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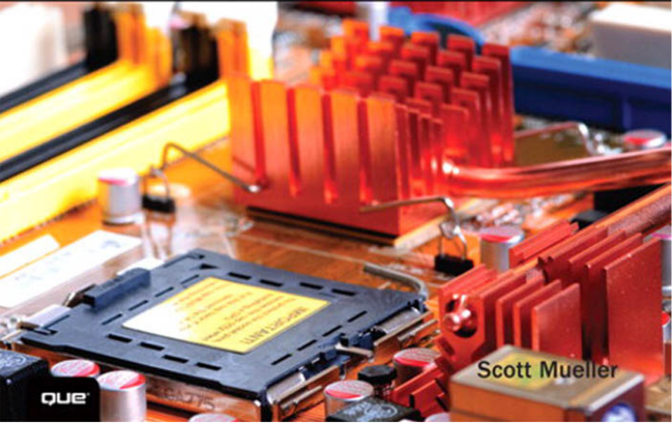

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Upgrading and Repairing PCs, 21st Edition

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Dedication

In memory of Mark Reddin. His wonderful technical input and insight over the years have made a tremendous impact on this and many other books. You will be missed.

About the Author

Scott Mueller is the president of Mueller Technical Research (MTR), an international research and corporate training firm. Since 1982, MTR has produced the industry's most in-depth, accurate, and effective seminars, books, articles, videos, and FAQs covering PC hardware and data recovery. MTR maintains a client list that includes Fortune 500 companies, the U.S. and foreign governments, major software and hardware corporations, as well as PC enthusiasts and entrepreneurs. Scott's seminars have been presented to several thousands of PC support professionals throughout the world.

Scott personally teaches seminars nationwide covering all aspects of PC hardware (including troubleshooting, maintenance, repair, and upgrade), A+ Certification, and data recovery/forensics. He has a knack for making technical topics not only understandable, but entertaining; his classes are never boring! If you have ten or more people to train, Scott can design and present a custom seminar for your organization.

Although he has taught classes virtually nonstop since 1982, Scott is best known as the author of the longest-running, most popular, and most comprehensive PC hardware book in the world, *Upgrading and Repairing PCs*, which has become the core of an entire series of books, including *Upgrading and Repairing PCs*, *Upgrading and Repairing Laptops*, and *Upgrading and Repairing Windows*.

Scott's premiere work, *Upgrading and Repairing PCs*, has sold more than two million copies, making it by far the most popular and longest-running PC hardware book on the market today. Scott has been featured in *Forbes* magazine and has written several articles for *PC World* magazine, *Maximum PC* magazine, the Scott Mueller Forum, various computer and automotive newsletters, and the Upgrading and Repairing PCs website.

Contact MTR directly if you have a unique book, article, or video project in mind or if you want Scott to conduct a custom PC troubleshooting, repair, maintenance, upgrade, or data-recovery seminar tailored for your organization:

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I must give a *very* special thanks to Rick Kughen at Que. Through the years, Rick is the number-one person responsible for championing this book and the *Upgrading and Repairing* series. I cannot say enough about Rick and what he means to all the *Upgrading and Repairing* books. With all that he's been through on this book, I have a feeling I might be responsible for a few gray hairs. (Sorry!)

I'd also like to thank Todd Brakke for doing the development editing for this edition, which was fairly substantial considering all the rewrites and new material. His excellent tips and suggestions really helped to keep the material concise and up-to-date.

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I also want to say thanks to my publisher, Greg Wiegand, who has stood behind all the *Upgrading and Repairing* book and video projects. Greg is a fellow motorcycle enthusiast—someday, hopefully, we can go riding together.

All the people at Que make me feel as if we are on the same team, and they are just as dedicated as I am to producing the best books possible.

I would like to thank both my wife Lynn and my son Emerson for helping to produce the DVD that comes with the book. Emerson did the camera work, and Lynn did all of the editing, rendering, and DVD production using the very machine that you see me build in the video. I hope you enjoy the DVD as much as we enjoyed producing it.

Many readers write me with suggestions and even corrections for the book, for which I am especially grateful. I welcome any and all of your comments and even your criticisms. I take them seriously and apply them to the continuous improvement of this book. Interaction with my readers is the primary force that helps maintain this book as the most up-to-date and relevant work available *anywhere* on the subject of PC hardware.

Finally, I want to thank the thousands of people who have attended my seminars; you have no idea how much I learn from each of you and all of your questions!

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Introduction

Welcome to *Upgrading and Repairing PCs,* 21st Edition. Since debuting as the first book of its kind on the market in 1988, no other book on PC hardware has matched the depth and quality of the information found in this tome. This edition continues *Upgrading and Repairing PCs'* role as not only the best-selling book of its type, but also the most comprehensive and complete PC hardware reference available. This book examines PCs in depth, outlines the differences among them, and presents options for configuring each system.

The 21*st* edition of *Upgrading and Repairing PCs* provides you with the in-depth knowledge you need to work with the most recent systems and components and gives you an unexcelled resource for understanding older systems. As with previous editions, we worked to make this book keep pace with the rapid changes in the PC industry so that it continues to be the most accurate, complete, and in-depth book of its kind on the market today.

I wrote this book for all PC enthusiasts who want to know everything about their PCs: how they originated; how they've evolved; how to upgrade, troubleshoot, and repair them; and everything in between. This book covers the full gamut of PC-compatible systems, from the oldest 8-bit machines to the latest high-end 64-bit multicore processors and systems. If you need to know everything about PC hardware from the original to the latest technology on the market today, this book and the accompanying information-packed disc is definitely for you.

Upgrading and Repairing PCs also doesn't ignore the less glamorous PC components. Every part of your PC plays a critical role in its stability and performance. Over the course of this book, you'll find out exactly why your motherboard's chipset might just be the most important part of your PC and what can go wrong when you settle for a run-of-the-mill power supply that can't get enough juice to that monster graphics card you just bought. You'll also find in-depth coverage of technologies such as new Intel Ivy Bridge and AMD Trinity core processors (including those with integrated graphics (including those with integrated graphics), how your choice of processor affects virtualization support, DDR3 memory, high-performance graphics cards based on AMD and NVIDIA GPUs for the fastest 3D gaming and the latest developments in OpenGL and DirectX 3D APIs, SATA 6Gbps and upcoming SATA Express interfaces, Thunderbolt and USB 3.0 interfaces in the latest motherboards, advances in solid-state drives, the benefits of 80 PLUS power supplies, and more—it's all in here, right down to the guts-level analysis of your mouse and keyboard.

Book Objectives

Upgrading and Repairing PCs focuses on several objectives. The primary objective is to help you learn how to maintain, upgrade, and troubleshoot your PC system. To that end, *Upgrading and Repairing PCs* helps you fully understand the family of computers that has grown from the original IBM PC, including all PC-compatible systems. This book discusses all areas of system improvement, such as motherboards, processors, memory, and even case and power-supply improvements. It covers proper system and component care, specifies the most failure-prone items in various PC systems, and tells you how to locate and identify a failing component. You'll learn about powerful diagnostics hardware and software that help you determine the cause of a problem and know how to repair it.

As always, PCs are moving forward rapidly in power and capabilities. Processor performance increases with every new chip design. *Upgrading and Repairing PCs* helps you gain an understanding of all the processors used in PC-compatible computer systems.

This book covers the important differences between major system architectures, from the original Industry Standard Architecture (ISA) to the latest PCI Express interface standards. *Upgrading and Repairing PCs* covers each of these system architectures and their adapter boards to help you make decisions about which type of system you want to buy in the future and help you upgrade and troubleshoot such systems.

The amount of storage space available to modern PCs is increasing geometrically. *Upgrading and Repairing PCs* covers storage options ranging from larger, faster hard drives to state-of-the-art solid-state storage devices.

When you finish reading this book, you will have the knowledge to upgrade, troubleshoot, and repair almost any system and component.

The 21st Edition DVD-ROM

The 21st edition of *Upgrading and Repairing PCs* includes a DVD that contains valuable content that greatly enhances this book!

There's the all-new DVD video with new segments showing a detailed tour of a high-end Z77 chipset motherboard, a detailed comparison of SSD (solid-state drive) to HDD (hard disk drive) technology, plus information about choosing a case and power supply. There are in-depth segments showing how to build a system using these components from scratch, including motherboard and chassis preparation, component installation, and finally cabling, including the dreaded front-panel connections.

The DVD-ROM content includes my venerable Technical Reference material, a repository of reference information that has appeared in previous editions of *Upgrading and Repairing PCs* but has been moved to the disc to make room for coverage of newer technologies. The DVD-ROM also includes the complete 19th edition of this book, the complete 20th edition of the book, a detailed list of acronyms, and much more available in printable PDF format. There's more PC hardware content and knowledge here than you're likely to find from any other single source.

My Website: upgradingandrepairingpcs.com

Don't forget about Que's dedicated *Upgrading and Repairing PCs* website! Here, you'll find a cache of helpful material to go along with the book you're holding. I've loaded this site with tons of material—mine as well as from other authors—ranging from video clips to book content and technology updates.

If you discover that the video on this book's disc isn't enough, you'll find even more of my previously recorded videos on the website. Not to mention that it is the best place to look for information on all of Que's *Upgrading and Repairing* titles.

I also have a private forum (www.forum.scottmueller.com) designed exclusively to support those who have purchased my recent books and DVDs. I use the forum to answer questions and otherwise help my loyal readers. If you own one of my current books or DVDs, feel free to join in and post questions. I endeavor to answer each question personally, but I also encourage knowledgeable members to respond. Anybody can view the forum without registering, but to post a question of your own you need to join. Even if you don't join in, the forum is a tremendous resource because you can still benefit from all the reader questions I have answered over the years.

Be sure to check the informit.com/upgrading website for more information on all my latest books, videos, articles, FAQs, and more!

A Personal Note

When asked which was his favorite Corvette, Dave McLellan, former manager of the Corvette platform at General Motors, always said, “Next year’s model.” Now with the new 21st edition, next year’s model has just become this year’s model, until *next* year that is….

I believe that this book is absolutely the best book of its kind on the market, and that is due in large part to the extensive feedback I have received from both my seminar attendees and book readers. I am so grateful to everyone who has helped me with this book through each edition, as well as all the loyal readers who have been using this book, many of you since the first edition was published. I have had personal contact with many thousands of you in the seminars I have been teaching since 1982, and I enjoy your comments and even your criticisms tremendously. Using this book in a teaching environment has been a major factor in its development. Some of you might be interested to know that I originally began writing this book in early 1985; back then it was self-published and used exclusively in my PC hardware seminars before being professionally published by Que in 1988.

In one way or another, I have been writing and rewriting this book for almost 30 years! In that time, *Upgrading and Repairing PCs* has proven to be not only the first, but also the most comprehensive and yet approachable and easy-to-understand book of its kind. With this new edition, it is even better than ever. Your comments, suggestions, and support have helped this book to become the best PC hardware book on the market. I look forward to hearing your comments after you see this exciting new edition.

—Scott

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Chapter

7

The ATA/IDE Interface

An Overview of the IDE Interface

The interface used to connect disk drives to a PC is typically called IDE (Integrated Drive Electronics); however, the official name of this interface is ATA (AT Attachment). The ATA designation refers to the fact that this interface was originally designed to connect a combined drive and controller directly to the 16-bit bus found in the 1984 vintage IBM PC-AT (Advanced Technology) and compatible computers. The AT bus is otherwise known as the ISA (Industry Standard Architecture) bus. Although ATA is the official name of the interface, IDE is a marketing term originated by some of the drive manufacturers to describe the drive/controller combination used in drives with the ATA interface. Integrated Drive Electronics refers to the fact that the interface electronics or controller is built into the drive and is not a separate board, as it was with earlier drive interfaces. Although the correct name for the particular IDE interface we most commonly use is technically ATA, many persist in using the IDE designation today. If you are being picky, you could say that IDE refers generically to any drive interface in which the controller is built into the drive, whereas ATA refers to the specific implementation of IDE that is used in most PCs.

ATA was originally a 16-bit parallel interface, meaning that 16 bits are transmitted simultaneously down the interface cable. A newer interface called Serial ATA (SATA) was officially introduced in late 2000 and was adopted in desktop systems starting in 2003 and in laptops starting in late 2005. SATA sends one bit down the cable at a time, enabling thinner and smaller cables to be used, as well as providing higher performance due to the higher cycling speeds it enables. Although SATA is a completely different physical interface design, it is backward compatible on the software level with Parallel ATA (PATA). Throughout this book, *ATA* refers to both the parallel and serial versions. *PATA* refers specifically to the parallel version, and *SATA* refers specifically to the serial version.

Precursors to IDE

Several types of hard disk interfaces have been used for PC hard disks over the years, as shown in Table 7.1. As time has passed, the number of choices has increased; however, many of the older interface standards are obsolete and no longer viable in newer systems.

Table 7.1 PC Drive Interfaces

Interface	When Used
ST-506/412	1978–1989 (obsolete)
ESDI	1983–1991 (obsolete)
Non-ATA IDE	1987–1993 (obsolete)
SCSI	1986–present
PATA (IDE)	1986–present
SATA	2003–present

ST = Seagate Technology
ESDI = Enhanced Small Device Interface
IDE = Integrated Drive Electronics
SCSI = Small Computer Systems Interface
ATA = AT (Advanced Technology) Attachment

Of these interfaces, only ST-506/412 and ESDI are what you could call true disk-controller-to-drive interfaces, and they are obsolete. Non-ATA versions of IDE were used primarily in the IBM PS/2 systems and are also obsolete. Current SCSI, ATA, and SATA are system-level interfaces that usually internally incorporate a chipset-based controller interface. For example, many SCSI, PATA, and SATA drives incorporate the same basic controller circuitry inside the actual drive. The SCSI interface then adds another layer that connects between the drive controller and the PCI (or ISA) bus, whereas PATA and SATA have a more direct connection from the controller to the AT bus attachment interface. Despite their differences, we call a SCSI, PATA, or SATA card a host interface adapter instead of a controller card because the actual controllers are inside the drives. Virtually all modern disk drives use SATA or PATA interfaces to connect to a system.

IDE Origins

Any drive with an integrated controller could be called an IDE drive, although normally when we say IDE, we really mean the specific version of IDE called ATA. No matter what you call it, combining the drive and controller greatly simplifies installation because no separate power or signal cables run from the controller to the drive. Also, when the controller and drive are assembled as a unit, the number of total components is reduced, signal paths are shorter, and the electrical connections are more noise-resistant. This results in a more reliable and less expensive design than is possible when a separate controller, connected to the drive by cables, is used.

Placing the controller, including the digital-to-analog encoder/decoder (endec), on the drive offers an inherent reliability advantage over interfaces with separate controllers such as ST506 and ESDI. Reliability is increased because the data encoding, from digital to analog, is performed directly on the drive in a tight noise-free environment. The timing-sensitive analog information does not have to travel along crude ribbon cables that are likely to pick up noise and insert propagation delays into the signals. The integrated configuration enables increases in the clock rate of the encoder and the storage density of the drive.

The earliest IDE drives were called hardcards and were nothing more than hard disks and controller cards bolted directly together and plugged into a slot as a single unit. Companies such as the Plus Development Division of Quantum took small 3 1/2-inch drives (either ST-506/412 or ESDI) and attached them directly to a standard controller card. The drive/controller assembly then was plugged into an ISA bus slot as though it were a normal disk controller card. Unfortunately, the mounting of a heavy, vibrating hard disk in an expansion slot with nothing but a single screw to hold it in place left a lot to be desired—not to mention the physical interference with adjacent cards, because many of these units were much thicker than a controller card alone.

Several companies got the idea to redesign the controller to replace the logic board assembly on a standard hard disk and then mount it in a standard drive bay just like any other drive. Because the built-in controller in these drives still needed to plug directly into the expansion bus just like any other controller, a cable was run between the drive and one of the slots. This was the origin of IDE.

Origins of ATA

Control Data Corporation (CDC; its disk drive division was later called Imprimis), Western Digital, and Compaq actually created what could be called the first ATA IDE interface drive and were the first to establish the 40-pin ATA connector pinout. The first ATA IDE drive was a 5 1/4-inch half-height CDC Wren II 40MB drive with an integrated WD controller and was initially used in the first Compaq 386 systems in 1986. I remember seeing this drive for the first time in 1986 at the fall COMDEX show. Besides the (at the time) unique 40-pin ribbon cable, I remember being surprised by the green activity LED on the front bezel. (Most drives up until then used red LEDs.)

Compaq was the first to incorporate a special bus adapter in its system to adapt the 98-pin AT-bus (also known as ISA) edge connector on the motherboard to a smaller 40-pin, header-style connector into which the drive would plug. The 40-pin connector was all that was necessary because it was known that a disk controller never would need more than 40 of the ISA bus lines. Smaller 2 1/2-inch ATA drives found in laptop computers use a superset 44-pin or 50-pin connection, which includes additional pins for power and configuration. The pins from the original ISA bus used in ATA are the only signal pins required by a standard-type AT hard disk controller. For example, because a primary AT-style disk controller uses only interrupt request (IRQ) line 14, the primary motherboard ATA connector supplies only that IRQ line; no other IRQ lines are necessary. Even if your ATA interface is integrated within the motherboard chipset South Bridge or I/O Controller Hub chip (as it would be in newer systems) and runs at higher bus speeds, the pinout and functions of the pins are still the same as the original design taken right off the ISA bus.

◀◀ See the Chapter 4 section, "Motherboard Connectors," **p. 228**.

◀◀ See the Chapter 4 section, "The ISA Bus," **p. 245**.

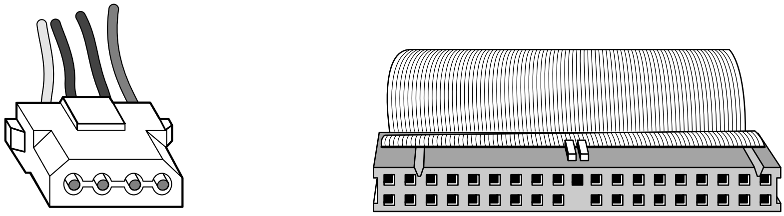
Note

Many people who use systems with ATA connectors on the motherboard believe that a hard disk controller is built into their motherboards, but in a technical sense the controller is actually in the drive. Although the integrated ATA ports on a motherboard often are referred to as controllers, they are more accurately called *host adapters* (although you'll rarely hear this term). You can think of a host adapter as a device that connects a controller to a bus.

Eventually, the 40-pin ATA connector and drive interface design was placed before one of the ANSI standards committees that, in conjunction with drive manufacturers, ironed out some deficiencies, tied up some loose ends, and then published what was known as the CAM ATA (Common Access Method AT Attachment) interface. The CAM ATA Committee was formed in October 1988, and the first working document of the ATA interface was introduced in March 1989. Before the CAM ATA standard, many companies, such as Conner Peripherals (which later merged with Seagate Technology), made proprietary changes to the original interface as designed by CDC. As a result, many older ATA drives from the late 1980s are difficult to integrate into a dual-drive setup because minor differences in the interfaces can cause compatibility problems among the drives. By the early 1990s, most drive manufacturers brought their drives into full compliance with the official standard, which eliminated many of these compatibility problems.

Some areas of the ATA standard have been left open for vendor-specific commands and functions. These vendor-specific commands and functions are the reason it is important to use the OEM-specific programs for testing ATA drives. To work to full capability, the diagnostic program you are using typically must know the specific vendor-unique commands for remapping defects. Unfortunately, these and other specific drive commands differ from OEM to OEM, thus clouding the standard somewhat. Most ATA drive manufacturers publish their drive-formatting/initialization software on their websites.

As I noted at the start of this chapter, PATA is a 16-bit parallel interface that has been largely phased out in favor of the serial interface of SATA. SATA's thinner and smaller cables provide higher performance due to the higher cycling speeds allowed and are considerably easier to work with than the wide PATA ribbon cables. Figure 7.1 shows how the power and data cables SATA uses compare in size to those PATA uses.



PATA power cable

PATA data cable

SATA power cable

SATA data cable

FIGURE 7.1 SATA data cables are much smaller than those used by PATA, whereas the power cables are similar in size.

ATA Standards

Today, the ATA interface is controlled by an independent group of representatives from major PC, drive, and component manufacturers. This group is called Technical Committee T13 (www.t13.org) and is responsible for all standards relating to the Parallel and Serial ATA storage interfaces. T13 is a part of the International Committee on Information Technology Standards (INCITS), which operates under rules approved by the American National Standards Institute (ANSI), a governing body that sets rules that control nonproprietary standards in the computer industry as well as many other industries. A second group called the Serial ATA International Organization (www.serialata.org) was formed to initially create the SATA standards, which are then passed on to the T13 Committee for refinement and official publication under ANSI. The ATA-7 and ATA-8 standards incorporate both parallel and serial interfaces.

The rules these committees operate under are designed to ensure that voluntary industry standards are developed by the consensus of people and organizations in the affected industry. INCITS specifically develops information processing system standards, whereas ANSI approves the process under which these standards are developed and then publishes them. Because T13 is essentially a public organization, all the working drafts, discussions, and meetings of T13 are open for all to see.

Copies of any of the published standards can be purchased from ANSI (www.ansi.org) or the IHS Standards Store (formerly Global Engineering Documents, http://global.ihs.com). Draft versions of the standards can be downloaded from the T13 Committee or Serial ATA International Organization (SATA-IO) website.

Each newer version of ATA is backward compatible with the previous versions. In other words, older ATA-1 and ATA-2 devices work fine on ATA-7 and ATA-8 interfaces. ATA-7 and ATA-8 include both PATA and SATA. Newer versions of ATA are normally built on older versions, and with few exceptions can be thought of as extensions of the previous versions. This means that ATA-8, for example, is generally considered equal to ATA-7 with the addition of some features.

Table 7.2 breaks down the various ATA standards. The following sections describe recent ATA versions in more detail.

Table 7.2 ATA Standards

Standard	Proposed	Published	Withdrawn	PIO Modes	DMA Modes	UDMA Modes	Parallel Speed (MBps)	Serial Speed (MBps)	Features
ATA-1	1988	1994	1999	0–2	0	—	8.33	—	Drives support up to 136.9GB; BIOS issues not addressed.
ATA-2	1993	1996	2001	0–4	0–2	—	16.67	—	Faster PIO modes; CHS/LBA BIOS translation defined up to 8.4GB; PC-Card.
ATA-3	1995	1997	2002	0–4	0–2	—	16.67	—	S.M.A.R.T.; improved signal integrity; LBA support mandatory; eliminated single-word DMA modes.
ATA-4	1996	1998	2012	0–4	0–2	0–2	33.33	—	Ultra-DMA modes; ATAPI Packet Interface; BIOS support up to 136.9GB.
ATA-5	1998	2000	—	0–4	0–2	0-4	66.67	—	Faster UDMA modes; 80-pin cable with auto-detection.
ATA-6	2000	2002	—	0–4	0–2	0-5	100	—	100MBps UDMA mode; extended drive and BIOS support up to 144PB.
ATA-7	2001	2004	—	0–4	0–2	0-6	133	150	133MBps UDMA mode; SATA.
ATA-8	2004	—	—	0–4	0–2	0-6	133	600	Minor revisions for PATA, includes SATA 2.x and 3.x.

S.M.A.R.T. = Self-Monitoring, Analysis, and Reporting Technology

ATAPI = AT Attachment Packet Interface

MB = Megabyte; million bytes

GB = Gigabyte; billion bytes

PB = Petabyte; quadrillion bytes

CHS = Cylinder, Head, Sector

LBA = Logical block address

PIO = Programmed I/O

DMA = direct memory access

UDMA = Ultra DMA (direct memory access)

ATA-1 (ATA Interface for Disk Drives)

ATA-1 defined the original ATA interface, which was an integrated bus interface between disk drives and host systems based on the ISA (AT) bus. These major features were introduced and documented in the ATA-1 specification:

- 40/44-pin connectors and cabling
- Master/slave or cable select drive configuration options
- Signal timing for basic Programmed I/O (PIO) and direct memory access (DMA) modes
- Cylinder, head, sector (CHS) and logical block address (LBA) drive parameter translations supporting drive capacities up to 2^{28}–2^{20} (267,386,880) sectors, or 136.9GB

Although ATA-1 had been in use since 1986, work on turning it into an official standard began in 1988 under the Common Access Method (CAM) committee. The ATA-1 standard was finished and officially published in 1994 as "ANSI X3.221-1994, AT Attachment Interface for Disk Drives." ATA-1 was officially withdrawn as a standard on August 6, 1999.

Although ATA-1 supported theoretical drive capacities up to 136.9GB (2^{28}–2^{20} = 267,386,880 sectors), it did not address BIOS limitations that stopped at 528MB (1024 × 16 × 63 = 1,032,192 sectors). The BIOS limitations would be addressed in subsequent ATA versions because, at the time, no drives larger than 528MB existed.

ATA-2 (ATA Interface with Extensions-2)

ATA-2 was a major upgrade to the original ATA standard. Perhaps the biggest change was almost a philosophical one. ATA-2 was updated to define an interface between host systems and storage devices in general and not only disk drives. The major features added to ATA-2 compared to the original ATA standard include the following:

- Faster PIO and DMA transfer modes
- Support for power management
- Support for removable devices
- PCMCIA (PC Card) device support
- `Identify Drive` command that reports more information
- Defined standard CHS/LBA translation methods for drives up to 8.4GB in capacity

The most important additions in ATA-2 were the support for faster PIO and DMA modes, as well as methods to enable BIOS support up to 8.4GB. The BIOS support was necessary because although ATA-1 was designed to support drives of up to 136.9GB in capacity, the PC BIOS could originally handle drives of up to 528MB. Adding parameter-translation capability now allowed the BIOS to handle drives up to 8.4GB. This is discussed in more detail later in this chapter.

ATA-2 also featured improvements in the `Identify Drive` command that enabled a drive to tell the software exactly what its characteristics are; this is essential for both Plug and Play (PnP) and compatibility with future revisions of the standard.

ATA-2 was also known by unofficial marketing terms, such as Fast-ATA or Fast-ATA-2 (Seagate/Quantum) and EIDE (Enhanced IDE, Western Digital).

Although work on ATA-2 began in 1993, the standard was not officially published until 1996 as "ANSI X3.279-1996 AT Attachment Interface with Extensions." ATA-2 was officially withdrawn in 2001.

ATA-3 (ATA Interface-3)

ATA-3 was a comparatively minor revision to the ATA-2 standard that preceded it. It consisted of a general cleanup of the specification and had mostly minor clarifications and revisions. The most major changes included the following:

- Eliminated single-word (8-bit) DMA transfer protocols
- Added S.M.A.R.T. (Self-Monitoring, Analysis, and Reporting Technology) support for prediction of device performance degradation
- Made LBA mode support mandatory (previously, it had been optional)
- Added ATA Security mode, allowing password protection for device access
- Provided recommendations for source and receiver bus termination to solve noise issues at higher transfer speeds

ATA-3 built on ATA-2, adding improved reliability, especially of the faster PIO mode 4 transfers; however, ATA-3 did not define faster modes. ATA-3 did add a simple password-based security scheme, more sophisticated power management, and S.M.A.R.T. This enables a drive to keep track of problems that might result in a failure and thus avoid data loss. S.M.A.R.T. is a reliability prediction technology that IBM initially developed.

Work on ATA-3 began in 1995, and the standard was finished and officially published in 1997 as "ANSI X3.298-1997, AT Attachment 3 Interface." ATA-3 was officially withdrawn in 2002.

ATA/ATAPI-4 (ATA with Packet Interface Extension-4)

ATA-4 included several important additions to the standard. It included the Packet Command feature known as the *AT Attachment Packet Interface* (ATAPI), which allowed devices such as CD-ROM and CD-RW drives, LS-120 SuperDisk floppy drives, Zip drives, tape drives, and other types of storage devices to be attached through a common interface. Until ATA-4 came out, ATAPI was a separately published standard. ATA-4 also added the 33MB per second (MBps) transfer mode known as Ultra-DMA or Ultra-ATA. ATA-4 is backward compatible with ATA-3 and earlier definitions of the ATAPI.

Work on ATA-4 began in 1996, and the standard was finished and officially published in 1998 as "ANSI NCITS 317-1998, AT Attachment - 4 with Packet Interface Extension." ATA-4 was officially withdrawn in 2012.

The major revisions added in ATA-4 were as follows:

- Ultra-DMA (UDMA)or Ultra-ATA/33) transfer modes up to Mode 2, which is 33MBps (called UDMA/33 or Ultra-ATA/33)
- Integral ATAPI support
- Advanced power management support
- An optional 80-conductor, 40-pin cable defined for improved noise resistance
- Host protected area (HPA) support
- Compact Flash Adapter (CFA) support
- Enhanced BIOS support for drives over 9.4ZB (zettabytes or trillion gigabytes) in size (even though ATA was still limited to 136.9GB)

The speed and level of ATA support in your system is mainly dictated by your motherboard chipset. Most motherboard chipsets come with a component called either a South Bridge or an I/O Controller

Hub that provides the ATA interface (as well as other functions) in the system. Check the specifications for your motherboard or chipset to see whether yours supports the faster ATA/33, ATA/66, ATA/100, or ATA/133 mode. One indication is to enter the BIOS Setup, put the hard disk on manual parameter settings (user defined), and see which (if any) Ultra-DMA modes are listed. Most boards built in 1998 support ATA/33. In 2000 they began to support ATA/66, and by late 2000 most started supporting ATA/100. ATA/133 support became widespread in mid-2002.

◀◀ See the Chapter 4 section, "Chipsets," **p. 181**.

ATA-4 made ATAPI support a full part of the ATA standard; therefore, ATAPI was no longer an auxiliary interface to ATA but merged completely within it. Thus, ATA-4 promoted ATA for use as an interface for many other types of devices. ATA-4 also added support for new Ultra-DMA modes (also called Ultra-ATA) for even faster data transfer. The highest-performance mode, called UDMA/33, had 33MBps bandwidth—twice that of the fastest programmed I/O mode or DMA mode previously supported. In addition to the higher transfer rate, because UDMA modes relieve the load on the processor, further performance gains were realized.

An optional 80-conductor cable (with cable select) is defined for UDMA/33 transfers. Although this cable was originally defined as optional, it would later be required for the faster ATA/66, ATA/100, and ATA/133 modes in ATA-5 and later.

Support for a reserved area on the drive called the HPA was added via an optional `SET MAX ADDRESS` command. This enables an area of the drive to be reserved for recovery software.

Also included was support for queuing commands, similar to those provided in SCSI-2. This enabled better multitasking as multiple programs request ATA transfers.

Another standard approved by the T13 committee in 1998 was "ANSI NCITS 316-1998 1394 to AT Attachment - Tailgate," which is a bridge protocol between the IEEE 1394 (i.LINK/FireWire) bus and ATA that enables ATA drives to be adapted to FireWire. A tailgate is an adapter device (basically a small circuit board) that converts IEEE 1394 (i.LINK or FireWire) to ATA, essentially allowing ATA drives to be plugged into a FireWire bus. This enabled vendors to quickly develop IEEE 1394 (FireWire) external drives for backup and high-capacity removable data storage. Inside almost any external FireWire drive enclosure you will find the tailgate device and a standard ATA drive.

▶▶ See the Chapter 14 section, "IEEE 1394 (FireWire or i.LINK)," **p. 718**.

ATA/ATAPI-5 (ATA with Packet Interface-5)

ATA-5 was built on the previous ATA-4 interface. ATA-5 includes Ultra-ATA/66 (also called *Ultra-DMA* or *UDMA/66*), which doubles the Ultra-ATA burst transfer rate by reducing setup times and increasing the clock rate. The faster clock rate increases interference, which causes problems with the standard 40-pin cable used by ATA and Ultra-ATA. To eliminate noise and interference, the newer 40-pin, 80-conductor cable was made mandatory for drives running in UDMA/66 or faster modes. This cable adds 40 additional ground lines between each of the original 40 ground and signal lines, which helps shield the signals from interference. Note that this cable works with older, non-Ultra-ATA devices as well because it still has the same 40-pin connectors.

Work on ATA-5 began in 1998, and the standard was finished and officially published in 2000 as "ANSI NCITS 340-2000, AT Attachment - 5 with Packet Interface."

The major additions in the ATA-5 standard include the following:

- Ultra-DMA (UDMA) transfer modes up to Mode 4, which is 66MBps (called UDMA/66 or Ultra-ATA/66).
- The 80-conductor cable now mandatory for UDMA/66 operation.

- Automatic detection of 40- or 80-conductor cables.
- UDMA modes faster than UDMA/33 enabled only if an 80-conductor cable is detected.

The 40-pin, 80-conductor cables support the cable select feature and have color-coded connectors. The blue (end) connector should be connected to the ATA host interface (usually the motherboard). The black (opposite end) connector is known as the *master position*, which is where the primary drive plugs in. The gray (middle) connector is for slave devices.

To use either the UDMA/33 or the UDMA/66 mode, your ATA interface, drive, BIOS, and cable must be capable of supporting the mode you want to use. The operating system also must be capable of handling direct memory access. Windows 95 OSR2 and later versions are ready out of the box, but older versions of Windows 95 and NT (prior to Service Pack 3) require additional or updated drivers to fully exploit these faster modes. Contact the motherboard or system vendor for the latest drivers.

For reliability, Ultra-DMA modes incorporate an error-detection mechanism known as *cyclical redundancy checking* (CRC). CRC is an algorithm that calculates a checksum used to detect errors in a stream of data. Both the host (controller) and the drive calculate a CRC value for each Ultra-DMA transfer. After the data is sent, the drive calculates a CRC value, and this is compared to the original host CRC value. If a difference is reported, the host might be required to select a slower transfer mode and retry the original request for data.

ATA/ATAPI-6 (ATA with Packet Interface-6)

ATA-6 includes Ultra-ATA/100 (also called Ultra-DMA or UDMA/100), which increases the Ultra-ATA burst transfer rate by reducing setup times and increasing the clock rate. As with ATA-5, the faster modes require the improved 80-conductor cable. Using the ATA/100 mode requires both a drive and motherboard interface that supports that mode.

Work on ATA-6 began in 2000, and the standard was finished and officially published in 2002 as "ANSI NCITS 361-2002, AT Attachment - 6 with Packet Interface."

The major changes or additions in the standard include the following:

- Ultra-DMA (UDMA) Mode 5 added, which allows 100MBps (called UDMA/100, Ultra-ATA/100, or just ATA/100) transfers.
- Sector count per command increased from 8 bits (256 sectors, or 131KB) to 16 bits (65,536 sectors, or 33.5MB), allowing larger files to be transferred more efficiently.
- LBA addressing extended from 228 to 248 (281,474,976,710,656) sectors, supporting drives up to 144.12PB (petabytes = quadrillion bytes). This feature is often referred to as 48-bit LBA or greater than 137GB support by vendors; Maxtor referred to this feature as Big Drive.
- CHS addressing was made obsolete; drives must use 28-bit or 48-bit LBA addressing only.

Besides adding the 100MBps UDMA Mode 5 transfer rate, ATA-6 extended drive capacity greatly, and just in time. ATA-5 and earlier standards supported drives of up to only 137GB in capacity, which became a limitation as larger drives were becoming available. Commercially available 3 1/2-inch drives exceeding 137GB were introduced in 2001, but they were originally available only in SCSI versions because SCSI doesn't have the same limitations as ATA. With ATA-6, the sector addressing limit has been extended from 2^{28} sectors to 2^{48} sectors. What this means is that LBA addressing previously could use only 28-bit numbers, but with ATA-6, LBA addressing can use larger 48-bit numbers if necessary. With 512 bytes per sector, this raises the maximum supported drive capacity to 144.12PB. That is equal to more than 144.12 quadrillion bytes! Note that the 48-bit addressing is optional and necessary only for drives larger than 137GB. Drives 137GB or smaller can use either 28-bit or 48-bit addressing.

ATA/ATAPI-7 (ATA with Packet Interface-7)

Work on ATA-7, which began late in 2001, was completed and officially published in 2004. As with the previous ATA standards, ATA-7 is built on the standard that preceded it (ATA-6), with some additions.

The primary additions to ATA-7 include the following:

- Ultra-DMA (UDMA) Mode 6 was added. This allows for 133MBps transfers (called UDMA/133, Ultra-ATA/133, or just ATA/133). As with UDMA Mode 5 (100MBps) and UDMA Mode 4 (66MBps), the use of an 80-conductor cable is required.
- Added support for long physical sectors. This allows a device to be formatted so that there are multiple logical sectors per physical sector. Each physical sector stores an ECC field, so long physical sectors allow increased format efficiency with fewer ECC bytes used overall.
- Added support for long logical sectors. This enables additional data bytes to be used per sector (520 or 528 bytes instead of 512 bytes) for server applications. Devices using long logical sectors are not backward compatible with devices or applications that use 512-byte sectors, such as standard desktop and laptop systems.
- SATA 1.0 incorporated as part of the ATA-7 standard. This includes the SATA physical interconnection as well as the related features and commands.
- The ATA-7 document split into three volumes. Volume 1 covers the command set and logical registers, which apply to both Serial and Parallel ATA. Volume 2 covers the parallel transport protocols and interconnects (PATA), and Volume 3 covers the serial transport protocols and interconnects (SATA).

The ATA/133 transfer mode was originally proposed by Maxtor, and only a few other drive and chipset manufacturers adopted it. Among the chipset manufacturers, VIA, ALi, and SiS added ATA/133 support to their chipsets, prior to moving on to SATA, but Intel decided from the outset to skip ATA/133 in its chipsets in lieu of adding SATA (150MBps or 300MBps). This means the majority of systems that utilize PATA do not support ATA/133; however, all ATA/133 drives do work in ATA/100 mode.

ATA/ATAPI-8

Work on ATA-8 began in 2004, and some initial parts of the standard were published in 2006 and 2008. Other parts are still in progress and continue to be revised as of 2013. As with the previous ATA standards, ATA-8 is built on the standard that preceded it, with some additions. As with the previous version, ATA-8 includes SATA but adds the newer 2.x and 3.x versions of the SATA specification.

The primary features added to ATA-8 include the following:

- The inclusion of SATA 2.x and 3.x for serial transport (physical) and command set functions
- The replacement of read long/write long functions
- Improved HPA management via additional HPA-related commands
- Defined `IDENTIFY DEVICE` word 217 to report drive rotational speed (rpm), where a value of 1 indicates nonrotating media (solid-state drive)
- Addition of the `TRIM` command for flash-based solid-state drives (SSDs). This allows the system to inform an SSD which blocks are no longer in use so they can be erased in preparation for future writes

As the development of ATA progresses, it is expected that newer features designed by the SATA-IO committee will be incorporated.

PATA

Parallel ATA was the most widely used drive interface for many years; however, currently it has been almost completely replaced by SATA for new systems. Even so, some new motherboards and drives are still available with PATA support, and many older systems, motherboards, and drives still in service use PATA as well. PATA has unique specifications and requirements regarding the physical interface, cabling, and connectors compared to SATA. The following sections detail the unique features of PATA.

PATA I/O Connector

The PATA interface connector is normally a 40-pin header-type connector with pins spaced 0.1 inch (2.54mm) apart. Generally, it is keyed to prevent the possibility of installing it upside down (see Figures 7.2 and 7.3). To create a keyed connector, the manufacturer usually removes pin 20 from the male connector and blocks pin 20 on the female cable connector, which prevents the user from installing the cable backward. Some cables also incorporate a protrusion on the top of the female cable connector that fits into a notch in the shroud surrounding the mating male connector on the device. The use of keyed connectors and cables is highly recommended. Plugging an ATA cable in backward normally doesn't cause permanent damage; however, it can lock up the system and prevent it from running.

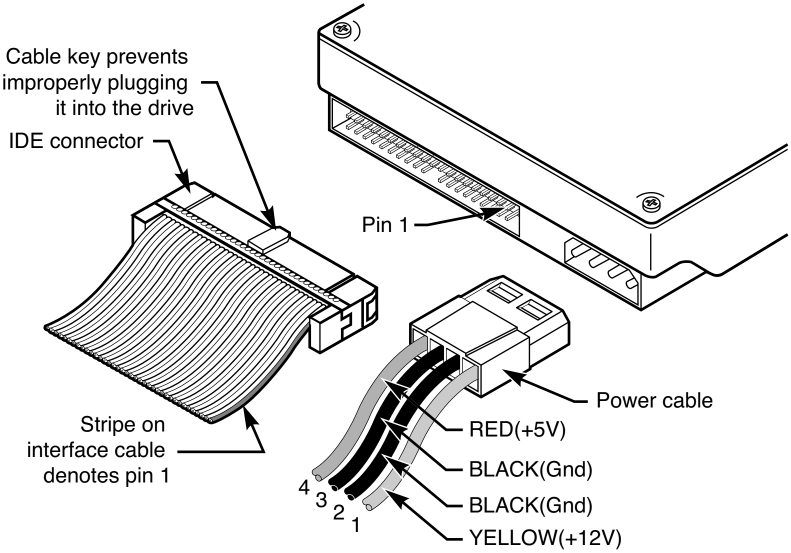


FIGURE 7.2 Typical PATA (IDE) hard drive connectors.

Table 7.3 shows the standard 40-pin PATA (IDE) interface connector pinout.

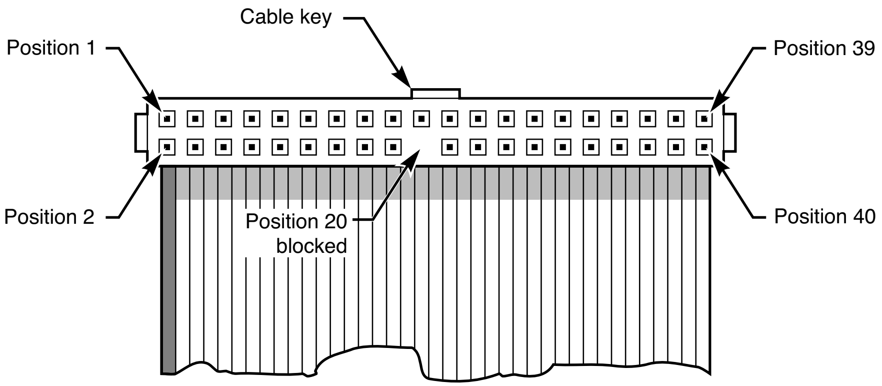


FIGURE 7.3 PATA (IDE) 40-pin interface connector detail.

Table 7.3 Pinout for the 40-Pin PATA Connector

Signal Name	Pin	Pin	Signal Name
-RESET	1	2	GROUND
Data Bit 7	3	4	Data Bit 8
Data Bit 6	5	6	Data Bit 9
Data Bit 5	7	8	Data Bit 10
Data Bit 4	9	10	Data Bit 11
Data Bit 3	11	12	Data Bit 12
Data Bit 2	13	14	Data Bit 13
Data Bit 1	15	16	Data Bit 14
Data Bit 0	17	18	Data Bit 15
GROUND	19	20	KEY (pin missing)
DRQ 3	21	22	GROUND
-IOW	23	24	GROUND
-IOR	25	26	GROUND
I/O CH RDY	27	28	CSEL:SPSYNC[1]
-DACK 3	29	30	GROUND
IRQ 14	31	32	Reserved[2]
Address Bit 1	33	34	-PDIAG
Address Bit 0	35	36	Address Bit 2
-CS1FX	37	38	-CS3FX
-DA/SP	39	40	GROUND

1 Pin 28 is usually cable select, but some older drives could use it for spindle synchronization between multiple drives.

2 Pin 32 was defined as -IOCS16 in ATA-2 but is no longer used.

Note that - preceding a signal name (such as -RESET) indicates the signal is "active low."

The 2 1/2-inch drives found in notebook/laptop-size computers typically use a smaller unitized 50-pin header connector with pins spaced only 2.0mm (0.079 inches) apart. The main 40-pin part of the connector is the same as the standard PATA connector (except for the physical pin spacing), but there are added pins for power and jumpering. The cable that plugs into this connector typically has 44 pins, carrying power as well as the standard ATA signals. The jumper pins usually have a jumper on them (the jumper position controls cable select, master, or slave settings). Figure 7.4 shows the unitized 50-pin connector used on the 2 1/2-inch PATA drives in laptop or notebook computers.

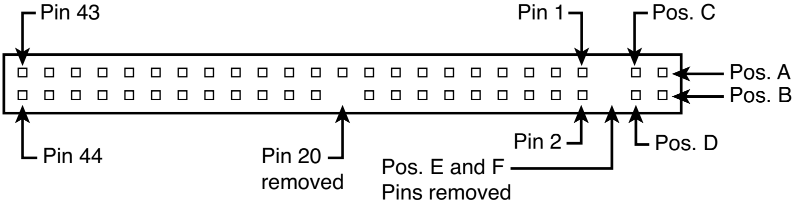


FIGURE 7.4 The 50-pin unitized PATA connector detail (used on 2 1/2-inch notebook/laptop PATA drives with a 44-pin cable).

Note the jumper pins at positions A–D; also notice that the pins at positions E and F are removed. A jumper usually is placed between positions B and D to set the drive for cable select operation. On this connector, pin 41 provides +5V power to the drive logic (circuit board), pin 42 provides +5V power to the motor (2 1/2-inch drives use 5V motors, unlike larger drives that typically use 12V motors), and pin 43 provides a power ground. The last pin (44) is reserved and not used.

Table 7.4 shows the 50-pin unitized PATA interface connector pinout as used on most 2 1/2-inch (laptop or notebook computer) drives.

Table 7.4 The 50-Pin Unitized PATA 2 1/2-Inch (Notebook/Laptop Drive) Connector Pinout

Signal Name	Pin	Pin	Signal Name
Jumper pin	A	B	Jumper pin
Jumper pin	C	D	Jumper pin
KEY (pin missing)	E	F	KEY (pin missing)
-RESET	1	2	GROUND
Data Bit 7	3	4	Data Bit 8
Data Bit 6	5	6	Data Bit 9
Data Bit 5	7	8	Data Bit 10
Data Bit 4	9	10	Data Bit 11
Data Bit 3	11	12	Data Bit 12
Data Bit 2	13	14	Data Bit 13
Data Bit 1	15	16	Data Bit 14
Data Bit 0	17	18	Data Bit 15
GROUND	19	20	KEY (pin missing)

Table 7.4 Continued

Signal Name	Pin	Pin	Signal Name
DRQ 3	21	22	GROUND
-IOW	23	24	GROUND
-IOR	25	26	GROUND
I/O CH RDY	27	28	CSEL
-DACK 3	29	30	GROUND
IRQ 14	31	32	Reserved
Address Bit 1	33	34	-PDIAG
Address Bit 0	35	36	Address Bit 2
-CS1FX	37	38	-CS3FX
-DA/SP	39	40	GROUND
+5V (Logic)	41	42	+5V (Motor)
GROUND	43	44	Reserved

Note

Many lower-cost board and cable manufacturers leave out the keying. Cheaper motherboards often don't have pin 20 removed on their ATA connectors; consequently, they don't supply a cable with pin 20 blocked. If they don't use a shrouded connector with a notch and a corresponding protrusion on the cable connector, no keying exists and the cables can be inserted backward. Fortunately, the only consequence of this in most cases is that the device won't work until the cable is attached with the correct orientation.

Note that some systems do not display video until the ATA drives respond to a spin-up command, which they can't receive if the cable is connected backward. So, if you connect an unkeyed ATA drive to your computer, turn on the computer, and it seems as if the system is locked up (you don't see anything on the screen), check the ATA cable. (See Figure 7.6 for examples of unkeyed and keyed ATA cables.)

In rare situations in which you are mixing and matching items, you might encounter a cable with pin 20 blocked (as it should be) and a board with pin 20 still present. In that case, you can break off pin 20 from the board—or for the more squeamish, remove the block from the cable or replace the cable with one without the blocked pin. Some cables have the block permanently installed as part of the connector housing, in which case you must break off pin 20 on the board or device end or use a different cable.

The simple rule of thumb is that pin 1 should be oriented toward the power connector on the device, which normally corresponds to the stripe on the cable.

PATA I/O Cable

A 40-conductor ribbon cable is specified to carry signals between the bus adapter circuits and the drive (controller). To maximize signal integrity and eliminate potential timing and noise problems, the cable should not be longer than 18 inches (0.46 meters), although testing shows that you can reliably use 80-conductor cables up to 27 inches (0.69 meters) in length.

Note that ATA drives supporting the higher-speed transfer modes, such as PIO Mode 4 or any of the Ultra-DMA (UDMA) modes, are especially susceptible to cable integrity problems. If the cable is too long, you can experience data corruption and other errors that can be maddening. This is manifested in problems reading from or writing to the drive. In addition, any drive using UDMA Mode 5 (66MBps transfer rate), Mode 6 (100MBps transfer rate), or Mode 7 (133MBps transfer rate) must use a special, higher-quality 80-conductor cable. I also recommend this type of cable if your drive is running at UDMA Mode 2 (33MBps) or slower because it can't hurt and can only help. I always keep a high-quality 80-conductor ATA cable in my toolbox for testing drives where I suspect cable integrity or cable length problems. Figure 7.5 shows the typical ATA cable layout and dimensions.

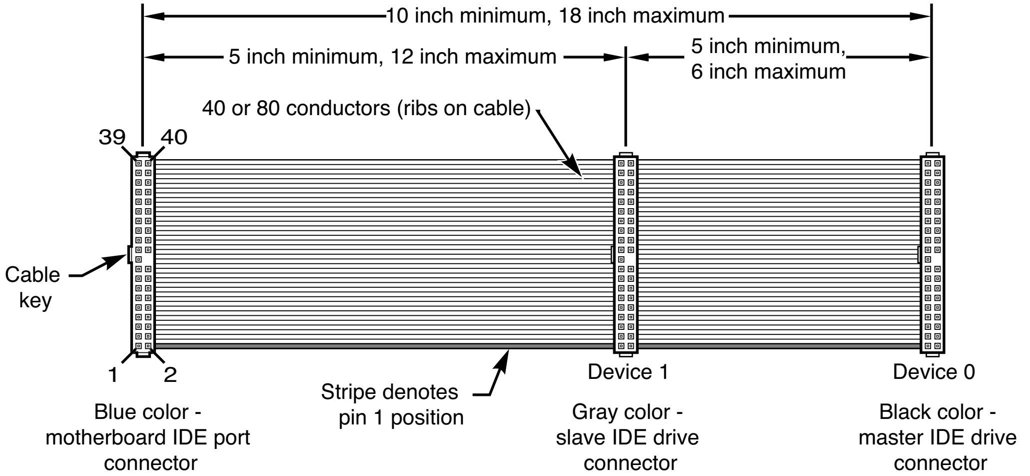


FIGURE 7.5 PATA (IDE) cable, with 40-pin connectors and either 40- or 80-conductor cables (additional wires are grounded in 80-conductor versions).

Note

Most 40-conductor cables do not have color-coded connectors, whereas all 80-conductor cables have color-coded connectors.

The two primary variations of PATA cables in use today—one with 40 conductors and the other with 80 conductors—are shown in Figure 7.6. As you can see, both use 40-pin connectors, and the additional wires in the 80-conductor version are simply wired to ground. The additional conductors are designed to reduce noise and interference and are required when setting the interface to run at 66MBps (ATA/66) or faster. The drive and host adapter are designed to disable the higher-speed ATA/66, ATA/100, and ATA/133 modes if an 80-conductor cable is not detected. In such cases, you might see a warning message when you start your computer if an ATA/66 or faster drive is connected to a 40-conductor cable. You can also use the 80-conductor cable at lower speeds to improve signal integrity. Therefore, it is the recommended version no matter which drive you use.

I once had a student ask me how to tell an 80-conductor cable from a 40-conductor cable. The simple answer is to count the ridges (conductors) in the cable. If you count only 40, it must be a 40-conductor cable, and if you count to 80…well, you get the idea! If you observe them side by side, the difference is clear: The 80-conductor cable has an obviously smoother, less ridged appearance than the 40-conductor cable.

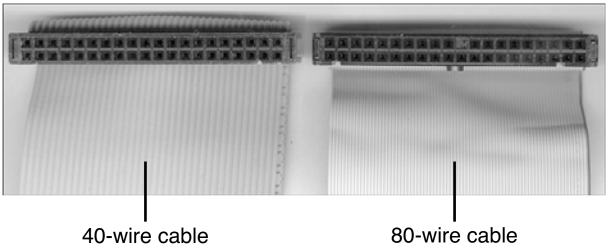


FIGURE 7.6 A 40-conductor PATA cable (left) and a 80-conductor PATA cable (right).

Note the keying on the 80-conductor cable that is designed to prevent backward installation. Note also that the poorly constructed 40-conductor cable shown in Figure 7.6 lacks keying. Most good 40-conductor cables include the keying; however, because it is optional, many cheaply constructed versions do not include it. Keying was made mandatory for all 80-conductor cables as part of the standard.

Longer or Rounded Cables

The official PATA standard limits cable length to 18 inches (0.46 meters); however, many of the cables sold are longer, up to 36 inches (0.91 meters) or more in length. I've had many readers write me questioning the length, asking, "Why would people sell cables longer than 18 inches if the standard doesn't allow it?" Well, just because something is for sale doesn't mean it conforms to the standards and will work properly! I see improperly designed, poorly manufactured, and nonconforming items for sale all the time. Many people have used the longer cables and their systems seem to work fine, but I've also documented numerous cases where using longer cables has caused problems, so I decided to investigate this issue more thoroughly.

What I discovered is that you can use longer 80-conductor cables reliably up to 27 inches (0.69 meters) in length, but 40-conductor cables should remain limited to 18 inches, just as the standard indicates.

In fact, an attempt was made to change the PATA standard to allow 27-inch cables. If you read www.t13.org/Documents/UploadedDocuments/technical/e00151r0.pdf, you'll see data from a proposal that shows "negligible differences in Ultra DMA Mode 5 signal integrity between a 27-inch, 80-conductor cable and an 18-inch, 80-conductor cable." This extended cable design was actually proposed back in October 2000, but it was never incorporated into the standard. Even though it was never officially approved, I take the information presented in this proposal as empirical evidence for allowing the use of 80-conductor cables up to 27 inches in length without problems.

To that, I would add another recommendation, which is that in general I do not recommend "rounded" ATA cables. A rounded design has not been approved in the ATA standard, and there is some evidence that it can cause problems with crosstalk and noise. The design of 80-conductor cables is such that a ground wire is interspersed between each data wire in the ribbon, and rounding the cable causes some of the data lines to run parallel or adjacent to each other at random, thereby causing crosstalk and noise and resulting in signal errors.

Of course, many people use rounded cables with success, but my knowledge of electrical engineering as well as the ATA standard has always made me somewhat uncomfortable with their use.

PATA Signals

This section describes in more detail some of the most important PATA signals having to do with drive configuration and installation. This information can help you understand how the cable select feature works, for example.

Pin 20 is used as a key pin for cable orientation and is not connected to the interface. This pin should be missing from any ATA connectors, and the cable should have the pin-20 hole in the connector plugged off to prevent the cable from being plugged in backward.

Pin 39 carries the drive active/slave present (DASP) signal, which is a dual-purpose, time-multiplexed signal. During power-on initialization, this signal indicates whether a slave drive is present on the interface. After that, each drive asserts the signal to indicate that it is active. Early drives could not multiplex these functions and required special jumper settings to work with other drives. Standardizing this function to allow for compatible dual-drive installations is one of the features of the ATA standard. This is why some drives require a slave present (SP) jumper, whereas others do not.

Pin 28 carries the cable select signal (CSEL). In some older drives, it could also carry a spindle synchronization signal (SPSYNC), but that is not commonly found on newer drives. The CSEL function is the most widely used and is designed to control the designation of a drive as master (drive 0) or slave (drive 1) without requiring jumper settings on the drives. If a drive sees the CSEL as being grounded, the drive is a master; if CSEL is open, the drive is a slave.

You can install special cabling to ground CSEL selectively. This installation usually is accomplished through a cable that has pin 28 missing from the middle connector but present in the connectors on each end. In that arrangement, with one end plugged into the motherboard and two drives set to cable select, the drive plugged into the end connector is automatically configured as master, whereas the drive attached to the middle connector is configured as slave. Note that although this is the most common arrangement, it is also possible to make cables where the middle connector is master (and the end is slave), or even to use a Y-cable arrangement, with the motherboard ATA bus connector in the middle, and each drive at opposite ends of the cable. In this arrangement, one leg of the Y would have the CSEL line connected through (master), and the other leg would have the CSEL line open (conductor interrupted or removed), making the drive at that end the slave.

PATA Dual-Drive Configurations

Dual-drive PATA installations can be problematic because each drive has its own controller, and both controllers must function while being connected to the same bus. There has to be a way to ensure that only one of the two controllers responds to a command at a time.

The ATA standard provides the option of operating on the AT bus with two drives in a daisy-chained configuration. The primary drive (drive 0) is called the *master*, and the secondary drive (drive 1) is called the *slave*. You designate a drive as being master or slave by setting a jumper or switch on the drive or by using a special line in the interface called the *cable select (CS) pin* and setting the CS jumper on the drive.

When only one drive is installed, the controller responds to all commands from the system. When two drives (and, therefore, two controllers) are installed, both controllers receive all commands from the system. Each controller then must be set up to respond only to commands for itself. In this situation, one controller must be designated as the master and the other as the slave. When the system sends a command for a specific drive, the controller on the other drive must remain silent while the selected controller and drive are functioning. Setting the jumper to master or slave enables discrimination between the two controllers by setting a special bit (the DRV bit) in the drive/head register of a command block.

Configuring ATA drives can be simple, as is the case with most single-drive installations. Or it can be troublesome, especially when it comes to mixing two older drives from different manufacturers on a single cable.

You can configure most ATA drives with four possible settings:

- Master (single drive)
- Master (dual drive)
- Slave (dual drive)
- Cable select

Most drives simplify this to three settings: master, slave, and cable select. Because each ATA drive has its own controller, you must specifically tell one drive to be the master and the other to be the slave. No functional difference exists between the two, except that the drive that's specified as the slave asserts a signal called DASP after a system reset informs the master that a slave drive is present in the system. The master drive then pays attention to the drive select line, which it otherwise ignores. Telling a drive that it's the slave also usually causes it to delay its spin-up for several seconds to allow the master to get going and thus to lessen the load on the system's power supply.

Until the ATA specification, no common implementation for drive configuration was in use. Some drive companies even used different master/slave methods for different models of drives. Because of these incompatibilities, some drives work together only in a specific master/slave or slave/master order. This situation mostly affects older IDE drives introduced before the ATA specification.

Most drives that fully follow the ATA specification now need only one jumper (master/slave) for configuration. A few also need a slave present jumper. Table 7.5 shows the jumper settings that most ATA drives require.

Table 7.5 Jumper Settings for Most ATA-Compatible Drives on Standard (Non–Cable Select) Cables

Jumper Name	Single-Drive	Dual-Drive Master	Dual-Drive Slave
Master (M/S)	On	On	Off
Slave Present (SP)	Off	On	Off
Cable Select (CS)	Off	Off	Off

Note

If a cable select cable is used, the CS jumper should be set to On and all others should be set to Off. The cable connector then determines which drive will be master or slave.

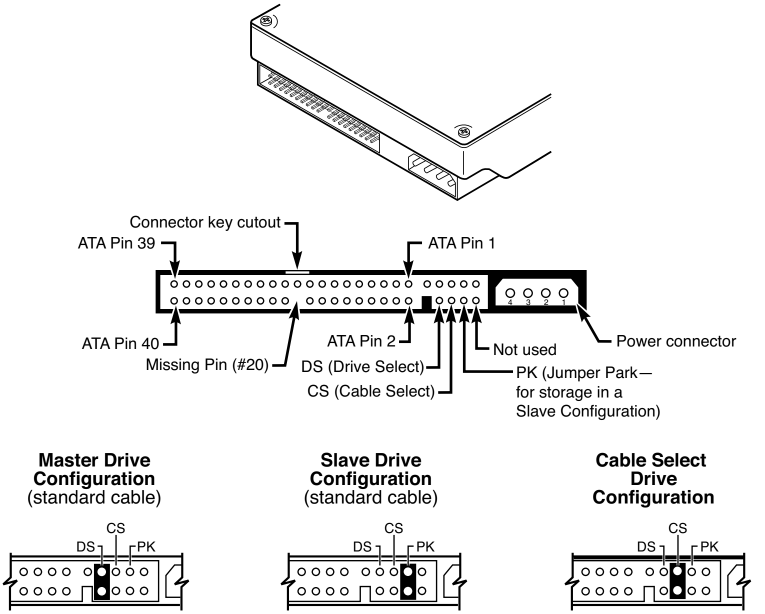
Figure 7.7 shows the jumpers on a typical ATA drive.

The master jumper indicates that the drive is a master or a slave. Some drives also require a slave present jumper, which is used only in a dual-drive setup and then installed only on the master drive, which is somewhat confusing. This jumper tells the master that a slave drive is attached. With many PATA drives, the master jumper is optional and can be left off. Installing this jumper doesn't hurt in these cases and can eliminate confusion; I recommend that you install the jumpers listed here.

Note

Some drives have these jumpers on the drive circuit board on the bottom of the drive, and as such they might not be visible on the rear.

To eliminate confusion over master/slave settings, most newer systems now use the cable select option. This involves two things. The first is having a special PATA cable that has all the wires except pin 28 running from the motherboard connector to both drive connectors. Pin 28 is used for cable select and is connected to one of the drive connectors (labeled master) and not to the other (labeled slave). Both drives are then configured in cable select mode via the CS jumper on each drive.



Master Drive Configuration (standard cable)

Slave Drive Configuration (standard cable)

Cable Select Drive Configuration

Use the Master Drive Configuration for the first (or only) drive on a standard (non-cable select) cable.

Use the Slave Drive Configuration for the second drive on a standard (non-cable select) cable; note that for a Slave Configuration, the jumper can be stored in the PK (Jumper Park) position, removed entirely, or stored on one of the DS Pins in a flag arrangement.

For Cable Select Drive Configurations, one or both drives are configured the same; the cable automatically determines which is Master or Slave by which connector the drive is plugged into.

FIGURE 7.7 PATA (IDE) drive jumpers for most drives.

With cable select, the drive that receives signals on pin 28 automatically becomes the master, and the other becomes the slave. Most cables implement this by removing the metal insulation displacement bit from the pin-28 hole, which can be difficult to see at a glance. Other cables have a section of pin 28 visibly cut from the cable somewhere along the ribbon. Because this is such a minor modification to the cable and can be difficult to see, cable select cables typically have the connectors labeled master, slave, and system, indicating that the cable controls these options rather than the drive. All 80-conductor Ultra-ATA cables are designed to use cable select.

With cable select, you simply set the CS jumper on all drives and then plug the drive you want to be the master into the connector labeled master on the cable and the drive you want to be the slave into the connector labeled slave.

The only downside I see to using cable select is that it can restrict how the cable is routed or where you mount the drive that is to be master versus slave because they must be plugged into specific cable connector positions.

PATA PIO Transfer Modes

ATA-2 and ATA-3 defined the first of several higher-performance modes for transferring data over the PATA interface, to and from the drive. These faster modes were the main part of the newer specifications and were the main reason they were initially developed. The following section discusses these modes.

The PIO (programmed I/O) mode determines how fast data is transferred to and from the drive using PIO transfers. In the slowest possible mode—PIO Mode 0—the data cycle time can't exceed 600 nanoseconds (ns). In a single cycle, 16 bits are transferred into or out of the drive, making the theoretical transfer rate of PIO Mode 0 (600ns cycle time) 3.3MBps, whereas PIO Mode 4 (120ns cycle time) achieves a 16.6MBps transfer rate.

Most motherboards with ATA-2 or greater support have dual ATA connectors on the motherboard. Most of the motherboard chipsets include the ATA interface in their South Bridge components, which in most systems is tied into the PCI bus.

Older 486 and some early Pentium boards have only the primary connector running through the system's PCI local bus. The secondary connector on those boards usually runs through the ISA bus and therefore supports up to Mode 2 operation only.

When interrogated with an `Identify Drive` command, a hard disk returns, among other things, information about the PIO and DMA modes it is capable of using. Most BIOSs automatically set the correct mode to match the capabilities of the drive. If you set a mode faster than the drive can handle, data corruption results.

ATA-2 and newer drives also perform Block Mode PIO, which means they use the Read/Write Multiple commands that greatly reduce the number of interrupts sent to the host processor. This lowers the overhead, and the resulting transfers are even faster.

PATA DMA Transfer Modes

ATA drives support two types of transfers: programmed input/output (PIO), and direct memory access (DMA) transfers. DMA means that the data is transferred directly between drive and memory without using the CPU as an intermediary, as opposed to PIO. This offloads much of the work of transferring data from the processor, in effect allowing the processor to do other things while the transfer is taking place. DMA transfers are much faster than PIO transfers and are supported by all modern ATA devices.

There are two distinct types of direct memory access: singleword (8-bit) and multiword (16-bit). Singleword DMA modes were removed from the ATA-3 and later specifications and are obsolete. DMA modes are also sometimes called *busmaster* ATA modes because they use a host adapter that supports busmastering. Ordinary DMA relies on the legacy DMA controller on the motherboard to perform the complex task of arbitration, grabbing the system bus and transferring the data. In the case of busmastering DMA, all this is done by a higher-speed logic chip in the host adapter interface (which is also on the motherboard).

Systems using the Intel PIIX (PCI IDE ISA eXcelerator) and later South Bridge chips (or equivalent) can support busmaster ATA. The singleword and multiword busmaster ATA modes and transfer rates are shown in Tables 7.6 and 7.7, respectively.

Table 7.6 Singleword (8-Bit) DMA Modes and Transfer Rates

8-Bit DMA Mode	Bus Width (Bits)	Cycle Speed (ns)	Bus Speed (MHz)	Cycles per Clock	Transfer Rate (MBps)	ATA Specification
0	16	960	1.04	1	2.08	ATA-1*
1	16	480	2.08	1	4.17	ATA-1*
2	16	240	4.17	1	8.33	ATA-1*

**Singleword (8-bit) DMA modes were removed from the ATA-3 and later specifications.*

Table 7.7 Multiword (16-Bit) DMA Modes and Transfer Rates

16-Bit DMA Mode	Bus Width (Bits)	Cycle Speed (ns)	Bus Speed (MHz)	Cycles per Clock	Transfer Rate (MBps)	ATA Specification
0	16	480	2.08	1	4.17	ATA-1
1	16	150	6.67	1	13.33	ATA-2*
2	16	120	8.33	1	16.67	ATA-2*

**ATA-2 was also referred to as EIDE (Enhanced IDE) or Fast-ATA.*

Note that multiword DMA modes are also called *busmaster DMA modes* by some manufacturers. Unfortunately, even the fastest multiword DMA Mode 2 results in the same 16.67MBps transfer speed as PIO Mode 4. However, even though the transfer speed is the same as PIO, because DMA offloads much of the work from the processor, overall system performance is higher. Even so, multiword DMA modes were never very popular and have been superseded by the newer Ultra-DMA modes supported in devices that are compatible with ATA-4 through ATA-7.

Table 7.8 shows the Ultra-DMA modes now supported in the ATA-4 through ATA-7 specifications. Note that you need to install the correct drivers for your host adapter and version of Windows to use this feature.

Table 7.8 Ultra-DMA Support in ATA-4 Through ATA-7

Ultra DMA Mode	Bus Width (Bits)	Cycle Speed (ns)	Bus Speed (MHz)	Cycles per Clock	Transfer Rate (MBps)	ATA Specification
0	16	240	4.17	2	16.67	ATA-4
1	16	160	6.25	2	25.00	ATA-4
2	16	120	8.33	2	33.33	ATA-4
3	16	90	11.11	2	44.44	ATA-5
4	16	60	16.67	2	66.67	ATA-5
5	16	40	25.00	2	100.00	ATA-6
6	16	30	33.00	2	133.00	ATA-7

ATA-4 UDMA Mode 2 is sometimes called Ultra-ATA/33 or ATA-33.

ATA-5 UDMA Mode 4 is sometimes called Ultra-ATA/66 or ATA-66.

ATA-6 UDMA Mode 5 is sometimes called Ultra-ATA/100 or ATA-100.

ATA-7 UDMA Mode 6 is sometimes called Ultra-ATA/133 or ATA-133.

SATA

The development of ATA-8 marked the beginning of the end for the PATA standard that has been in use since 1986. Sending data at rates faster than 133MBps down a parallel ribbon cable originally designed for only 8.3Mbps is fraught with all kinds of problems because of signal timing, electromagnetic interference (EMI), and other integrity problems. The solution, Serial ATA, is an evolutionary replacement for the venerable PATA physical storage interface. When set in non-AHCI/RAID modes (in other words, IDE or legacy mode), SATA is software-compatible with PATA, which means it emulates all the commands, registers, and controls so existing software can run without changes. In other words, the existing BIOSs, operating systems, and utilities that work on PATA also work with SATA.

Of course, they do differ physically—that is, you can't plug PATA drives into SATA host adapters, and vice versa, although signal converters do make that possible. The physical changes are all for the better because SATA uses much smaller and thinner cables with only seven conductors that are easier to route inside the PC and easier to plug in with smaller, redesigned cable connectors. The interface chip designs also are improved, with far fewer pins and lower voltages. All these improvements are designed to eliminate the design problems inherent in PATA.

Figure 7.8 shows the official Serial ATA International Organization working group logo that identifies most SATA devices.

FIGURE 7.8 Serial ATA official logo, which identifies SATA devices.

Although SATA didn't immediately replace PATA, most systems sold following SATA's standardization included SATA interfaces alongside PATA interfaces. Over time, SATA has predominantly replaced PATA as the de facto standard internal storage device interface found in PCs, and most current systems lack PATA support. However, some motherboards and devices with PATA support are still available, and where repairs are considered they will likely remain available at a minimum level for some time.

SATA Standards and Performance

Development for SATA started when the Serial ATA Working Group effort was announced at the Intel Developer Forum in February 2000. The initial members of the Serial ATA Working Group included APT Technologies, Dell, IBM, Intel, Maxtor, Quantum, and Seagate. The original group later became known as the Serial ATA II Working Group, and finally in July 2004, it became the Serial ATA International Organization. These groups have released the following SATA specifications:

- The first SATA 1.0 draft specification was released in November 2000 and was officially published as a final specification in August 2001.
- The first SATA II Working Group extensions to this specification, which made SATA suitable for network storage, were released in October 2002.
- SATA Revision 2 was released in April 2004. It added the 3Gbps (300MBps) signaling speed.

- SATA Revision 2.5 was released in August 2005. It added Native Command Queuing (NCQ), staggered spin-up, hot plug, port multiplier, and eSATA support.
- SATA Revision 2.6 was released in March 2007. It added new internal Slimline and Micro cables and connectors as well as modifications to NCQ.
- SATA Revision 3.0 was released in 2009. It added the 6Gbps (600MBps) signaling speed.
- SATA Revision 3.1 was released in 2011. It added improvements in power management, hardware control, and a Queued Trim Command for improving SSD performance.
- SATA Revision 3.2 was released in 2013. It adds a new interface called SATA Express, which uses SATA commands over a PCIe hardware interface for transfer speeds up to 16Gbps.

You can download the specifications from the Serial ATA International Organization website at www.serialata.org. Since forming, the group has grown to include more than 200 contributor and adopter companies from all areas of industry.

Systems using SATA were released in late 2002 using discrete PCI interface boards and chips. SATA was integrated directly into motherboard chipsets in April 2003 with the introduction of the Intel ICH5 chipset component. Since then, virtually all new motherboard chipsets have included SATA.

The performance of SATA is impressive, although current hard drive designs can’t fully take advantage of its bandwidth. Solid State Drives (SSDs), on the other hand, can and do take advantage of all of the bandwidth that SATA has to offer and are the driving force for the introduction of even higher bandwidth standards. Three main variations of the original standard use the same cables and connectors; they differ only in transfer rate performance. SATA Express, in contrast, uses new cables and connectors for dramatically increased throughput. Table 7.9 shows the bandwidth specifications; devices supporting the second-generation 300MBps (3Gbps) version became available in 2005, and devices supporting the third-generation 600MBps (6Gbps) versions became available in 2011. SATA Express devices are expected to be available in 2014.

Table 7.9 SATA Transfer Modes

SATA Type	Signal Rate (Gbps)	Bus Width (Bits)	Bus Speed (MHz)	Data Cycles per Clock	Throughput
SATA-150	1.5	1	1,500	1	150
SATA-300	3.0	1	3,000	1	300
SATA-600	6.0	1	6,000	1	600
SATA Express	8.0	2	16,000	1	1,969*

**Note SATA Express uses 128b/130b encoding, which is 98.5% efficient vs. the 80% efficient 8b/10b encoding used by SATA.*

SATA Express

The advent of high-performance SSD (solid-state drive) storage has pushed the need for greater and greater interface bandwidth. SATA 3.0 offers up to 600MBps throughput, which by 2011 many SSDs could deliver. Since then the development of faster and faster drives has been mostly limited by the interface bandwith, and that SATA had become the bottleneck. To eliminate this bottleneck, the Serial ATA International Organization (SATA-IO) first studied doubling the SATA 6Gbps rate to 12Gbps;

however, they found that doing so required extensive (and expensive) changes in cabling and signaling, not to mention that development would take some time. Instead, they decided to take a much easier way out by using the existing PCI Express interface. SATA-IO first announced in 2011 that it was developing a faster version of SATA called SATA Express, which was finally completed and published in 2013 as part of the SATA 3.2 specification.

SATA Express combines PCI Express signaling with the SATA software protocol (command set), plus a new set of cables and connectors that are backward compatible with SATA. When using PCIe 3.0 signaling, SATA Express offers up to 16Gbps in raw data throughput, which translates to nearly 2 gigabytes per second of actual data bandwidth. That is nearly 3.3 times faster than conventional SATA at 600MBps.

Not only is the SATA Express signaling speed much faster, but it is also more efficient, resulting in even higher bandwiths than the raw signaling rate would imply. Conventional SATA uses 8b/10b encoding, which is 80% efficient. That means that 8 out of every 10 bits (or 80%) in the raw data stream are actual data; the other 2 bits (or 20%) are overhead. SATA Express uses the more advanced 128b/130b encoding scheme found in PCI Express 3.0, which is an incredible 98.5% efficient, with only 1.5% overhead. This is achieved by scrambling the raw data to be sent using a known binary polynomial and then unscrambling it at the other end using the inverse polynomial. Because SATA Express uses two PCIe lanes with up to 8Gbps per lane, combined with the more efficient encoding, the end result is a whopping 1,969MBps maximum throughput as compared to 600MBps for conventional SATA.

SATA Express uses a wider cable with 18 conductors vs. the 7 conductors in a standard SATA cable. SATA Express motherboard connectors are backward compatible with SATA, meaning you can plug one or two standard SATA cables into a single SATA Express connector (see Figure 7.9). Connecting conventional SATA drives to a SATA Express port causes the port to shift down to conventional SATA mode.

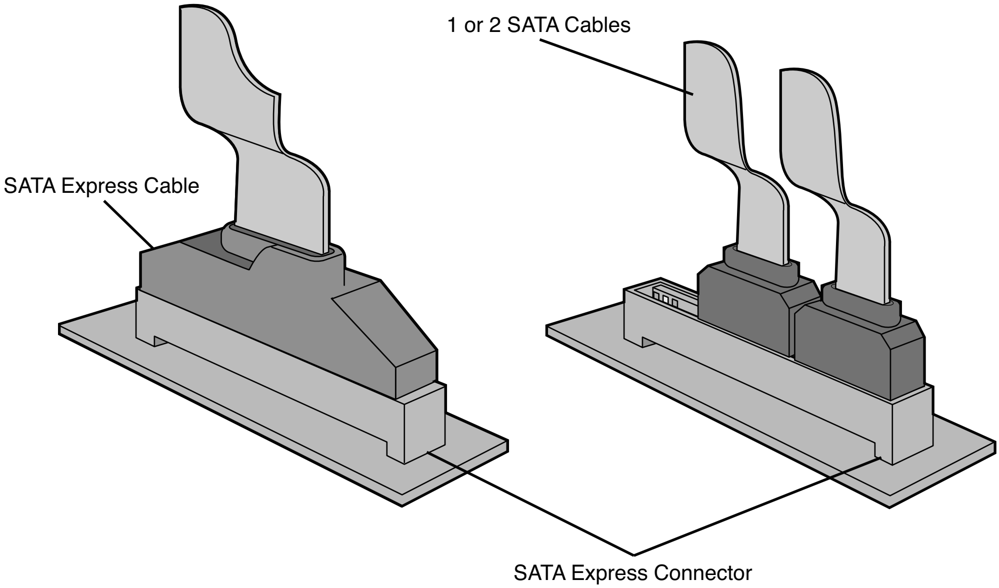


FIGURE 7.9 SATA Express motherboard and cable connectors, showing backward compatibility with conventional SATA.

With SATA Express offering more than three times the throughput of conventional SATA, high-performance storage devices like SSDs will become even faster in the future.

SATA Cables and Connectors

From Table 7.9, you can see that conventional SATA sends data only a single bit at a time, while SATA Express sends 2 bits. The cable used for SATA has only seven wires (four signal and three ground) and is a thin design, with keyed connectors only 14mm (0.55 inches) wide on each end. This eliminates problems with airflow compared to the wider PATA ribbon cables. Each cable has connectors only at each end, and each cable connects the device directly to the host adapter (typically on the motherboard). There are no master/slave settings because each cable supports only a single device. The cable ends are interchangeable; the connector on the motherboard is the same as on the device, and both cable ends are identical. Maximum SATA cable length is 1 meter (39.37 inches), which is considerably longer than the 18-inch maximum for PATA.

Although SATA-600 uses the same cables and connectors as the previous (slower) versions, it does place higher demands for quality, so some manufacturers will mark higher quality cables with a rating like “SATA 6Gbps.” One issue that becomes more of a problem is bending cables. Data moving at the higher 3Gbps and 6Gbps rates can be corrupted when encountering a severe right-angle bend, so it is recommended that when routing SATA cables you do not crimp or bend them sharply with a pliers; use more gradual curves or bends instead. Note that this does not apply to cables with right-angle connectors; the wires in the connectors have multiple bends or curve instead.

SATA uses a special encoding scheme called 8b/10b to encode and decode data sent along the cable. IBM initially developed (and patented) the 8b/10b transmission code in the early 1980s for use in high-speed data communications. Many high-speed data transmission standards, including Gigabit Ethernet, Fibre Channel, FireWire, and others, use this encoding scheme. The main purpose of the 8b/10b encoding scheme is to guarantee that never more than four 0s (or 1s) are transmitted consecutively. This is a form of Run Length Limited (RLL) encoding called RLL 0,4, in which the 0 represents the minimum and the 4 represents the maximum number of consecutive 0s or 1s in each encoded character.

The 8b/10b encoding also ensures that there are never more than six or fewer than four 0s (or 1s) in a single encoded 10-bit character. Because 1s and 0s are sent as voltage changes on a wire, this ensures that the spacing between the voltage transitions sent by the transmitter is fairly balanced, with a more regular and steady stream of pulses. This presents a steadier load on the circuits, increasing reliability. The conversion from 8-bit data to 10-bit encoded characters for transmission leaves several 10-bit patterns unused. Many of these additional patterns provide flow control, delimit packets of data, perform error checking, or perform other special functions.

The physical transmission scheme for SATA uses *differential NRZ* (Non Return to Zero). This uses a balanced pair of wires, each carrying +0.25V (one-quarter volt). The signals are sent differentially: If one wire in the pair carries +0.25V, the other wire carries –0.25V, where the differential voltage between the two wires is always 0.5V (one-half volt). So, for a given voltage waveform, the opposite voltage waveform is sent along the adjacent wire. Differential transmission minimizes electromagnetic radiation and makes the signals easier to read on the receiving end.

A 15-pin power cable and power connector is optional with SATA, providing 3.3V power in addition to the 5V and 12V provided via the industry-standard 4-pin device power connectors. Although it has 15 pins, this new power connector design is only 24mm (0.945 inches). With 3 pins designated for each of the 3.3V, 5V, and 12V power levels, enough capacity exists for up to 4.5 amps of current at each voltage, which is plenty for even the most power-hungry drives. For compatibility with existing power supplies, SATA drives can be made with the original, standard 4-pin device power connector or the new 15-pin SATA power connector (or both). If the drive doesn't have the type of connector you need, adapters are available to convert from one type to the other.

Figure 7.10 shows what the SATA signal and power connectors look like, and Figure 7.11 shows SATA and PATA host adapters on a typical motherboard.

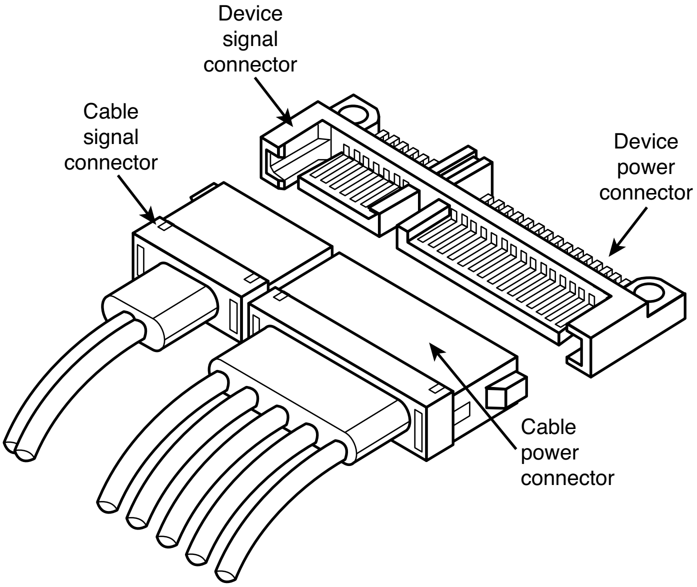


FIGURE 7.10 SATA signal and power connectors on a typical SATA hard drive.

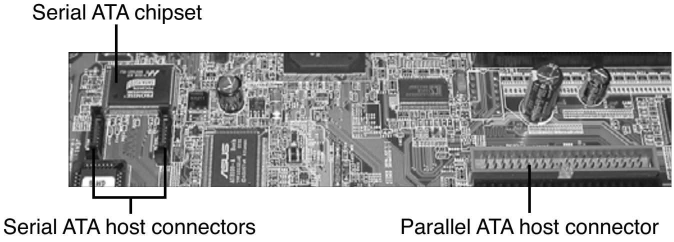


FIGURE 7.11 A motherboard with SATA and PATA host adapters.

The pinouts for the SATA data and optional power connectors are shown in Tables 7.10 and 7.11, respectively.

Table 7.10 SATA Data Connector Pinout

Signal Pin	Signal	Description
S1	Gnd	First mate
S2	A+	Host Transmit +
S3	A-	Host Transmit –

Signal Pin	Signal	Description
S4	Gnd	First mate
S5	B–	Host Receive –
S6	B+	Host Receive +
S7	Gnd	First mate

All pins are in a single row spaced 1.27mm (.050 inches) apart.
All ground pins are longer so they will make contact before the signal/power pins to allow hot-plugging.

Table 7.11 SATA Optional Power Connector Pinout

Signal Pin	Signal	Description
P1	+3.3V	3.3V power
P2	+3.3V	3.3V power
P3	+3.3V	3.3V power
P4	Gnd	First mate
P5	Gnd	First mate
P6	Gnd	First mate
P7	+5V	5V power
P8	+5V	5V power
P9	+5V	5V power
P10	Gnd	First mate
P11	Gnd	First mate
P12	Gnd	First mate
P13	+12V	12V power
P14	+12V	12V power
P15	+12V	12V power

All pins are in a single row spaced 1.27mm (.050 inches) apart.
All ground pins are longer, so they make contact before the signal/power pins to allow hot-plugging.
Three power pins carry 4.5 amps, a maximum current for each voltage.

Mini-SATA (mSATA)

Mini-SATA (mSATA) is a form factor specification developed by Intel for very small solid-state drives (SSDs), primarily in laptop or tablet systems. The mSATA form factor is virtually identical to Mini-PCI Express, which is the form factor used for mobile WLAN (wireless local area network or WiFi) and WWAN (wireless wide-area network) adapters. By using the same card size and shape but with a slightly modified connector design, a Mini-PCIe socket can function in both Mini-PCIe and mSATA modes.

mSATA drives are significantly smaller than the standard 2.5-inch drives used in most laptops (see Figure 7.12).

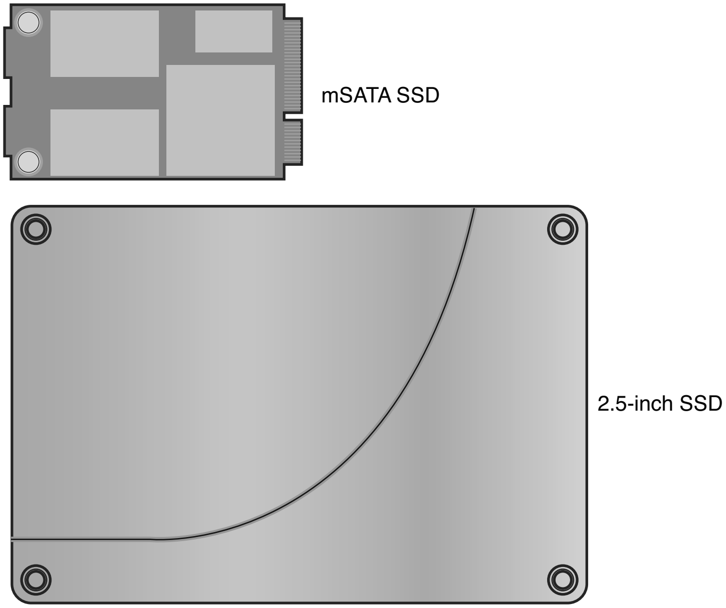


FIGURE 7.12 An mSATA drive compared to a standard 2.5-inch drive.

Tablet devices typically have a dedicated mSATA connector internally, which is designed solely for mSATA SSDs. Many laptops, however, have an internal combination mSATA/WWAN connector, which can accept either an mSATA SSD or a WWAN interface card. Depending on which type of device is installed, the port will automatically switch to the proper mode.

mSATA SSDs are not available in nearly as high capacities as 2.5-inch SSDs, but they are also physically smaller and less expensive. Laptops with mSATA/WWAN ports can have a high-performance mSATA SSD installed as the boot drive, and then use a much cheaper and higher capacity conventional HDD as a data storage drive.

eSATA

When SATA was first released, the ability to run longer cables of up to 1 meter (3.3 ft.) made people think about running cables out of the system to external drives. Some companies jumped on this demand, creating a market for proprietary cable and connector designs allowing SATA drives to be run in external enclosures. Unfortunately, the designs were proprietary, and since SATA cables lacked the shielding and other design criteria to allow external operation, some of the designs were unreliable. Realizing that there was a market for external SATA, the Serial ATA International Organization (SATA-IO) released the official standard for external SATA called eSATA in 2004.

eSATA is a variation on SATA specifically designed for external connections. The main differences between SATA and eSATA are in the cables. eSATA allows for longer cables of up to 2 meters (6.6 ft.), and the cables have extra shielding. The connectors are different both electrically and mechanically as well. They have deeper contacts, metal springs for shielding and mechanical retention, and are designed for up to 5,000 mating cycles vs. only 50 for internal cables. The eSATA cable and port connectors are shown in Figure 7.13.

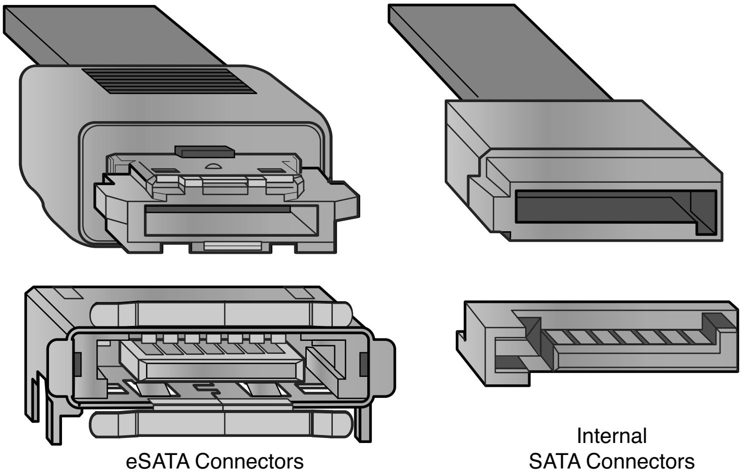


FIGURE 7.13 eSATA (left) and standard internal SATA (right) cable and port connectors compared.

eSATA supports all SATA transfer speeds up to 6Gbps rate (600MBps); however, some are limited to 3Gbps (300MBps) or less. Even at 300MBps, eSATA is significantly faster than other popular external interfaces such as 1394a/FireWire 400 (50MBps) and USB 2.0 (60MBps). In fact, with 300MBps or 600MBps of bandwidth, eSATA is three to six times faster than 1394b/FireWire 800 (100MBps), and even the 3Gbps (300MBps) mode of eSATA is faster than USB 3.0 (5Gbps or 500MBps). How can 300MBps eSATA be faster than 500GBps USB 3.0? One reason is that there is a large amount of overhead in the USB specification to allow for even longer cable lengths (5 meters or 16 ft.), which drops the actual data throughput to well under 400MBps, but the other reality is that any external drive connected via USB 3.0 consists of a SATA drive plus circuitry converting the data from SATA to USB 3.0 inside the enclosure, thereby reducing efficiency even more. When using eSATA, there is no signal conversion inside the external enclosure (eSATA is SATA, after all) making the interface much more efficient. In short, eSATA is just about the ideal connection for external drives, allowing them to work just as if they were internal to the system.

If your system doesn't have an eSATA port built in, you can easily add one using a very inexpensive cable and bracket assembly. The cable will plug into one of your motherboard-based SATA ports, and the other end of the cable will be an eSATA connector mounted in an expansion card bracket (see Figure 7.14). Brackets are available with one or two ports as necessary.

Power Over eSATA (eSATAp)

One drawback to eSATA over USB is that eSATA does not provide power. To rectify this, several manufacturers got together and informally created the eSATA USB Hybrid Port (EUHP) that combines USB and eSATA ports into a single physical connector. The SATA International Organization (SATA-IO) is working to make this an official standard called the Power Over eSATA (eSATAp) specification.

An eSATAp port is basically both a USB port and an eSATA port combined in one single connector (see Figure 7.15). These ports will normally be identified with an "eSATA + USB" notation. They accept standard USB or eSATA cables, and when attached, the proper connections will be made for the desired interface to function. A third option is to plug in an eSATAp cable, which will combine the eSATA and USB signals with +5V or +12V power, allowing the connection of USB, SATA, or eSATAp devices with no separate power adapter necessary. eSATAp ports have become very popular in laptops for connecting high-speed external drives, and you can get bracket adapters to add them to desktop systems (see Figure 7.16).

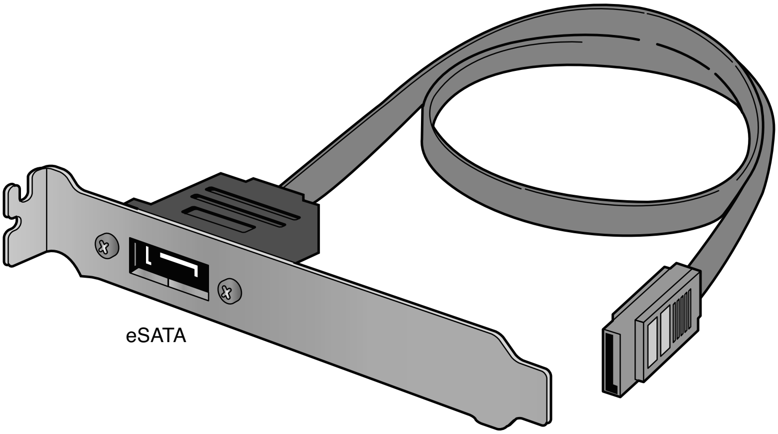


FIGURE 7.14 SATA to eSATA bracket assembly for adding eSATA ports to a system.

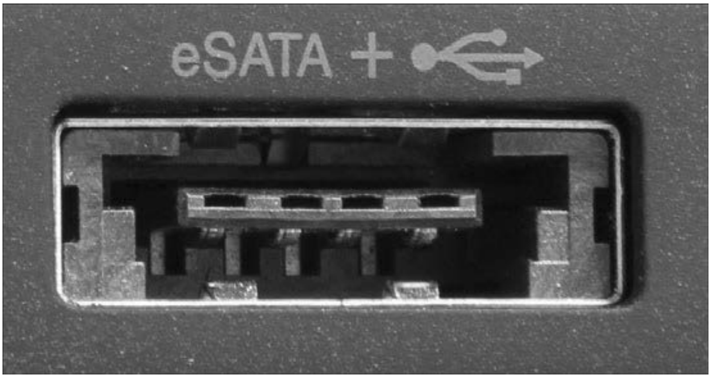


FIGURE 7.15 An eSATAP (Power Over eSATA) combination eSATA and USB connector.

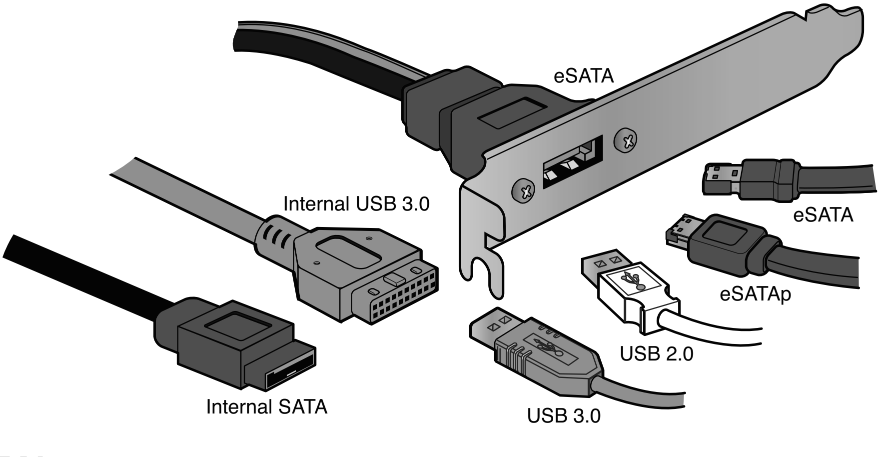


FIGURE 7.16 An eSATAp (Power Over eSATA) bracket showing optional USB 3.0/2.0, eSATAp, and eSATA connections.

There are several variations on eSATAp ports. The USB part of eSATAp can be either USB 2.0 or 3.0, depending on the specific implementation. Just as with standard USB only ports, if the eSATAp port is blue in color, that indicates USB 3.0 capability. Another variation is the eSATA speed. Some supply the full 6Gbps (600MBps) rate of SATA 3.0, while others allow only 3Gbps (300MBps) mode. Finally, another variation is in the power. In most laptop systems, an eSATAp port will only supply +5V power, which is fine for powering external 2.5-inch drives. Desktop versions of eSATAp can supply both +5V and +12V power, allowing external 3.5-inch drives to be powered as well.

Besides allowing faster data transfer than even USB 3.0, connecting external drives using eSATA or eSATAp has another major advantage over USB, and that is bootability. Windows does not allow booting from USB drives; however, drives connected via eSATA or eSATAp do not have that restriction. Windows will treat them the same as if they were internally connected. Using eSATA or eSATAp, one can use and easily swap external bootable drives, a feature especially useful for diagnostics and testing purposes.

SATA Configuration

Configuration of SATA devices is also much simpler because the master/slave or cable select jumper settings used with PATA are no longer necessary.

BIOS setup for SATA drives is also quite simple. Because SATA is based on ATA, autodetection of drive settings on systems with SATA connectors is performed in the same way as on PATA systems. Depending on the system, SATA interfaces will support legacy (usually called "IDE"), AHCI (Advanced Host Controller Interface) or RAID (redundant array of independent disks) modes. In most cases you will want to set AHCI mode for the SATA host adapter to run in its native, most fully featured mode. RAID mode is a superset of AHCI and allows multiple drives to be configured in an array to act as a single drive. (See Chapter 5, "BIOS," for details.)

If you want to use SATA drives but don't want to install a new motherboard with SATA host adapters already included, you can install a separate SATA host adapter into a PCI or PCIe expansion slot (see Figure 7.17). Many of these adapters include RAID capability as well.

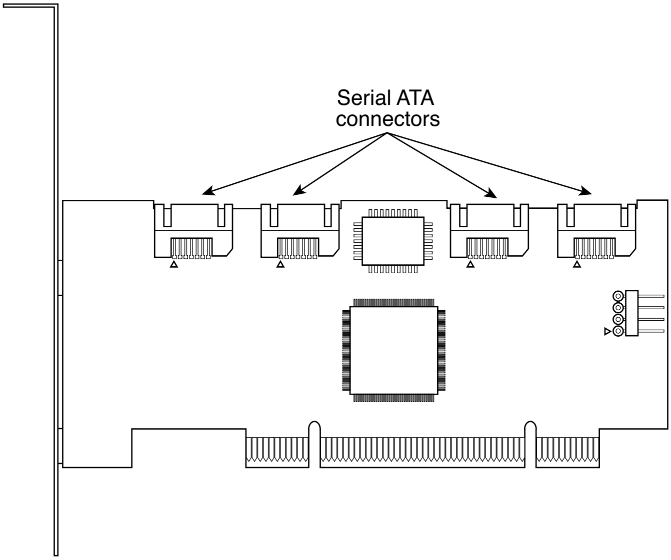


FIGURE 7.17 Typical 4-port SATA RAID host adapter.

Advanced Host Controller Interface (AHCI)

SATA was designed not only as a replacement for PATA, but as an interface that would evolve into something with many more capabilities and features than its predecessor. Initially, compatibility with PATA was one of the most important features of SATA because it enabled a smooth and easy transition from one to the other. This compatibility extends to the driver level, allowing SATA devices to use the same BIOS-level drivers and software as legacy PATA devices.

Although the intent of SATA was to allow an easy transition from PATA, it was also designed to allow future growth and expansion of capabilities. To accomplish this, an enhanced software interface called the *Advanced Host Controller Interface* (AHCI) was initially developed by the AHCI Contributor Group, a group chaired by Intel and originally consisting of AMD, Dell, Marvell, Maxtor, Microsoft, Red Hat, Seagate, and StorageGear. The AHCI Contributor Group released a preliminary version of AHCI v0.95 in May 2003 and released the 1.0 version of the specification in April 2004. You can download the latest version (1.3, released in 2008) from Intel at www.intel.com/technology/serialata/ahci.htm.

AHCI provides an industry-standard, high-performance interface to system driver/OS software for discovering and implementing such advanced SATA features as command queuing, hot-plugging, and power management. AHCI was integrated into SATA-supporting chipsets in 2004 and is supported by AHCI drivers for Windows. The main idea behind AHCI is to have a single driver-level interface supported by all advanced SATA host adapters. This greatly simplifies the installation of operating systems, eliminating the need for custom SATA drivers for each manufacturer's SATA host adapter. For example, Windows Vista and later include AHCI drivers and automatically support any advanced SATA host adapters that are AHCI compatible.

Unfortunately, AHCI drivers are not included by default on the Windows XP and earlier installation CDs, because AHCI was developed long after XP was released. This means, for example, that if you install Windows XP on a system with an integrated SATA host adapter set to AHCI mode, you will probably need to press the F6 key at the beginning of the installation and provide a floppy disk with the AHCI drivers; otherwise, Windows XP will not be able to recognize the drives. The implication here is that the system must include a floppy drive, and you must have copied the drivers to a floppy disk in advance. But what if your system doesn't even include a floppy drive? Fortunately, several solutions are available.

One option is to keep a spare floppy drive in your toolkit and temporarily connect it during the installation. Just open the case, plug in a floppy cable from the floppy drive connector (FDC) on the motherboard to the drive, and connect power to the drive. There is no need to actually mount the drive in the chassis because you will only need to read the disk once at the beginning of the installation.

Another option is to set the SATA host adapter to ATA/IDE compatibility mode (disable AHCI/RAID) in the BIOS Setup, after which you can boot from a standard Windows XP CD and install Windows without requiring special drivers. You could leave the adapter in compatibility mode, but you might be missing out on the performance offered by the advanced capabilities your hard drives support.

Although the first two options can work in most situations, I think the best overall solution is to simply create a custom Windows XP installation disc that already has the SATA AHCI (and even RAID) drivers preinstalled. This can be accomplished via a somewhat tedious manual integration process for each set of drivers, but to make things really easy you can use the menu-driven BTS DriverPacks from www.driverpacks.net to integrate virtually all the popular mass storage drivers directly into your Windows XP install disc. The DriverPacks allow you to easily add all kinds of drivers to your Windows XP installation discs. For example, in addition to the mass storage drivers, I like to integrate the various processor, chipset, and network (both wired and wireless) drivers because all of these still fit on a CD. If you are willing to move to a DVD instead of a CD, you can fit Windows XP and all of the available XP DriverPacks on a single DVD.

Non-Volatile Memory Express (NVMe)

The Advanced Host Controller Interface (AHCI) has long been the preferred software interface for SATA devices. AHCI can be used with conventional SATA as well as SATA Express devices, allowing both to use the same software interface and therefore the same drivers. While using AHCI mode with SATA Express allows for maximum compatibility, it does not allow for maximum performance when interfacing with low-latency devices like solid-state drives (SSDs), which internally behave more like RAM than a spinning disk. To improve the performance of SSDs connected via high-speed PCI Express–based interfaces like SATA Express, a new software interface called the Non-Volatile Memory Host Controller Interface (NVMHCI) was first defined in 2007 by the NVMHCI Workgroup (www.nvmexpress.org), a group including more than 75 major companies from the computing and storage industries. Owing to its intention on being used in combination with PCIe and SATA Express devices, the NVMHCI specification was subsequently named NVM Express (NVMe), and the NVMe specification 1.0 was published in 2011.

Like AHCI before it, NVMe is a software interface specification that defines the commands and functions for communicating with PCIe or SATA Express devices. SSDs are by nature very low latency devices, a characteristic that NVMe is designed to fully exploit. NVMe is also designed to more fully utilize the parallelism built in to modern systems such as multicore hyper-threaded processors, multilane buses, and multi-tasking operating systems. The biggest technical difference between AHCI and NVMe is that AHCI supports a single command queue with up to 32 commands, while NVMe supports up to 64K queues with up to 64K commands per queue. Having many more and much deeper queues allows for commands to be far more rapidly delivered to SSDs, where due to their low-latency characteristics they can be processed much more rapidly than drives with spinning disks.

SATA Express host adapters support both AHCI and NVMe modes. Using AHCI mode will allow for backward compatibility with existing AHCI drivers, while choosing NVMe mode will require new NVMe drivers. Since NVMe drivers were not included by default with Windows 8 and earlier versions, NVMe drivers will need to be supplied during the OS installation procedure for Windows to recognize any devices connected to SATA Express host adapters in NVMe mode. Using AHCI mode instead, you can install Windows Vista and later on SATA Express drives right out of the box, with no additional drivers necessary; however, there will be some loss in performance.

SATA Transfer Modes

SATA transfers data in a completely different manner from PATA. As indicated previously, the transfer rates are 1.5Gbps (150MBps), 3Gbps (300MBps), and 6Gbps (600MBps), with most drives today supporting the 3Gbps or 6Gbps rates. Note that speeds are backward compatible—for example, drives supporting the 6Gbps rate also work at 3Gbps or 1.5Gbps. Note that because SATA is designed to be backward compatible with PATA, some confusion can result because the BIOS and drives can report speeds and modes that emulate PATA settings for backward compatibility.

For example, many motherboards detect and report a SATA drive as supporting Ultra DMA Mode 5 (ATA/100), which is a PATA mode operating at 100MBps. This is obviously incorrect because even the slowest SATA mode (1.5Gbps) is 150MBps, and Ultra DMA modes simply do not apply to SATA drives.

PATA and SATA are completely different electrical and physical specifications, but SATA does *emulate* PATA in a way that makes it completely software transparent. In fact, the PATA emulation in SATA specifically conforms to the ATA-5 specification.

This is especially apparent in the `IDENTIFY DEVICE` command that the autodetect routines use in the BIOS to read the drive parameters. The SATA specification indicates that many of the items returned by `IDENTIFY DEVICE` are to be “set as indicated in ATA/ATAPI-5,” including available UDMA modes and settings.

The SATA 1 specification also says,

> Emulation of parallel ATA device behavior, as perceived by the host BIOS or software driver, is a cooperative effort between the device and the SATA host adapter hardware. The behavior of Command and Control Block registers, PIO and DMA data transfers, resets, and interrupts are emulated. The host adapter contains a set of registers that shadow the contents of the traditional device registers, referred to as the Shadow Register Block. All SATA devices behave like Device 0 devices. Devices shall ignore the DEV bit in the Device/Head field of received Register FISs, and it is the responsibility of the host adapter to gate transmission of Register FISs to devices, as appropriate, based on the value of the DEV bit.

This means the shadow register blocks are "fake" PATA registers, allowing all ATA commands, modes, and so on to be emulated. SATA was designed to be fully software compatible with ATA/ATAPI-5, which is why a SATA drive can report in some ways as if it were PATA or running in PATA modes, even though it isn't.

ATA Features

The ATA standards have gone a long way toward eliminating incompatibilities and problems with interfacing SATA and PATA drives to systems. The ATA specifications define the signals on the cables and connectors, the functions and timings of these signals, the cable specifications, the supported commands, the features, and so on. The following section lists some of the elements and functions the ATA specifications define.

ATA Commands

One of the best features of the ATA interface is the enhanced command set. The ATA command interface was modeled after the WD1003 controller IBM used in the original AT system. All ATA drives must support the original WD command set (eight commands) with no exceptions, which is why ATA drives are so easy to install in systems today. All IBM-compatible systems have built-in ROM BIOS support for the WD1003, so they essentially support ATA as well.

In addition to supporting all the WD1003 commands, the ATA specification added numerous other commands to enhance performance and capabilities. These commands are an optional part of the ATA interface, but several of them are used in most drives available today and are important to the performance and use of ATA drives in general.

Perhaps the most important is the `IDENTIFY DEVICE` command. This command causes the drive to transmit a 512-byte block of data that provides all details about the drive. Through this command, any program (including the system BIOS) can find out exactly which type of drive is connected, including the drive manufacturer, model number, operating parameters, and even serial number of the drive. Many modern BIOSs use this information to automatically receive and enter the drive's parameters into Complementary Metal Oxide Semiconductor (CMOS) memory, eliminating the need for the user to enter these parameters manually during system configuration. This arrangement helps prevent mistakes that can later lead to data loss when the user no longer remembers what parameters he used during setup.

The `Identify Device` data can tell you many things about your drive, including the following:

- Whether the drive has rotating media (and if so, how fast), or whether it is a solid-state drive (SSD) instead
- Whether the `TRIM` command is supported (or not) on SSDs
- Number of logical block addresses available using LBA mode

- Number of physical cylinders, heads, and sectors available in P-CHS mode
- Number of logical cylinders, heads, and sectors in the current translation L-CHS mode
- Transfer modes (and speeds) supported
- Manufacturer and model number
- Internal firmware revision
- Serial number
- Buffer type/size, indicating sector buffering or caching capabilities
- What security functions are available, and much, much more

Several freely available programs such as HWiNFO (www.hwinfo.com) or CrystalDiskInfo (www.crystalmark.info) can execute this command, then translate and report the information onscreen.

Many other enhanced commands are available, including room for a given drive manufacturer to implement what are called *vendor-unique* commands. Certain vendors often use these commands for features unique to that vendor. Often, vendor-unique commands control features such as low-level formatting and defect management. This is why low-level format or initialization programs can be so specific to a particular manufacturer's ATA drives and why many manufacturers make their own LLF programs available.

ATA Security Mode

Support for drive passwords (called *ATA Security Mode*) was added to the ATA-3 specification in 1995. The proposal adopted in the ATA specification was originally from IBM, which had developed this capability and had already begun incorporating it into ThinkPad systems and IBM 2.5-inch drives. Because it was then incorporated into the official ATA-3 standard (finally published in 1997), most other drive and system manufacturers have also adopted this, especially for laptop systems and 2.5-inch and smaller drives. Note that these passwords are *very* secure. If you lose or forget them, they usually cannot be recovered, and you will never be able to access the data on the drive.

More recently, ATA security has been augmented by drives that support internal encryption/decryption using the Advanced Encryption Standard (AES). Drives supporting AES automatically encrypt all data that is written and automatically decrypt the data when it is read. When combined with a password set via ATA Security mode commands, the data on the drive will be unrecoverable even if the HDD password is bypassed or the media (that is, platters or flash memory chips) are removed from the drive and read directly. When AES encryption is employed on a drive with a strong HDD password, without knowing the HDD password there is essentially no way to recover the data. This type of security is recommended for laptops that can easily be lost or stolen.

Drive security passwords are set via the BIOS Setup, but not all systems support this feature. Most laptops support drive security, but many desktops do not. If supported, two types of drive passwords can be set, called *user* and *master*. The user password locks and unlocks the drive, whereas the master password is used only to unlock. You can set a user password only, or you can set user+master, but you cannot set a master password alone.

When a user password is set (with no master), or when both user+master passwords are set, access to the drive is prevented (even if the drive is moved to a different system), unless the user (or master) password is entered upon system startup.

The master password is designed to be an alternative or backup password for system administrators as a master unlock. With both master and user passwords set, the user is told the user password but not the master password. Subsequently, the user can change the user password as desired; however, a system administrator can still gain access by using the master password.

If a user or user+master password is set, the disk must be unlocked at boot time via a BIOS-generated password prompt. The appearance of the prompt varies from system to system. For example, in ThinkPad systems, an icon consisting of a cylinder with a number above it (indicating the drive number) next to a padlock appears onscreen. If the drive password prompt appears, you must enter it; otherwise, you will be denied access to the drive, and the system will not boot.

As with many security features, a workaround might be possible if you forget your password. In this case, at least one company can either restore the drive to operation (with all the data lost) or restore the drive and the data. That company is Nortek. (See www.nortek.on.ca for more information.) The password-removal procedure is relatively expensive (more than the cost of a new drive in most cases), and you must provide proof of ownership when you send in the drive. As you can see, password restoring is worthwhile only if you absolutely need the data back. Note that even this will not work if the drive employs internal AES encryption. In that case, without the password, the data simply cannot be recovered.

Passwords are not preset on a new drive, but they might be preset if you are buying a used drive or if the people or company you purchased the drive or system from entered them. This is a common ploy when selling drives or systems (especially laptops) on eBay—for example, the seller might set supervisor or drive passwords and hold them until payment is received. Or he might be selling a used (possibly stolen) product "as is," for which he doesn't have the passwords, which renders them useless to the purchaser. Be sure that you do not purchase a used laptop or drive unless you are certain that no supervisor or drive passwords are set.

Most systems also support other power-on or supervisor passwords in the BIOS Setup. In most systems, when you set a supervisor password, it automatically sets the drive password to the same value. In most cases, if a supervisor password is set and it matches the drive user or master password, when you enter the supervisor password, the BIOS automatically enters the drive password at the same time. This means that even though a drive password is set, you might not even know it because the drive password is entered automatically at the same time that you enter the supervisor password; therefore, you won't see a separate prompt for the drive password. However, if the drive is later separated from the system, it will not work on another system or be readable until you enter the correct drive password. Without the services of a company such as Nortek, you can remove a drive password only if you know the password to begin with.

Host Protected Area

Most PCs sold on the market today include some form of automated product recovery or restoration feature that allows a user to easily restore the operating system and other software on the system to the state it was in when the system was new. Originally, this was accomplished via one or more product-recovery discs containing automated scripts that reinstalled all the software that came preinstalled on the system when it was new.

Unfortunately, the discs could be lost or damaged, they were often problematic to use, and including them by default cost manufacturers a lot of money. This prompted PC manufacturers to move the recovery software to a hidden partition of the boot hard drive. However, this does waste some space on the drive—usually several gigabytes. With 60GB or larger drives, this amounts to 5% or less of the total space. Still, even the hidden partition was less than satisfactory because the partition could easily be damaged or overwritten by partitioning software or other utilities, so there was no way to make it secure.

In 1996, Gateway proposed a change to the ATA-4 standard under development that would allow the HPA to be reserved on a drive. This change was ratified, and the HPA feature set was incorporated into the ATA-4 specification that was finally published in 1998. A separate BIOS firmware interface specification called Protected Area Run Time Interface Extension Services (PARTIES) was initiated in

1999 that defined services an operating system could use to access the HPA. The PARTIES standard was completed and published in 2001 as "NCITS 346-2001, Protected Area Run Time Interface Extension Services."

The HPA works by using the optional `ATA SET MAX ADDRESS` command to make the drive appear to the system as slightly smaller. Anything from the new max address (the newly reported end of the drive) to the true end of the drive is considered the HPA and is accessible only using PARTIES commands. This is more secure than a hidden partition because any data past the end of the drive simply cannot be seen by a normal application or even a partitioning utility. Still, if you want to remove the HPA, you can use some options in the BIOS Setup or separate commands to reset the max address, thus exposing the HPA. At that point, you can run something such as Parted Magic or Partition Commander to resize the adjacent partition to include the extra space that was formerly hidden and unavailable.

Starting in 2003, some systems using Phoenix BIOS have included recovery software and diagnostics in the HPA. Most if not all current drives support the HPA command set; however, because of the complexity in dealing with the hidden area, I have seen most manufacturers back away from using the HPA and revert to a more standard (and easier to deal with) hidden partition instead.

◀◀ For more information on the HPA and what might be stored there, see the Chapter 5 section, "Preboot Environment," **p. 287**.

ATAPI

ATAPI is a standard designed to provide the commands necessary for devices such as optical drives, removable media drives such as SuperDisk and Zip, and tape drives that plug into an ordinary SATA or PATA (IDE) connector. Although ATAPI optical drives use the hard disk interface, they don't necessarily look like ordinary hard disks. To the contrary, from a software point of view, they are a completely different kind of animal. They most closely resemble a SCSI device. All modern ATA optical drives support the ATAPI protocols, and generally the terms are synonymous. In other words, an ATAPI optical drive is an ATA optical drive, and vice versa.

Caution

Most systems starting in 1998 began supporting the Phoenix El Torito specification, which enables booting from ATAPI CD or DVD drives. Systems without El Torito support in the BIOS can't boot from an ATAPI CD or DVD drive. Even with ATAPI support in the BIOS, you still must load a driver to use ATAPI under DOS or Windows. Windows 95 and later (including 98 and Me) and Windows NT (including Windows 2000 forward) have native ATAPI support. Some versions of the Windows 98 and Me CD-ROMs are bootable, whereas all Windows NT, 2000, and newer discs are directly bootable on those systems, thus greatly easing installation.

ATA Drive Capacity Limitations

ATA interface versions up through ATA-5 suffered from a drive capacity limitation of about 137GB (billion bytes). Depending on the BIOS used, you can further reduce this limitation to 8.4GB, or even as low as 528MB (million bytes). This is due to limitations in both the BIOS and the ATA interface, which when combined create even further limitations. To understand these limits, you have to look at the BIOS (software) and ATA (hardware) interfaces together.

Note

In addition to the BIOS/ATA limitations discussed in this section, various operating system limitations exist. These are described later in this chapter.

The limitations when dealing with ATA drives are those of the ATA interface as well as the BIOS interface used to talk to the drive. A summary of the limitations is shown in Table 7.12.

Table 7.12 ATA/IDE Capacity Limitations for Various Sector Addressing Methods

Sector Addressing Method	Total Sectors Calculation	Maximum Total Sectors	Maximum Capacity (Bytes)	Capacity (Decimal)	Capacity (Binary)
CHS: BIOS w/o TL	1024 ×16 × 63	1,032,192	528,482,304	528.48MB	504.00MiB
CHS: BIOS w/ bit-shift TL	1024 × 240 × 63	15,482,880	7,927,234,560	7.93GB	7.38GiB
CHS: BIOS w/ LBA-assist TL	1024 × 255 × 63	16,450,560	8,422,686,720	8.42GB	7.84GiB
CHS: BIOS INT13h	1024 × 256 × 63	16,515,072	8,455,716,864	8.46GB	7.88GiB
CHS: ATA-1/ ATA-5	65536 × 16 × 255	267,386,880	136,902,082,560	136.90GB	127.50GiB
LBA: ATA-1/ ATA-5	2^{28}	268,435,456	137,438,953,472	137.44GB	128.00GiB
LBA: ATA-6+	2^{48}	281,474,976,710,655	144,115,188,075,855,872	144.12PB	128.00PiB
LBA: EDD BIOS	2^{64}	18,446,744,073, 709,551,616	9,444,732,965,739, 290,427,392	9.44ZB	8.00ZiB

BIOS = Basic input/output system
ATA = AT Attachment (IDE)
CHS = Cylinder head sector
LBA = Logical block (sector) address
w/ = with
w/o = without
TL = Translation
INT13h = Interrupt 13 hex
EDD = Enhanced Disk Drive specification (Phoenix/ATA)

MB = megabyte (million bytes)
MiB = mebibyte
GB = gigabyte (billion bytes)
GiB = gibibyte
PB = petabyte (quadrillion bytes)
PiB = pebibyte
ZB = zettabyte (sextillion bytes)
ZiB = zebibyte

This section details the differences between the various sector-addressing methods and the limitations incurred by using them.

Prefixes for Decimal and Binary Multiples

Many readers are unfamiliar with the MiB (mebibyte), GiB (gibibyte), and so on designations I am using in this section and throughout the book. These are part of a standard designed to eliminate confusion between decimal- and binary-based multiples, especially in computer systems. Standard SI (system international or metric system) units are based on multiples of 10. This worked well for most things, but not for computers, which operate in a binary world where most numbers are based on powers of 2. This has resulted in different meanings being assigned to the same prefix—for example, 1KB (kilobyte) could mean either 1,000 (10^3) bytes or 1,024 (2^{10}) bytes. To eliminate confusion, in December 1998 the International Electrotechnical Commission (IEC) approved as an international standard the prefix names and symbols for binary multiples used in data processing and transmission. Some of these prefixes are shown in Table 7.13.

Table 7.13 Standard Prefix Names and Symbols for Decimal and Binary Multiples

Binary Prefixes:				**Binary Prefixes:**				
Factor	**Symbol**	**Name**	**Value**	**Factor**	**Symbol**	**Name**	**Derivation**	**Value**
10^3	k	Kilo	1,000	2^{10}	Ki	Kibi	Kilobinary	1,024
10^6	M	Mega	1,000,000	2^{20}	Mi	Mebi	Megabinary	1,048,576
10^9	G	Giga	1,000,000,000	2^{30}	Gi	Gibi	Gigabinary	1,073,741,824
10^{12}	T	Tera	1,000,000,000,000	2^{40}	Ti	Tebi	Terabinary	1,099,511,627,776
10^{15}	P	Peta	1,000,000,000,000,000	2^{50}	Pi	Pebi	Petabinary	1,125,899,906,842,624
10^{18}	E	Exa	1,000,000,000,000,000,000	2^{60}	Ei	Exbi	Exabinary	1,152,921,504,606,846,976
10^{21}	Z	Zetta	1,000,000,000,000,000,000,000	2^{70}	Zi	Zebi	Zettabinary	1,180,591,620,717,411,303,424

The symbol for kilo (k) is in lowercase (which is technically correct according to the SI standard), whereas all other decimal prefixes are uppercase.

Under this standard terminology, a megabyte would be 1,000,000 bytes, whereas a mebibyte would be 1,048,576 bytes.

Note

For more information on these industry-standard decimal and binary prefixes, check out the National Institute for Standards and Technology (NIST) website at http://physics.nist.gov/cuu/Units/prefixes.html.

BIOS Limitations

Motherboard ROM BIOSs have been updated throughout the years to support larger and larger drives. Table 7.14 shows the most important relative dates when drive capacity limits were changed.

Table 7.14 Dates of Changes to Drive Capacity Limitations in the ROM BIOS

BIOS Date	**Capacity Limit**
August 1994	528MB
January 1998	8.4GB
September 2002	137GB
January 2011	2.2TB*

**Note: A UEFI BIOS or enabled UEFI Boot option is required to boot from 2.2TB or larger drives. Some BIOS, had this capability as early as 2006, but it wasn't widespread until 2011.*

These dates are when the limits were broken, such that BIOSs older than August 1994 are generally limited to drives of up to 528MB, whereas BIOSs older than January 1998 are generally limited to 8.4GB. Most BIOSs dated 1998 or newer support drives up to 137GB, and those dated September 2002 or newer should support drives larger than 137GB. These are only general guidelines, though; to accurately determine this for a specific system, you should check with your motherboard manufacturer. You can also use the System Information for Windows (SIW) utility from http://gtopala.com/, which tells you the BIOS date from your system and specifically whether your system supports the Enhanced Disk Drive specification (which means drives over 8.4GB).

If your BIOS does not support EDD (drives over 8.4GB), the three possible solutions are as follows:

- Upgrade your motherboard BIOS to a 1998 or newer version that supports >8.4GB.
- Install a BIOS upgrade card, such as the UltraATA cards from www.siig.com.
- Install a software patch to add >8.4GB support.

Of these, the first one is the most desirable because it is usually free. Visit your motherboard manufacturer's website to see whether it has newer BIOSs available for your motherboard that support large drives. If it doesn't, the next best thing is to use a card such as one of the UltraATA cards from SIIG (www.siig.com). I almost never recommend the software-only solution because it merely installs a software patch in the boot sector area of the hard drive, which can result in numerous problems when booting from different drives, installing new drives, or recovering data.

The most recent 2.2TB barrier is not a true BIOS barrier in the same way that the previous barriers were. The issue here is not that the BIOS can't recognize drives 2.2TB or larger; the problem is that it can't normally *boot* from them. Booting from a 2.2TB or larger drive requires a UEFI (Unified Extensible Firmware Interface) BIOS, or at a minimum one with an enabled UEFI Boot option. Drives larger than 2.2TB can be used as data drives even without a UEFI BIOS. Finally, note that both booting from and recognizing a 2.2TB or larger drive as a data drive also requires that the drive be formatted using a GPT (GUID Partition Table). The operating system must have GPT support as well.

CHS Versus LBA

There are two primary methods to address (or number) sectors on an ATA drive. The first method is called *CHS* (cylinder head sector) after the three respective coordinate numbers used to address each sector of the drive. The second method is called *LBA* (logical block address) and uses a single number to address each sector on a drive. CHS was derived from the physical way drives were constructed (and is how they work internally), whereas LBA evolved as a simpler and more logical way to number the sectors regardless of the internal physical construction.

▶▶ For more information on cylinders, heads, and sectors as they are used internally within the drive, see the Chapter 9 section, "HDD Operation," **p. 466**.

The process of reading a drive sequentially in CHS mode starts with cylinder 0, head 0, and sector 1 (which is the first sector on the disk). Next, all the remaining sectors on that first track are read; then the next head is selected; and then all the sectors on that track are read. This goes on until all the heads on the first cylinder are read. Then the next cylinder is selected, and the sequence starts again. Think of CHS as an odometer of sorts: The sector numbers must roll over before the head number can change, and the head numbers must roll over before the cylinder can change.

The process of reading a drive sequentially in LBA mode starts with sector 0, then 1, then 2, and so on. The first sector on the drive in CHS mode would be 0,0,1, and the same sector in LBA mode would be 0.

As an example, imagine a drive with one platter, two heads (both sides of the platter are used), two tracks on each platter (cylinders), and two sectors on each track. We would say the drive has two cylinders (tracks per side), two heads (sides), and two sectors per track. This would result in a total capacity of eight (2 × 2 × 2) sectors. Noting that cylinders and heads begin numbering from 0—whereas physical sectors on a track number from 1. Using CHS addressing, we would say the first sector on the drive is cylinder 0, head 0, sector 1 (0,0,1); the second sector is 0,0,2; the third sector is 0,1,1; the fourth sector is 0,1,2; and so on until we get to the last sector, which would be 1,1,2.

Now imagine that we could take the eight sectors and—rather than refer directly to the physical cylinder, head, and sector—number the sectors in order from 0 to 7. Thus, if we wanted to address the fourth sector on the drive, we could reference it as sector 0,1,2 in CHS mode or as sector 3 in LBA mode. Table 7.15 shows the correspondence between CHS and LBA sector numbers for this eight-sector imaginary drive.

Table 7.15 CHS and LBA Sector Numbers for an Imaginary Drive with Two Cylinders, Two Heads, and Two Sectors per Track (Eight Sectors Total)

Mode	Equivalent Sector Numbers							
CHS:	0,0,1	0,0,2	0,1,1	0,1,2	1,0,1	1,0,2	1,1,1	1,1,2
LBA:	0	1	2	3	4	5	6	7

As you can see from this example, using LBA numbers is simpler and generally easier to handle; however, when the PC was first developed, all BIOS and ATA drive-level addressing was done using CHS addressing.

CHS/LBA and LBA/CHS Conversions

You can address the same sectors in either CHS or LBA mode. The conversion from CHS to LBA is always consistent in that for a given drive, a particular CHS address always converts to a given LBA address, and vice versa. The ATA-1 document specifies a simple formula that can be used to convert CHS parameters to LBA:

$$LBA = (((C \times HPC) + H) \times SPT) + S - 1$$

By reversing this formula, you can convert the other way—that is, from LBA back to CHS:

C = int (LBA / SPT / HPC)

H = int ((LBA / SPT) mod HPC)

S = (LBA mod SPT) + 1

For these formulas, the abbreviations are defined as follows:

LBA = Logical block address

C = Cylinder

H = Head

S = Sector

HPC = Heads per cylinder (total number of heads)

SPT = Sectors per track

int X = Integer portion of X

X mod Y = Modulus (remainder) of X/Y

Using these formulas, you can calculate the LBA for any given CHS address, and vice versa. Given a drive of 16,383 cylinders, 16 heads, and 63 sectors per track, Table 7.16 shows the equivalent CHS and LBA addresses.

Table 7.16 Equivalent CHS and LBA Sector Numbers for a Drive with 16,383 Cylinders, 16 Heads, and 63 Sectors per Track (16,514,064 Sectors Total)

Cylinder	Head	Sector	LBA
0	0	1	0
0	0	63	62
0	1	0	63
999	15	63	1,007,999
1,000	0	1	1,008,000
9,999	15	63	10,079,999
10,000	0	1	10,080,000
16,382	15	63	16,514,063

BIOS Commands Versus ATA Commands

In addition to the two methods of sector addressing (CHS or LBA), there are two levels of interface where sector addressing occurs. One interface is where the operating system talks to the BIOS (using driver commands); the other is where the BIOS talks to the drive (using ATA commands). The specific commands at these levels are different, but both support CHS and LBA modes. Figure 7.18 illustrates the two interface levels.

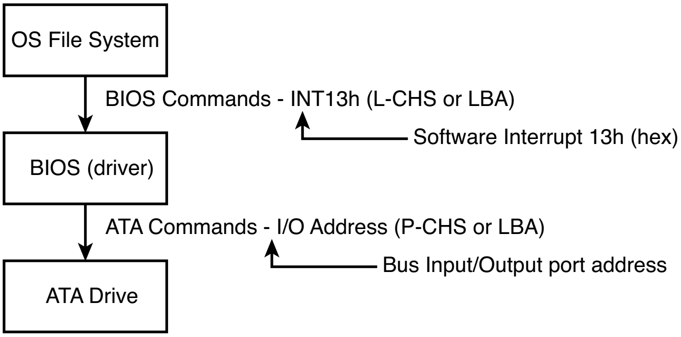


FIGURE 7.18 The relationship between BIOS and physical sector addressing. (In this figure, L-CHS stands for Logical CHS, and P-CHS stands for Physical CHS.)

When the operating system talks to the BIOS to read or write sectors, it issues commands via software interrupt (not the same as an IRQ) INT13h, which is how the BIOS subroutines for disk access are called. Various INT13h subfunctions allow sectors to be read or written using either CHS or LBA addressing. The BIOS routines then convert the BIOS commands into ATA hardware-level commands, which are sent over the bus I/O ports to the drive controller. Commands at the ATA hardware level can also use either CHS or LBA addressing, although the limitations are different. Whether your BIOS and drive use CHS or LBA addressing depends on the drive capacity, age of the BIOS and drive, BIOS Setup settings used, and operating system used.

CHS Limitations (the 528MB Barrier)

The original BIOS-based driver for hard disks is accessed via software interrupt 13h (13 hex) and offers functions for reading and writing drives at the sector level. Standard INT13h functions require that a particular sector be addressed by its cylinder, head, and sector location—otherwise known as *CHS addressing*. This interface is used by the operating system and low-level disk utilities to access the drive. IBM originally wrote the INT13h interface for the BIOS on the PC XT hard disk controller in 1983, and in 1984 the company incorporated it into the AT motherboard BIOS. This interface used numbers to define the particular cylinder, head, and sector being addressed. Table 7.17, which shows the standard INT13h BIOS CHS parameter limits, includes the maximum values for these numbers.

Table 7.17 INT13h BIOS CHS Parameter Limits

Field	Field Size	Maximum Value	Range	Total Usable
Cylinder	10 bits	1,024	0–1023	1,024
Head	8 bits	256	0–255	256
Sector	6 bits	64	1–63	63

The concept of a maximum value given a number of digits is simple: If you had, for example, a hotel with two-digit decimal room numbers, you could have only 100 (10^2) rooms, numbered 0–99. The CHS numbers used by the standard BIOS INT13h interface are binary, and with a 10-bit number being used to count cylinders, you can have only 1,024 (210) maximum, numbered 0–1,023. Because the head is identified by an 8-bit number, the maximum number of heads is 256 (2^8), numbered 0–255. Finally, with sectors per track there is a minor difference. Sectors on a track are identified by a 6-bit number, which would normally allow a maximum of 64 (2^6) sectors; however, because sectors are numbered starting with 1 (instead of 0), the range is limited to 1–63, which means a total of 63 sectors per track is the maximum the BIOS can handle.

These BIOS limitations are true for all BIOS versions or programs that rely on CHS addressing. Using the maximum numbers possible for CHS at the BIOS level, you can address a drive with 1,024 cylinders, 256 heads, and 63 sectors per track. Because each sector is 512 bytes, the math works out as follows:

```
                Max. Values
---------------------------
    Cylinders         1,024
        Heads           256
Sectors/Track            63
===========================
Total Sectors    16,515,072
---------------------------
Total Bytes   8,455,716,864
Megabytes (MB)        8,456
Mebibytes (MiB)       8,064
Gigabytes (GB)          8.4
Gibibytes (GiB)         7.8
```

From these calculations, you can see that the maximum capacity drive addressable via the standard BIOS INT13h interface is about 8.4GB (where GB equals roughly 1 billion bytes), or 7.8GiB (where GiB means *gigabinarybytes*).

Unfortunately, the BIOS INT13h limits are not the only limitations that apply. Limits also exist in the ATA interface. The ATA CHS limits are shown in Table 7.18.

Table 7.18 Standard ATA CHS Parameter Limitations

Field	Field Size	Maximum Value	Range	Total Usable
Cylinder	16 bits	65,536	0–65,535	65,536
Head	4 bits	16	0–15	16
Sector	8 bits	256	1–255	255

As you can see, the ATA interface uses different-sized fields to store CHS values. Note that the ATA limits are higher than the BIOS limits for cylinders and sectors but lower than the BIOS limit for heads. The CHS limits for capacity according to the ATA-1 through ATA-5 specification are as follows:

```
                Max. Values
-----------------------------
    Cylinders          65,536
        Heads              16
Sectors/Track             255
=============================
Total Sectors     267,386,880
-----------------------------
Total Bytes   136,902,082,560
Megabytes (MB)        136,902
Mebibytes (MiB)       130,560
Gigabytes (GB)          136.9
Gibibytes (GiB)         127.5
```

When you combine the limitations of the BIOS and ATA CHS parameters, you end up with the situation shown in Table 7.19.

Table 7.19 Combined BIOS and ATA CHS Parameter Limits

	BIOS CHS Parameter Limits	ATA CHS Parameter Limits	Combined CHS Parameter Field Limits
Cylinder	1,024	65,536	1,024
Head	256	16	16
Sector	63	255	63
Total sectors	16,515,072	267,386,880	1,032,192
Maximum capacity	8.4GB	136.9GB	528MB

As you can see, the lowest common denominator of the combined CHS limits results in maximum usable parameters of 1,024 cylinders, 16 heads, and 63 sectors, which results in a maximum drive capacity of 528MB. This became known as the 528MB barrier (also called the 504MiB barrier), and it affects virtually all PCs built in 1993 or earlier.

CHS Translation (Breaking the 528MB Barrier)

Having a barrier limiting drive capacity to 528MB or less wasn't a problem when the largest drives available were smaller than that. But by 1994, drive technology had developed such that making drives larger than what the combined BIOS and ATA limitations could address was possible. Clearly a fix for the problem was needed.

Starting in 1993, the BIOS developer Phoenix Technologies began working on BIOS extensions to work around the combined CHS limits. In January of 1994, the company released the "BIOS Enhanced Disk Drive (EDD) Specification," which was later republished by the T13 committee (also responsible for ATA) as "BIOS Enhanced Disk Drive Services (EDD)." The EDD documents detail several methods for circumventing the limitations of older BIOSs without causing compatibility problems with existing software. These include the following:

- BIOS INT13h extensions supporting 64-bit LBA
- Bit-shift geometric CHS translation
- LBA-assist geometric CHS translation

The method for dealing with the CHS problem was called *translation* because it enabled additional subroutines in the BIOS to translate CHS parameters from ATA maximums to BIOS maximums (and vice versa). In an effort to make its methods standard among the entire PC industry, Phoenix released the EDD document publicly and allowed the technology to be used free of charge, even among its competitors such as AMI and Award. The T-13 committee in charge of ATA subsequently adopted the EDD standard and incorporated it into official ATA documents.

Starting in 1994, most BIOSs began implementing the Phoenix-designed CHS translation methods, which enabled drives up to the BIOS limit of 8.4GB to be supported. The fix involved what is termed *parameter translation* at the BIOS level, which adapted or translated the cylinder, head, and sector numbers to fit within the allowable BIOS parameters. There are two types of translation: One works via a technique called *CHS bit-shift* (usually called "Large" or "Extended CHS" in the BIOS Setup), and the other uses a technique called *LBA-assist* (usually called "LBA" in the BIOS Setup). These refer to the different mathematical methods of doing essentially the same thing: converting one set of CHS numbers to another.

CHS bit-shift translation manipulates the cylinder and head numbers but does not change the sector number. It begins with the physical (drive reported) cylinders and heads and, using some simple division and multiplication, comes up with altered numbers for the cylinders and heads. The sectors-per-track value is not translated and is passed unaltered. The term *bit-shift* is used because the division and multiplication math is actually done in the BIOS software by shifting bits in the CHS address.

With CHS bit-shift translation, the drive reported (physical) parameters are referred to as *P-CHS*, and the BIOS-altered logical parameters are referred to as *L-CHS*. After the settings are made in the BIOS Setup, L-CHS addresses are automatically translated to P-CHS at the BIOS level. This enables the operating system to send commands to the BIOS using L-CHS parameters, which the BIOS automatically converts to P-CHS when it talks to the drive using ATA commands. Table 7.20 shows the rules for calculating CHS bit-shift translation.

CHS bit-shift translation is based on dividing the physical cylinder count by a power of 2 to bring it under the 1,024 cylinder BIOS INT13h limit and then multiplying the heads by the same power of 2, leaving the sector count unchanged. The power of 2 used depends on the cylinder count, as indicated in Table 7.20.

Table 7.20 CHS Bit-Shift Translation Rules

Physical (Drive Reported) Cylinders	Physical Heads	Logical Cylinders	Logical Heads	Maximum Capacity
1 < C <= 1,024	1 < H <= 16	C = C	H = H	528MB
1,024 < C <= 2,048	1 < H <= 16	C = C/2	H = H × 2	1GB
2,048 < C <= 4,096	1 < H <= 16	C = C/4	H = H × 4	2.1GB
4,096 < C <= 8,192	1 < H <= 16	C = C/8	H = H × 8	4.2GB
8,192 < C <= 16,384	1 < H <= 16	C = C/16	H = H × 16	8.4GB

The drive reported sector count is not translated.
The logical heads value can't exceed 255 with some operating systems, such as DOS/Win9x/Me.

Here is an example of CHS bit-shift translation:

```
                                    Bit-shift
                          P-CHS         L-CHS
                     Parameters    Parameters
---------------------------------------------
      Cylinders           8,000         1,000
          Heads              16           128
  Sectors/Track              63            63
=============================================
  Total Sectors       8,064,000     8,064,000
---------------------------------------------
    Total Bytes   4,128,768,000 4,128,768,000
 Megabytes (MB)           4,129         4,129
Mebibytes (MiB)           3,938         3,938
 Gigabytes (GB)            4.13          4.13
Gibibytes (GiB)            3.85          3.85
```

This example shows a drive with 8,000 cylinders and 16 heads. The physical cylinder count is way above the BIOS limit of 1,024, so if CHS bit-shift translation is selected in the BIOS Setup, the BIOS then divides the cylinder count by 2, 4, 8, or 16 to bring it below 1,024. In this case, it would divide by 8, which results in a new logical cylinder count of 1,000—which is below the 1,024 maximum. Because the cylinder count is divided by 8, the head count is then multiplied by the same number, resulting in 128 logical heads, which is also below the limit the BIOS can handle.

So, although the drive reports having 8,000 cylinders and 16 heads, the BIOS and all software (including the operating system) instead see the drive as having 1,000 cylinders and 128 heads. Note that the 63 sectors/track figure is simply carried over without change. The result is that by using the logical parameters, the BIOS can see the entire 4.13GB drive and won't be limited to just the first 528MB.

When you install a drive, you don't have to perform the translation math to convert the cylinders and heads; the BIOS does that for you automatically. All you have to do is allow the BIOS to autodetect the P-CHS parameters and then enable the translation in the BIOS Setup. Selecting Large or ECHS translation in the BIOS Setup enables the CHS bit-shift. The BIOS does the rest of the work for you.

CHS bit-shift is a simple and fast (code-wise) scheme that can work with all drives, but unfortunately it can't properly translate all theoretically possible drive geometries for drives under 8.4GB. To solve this, an addendum was added to the ATA-2 specification to specifically require drives to report certain ranges of geometries to allow bit-shift translation to work. Thus, all drives that conform to the ATA-2 specification (or higher) can be translated using this method.

The 2.1GB and 4.2GB Barriers

Some BIOSs incorrectly allocated only 12 bits for the P-CHS cylinder field, thereby allowing a maximum of 4,096 cylinders. Combined with the standard 16-head and 63-sector limits, this resulted in the inability to support any drives over 2.1GB in capacity. Fortunately, this BIOS defect affected only a limited number of systems with BIOS dates prior to about mid-1996.

Even so, some problems still existed with bit-shift translation. Because of the way DOS and Windows 9x/Me were written, they could not properly handle a drive with 256 heads. This was a problem for drives larger than 4.2GB because the CHS bit-shift translation rules typically resulted in 256 heads as a logical value, as seen in the following example:

```
                                     Bit-shift
                          P-CHS          L-CHS
                     Parameters     Parameters
----------------------------------------------
       Cylinders         12,000            750
           Heads             16            256
   Sectors/Track             63             63
==============================================
   Total Sectors     12,096,000     12,096,000
----------------------------------------------
     Total Bytes  6,193,152,000  6,193,152,000
  Megabytes (MB)          6,193          6,193
 Mebibytes (MiB)          5,906          5,906
  Gigabytes (GB)           6.19           6.19
 Gibibytes (GiB)           5.77           5.77
```

This scheme failed when you tried to install Windows 9x/Me (or DOS) on a drive larger than 4.2GB because the L-CHS parameters included 256 heads. Any BIOS that implemented this scheme essentially had a 4.2GB barrier, so installing a drive larger than that and selecting CHS bit-shift translation caused the drive to fail. Note that this was not a problem for Windows NT or later.

Note

The BIOS is not actually at fault here; the problem instead lies with the DOS/Win9x/Me file system code, which stores the sector-per-track number as an 8-bit value. The number 256 causes a problem because 256 equals 100000000b, which takes 9 bits to store. The value 255 (which equals 11111111b) is the largest value that can fit in an 8-bit binary register and is therefore the maximum number of heads those operating systems can support.

To solve this problem, CHS bit-shift translation was revised by adding a rule such that if the drive reported 16 heads and more than 8,192 cylinders (which would result in a 256-head translation), the P-CHS head value would be assumed to be 15 (instead of 16) and the P-CHS cylinder value would be multiplied by 16/15 to compensate. These adjusted cylinder and head values would then be translated. The following example shows the results:

```
                                         Bit-shift   Revised Bit-
                          P-CHS          L-CHS    shift L-CHS
                     Parameters     Parameters     Parameters
-------------------------------------------------------------
       Cylinders         12,000            750            800
           Heads             16            256            240
   Sectors/Track             63             63             63
=============================================================
   Total Sectors     12,096,000     12,096,000     12,096,000
-------------------------------------------------------------
     Total Bytes  6,193,152,000  6,193,152,000  6,193,152,000
  Megabytes (MB)          6,193          6,193          6,193
 Mebibytes (MiB)          5,906          5,906          5,906
  Gigabytes (GB)           6.19           6.19           6.19
 Gibibytes (GiB)           5.77           5.77           5.77
```

As you can see from this example, a drive with 12,000 cylinders and 16 heads translates to 750 cylinders and 256 heads using the standard CHS bit-shift scheme. The revised CHS bit-shift scheme rule does a double translation in this case, first changing the 16 heads to 15 and then multiplying the 12,000 cylinders by 16/15, resulting in 12,800 cylinders. Then, the new cylinder value is CHS bit-shift-translated (it is divided by 16), resulting in 800 logical cylinders. Likewise, the 15 heads are multiplied by 16, resulting in 240 logical heads. If the logical cylinder count calculates to more than 1,024, it is truncated to 1,024. In this case, what started out as 12,000 cylinders and 16 heads P-CHS becomes 800 cylinders and 240 heads (instead of 750 cylinders and 256 heads) L-CHS, which works around the bug in the DOS/Win9x/Me operating systems.

So far, all my examples have been clean—that is, the L-CHS parameters have calculated to the same capacity as the P-CHS parameters. Unfortunately, it doesn't always work out that way. The following shows a more typical example in the real world. Several 8.4GB drives from Maxtor, Quantum, Seagate, and others report 16,383 cylinders and 16 heads P-CHS. For those drives, the translations would work out as follows:

```
                                         Bit-shift   Revised Bit-
                          P-CHS          L-CHS    shift L-CHS
                     Parameters     Parameters     Parameters
-------------------------------------------------------------
       Cylinders         16,383          1,023          1,024
           Heads             16            256            240
   Sectors/Track             63             63             63
=============================================================
   Total Sectors     16,514,064     16,498,944     15,482,880
-------------------------------------------------------------
     Total Bytes  8,455,200,768  8,447,459,328  7,927,234,560
  Megabytes (MB)          8,455          8,447          7,927
 Mebibytes (MiB)          8,064          8,056          7,560
  Gigabytes (GB)           8.46           8.45           7.93
 Gibibytes (GiB)           7.87           7.87           7.38
```

Note that the revised CHS bit-shift translation rules result in supporting only 7.93GB of the 8.46GB total on the drive. In fact, the parameters shown (with 240 heads) are the absolute maximum that revised CHS bit-shift supports. Fortunately, another translation mode is available that improves this situation.

LBA-Assist Translation

The LBA-assist translation method places no artificial limits on the reported drive geometries, but it works only on drives that support LBA addressing at the ATA interface level. Fortunately, though, virtually all ATA drives larger than 2GB support LBA. LBA-assist translation takes the CHS parameters the drive reports, multiplies them together to get a calculated LBA maximum value (total number of sectors), and then uses this calculated LBA number to derive the translated CHS parameters. Table 7.21 shows the rules for LBA-assist translation.

Table 7.21 LBA-Assist Translation Rules

	Logical Cylinders	Logical Heads	Logical Sectors
1 < T <= 1,032,192	T/1,008	16	63
1,032,192 < T <= 2,064,384	T/2,016	32	63
2,064,384 < T <= 4,128,768	T/4,032	64	63
4,128,768 < T <= 8,257,536	T/8,064	128	63
8,257,536 < T <= 16,450,560	T/16,065	255	63

T = Total sectors, calculated by multiplying the drive-reported P-CHS parameters (C × H × S)

LBA-assist translation fixes the sectors at 63 no matter what and divides and multiplies the cylinders and heads by predetermined values depending on the total number of sectors. This results in a set of L-CHS parameters the operating system uses to communicate with the BIOS. The L-CHS numbers are then translated to LBA numbers at the ATA interface level. Because LBA mode is more flexible at translating, you should use it in most cases instead of CHS bit-shift.

Normally, both the CHS bit-shift and LBA-assist translations generate the same L-CHS geometry for a given drive. This should always be true if the drive reports 63 sectors per track and 4, 8, or 16 heads. In the following example, both translation schemes result in identical L-CHS values:

```
                            Revised bit-     LBA-assist
                     P-CHS   shift L-CHS          L-CHS
                Parameters    Parameters     Parameters
-------------------------------------------------------------
     Cylinders       8,192         1,024          1,024
         Heads          16           128            128
 Sectors/Track          63            63             63
=============================================================
 Total Sectors   8,257,536     8,257,536      8,257,536
-------------------------------------------------------------
   Total Bytes 4,227,858,432 4,227,858,432 4,227,858,432
Megabytes (MB)       4,228         4,228          4,228
Mebibytes (MiB)      4,032         4,032          4,032
Gigabytes (GB)        4.23          4.23           4.23
Gibibytes (GiB)       3.94          3.94           3.94
```

However, if the drive reports a value other than 63 sectors per track or has other than 4, 8, or 16 heads, LBA-assist translation does not result in the same parameters as CHS bit-shift translation. In the following example, different translations result:

	P-CHS Parameters	Revised bit-shift L-CHS Parameters	LBA-assist L-CHS Parameters
Cylinders	16,383	1,024	1,024
Heads	16	240	255
Sectors/Track	63	63	63
Total Sectors	16,514,064	15,482,880	16,450,560
Total Bytes	8,455,200,768	7,927,234,560	8,422,686,720
Megabytes (MB)	8,455	7,927	8,423
Mebibytes (MiB)	8,064	7,560	8,033
Gigabytes (GB)	8.46	7.93	8.42
Gibibytes (GiB)	7.87	7.38	7.84

The LBA-assist translation supports 8.42GB, which is nearly 500MB more than the revised CHS bit-shift translation. More importantly, these translations are different, which can result in problems if you change translation modes with data on the drive. If you were to set up and format a drive using CHS bit-shift translation and then change to LBA-assist translation, the interpreted geometry could change and the drive could then become unreadable until it is repartitioned and reformatted (which would destroy all the data). Bottom line: After you select a translation method, don't plan on changing it unless you have your data securely backed up.

Virtually all PC BIOSs since 1994 have translation capability in the BIOS Setup, and virtually all offer both translation modes as well as an option to disable translation entirely. If both CHS bit-shift and LBA-assist translation modes are offered, you should probably choose the LBA method of translation because it is the more efficient and flexible of the two. LBA-assist translation also gets around the 4.2GB operating system bug because it is designed to allow a maximum of 255 logical heads no matter what.

You usually can tell whether your BIOS supports translation by the capability to specify more than 1,024 cylinders in the BIOS Setup, although this can be misleading. The best clue is to look for the translation setting parameters in the ATA/IDE drive setup page in the BIOS Setup. See Chapter 5 for more information on how to enter the BIOS Setup on your system. If you see drive-related settings, such as LBA or ECHS (sometimes called Large or Extended), these are telltale signs of a BIOS with translation support. Most BIOSs with a date of 1994 or later include this capability, although some AMI BIOS versions from the mid-1990s locate the LBA setting on a screen different from the hard drive configuration screen. If your system currently does not support parameter translation, you might be able to get an upgrade from your motherboard manufacturer or install a BIOS upgrade card with this capability, such as the LBA Pro card from eSupport.com.

Table 7.22 summarizes the four ways today's BIOSs can handle addressing sectors on the drive: Standard CHS (no translation), Extended CHS translation, LBA translation, and pure LBA addressing.

Table 7.22 Drive Sector Addressing Methods

BIOS Mode	OS to BIOS	BIOS to Drive
Standard (Normal), no translation	P-CHS	P-CHS
CHS bit-shift (ECHS) translation	L-CHS	P-CHS
LBA-assist (LBA) translation	L-CHS	LBA
Pure LBA (EDD BIOS)	LBA	LBA

Standard CHS has only one possible translation step internal to the drive. The drive's actual physical geometry is completely invisible from the outside with all zoned recorded ATA drives today. The cylinders, heads, and sectors printed on the label for use in the BIOS Setup are purely logical geometry and do not represent the actual physical parameters. Standard CHS addressing is limited to 16 heads and 1,024 cylinders, which provides a limit of 504MiB (528MB).

This is often called "Normal" in the BIOS Setup and causes the BIOS to behave like an old-fashioned one without translation. Use this setting if your drive has fewer than 1,024 cylinders or if you want to use the drive with an operating system that doesn't require translation.

ECHS, or "Large" in the BIOS Setup, is CHS bit-shift, and most BIOSs from 1997 and later use the revised method (240 logical heads maximum).

LBA, as selected in the BIOS Setup, indicates LBA-assist translation, not pure LBA mode. This enables software to operate using L-CHS parameters while the BIOS talks to the drive in LBA mode.

The only way to select a pure LBA mode, from the OS to the BIOS as well as from the BIOS to the drive, is with a drive that is over 8.4GB. All drives over 137GB must be addressed via LBA at both the BIOS and drive levels, and most PC BIOSs automatically address any drive over 8.4GB in that manner, as well. In that case, no special BIOS Setup settings are necessary, other than setting the type to auto or autodetect.

Caution

A word of warning with these BIOS translation settings: If you have a drive 8.4GB or less in capacity and switch between Standard CHS, ECHS, or LBA, the BIOS can change the (translated) geometry. The same thing can happen if you transfer a disk that has been formatted on an old, non-LBA computer to a new one that uses LBA. This causes the logical CHS geometry seen by the operating system to change and the data to appear in the wrong location from where it actually is! This can cause you to lose access to your data if you are not careful. I always recommend recording the CMOS Setup screens associated with the hard disk configuration so that you can properly match the setup of a drive to the settings to which it was originally set. This does not affect drives over 8.4GB because in those cases pure LBA is automatically selected.

The 8.4GB Barrier

Although CHS translation breaks the 528MB barrier, it runs into another barrier at 8.4GB. Supporting drives larger than 8.4GB requires leaving CHS behind and changing from CHS to LBA addressing at the BIOS level. The ATA interface had always supported LBA addressing, even in the original ATA-1 specification. One problem was that LBA support at the ATA level originally was optional, but the main problem was that there was no LBA support at the BIOS interface level. You could set LBA-assist translation in the BIOS Setup, but all that did was convert the drive LBA numbers to CHS numbers at the BIOS interface level.

Phoenix Technologies recognized that the BIOS interface needed to move from CHS to LBA early on and, beginning in 1994, published the “BIOS Enhanced Disk Drive Specification (EDD),” which addressed this problem with new extended INT13h BIOS services that worked with LBA rather than CHS addresses.

To ensure industry-wide support and compatibility for these new BIOS functions, in 1996 Phoenix turned this document over to the International Committee on Information Technology Standards (INCITS) T13 technical committee for further enhancement and certification as a standard called the “BIOS Enhanced Disk Drive Specification (EDD).” Starting in 1998, most of the other BIOS manufacturers began installing EDD support in their BIOS, enabling BIOS-level LBA mode support for ATA drives larger than 8.4GB. Coincidentally (or not), this support arrived just in time because ATA drives of that size and larger became available that same year.

The EDD document describes new extended INT13h BIOS commands that allow LBA addressing up to 2^{64} sectors, which results in a theoretical maximum capacity of more than 9.44ZB (zettabytes, or quadrillion bytes). That is the same as saying 9.44 trillion GB, which is 9.44×10^{21} bytes or, to be more precise, 9,444,732,965,739,290,427,392 bytes! I say theoretical capacity because even though by 1998 the BIOS could handle up to 2^{64} sectors, ATA drives were still using only 28-bit addressing (2^{28} sectors) at the ATA interface level. This limited an ATA drive to 268,435,456 sectors, which was a capacity of 137,438,953,472 bytes, or 137.44GB. Thus, the 8.4GB barrier had been broken, but another barrier remained at 137GB because of the 28-bit LBA addressing used in the ATA interface. The numbers work out as follows:

```
                      Max. Values
---------------------------------
Total Sectors         268,435,456
---------------------------------
Total Bytes       137,438,953,472
Megabytes (MB)            137,439
Mebibytes (MiB)           131,072
Gigabytes (GB)             137.44
Gibibytes (GiB)            128.00
```

By using the new extended INT13h 64-bit LBA mode commands at the BIOS level, as well as the existing 28-bit LBA mode commands at the ATA level, no translation would be required and the LBA numbers would be passed unchanged. The combination of LBA at the BIOS and the ATA interface levels meant that the clumsy CHS addressing could finally die. This also means that when you install an ATA drive larger than 8.4GB in a PC that has an EDD-capable BIOS (1998 or newer), both the BIOS and the drive are automatically set to use LBA mode.

An interesting quirk is that to allow backward compatibility when you boot an older operating system that doesn’t support LBA mode addressing (DOS or the original release of Windows 95, for example), most drives larger than 8.4GB report 16,383 cylinders, 16 heads, and 63 sectors per track, which is 8.4GB. For example, this enables a 120GB drive to be seen as an 8.4GB drive by older BIOSs or operating systems. That sounds strange, but I guess having a 120GB drive being recognized as an 8.4GB is better than not having it work at all. If you did want to install a drive larger than 8.4GB into a system dated before 1998, the recommended solution is either a motherboard BIOS upgrade or an add-on BIOS card with EDD support.

The 137GB Barrier and Beyond

By 2001, the 137GB barrier had become a problem because 3 1/2-inch hard drives were poised to breach that capacity level. The solution came in the form of ATA-6, which was being developed during that year. To enable the addressing of drives of greater capacity, ATA-6 upgraded the LBA functions from using 28-bit numbers to using larger 48-bit numbers.

The ATA-6 specification extends the LBA interface such that it can use 48-bit sector addressing. This means that the maximum capacity is increased to 248 (281,474,976,710,656) total sectors. Because each sector stores 512 bytes, this results in the maximum drive capacity shown here:

```
                           Max. Values
--------------------------------------
Total Sectors      281,474,976,710,656
--------------------------------------
Total Bytes    144,115,188,075,855,872
Megabytes (MB)         144,115,188,076
Mebibytes (MiB)        137,438,953,472
Gigabytes (GB)             144,115,188
Gibibytes (GiB)            134,217,728
Terabytes (TB)                 144,115
Tebibytes (TiB)                131,072
Petabytes (PB)                  144.12
Pebibytes (PiB)                 128.00
```

As you can see, the 48-bit LBA in ATA-6 allows a capacity of just over 144PB (petabytes = quadrillion bytes)!

Because the EDD BIOS functions use a 64-bit LBA number, they have a much larger limit:

```
                                  Max. Values
---------------------------------------------
Total Sectors      18,446,744,073,709,551,616
---------------------------------------------
Total Bytes     9,444,732,965,739,290,427,392
Megabytes (MB)          9,444,732,965,739,290
Mebibytes (MiB)         9,007,199,254,740,992
Gigabytes (GB)              9,444,732,965,739
Gibibytes (GiB)             8,796,093,022,208
Terabytes (TB)                  9,444,732,966
Tebibytes (TiB)                 8,589,934,592
Petabytes (PB)                      9,444,733
Pebibytes (PiB)                     8,388,608
Exabytes (EB)                           9,445
Exbibytes (EiB)                         8,192
Zettabytes (ZB)                          9.44
Zebibytes (ZiB)                          8.00
```

Although the BIOS services use 64-bit LBA (allowing up to 2^{64} sectors) for even greater capacity, the 144 petabyte ATA-6 limitation is the lowest common denominator that would apply. Still, that should hold us for some time to come.

Because hard disk drives have been doubling in capacity every 1.5 to 2 years (a corollary of Moore's Law), I estimate that it will take us until sometime between the years 2031 and 2041 before we reach the 144PB barrier (assuming hard disk technology hasn't been completely replaced by then). Similarly, I estimate that the 9.44ZB EDD BIOS barrier won't be reached until between the years 2055 and 2073! Phoenix originally claimed that the EDD specification would hold us until 2020, but it seems they were being quite conservative.

The 137GB barrier proved a bit more complicated than previous barriers because, in addition to BIOS issues, operating system issues also had to be considered.

Internal ATA drives larger than 137GB require 48-bit LBA (logical block address) support. This support absolutely needs to be provided in the OS, but it can also be provided in the BIOS. It is best if both the OS and BIOS provide this support, but it can be made to work if only the OS has the support.

Having 48-bit LBA support in the OS requires one of the following:

- Windows XP with Service Pack 1 (SP1) or later.
- Windows 2000 with Service Pack 4 (SP4) or later.
- Windows 98/98SE/Me or NT 4.0 with the Intel Application Accelerator (IAA) loaded and a motherboard with an IAA-supported chipset. See http://downloadcenter.intel.com and search for IAA.

Having 48-bit LBA support in the BIOS requires either of the following:

- A motherboard BIOS with 48-bit LBA support (most of those dated September 2002 or later)
- An ATA host adapter card with onboard BIOS that includes 48-bit LBA support

If your motherboard BIOS does not have the support and an update is not available from your motherboard manufacturer, you may be able to use a card. Promise Technology (www.promise.com) makes several PCI cards with 3Gbps SATA/eSATA interfaces as well as an onboard BIOS that adds 48-bit LBA support.

Note that if you have both BIOS and OS support, you can simply install and use the drive like any other. If you have no BIOS support, but you do have OS support, portions of the drive past 137GB are not recognized or accessible until the OS is loaded. If you are installing the OS to a blank hard drive and booting from an original XP (pre-SP1) CD or earlier, you will only be able to partition up to the first 137GB of the drive at installation time. After installing the OS and then the SP1 (or SP2/SP3) update, you can either partition the remainder of the drive as a second partition in Windows or use a free third-party partitioning program such as Parted Magic to expand the 137GB partition to use the full drive. If you are booting from an XP CD with SP1 or later integrated, Windows will recognize the entire drive during the OS installation and allow partitioning of the entire drive as a single partition greater than 137GB.

Operating System and Other Software Limitations

Note that if you use older software, including utilities, applications, or even operating systems that rely exclusively on CHS parameters, these items will see all drives over 8.4GB as 8.4GB only. You will need not only a newer BIOS, but also newer software designed to handle the direct LBA addressing to work with drives over 8.4GB.

Operating system limitations with respect to drives over 8.4GB are shown in Table 7.23.

Table 7.23 Operating System Limitations

Operating System	Limitations for Hard Drive Size
DOS/Windows 3x	DOS 6.22 or lower can't support drives greater than 8.4GB. DOS 7.0 or higher (included with Windows 95 or later) is required to recognize a drive over 8.4GB.
Windows 9x/Me	Windows 95a (original version) does support the INT13h extensions, which means it does support drives over 8.4GB; however, due to limitations of the FAT16 file system, the maximum individual partition size is limited to 2GB. Windows 95B/OSR2 and later (including Windows 98/Me) support the INT13h extensions, which allow drives over 8.4GB, and they also support FAT32, which allows partition sizes up to the maximum capacity of the drive. However, Windows 95 doesn't support hard drives larger than 32GB because of limitations in its design. Windows 98 requires an update to FDISK to partition drives larger than 64GB.
Windows NT	Windows NT 3.5x does not support drives greater than 8.4GB. Windows NT 4.0 does support drivers greater than 8.4GB; however, when a drive larger than 8.4GB is being used as the primary bootable device, Windows NT will not recognize more than 8.4GB. Microsoft has released Service Pack 4, which corrects this problem.
Windows 2000 and later	All Windows 2000 SP3+, Windows XP SP1+, Windows Vista, Windows 7/8, and later systems support MBR-formatted drives up to 2.19TB by default. 64-bit versions of Windows Vista SP1+ and Windows 7/8 and later support GPT-formatted drives of 2.2TB or larger, up to a maximum of 281TB (256TiB).
Linux	Most versions support MBR-formatted drives up to 2.19TB by default, whereas most current versions support GPT formatted drives of 2.2TB or larger, up to 16TiB or 1EiB depending on the file system.
OS/2 Warp	Some versions of OS/2 are limited to a boot partition size of 3.1GB or 4.3GB. IBM has a Device Driver Pack upgrade that enables the boot partition to be as large as 8.4GB. The HPFS file system in OS/2 supports drives up to 64GB.
Novell	NetWare 5.0 and later support drives greater than 8.4GB.

In the case of operating systems that support drives over 8.4GB, the maximum drive size limitations depend on the BIOS and hard drive interface standard, not the OS. Instead, other limitations come into play for the volumes (partitions) and files that can be created and managed by the various operating systems. These limitations depend on not only the operating system involved, but also the file system that is used for the volume. Table 7.24 shows the minimum and maximum volume (partition) size and file size limitations of the various Windows operating systems. As noted in the previous section, the original version of XP, as well as Windows 2000/NT or Windows 95/98/Me, does not currently provide native support for ATA hard drives that are larger than 137GB. You need to use Windows 7/8, Vista, or XP with Service Pack 1 or later installed to use an ATA drive over 137GB. This does not affect drives attached via USB, FireWire, SCSI, or other interfaces.

Table 7.24 Operating System Volume/File Size Limitations by File System

OS Limitations by File System	FAT16	FAT32	NTFS
Min. volume size (9x/Me)	2.092MB	33.554MB	—
Max. volume size (95)	2.147GB	33.554MB	—
Max. volume size (98)	2.147GB	136.902GB	—

Table 7.24 Continued

OS Limitations by File System	FAT16	FAT32	NTFS
Max. volume size (Me)	2.147GB	8.796TB	—
Min. volume size (NT+)	2.092MB	33.554MB	1.000MB
Max. volume size (NT+)	4.294GB	8.796GB	281.475TB
Max. file size (all)	4.294GB	4.294GB	16.384TB

— = not applicable

NT+ = Windows NT, 2000, XP, Vista, and Windows 7/8

MB = megabyte = 1,000,000 bytes

GB = gigabyte = 1,000,000,000 bytes

TB = terabyte = 1,000,000,000,000 bytes

GPT and the 2.2TB Barrier

Although most of the previous barriers in disk capacity have been hardware related, the 2.2TB barrier is more of a software than a hardware problem. Even more specifically, it is a disk formatting and OS problem, and it's a BIOS problem if you consider boot drives versus data drives.

This problem stems from the way hard disks have been formatted since DOS 2.0 and the first PC hard drives appeared in 1983. Back then IBM and Microsoft came up with a scheme for partitioning drives called the *MBR* (Master Boot Record). The MBR is the first sector on a disk, and it is internally defined with the ability to control four primary partitions. Each partition is described by a 16-byte table entry, with 4-byte (32-bit) fields that define the LBA (Logical Block Address) for both where the partition starts and how big it is.

The largest number that can be written using 32 binary digits is 2^{32}, which is equal to 4,294,967,296. Because each sector is normally limited to 512 bytes, this means that the maximum amount of a drive that can be recognized is 2.2TB. Combine the MBR limitation with the fact that most PC BIOSs can only boot from MBR-formatted drives, and most older operating systems only support MBR-formatted drives for both boot drives and data drives, and you can see that the 2.2TB limitation can be a problem.

Several changes are necessary to break this barrier. The first is to develop a new partitioning scheme without the limitations the MBR imposes. This replacement is called GPT, which stands for GUID (globally unique identifier) Partition Table. Intel initially developed the GPT as part of its EFI (Extensible Firmware Interface) specification in 2000; since then Microsoft and other OS vendors have been incorporating it into operating systems. The GPT uses 64-bit LBA numbers, meaning disks of up to 9.4ZB (8ZiB) can be managed. That's equal to 9.4 *billion* terabytes, a limit that won't be reached any time soon.

Figure 7.19 illustrates the differences between MBR and GPT partitions.

Although GPT breaks the 2.2TB barrier from a drive formatting perspective, other elements must be in place for GPT to be usable in a PC. To format or recognize a GPT-formatted disk, you need an OS that supports GPT. That alone allows you to use GPT-formatted disks as secondary (data) disks, but to boot from a GPT-formatted drive, you also need a motherboard with a UEFI BIOS or UEFI Boot option. Table 7.25 summarizes the requirements to break the 2.2TB barrier.

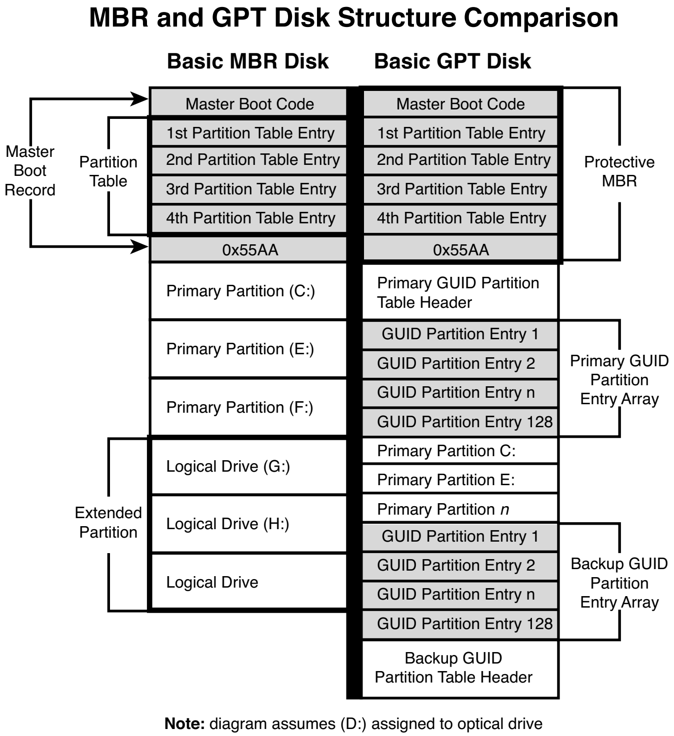


FIGURE 7.19 GPT includes a backup for partition entries and the partition table header.

Table 7.25 Operating System GPT Boot/Data Disk Support

Operating System	GPT Boot Disk	GPT Data Disk
Windows XP (x86)	No	No[1]
Windows XP (x64)	No	Yes
Windows Vista SP1+ (x86)	No	Yes
Windows Vista SP1+ (x64)	Yes[2]	Yes
Windows 7/8 (x86)	No	Yes
Windows 7/8 (x64)	Yes[2]	Yes
Linux UBUNTU 8.04+/SUSE (x86, x64)	Yes	Yes

Note: x86 = 32-bit, x64 = 64-bit

1 Yes with third-party software such as the Paragon GPT Loader

2 Only on systems with a UEFI BIOS or an enabled UEFI Boot option

Drives 2.2TB or larger can also be supported externally via USB without having to resort to GPT partitioning. This is accomplished within the USB Bridge chipset firmware, which can be designed to present 2.2TB or larger drives using 4K sectors instead of the normal 512-byte sectors. USB enclosures or drive docks with this feature can use standard MBR formatting to allow the drive to be supported in Windows XP with no special software required.

In summary, to use a 2.2TB or larger drive as an internal secondary/data drive, you need to format it using GPT, and you need to run a GPT-aware OS (Vista SP1 or later). Booting from such a drive also requires a UEFI BIOS or an enabled UEFI Boot option. You can use GPT-formatted secondary/data drives with Windows XP by installing third-party GPT support software such as the Paragon GPT Loader (www.Paragon-Software.com).

PATA/SATA RAID

RAID is an acronym for redundant array of independent (or inexpensive) disks and was designed to improve the fault tolerance and performance of computer storage systems. RAID was developed at the University of California at Berkeley in 1987 and was designed so that a group of smaller, less expensive drives could be interconnected with special hardware and software to make them appear as a single larger drive to the system. By using multiple drives to act as one drive, increases in fault tolerance and performance could be realized.

Initially, RAID was conceived to simply enable all the individual drives in the array to work together as a single, larger drive with the combined storage space of all the individual drives, which is called a *JBOD* (Just a Bunch of Disks) configuration. Unfortunately, if you had four drives connected in a JBOD array acting as one drive, you would be four times more likely to experience a drive failure than if you used just a single larger drive. And because JBOD does not use striping, performance would be no better than a single drive either. To improve both reliability and performance, the Berkeley scientists proposed six levels (corresponding to different methods) of RAID. These levels provide varying emphasis on fault tolerance (reliability), storage capacity, performance, or a combination of the three.

Although it no longer exists, an organization called the RAID Advisory Board (RAB) was formed in July 1992 to standardize, classify, and educate on the subject of RAID. The RAB developed specifications for RAID, a conformance program for the various RAID levels, and a classification program for RAID hardware.

The RAID Advisory Board defined seven standard RAID levels, called RAID 0–6. Most RAID controllers also implement a RAID 0+1 combination, which is usually called RAID 10. The levels are as follows:

- **RAID Level 0**—Striping-File data is written simultaneously to multiple drives in the array, which act as a single larger drive. This offers high read/write performance but low reliability. Requires a minimum of two drives to implement.
- **RAID Level 1**—Mirroring-Data written to one drive is duplicated on another, providing excellent fault tolerance (if one drive fails, the other is used and no is data lost) but no real increase in performance as compared to a single drive. Requires a minimum of two drives to implement (same capacity as one drive).
- **RAID Level 2**—Bit-level ECC-Data is split one bit at a time across multiple drives, and error correction codes (ECCs) are written to other drives. This is intended for storage devices that do not incorporate ECC internally. (All SCSI and ATA drives have internal ECC.) It's a standard that theoretically provides high data rates with good fault tolerance, but seven or more drives are required for greater than 50% efficiency, and no commercial RAID 2 controllers or drives without ECC are available.
- **RAID Level 3**—Striped with parity-Combines RAID Level 0 striping with an additional drive used for parity information. This RAID level is really an adaptation of RAID Level 0 that sacrifices some capacity, for the same number of drives. However, it also achieves a high level of data integrity or fault tolerance because data usually can be rebuilt if one drive fails. Requires a minimum of three drives to implement (two or more for data and one for parity).

- **RAID Level 4**—Blocked data with parity—Similar to RAID 3 except data is written in larger blocks to the independent drives, offering faster read performance with larger files. Requires a minimum of three drives to implement (two or more for data and one for parity).
- **RAID Level 5**—Blocked data with distributed parity—Similar to RAID 4 but offers improved performance by distributing the parity stripes over a series of hard drives. Requires a minimum of three drives to implement (two or more for data and one for parity).
- **RAID Level 6**—Blocked data with double distributed parity—Similar to RAID 5 except parity information is written twice using two parity schemes to provide even better fault tolerance in case of multiple drive failures. Requires a minimum of four drives to implement (two or more for data and two for parity).

There are also *nested* RAID levels created by combining several forms of RAID. The most common are as follows:

- **RAID Level 01: Mirrored stripes**—Drives are first combined in striped RAID 0 sets; then the RAID 0 sets are mirrored in a RAID 1 configuration. A minimum of four drives is required, and the total number of drives must be an even number. Most PC implementations allow four drives only. The total usable storage capacity is equal to half of the number of drives in the array times the size of the lowest capacity drive. RAID 01 arrays can tolerate a single drive failure and some (but not all) combinations of multiple drive failures. This is not generally recommended because RAID 10 offers more redundancy and performance.
- **RAID Level 10: Striped mirrors**—Drives are first combined in mirrored RAID 1 sets; then the RAID 1 sets are striped in a RAID 0 configuration. A minimum of four drives is required, and the total number of drives must be an even number. Most PC implementations allow four drives only. The total usable storage capacity is equal to half of the number of drives in the array times the size of the lowest capacity drive. RAID 10 arrays can tolerate a single drive failure and many (but not all) combinations of multiple drive failures. This is similar to RAID 01, except with somewhat increased reliability because more combinations of multiple drive failures can be tolerated, and rebuilding an array after a failed drive is replaced is much faster and more efficient.

Additional custom or proprietary RAID levels exist that were not originally supported by the RAID Advisory Board. For example, from 1993 through 2004, “RAID 7” was a trademarked marketing term used to describe a proprietary RAID implementation released by the (now defunct) Storage Computer Corp.

When set up for maximum performance, arrays typically run RAID Level 0, which incorporates data striping. Unfortunately, RAID 0 also sacrifices reliability such that if any one drive fails, all data in the array is lost. The advantage is in extreme performance. With RAID 0, performance generally scales up with the number of drives you add in the array. For example, with four drives you won’t necessarily have four times the performance of a single drive, but many controllers can come close to that for sustained transfers. Some overhead is still involved in the controller performing the striping, and issues still exist with latency—that is, how long it takes to find the data—but performance will be higher than any single drive can normally achieve.

When set up for reliability, arrays generally run RAID Level 1, which is simple drive mirroring. All data written to one drive is written to the other. If one drive fails, the system can continue to work on the other drive. Unfortunately, this does not increase performance, and it also means you get to use only half of the available drive capacity. In other words, you must install two drives, but you get to use only one. (The other is the mirror.) However, in an era of high capacities and low drive prices, this is not a significant issue.

Combining performance with fault tolerance requires using one of the other RAID levels, such as RAID 5 or 10. For example, virtually all professional RAID controllers used in network file servers are designed to use RAID Level 5. Controllers that implement RAID Level 5 used to be very expensive, and RAID 5 requires at least three drives to be connected, whereas RAID 10 requires four drives.

With four 500GB drives in a RAID 5 configuration, you would have 1.5TB of total storage, and you could withstand the failure of any single drive. After a drive failure, data could still be read from and written to the array. However, read/write performance would be exceptionally slow, and it would remain so until the drive was replaced and the array was rebuilt. The rebuild process could take a relatively long time, so if another drive failed before the rebuild completed, all data would be lost.

With four drives in a RAID 10 configuration, you would have only 1TB of total storage. However, you could withstand many cases of multiple drive failures. In addition, after a drive failure, data could still be read from and written to the array at full speed, with no noticeable loss in performance. In addition, once the failed drive is replaced, the rebuild process would go relatively quickly as compared to rebuilding a RAID 5 array. Because of the advantages of RAID 10, many are recommending it as an alternative to RAID 5 where maximum redundancy and performance are required.

Many motherboards include SATA RAID capability as a built-in feature. For those that don't, or where a higher performance or more capable SATA RAID solution is desired, you can install a SATA RAID host adapter in a PCIe slot in the system. A typical PCIe SATA RAID controller enables up to four, six, or eight drives to be attached, and you can run them in RAID Level 0, 1, 5, or 10 mode. Most PCIe SATA RAID cards use a separate SATA data channel (cable) for each drive, allowing maximum performance. Motherboard-based RAID controllers almost exclusively use SATA drives.

If you are considering a SATA RAID controller (or a motherboard with an integrated SATA RAID controller), here are some things to look for:

- RAID levels supported. (Most support 0, 1, 5, and 10. A lack of RAID 5/6 or RAID 10 support indicates a very low-end product.)
- Support for four, six, or eight drives.
- Support for 6Gbps SATA transfer rates.
- PCIe card with onboard controller (provides best performance and future compatibility; note that low-cost PCIe cards are host-based and rely on the CPU).

Software RAID

Some operating systems include software-based RAID capability; in fact, limited RAID 0, 1, and even RAID 5 functionality has been built in to some versions of Windows since Windows 2000. When Microsoft released Windows Home Server in 2007 it greatly enhanced this capability with a feature called Drive Extender, which allowed for the creation and arbitrary expansion of an array using virtually any type of drive (SATA, PATA, USB, FireWire, etc.) in any capacity. Drive Extender creates a virtual drive that is a combination of the assigned physical drives. There is limited redundancy in that by default each file saved on a Drive Extender volume is automatically stored on two different drives such that if one drive fails it can theoretically be replaced without losing any data. If more than one drive fails, then data will be lost. Unfortunately, problems with Drive Extender caused Microsoft to remove the feature from Windows Home Server 2011.

Microsoft has included a newer and better replacement for Drive Extender in Windows 8, which is now called Storage Spaces. Just like Drive Extender, it allows you to build a virtual drive using an array of drives of just about any type or capacity. One area where Storage Spaces differs from Drive Extender is in the redundancy options. In addition to two-way redundancy where data is saved on two drives, Storage Spaces allows for three-way redundancy, meaning that data will be saved on three drives. This also means that up to two drives can fail in the array without losing data. While the redundancy and reliability has been improved, just as with most software-based RAID, performance falls dramatically as compared to either a physical drive or hardware-based RAID, especially in write performance.

While the Storage Spaces feature in Windows 8 looks like an excellent option for a home server with multiple data drives, just like any other RAID array, it doesn't replace the need for backup, meaning you would need somewhere else to back up all of the data on the Storage Spaces virtual drive.

Normally, if you want both performance and reliability, you should look for hardware-based SATA RAID controllers that support RAID Level 5 or 10, or an external storage device with built-in RAID capability. You can install a PCIe-based RAID controller; however, many motherboards have RAID capability built in via the motherboard chipset. Another option is external storage devices like the Drobo (www.drobo.com), which can create and manage virtual drives using the various physical drives mounted in the enclosure. Because they rely on dedicated management hardware, they can offer better performance and reliability than even some hardware-based RAID setups.

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