com

Eastman Kodak
www.kodak.com

Epson
www.epson.com

Fujifilm
www.fujifilm.com

Fujitsu Computer Systems
www.fujitsupc.com

GS Magicstor
www.gs-magicstor.com

Hewlett-Packard
www.hp.com

Hitachi
www.hitachi.com

Hynix
www.hynix.com

Infineon
www.infineon.com

Intel
www.intel.com

Kanguru Solutions
www.kanguru.com

Kyocera
www.kyocera.com

Lexar Media
www.digitalfilm.com

Matsushita/Panasonic
www.panasonic.com

Micron Technology
www.micron.com

Microsoft
www.microsoft.com

Motorola
www.motorola.com

M-Systems
www.m-sys.com

MultiMediaCard Association
www.mmca.org

Olympus
www.olympus.com

PCMCIA
www.expresscard.org
www.pcmcia.org

Pentax
www.pentax.com

Powerchip Semiconductor
www.psc.com.tw

Pretec Electronics
www.pretec.com

Renesas Technology
www.renesas.com

Saifun Semiconductors
www.saifun.com

Samsung
www.samsung.com

Sandisk
www.sandisk.com

SD Association
www.sdcard.com
www.sdcard.org

Seagate
www.seagate.com

Sony
www.memorystick.com
www.memorystick.org
www.sony.com

Sprint PCS
www.sprintpcs.com

STMicroelectronics
www.st.com

Toshiba
www.toshiba.com

Twin Paradox
www.twin-paradox.com

Universal Transportable Memory Association
www.fishmemory.org

USB Flash Drive Alliance
www.usbflashdrive.org

Victorinox
www.victorinox.com