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IEEE 1394: Changing the Way We Do Multimedia Communications

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The mark of a good bus design is to be general-purpose enough so that its use expands to applications beyond those for which it was originally intended. Compare the narrowly defined EISA (Extended Industry Standard Architecture) specification and the now-defunct MicroChannel bus to the vibrant IEEE 1394 standard, which has numerous specifications built around it already, and many more under development.

This article highlights some of the many applications made possible—or made better—by expanding on the 1394 standard. It also directs you to the key specifications that have developed for each of the application areas.

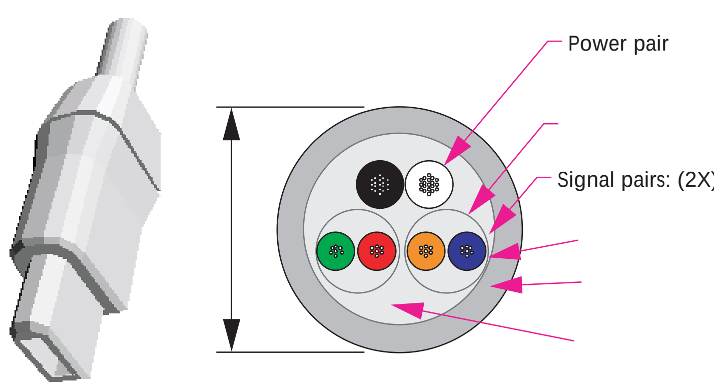
What is the 1394 specification?

First introduced as Firewire by Apple Computer in the late 1980s, the now-approved IEEE 1394 standard was designed to support high-bandwidth requirements of devices such as digital video equipment and high-performance mass storage. The original specification, IEEE 1394-1995, was ratified in 1995. An updated specification, IEEE Std. 1394a-2000, was approved in March 2000. IEEE 1394a describes a serial bus that supports speeds of 100 Mbytes per second, 200 Mbps, and up to 400 Mbps with much improved traffic control and power management features. The standard provides a way to move high-bandwidth video and audio digital traffic among peer devices—digital video recorders, DVD, camcorders, and high-speed/high-resolution printers and scanners. It supports hot-swapping and plug-and-play to improve the experience of consumers who want to use 1394-enabled products. In addition, IEEE 1394b is waiting in the wings with speeds up to 1,600 Mbps and 3,200 Mbps on the horizon.

One of the advantages of choosing a serial interface over a parallel interface is the reduced size of the required connectors and cables—an important consideration in portable consumer products where the IEEE 1394 first made inroads. The 1394 spec calls for six wires—two differential pairs plus power and ground. The protocol defines two connectors. The four-pin 1394 connector has the size advantage: at 5 mm × 3 mm, it's about half the size of a universal serial bus (USB) connector. The six-pin connector measures 10 mm × 5 mm and includes power and ground wires in addition to the signal wires. Figure 1 shows a cross-section of 1394 cable and the relative sizes of the four- and six-pin connectors.

Throughout the history of the 1394 standard, there has been great debate over the connector. Some groups opposed a four-pin connector

Figure 1. IEEE 1394 six-wire cable and space-saving plug (six-pin version).



because of its lack of power and ground wires. However, its size has made it one of the key reasons for the spec's rapid acceptance.

The four-pin connector was so much smaller than the USB connector that it was the connector of choice for many consumer electronics products. Products such as camcorders—the first market where the 1394 spec achieved broad acceptance—will always be self-powered, as will any portable device. However, many PC peripherals such as conferencing cameras and portable disk drives can take advantage of bus power from a six-pin connector—and they do. By having power and ground wires in the connector, designers can produce bus-powered peripherals at considerably lower cost than a battery-powered portable model of the same peripheral. Therefore, the six-pin connector is more desirable when size isn't the primary consideration.

In addition to providing low-cost, high-speed, peer-to-peer communications with huge amounts of memory-mapped address space, the IEEE 1394 protocol is highly scalable. More importantly, for multimedia applications IEEE 1394 supports both asynchronous and isochronous communications.

Asynchronous transport is the traditional memory-mapped, load-and-store interface that ensures error-free delivery of data, but its error-checking protocols introduce time delays that make it unsuitable for multimedia. On the other hand, error-checking is crucial for such tasks as writing data to disks. Isochronous data transfer guarantees throughput at a predetermined rate, making it ideal for the transmission of time-critical multimedia data where some error can be tolerated. IEEE 1394 manages the packeting process, whereby space can be reserved for the transmission of both schemes.

IEEE 1394 building blocks

The IEEE 1394 standard defines three layers: physical, link, and transaction (see Figure 2). The link and physical layers are the main building blocks of a 1394 interface. The link layer communicates with the transaction layer using an acknowledged datagram, a one-way data transfer with request confirmation. The link layer handles packet transmission and reception, as well as the cycle control for isochoronous channels. A transceiver (physical interface) provides initialization and arbitration services and manages the physical layer by ensuring that only one node sends data at any time. The transceiver translates the serial data stream and signal levels before sending them to the link layer.

Physical interface devices can be repeaters as well, allowing data to pass from one device to another without passing through the link. For example, if a PC has two 1394 ports—one connected to a printer and the other to a camcorder—and the PC is designed to keep the physical interface device powered, traffic can still pass between the printer and the camcorder, even if the PC is turned off.

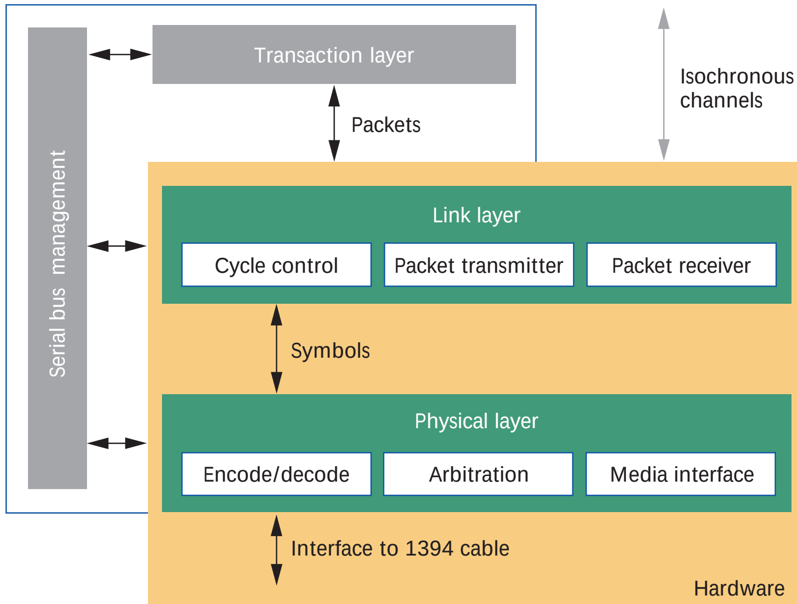


Figure 2. The link and physical layers provide the hardware connectivity for IEEE 1394.

The transaction layer implements the request-response protocol specified in the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) 13213: 1994 Standard Control and Status Register (CSR) Architecture for Microcomputer Buses (see http://standards.ieee.org/catalog/bus.html#gen18). The transaction layer can be implemented in firmware or hardware. The link and physical layers are implemented in digital and mixed-signal hardware technology, respectively.

Physical interface devices

Physical interface devices connect PCs, workstations, and peripherals to an IEEE 1394 cable and implement handshaking for data transfers. At the same time, physical interface devices define the transmission speed. Because of the enormous difficulty of integrating analog and digital technologies on a physical interface device chip, just a handful of manufacturers can design and build these devices. The design challenge to build these chips is intensified with the step up to 800 Mbps and IEEE 1394b.

Although all physical interface devices must

As portable multimedia and computing devices become increasingly popular, power management is becoming increasingly important.

meet certain standards the IEEE establishes, they nevertheless differ from one another in various ways, with the number of ports supported representing a key differentiating feature. For example, some physical interface devices may have as few as 48 pins in a 100-Mbps first-generation, one-port thin quad flat pack (TQFP). Others may have as many as 100 pins to accommodate 800-Mbps speeds. The thermal characteristics of the physical interface device chip package and the power dissipation of the physical interface device place potential limits on the maximum number of ports on one physical interface device chip. The IEEE 1394a specification places a 16-port limit on a single physical interface device chip.

Another important defining factor for physical interface devices is power considerations. A wide range of power-saving functions are available in different physical interface devices. I'll further discuss power management below.

Links

Links are the interface blocks between the application and the transceiver, or physical interface device. Links provide the encoding and decoding functions that allow a PC to interact with a physical interface device. IEEE 1394 links have gone through three generations to date. First-generation links came in two flavors. One type provided only the general-purpose functionality defined in the IEEE 1394 specification. At 3,500 gates, these devices communicated with a transaction layer that was done in firmware to link physical interface devices to a 32-bit microprocessor or microcomputer bus. The second flavor, which linked physical interface devices to a PCI bus, rolled the transaction layer into the link hardware to create a much larger device (150 K gates). Second-generation links were able to take advantage of the Open Host Controller Interface (OHCI) standard software interface, which dramatically increased the usability of the 1394 standard with PC applications. The third generation of links integrates the physical interface device and link functions. These integrated devices further enhance the simplicity of designing a 1394 interface by reducing part count and cost (see the sidebar "Integrating Layers").

Helper specifications

While the 1394 specification carefully details physical interface device and link operation, it doesn't define a standard application system interface. As a result, each vendor of first-generation link products had a different system interface. This fact limited the portability of early 1394 products across system-level applications. Additional specifications were needed to "help" improve the 1394 user experience. The OHCI and power management specifications are two examples of "helper" specifications.

Open Host Controller Interface

OHCI provides a standard operating-system interface to the application. It defines common register sets and services for a generic host controller. The interface targets silicon vendors and software developers creating operating systems and applications for OHCI-compliant 1394 chips.

OHCI allows communication between any 1394 controllers that support the standard through an implementation of the link layer protocol of the 1394 serial bus, with additional features to support the transaction and bus management layers. OHCI also includes direct memory access (DMA) engines for high-performance data transfer, as well as a host bus interface, typically peripheral component interconnect (PCI).

OHCI guarantees operating system compatibility over multiple hardware platforms, provides clean plug-and-play at the firmware level, and guarantees that a hardware platform has multiple operating system choices.

OHCI version 1.1 is now in committee. It updates version 1.0 to include standard power management mechanisms, refinements to operation, and clarifications. For more information visit ftp://ftp.austin.ibm.com/pub/chrptech/1394ohci.

Power management

A wide range of power-saving functions is available in various physical interface devices and also various operating systems. Power management is a crucial issue, with both hardware and software aspects to consider. Currently, the IEEE 1394 specification doesn't fully specify power standards. Particularly, very little in the latest version addresses software power management considerations. As a consequence, Microsoft is driving a power management specification that addresses them.

In the 1394 world, devices can be configured as either consumers or suppliers of power. For example, a digital camera with a single port would be a power consumer. A set-top box configured as a home entertainment center with many ports could be a power supplier.

As portable multimedia and computing devices become increasingly popular, power management is becoming increasingly important. Hardware and software development work is still required to reduce power dissipation. Although IEEE 1394a supports the delivery of up to 60 watts of power via the power and ground connections inside the standard six-pin cable, the four-pin cable most typically used for small portable devices, as discussed above, doesn't include the power and ground lines. It's important to reduce power demands wherever possible.

Hardware designers can lower power requirements by including automatic device power-down during suspend, a link interface disable, and the ability to power-down an inactive port automatically. Operating system developers are just beginning to take advantage of some of the hardware features, but much work needs to be done. By 2001 or 2002, operating systems should be taking considerably more advantage of power saving features.

Some of the specifications under development by the 1394 Trade Association are covered in the 1394TA Power Spec, which describes a uniform method for power management, including how nodes should supply, limit, pass, and consume power; implementation of suspend and resume power saving mechanisms; and a model for managing power states. More information is available at http://www.1394-pcwg.org/.

1394b—the next step

An enhanced specification, 1394b should be finalized this year. IEEE 1394b will extend bus speeds to 800 and 1,600 Mbps. The enhancements also include architectural support for 3,200 Mbps, although the signaling parameters for 3,200 Mbps are not yet available. The IEEE 1394b also supports forms of cabling not supported in the existing 1394a specification, resulting in a dramatic increase in cable lengths—from the 4.5 meters of the original standard copper cable to 100 meters for plastic optical fiber, multiple kilometers (km) for glass optical fiber cables, and 100 meters for category 5 (CAT-5) at 100 Mbps.

Some companies are already producing prototypes and products that meet or surpass the requirements of 1394b. Lucent Technologies Microelectronics Group demonstrated the first bilingual 1394b physical interface device at Comdex 1998. This two-port device automatically switched from 1394a operation to operation at 800 Mbps (a different style for Mbps occurred when it detected connection to a 1394b physical interface device).

Another example comes from NEC. In a recent press release, NEC announced a 1394b-like physical-layer chip. In addition, the company prototyped a bridge device that the company says will

Integrating Layers

Physical interface and link devices can simplify the implementation of IEEE 1394 applications. A hybrid analog and digital device, the physical interface device has been on the market for some time. During that period, its functionality has increased from basic single-port support at 100 Mbps to a broad range of products targeted at different types of applications. Like the supplemental standards that support different applications, the proliferation of physical interface devices makes 1394 implementation much faster, easier, and less expensive.

Lucent Technologies Microelectronics Group has been a leader in 1394 hardware technology. Bell Labs, Lucent's research and development arm, created the technology that first enabled PC and workstation manufacturers to connect high-end consumer multimedia appliances to a PC and to each other at 400 Mbps, the top speed in the 1394a specification.

In designing this technology, Lucent had to overcome three key challenges. The first was to accommodate clock speeds as high as 400 MHz. The second was to incorporate both analog and digital circuitry on a single chip. The third was to design the chip to conform to the new power management requirements imposed by operating systems. These technical challenges had been the choke point for the industry in the development of next-generation multimedia PCs and consumer digital electronics devices.

Another Lucent innovation was a three-port IEEE 1394a-compliant physical interface device housed in a 64-pin TQFP package that pioneered a round of smaller footprint designs. These new physical interface devices provided a combination of small size and low power that helps reduce final system costs and extends the 1394 design options for portable PCs and other compact, battery-powered systems. Most recently, Lucent expanded on the Bell Labs technology to introduce the first integrated physical interface/OHCI device. The newest level of integration further enhances IEEE 1394 application opportunities by enabling smaller, simpler, more efficient motherboard and add-in card designs.

The 1394 market is an excellent illustration of the benefits of cooperation in taking advantage of a well-designed general-purpose standard and expanding it to benefit an increasing number of applications. Each innovation builds on those that have gone before.

enable 1-km networks. The physical interface device chip, designated the PD72880, is capable of 400 Mbps. NEC claims its architecture is superior in addressing signal delay and thus capable of 500-meter transmission—a fivefold improvement over the 1394b requirement. The chip supports full-duplex transmission as well, also required by the 1394b specification.

Specifications for multimedia applications

Implementation of 1394-enabled applications requires an understanding of the specifications targeted to the functionality required. Here I'll discuss four of the most popular multimedia applications: digital video, mass storage, home networking, and wireless.

Digital video

Of particular interest to multimedia systems designers is that IEEE 1394 offers a way to move high-bandwidth video and audio digital traffic among peer devices—digital cameras, DVD, camcorders, and high-speed, high-resolution printers and scanners—without a hub or master (PC) in between. For example, a digital camera can send pictures directly to a printer or a camcorder can connect to a set-top box. The 1394 standard has been endorsed in the digital TV market by the Electronics Industries Association and Advanced Television Systems Committee (ATSC) in the US, and the Digital Video Broadcasting (DVB) standards in Europe.

The IEEE 1394 specification for high-speed data rates has allowed applications that were once only possible in movie and TV studios to be done with consumer-electronic systems, such as capturing movies to disk or using a camcorder as a TV simply by "plugging in." The 1394b spec adds additional value by promising to support multiple streams of real-time video.

A number of specifications have evolved around this area of high-speed digital video and audio. For example, the IEC 61883 specifications describe the standard for hardware protocols used for Digital Video Consortium (DVC) devices. The six volumes of IEC 61883-1, -2, -3, -4, -5, and -6 are available from http://www.ansi.org or http://www.iec.ch.

Four main subsections to the specifications have evolved to support digital video—camera control, content protection, audio/music, and videoconferencing.

Camera control. The IEC 61883 specifications describe a variety of isochronous transport protocols that can be used with different multimedia formats such as AV/C, DVC, MPEG, and AMP. This expandable set of specifications includes not only protocols widely used today, but also emerging protocols such as high-definition digital video.

IEC 61883 provides a standard interface for software commands to a camcorder or other device. No matter what device and what software application, the commands for play, stop, rewind, and other camera functions are the same at the bit level.

The other critical aspect to the specifications is a common definition of headers, the part of a data transmission that tells the device that the next set of ones and zeros is a command. It's necessary to describe how to send things down a 1394 pipe so they come out the other end properly. For further information on IEC 61883 visit http://www.iec.ch/cs1oi-e.htm.

The AV/C general and enhancement specifications define control and data for audio/video (A/V) applications. More specifically, they define general commands used to control consumer audio/video electronics and specific enhancements for VCR, digital VHS (DVHS), 8mm, and other A/V products. For information on AV/C specifications visit http://www.1394ta.org/Technology/Specifications/.

A variety of protocol specifications are available to cover the wealth of video compression formats, including MPEG2-TS (digital satellite system, or DSS, transport stream) across 1394, which is now in committee (http://www.1394ta.org), the Consumer Electronics Manufacturers Association (CEMA) Subcommittee R4.8 digital interface standard EIA 775, and the AV/C tuner general model for analog and digital video tuners as well as digital video broadcast (DVB) and DSS video tuners.

Content protection. Multimedia devices must include a content protection scheme for copyrighted material. Technologies such as 1394 make it easy to transport digital video and digital audio. To address this issue, in 1998 a consortium of five companies—Sony, Toshiba, Intel, Hitachi, and Matsushita Electric Industrial—developed the Digital Transmission Content Protection (DTCP) method, a copy protection method for copyrighted content transferred across digital interfaces.

The five companies established the Digital Transmission Licensing Administrator, or DTLA, to license the content protection system and to generate and distribute cryptographic materials such as keys and certificates. For a technical white paper describing the DTCP method and licensing information from the DTLA, visit the DTLA Web site at http://www.dtcp.com.

Other organizations such as the Copy Protection Technical Working Group (CPTWG), the Digital Transmission Discussion Group (DTDG), the CEMA 1394 Interface Committed, the DVD Forum, and the Secure Music Initiative are exploring copy protection schemes.

CEMA's R4.8 1394 Interface Subcommittee created a report documenting amendments necessary to EIA 775, 761, and 762 to support each of the copy protection approaches. It provides a valuable set of comparisons of the different copy protection schemes available.

Multimedia devices must include a content protection scheme for copyrighted material, since it's easy to transport digital files.

Audio/music. Oddly enough, audio/music seems to fall under the general category of digital video. Because audio—and music in particular—has some special characteristics, the 1394 Trade Association has a set of specifications specifically for audio functions. These specifications include audio and super-audio CD control models, and a tape recorder subunit. More information is available at http://www.1394ta.org/Technology/Specifications.

Videoconferencing. Uncompressed digital videoconferencing has special requirements that the 1394 Digital Video Conferencing Camera Specification defines. Specification 1.2 is the most recent set of functions, services, and register definitions that the 1394 Trade Association has accepted. Updates have been proposed and are under consideration. For more information, check out http://www.1394ta.org/Technology/Specifications/index.htm.

Mass storage

Although many mass storage devices have taken advantage of IEEE 1394a, the move to IEEE 1394b is particularly accommodating to hard-disk manufacturers, who need the higher data transfer rates. The principal specifications for mass storage are the Serial Bus Protocol 2 (SBP-2) and the Device Bay. In addition, there exist a variety of subspecifications, including the Reduced Block Commands (RBC) Command Set and a variety of AV/C descriptions.

SBP-2 describes a transport protocol for asynchronous commands or data and is widely adopted by computer peripherals manufacturers. SPB-2 is not just for disk drives—it's also used for scanners and printers. Examples include the newly announced scanners from Epson, Umax and a printer from Epson.

The specification is released through the T10, a technical committee of the National Committee of Information Technology Standards. Draft specifications are available at ftp://ftp.t10.org/t10/drafts/sbp2/. More general information is available at http://www.T10.org.

The Device Bay specification defines a uniform set of mechanical and electrical requirements for hot swapping PC peripherals. Aimed at devices such as readable/writeable CD and DVD drives, hard drives, and high-capacity removable media devices, as well as more esoteric multimedia devices, Device Bay is the answer to customer requests to make upgrading and customizing PCs easy. A Device Bay slot in a PC allows any Device-Bay-compatible product to be quickly plugged in, used, and removed, without lengthy software installation procedures. It supports both casual use and hot-swapping for fast repairs. For more information on Device Bay, see: http://www.devicebay.org.

The T10 also monitors the RBC. Draft specifications are available at ftp://ftp.t10.org/t10/drafts/rbc. For more general information visit http://www.t10.org.

The AV/C specifications include mass storage models including minidisks, hard disks, and compact disks, plus a descriptor for storage-class devices. More information can be found at http://www.1394ta.org/Technology/Specifications.

Home networking

High-bandwidth home networking is approaching reality for the general population. The Home Audio Video interoperability (HAVi) architecture defined software protocols and application programming interfaces (APIs), as well as addressing, versioning, and management of isochronous streams for consumer electronics and computing devices. The 1394 Trade Association accepted the HAVi, and a definition of allowable command set

Resources

The IEEE 1394 protocols are complex and on a rapid evolutionary path. If you're interested in keeping up on the latest developments in this area you may want to access the following:

- The 1394 Trade Association's Web site: http://www.1394TA.org
- A PC99 developer's guide for 1394, co-authored by Microsoft, Intel, and Compaq: http://www.eu.microsoft.com/hwdev/xpapers/pc99/08PC99.htm
- Zayante sites with links to a wealth of resources: "1394 Community" at http://www.zayante.com/html/IEEEinfo/IEEEcom.html and "P1394b (Gigabit 1394)" at http://www.zayante.com/p1394b/index.shtml. The complete draft of the 1394b proposal in PDF format: http://www.zayante.com/p1394b/drafts/p1394b_rev100.pdf.

codes is now in committee. First demonstrated running over 1394 at Comdex 1998, HAVi enables many of the rich multimedia transfer and manipulation functions gaining in popularity in the home market. For more information, check http://www.1394ta.org/Technology/Specifications/index.htm and http://www.havi.org.

The Video Electronics Standards Association (VESA) is developing a document that describes the physical and data link layers and midlayer protocols required for a home network. The white paper is now complete, and the first draft home network specification was released for VESA membership review last August. The proposed specification will make it possible for consumers to access all networked appliances through a device in the home such as a TV or PC. It takes advantage of the longer distance capabilities of the 1394b specification. The VESA Home Network Committee has successfully completed a test of the home networking concept with several companies, and portions have been demonstrated at trade shows including Comdex and the Consumer Electronics Show. For more information, see http://www.vesa.org/committees.html.

Asychronous connection management is defined by an AV/C document that the 1394 Trade Association has accepted. Currently, updates are being proposed. Visit http://www.1394ta.org/Technology/Specifications/index.htm for more information.

Wireless

Although the current 1394 specification doesn't include a specification for wireless transmission, some companies are working on it. Philips Semiconductor and Wi-LAN showed a demo of wireless IEEE 1394 on two prototype transceivers at the 1999 Internationale Funkausstellung (IFA, or International Radio Exhibition) in Berlin. Two MPEG-2 streams were sent to two set-top boxes for decoding, then into a pair of TV sets. The raw data rate reported was 48 Mbps, resulting in a 30-Mbps burst transfer rate, which can ultimately deliver up to six MPEG-2 streams in two directions simultaneously. Similar wireless demonstrations of 1394 have been shown by companies such as Sony (at Comdex 99) and NEC (at CES 2000).

Conclusion

With the demonstration of 1394 over wireless media, it's clear that Apple's Firewire has satisfied the definition of a good bus design—it has expanded far beyond its original intent. As consumer multimedia and computing applications continue to merge, the peer-to-peer flexibility and the serial bus advantages of the IEEE 1394 standard will become increasingly popular. As demonstrated by the increasing bandwidth of 1394b, there's no immediate end in sight to the amount of performance that can be extracted from this protocol. With backward compatibility in mind, contributors to the evolving standard are opening up a new way of computing that will provide increasing flexibility and portability of applications. MM

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