1394 Serial Bus Interface: Convergence Bus Promises to Unite PCs and Digital Consumer Equipment

High-Performance, Easy-to-Use Bus
Carries Data plus Digital Video and Audio in Real Time

Overview/Executive Summary

The IEEE 1394 high-speed serial bus will change the transport of digital data for computers and consumer electronics products. A truly universal I/O connection, IEEE 1394 provides a non-proprietary, high-performance method of interconnecting digital devices. Its scaleable architecture and flexible peer-to-peer topology make IEEE 1394 ideal for connecting devices from computers and hard drives to digital video and audio equipment with real-time processing requirements for on-time multimedia.

IEEE 1394's main features are:

- Cross-platform solution standardized for transporting all types of digital data
- Easy-to-use cable and connector allow users to attach or remove devices at any time, even with power on
- High-speed transport from 100 to 400 Mbps, with 1 Gbps and higher in the future
- Asynchronous data transport provides connectivity to legacy technology such as printers and modems, while providing command and control for new devices
- Isochronous data transport guarantees delivery of multiple, time-critical multimedia data streams

1999 has been a stellar year for IEEE 1394 with many consumer products now taking advantage of the 1394 interface. Year 2000 and beyond will continue to have a myriad of new and improved line of products offering 1394 support, including hard drives.

The Need for a High-Speed Data Transfer Medium

The demand for higher throughput on peripheral devices has become crucial with the growing multimedia content in PCs such as real-time color video. Digital devices generate large volumes of data, especially when high resolution and high quality results are desired—and video makes the heaviest demands on throughput. To handle the huge amounts of data from digital video and audio data streams in real time, a high-performance transport medium such as IEEE 1394 is needed.

Serial interfaces (few wires) typically have advantages over parallel interfaces (many wires) in applications where the cost of supporting many wires is greater than the cost of the serial interface's more sophisticated electrical protocol. Issues such as die size, I/O count, connector size and cable routing can be optimized to provide the serial interface with a cost/performance advantage in some high volume applications. Serial interfaces are generally preferred in applications where the distances between devices complicate the use of parallel interfaces.

The IEEE 1394 high-speed serial bus hardware and software standard describes a digital interface that enables the interconnection of computers, peripherals, communications equipment and digital consumer electronics devices in any combination. This technology features real-time data transfer at rates of 100 to 400 Mbps, with 1 Gbps and higher expected in future-generation implementations. IEEE 1394 is designed for use in computer and consumer peripheral products such as hard disk devices, printers, scanners, DVDs, camcorders, digital cameras, set-top boxes, stereo systems, TVs and VCRs.

The IEEE 1394 serial bus interface offers scaleable high performance and bridges PC and consumer electronics with one easy-to-use cable. In addition to handling high data rates, 1394 accommodates time-sensitive video and audio data through isochronous data transfers. The 1394 bus needs no central controller or dedicated host computer for the data transfers, but instead operates peer-to-peer to allow any device on the bus to initiate transfers on its own—an important feature for consumer equipment not linked to PCs.

IEEE 1394 improves the performance of consumer video and audio equipment by replacing conventional analog connections and the need for costly, imperfect conversions between analog and digital formats that inject loss and distortion. It is also emerging as the key data channel for PCs.

Background/History

In 1986, the IEEE Microcomputer Standards Committee began unifying various serial bus implementations to provide a standard for desktop computer applications. Since 1,393 standards had already been considered, their efforts were called IEEE 1394. Initially the development was largely undertaken by Apple Computer, who called it FireWire, in an attempt to provide an inexpensive replacement for the SCSI bus.

In September 1994, the 1394 Trade Association was formed to promote and develop the interface. This effort resulted in the development of what became the IEEE 1394-1995 standard in Fall 1995. The 1394 Trade Association has members from both the computer and consumer electronics industries, and is still actively developing the 1394 interface.

The IEEE 1394 High Performance Serial Bus standard, informally referred to as 1394, provides the same services as existing IEEE-standard parallel buses at a potentially lower cost. Rather than transferring data via a parallel interface, such as EIDE and SCSI with expensive cables and connectors with as many as 68 pins, 1394 requires only four signal conductors in a low cost interconnecting cable. 1394 also requires considerably fewer I/O pins on host and peripheral silicon.

Key Features
Among the features contributing to the IEEE 1394's ease of use is its *hot plug-in* capability. Equipment can be connected and disconnected without having to turn the power off. External peripherals may be hot-plugged. In contrast, conventional computer ports—those for hard drive, keyboard, mouse, monitor, etc.—are not designed for hot plug-in, and can fail or damage the port if connected while the power is on. The ultimate objective is to make attaching a 1394 device as easy as plugging a cord into an electrical outlet. In addition, unlike conventional buses, IEEE 1394 needs no special terminators along the bus and no special settings to assign device addresses. Figure 1 illustrates some of the interface configuration capabilities.

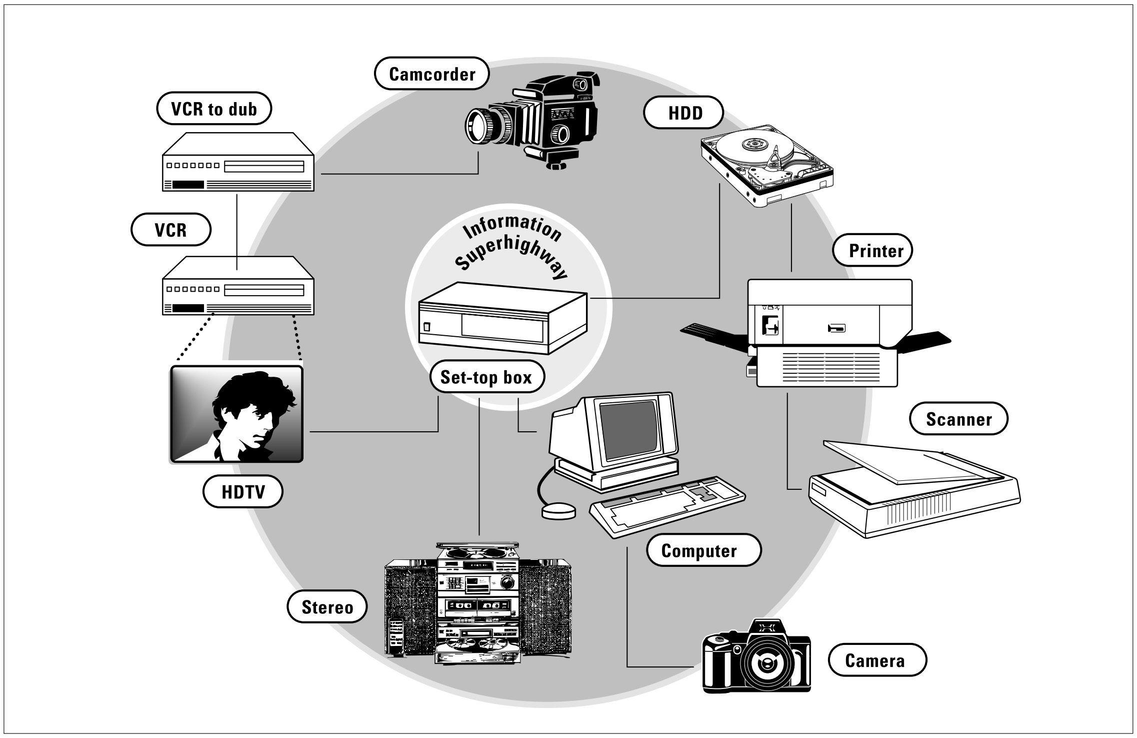

Figure 1: Interface Configuration Examples

Scalability is another key IEEE 1394 feature. Devices having different data rates allowed by the bus standard—namely, 100, 200 and 400 Mbps, as well as higher rates as they appear—can all share the bus at the same time. For continuous data streams that must be delivered on time, as with video and audio, the IEEE 1394 sets up isochronous channels, i.e., channels with a calculable, bounded, worst-case delay. Assigning data to an isochronous channel guarantees its timely delivery and reduces the need for costly buffer memories.

Another feature of the bus standard is *flexibility*. For example, it accommodates networks of devices that can be daisy chained, i.e., connected one to another in series, or that can branch off on their own in star or tree configurations. Because it is a peer-to-peer memory bus, the 1394 serial bus interface is easy to program and allows devices to communicate without tying up computing resources.

A summary of 1394 features includes:

- ***Fast data transfer rates*****:** 100, 200, or 400 Mbps
- ***Digital interface*****:** No need to convert digital data into analog and tolerate a loss of data integrity
- ***Physically small*****:** The thin serial cable can replace larger, more expensive interfaces
- ***Easy to use*****:** No need for terminators, device IDs or elaborate setup
- ***Hot pluggable:*** Users can add or remove 1394 devices with the bus active, using rugged connectors and cables
- ***Scaleable architecture:*** Able to mix 100, 200, and 400 Mbps devices on a bus
- ***Self configuring:*** No need for address switches
- ***Flexible topology:*** Up to 63 devices on up to 1023 buses with a maximum of 16 hops of up to 4.5 meters between each device
- ***Bus management:*** Is efficient for both large and small configurations
- ***Both asynchronous and isochronous data transfer:*** Guaranteed bandwidth with low overhead for isochronous data transfer
- ***Three layer architecture:*** Consistent with IEEE 1212 Control and Status Register Architecture Specification ensuring future architectural compatibility
- ***A fair arbitration system:*** Allows all nodes appropriate access to the bus
- ***Peer-to-peer communication:*** Supports daisy chaining and branching
- ***Reduced buffer costs*****:** Guaranteed delivery of time-critical data reduces costly buffer requirements
- ***Non-proprietary:*** Licensing is not required
- The 1394a extension to the standard improves the efficiency of the data transfer and arbitration mechanisms while remaining backwards compatible to the original standard
- The 1394b extension of the standard now being developed will extend the signaling rate of the original standard allowing 800 Mbps, 1600 Mbps and higher

Data Transfer

The two types of 1394 data transfer are *asynchronous* and *isochronous*. Asynchronous transport is the traditional computer memory-mapped, load and store interface. Data requests are sent to a specific address and an acknowledgment is returned. Isochronous data channels provide guaranteed data transport at a pre-determined rate. This is especially important for time-critical multimedia data where just-in-time delivery eliminates the need for costly buffering. Combined, these capabilities support all the necessary data flow required to optimize the use of peripheral devices such as video cameras, CD-ROM drives, printers, storage devices, camcorders, VCRs, etc.

Cables and Connectors

The 1394 interface uses thin, flexible, durable cables and simple connectors to allow up to 63 devices to share a single bus in a daisy chain or tree configuration. Up to 1023 buses can be connected, bringing the total number of devices to over 64,000. They can carry multiple channels of isochronous and asynchronous data simultaneously.

Connectors are derived from the Nintendo GameBoy™ design and use either a friction detent (standard) or the special side-locking tab restraints shown in Figure 2. This type of connector has been field tested by children, and is very durable and easy to use. There are no terminators required or manual IDs to be set. 1394 connectors are available from Molex and several other firms.

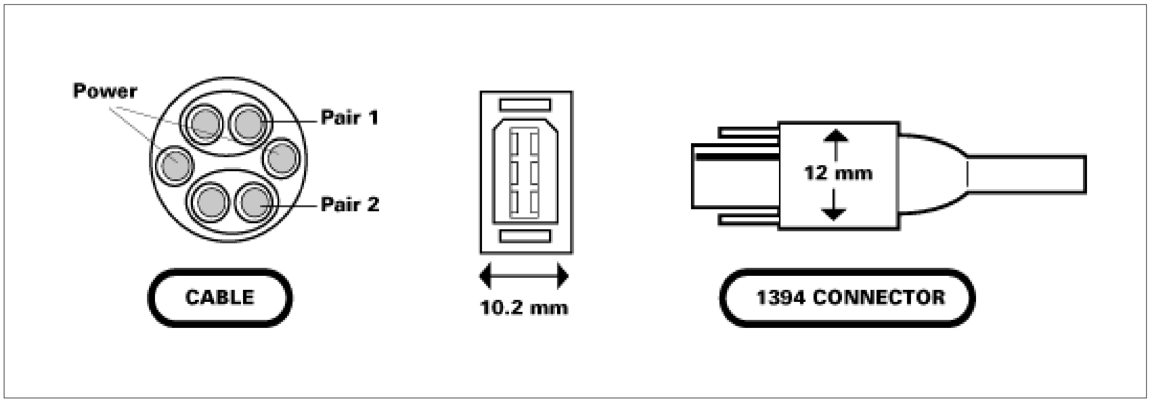

Figure 2. 1394 Cables and Connectors

1394 Layered Structure

The 1394 architecture is consistent with IEEE 1212 Control and Status Register Architecture Specification, which defines bus functions, address space and registers. The architecture consists of three layers—physical, link and transaction—that correspond to the lowest three layers of ISO's Open Systems Interconnection (OSI) model. The physical layer connects to the 1394 connector and the other two layers connect to the application. To implement a specific device, additional protocol and application layers must be placed on top of these layers to provide the unique functionality of particular devices that use 1394 as an interconnect medium.

The three stacked layers shown in Figure 3 implement the 1394 protocol. They perform the following functions:

- ***The physical layer (PHY)*** provides the electrical and mechanical connections between the 1394 device and the 1394 cable. In addition to actual data transmission and reception, the physical layer provides arbitration to ensure that all devices have appropriate access to the bus.
- ***The link layer (Link)*** provides data packet delivery service for both asynchronous and isochronous packets to nodes. Isochronous data packets are formatted and transferred directly to the application.

- ***The transaction layer*** supports the asynchronous protocol write, read and lock commands. A write sends data from the originator to the receiver, and a read returns the data to the originator. Lock combines the function of the write and read commands by producing a round-trip routing of data between sender and receiver, including processing by the receiver.

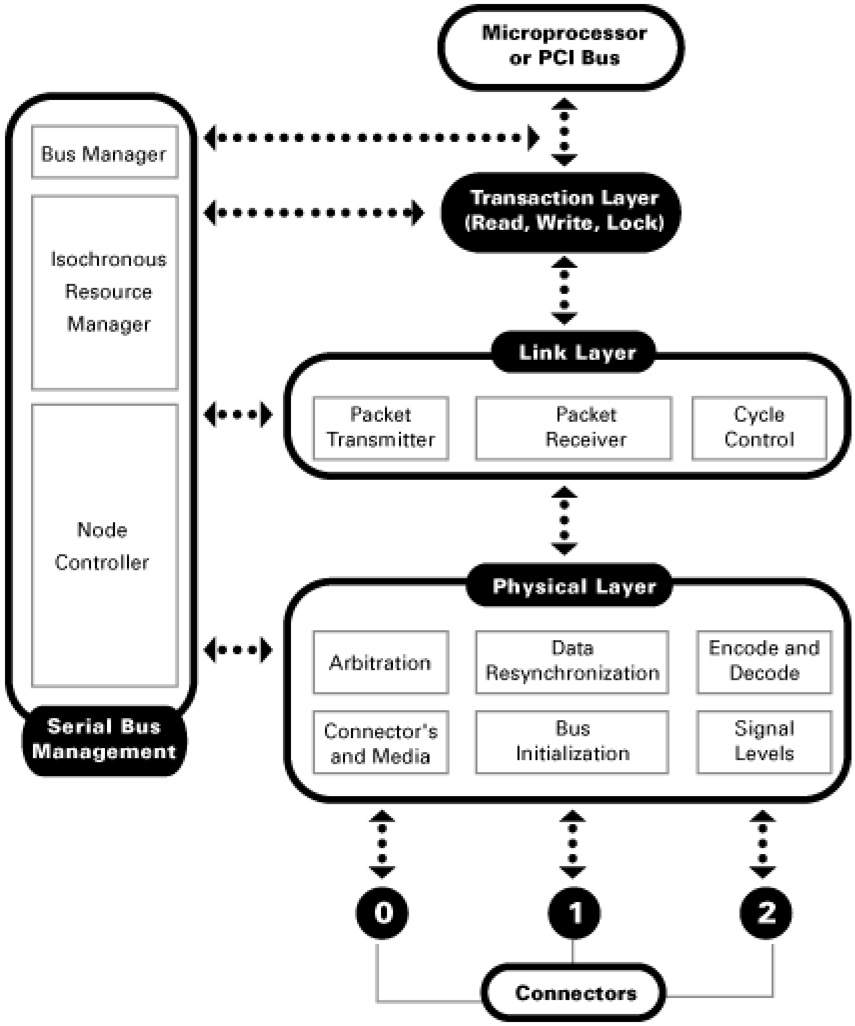

Figure 3. 1394 Layers

The 1394 standard defines both a backplane physical layer and a point-to-point cable-connected virtual bus implementation. Both are compatible at the link layer and above.

Hard Drive Specifications

Most hard drive-specific work has been invested in the development of the additional protocol and application layers required to support mass storage functions. The IEEE sanctioned working group responsible for 1394 support for mass storage devices developed three specifications that enable mass storage to use the 1394 serial bus:

- ***The Serial Bus Protocol-2 (SBP-2) specification*** defines the protocol for command and data transfer of mass storage devices using the 1394 bus. It describes the basic transport protocol for mass storage devices, and specifies the data structures and operations above the transaction layer that provide efficient mechanisms for this class of devices. Western Digital was a key contributor to this standard.
- ***The Reduced Block Command (RBC) specification*** defines the actual commands that hard drives must support. Hard drives use a subset of this specification, which includes commands for removable storage and other forms of storage such as optical disks.
- ***The 1394 to EIDE Bridge Controller (Tailgate) specification*** defines the requirements for a low-cost bridge device that allows existing legacy EIDE/ATAPI devices to be connected to the 1394 bus using EIDE protocol.

1394 Bus Management and Operation

The 1394 serial bus management provides overall configuration control of the serial bus by optimizing arbitration timing, guaranteeing adequate electrical power for all devices on the bus, assigning which 1394 device is to be the cycle master, assigning isochronous channel IDs, and providing basic notification of errors. This bus management process connects to all three layers in the 1394 layer structure.

To transmit asynchronous data, a 1394 device requests control of the physical layer. The addresses of both sender and receiver are transmitted, followed by the packet data. After the receiver accepts the packet, a packet acknowledgment is returned to the original sender. To improve throughput, the sender may continue transmission until 64 transactions are outstanding. If a negative acknowledgment is returned, error recovery is initiated.

For isochronous transport, the sender requests an isochronous channel with a specific bandwidth. Isochronous channel IDs are transmitted, followed by the packet data. The receiver monitors the incoming data's channel ID and accepts only data with the specified ID. User applications determine how many isochronous channels are needed and their required bandwidths. Up to 64 isochronous channels may be defined.

Consumer Products that Support 1394

The adoption of 1394 for the digital video and audio consumer markets ensures popularity for the interface in multiple high volume markets. The capabilities of the 1394 bus are sufficient to support a variety of high-end digital audio/video applications.

The categories listed below are a sample of the consumer products currently supporting the 1394 interface:

- Digital camcorders and digital VCRs
- Digital video-conferencing systems
- Direct-to-home (DTH) satellite video and audio MPEG-2 data streams
- Musical synthesizers with MIDI and digital audio capabilities, initially from Yamaha
- Printers for video and computer data
- Fixed and removable PC disk drives, internal and external
- PC-to-PC networking (the 1394 "home PC network") and PC peripheral component sharing
- Cable TV and MMDS ("wireless cable") set-top boxes
- Digital video disk (DVD) drives

Looking to the Future

There is currently an effort underway in IEEE working groups to extend the capabilities of the original 1394-1995 standard. The effort, known as 1394b, will extend the standard by improving the signaling protocol to allow for more efficient transfer of data. The second, known as 1394b, will extend the standard further by permitting operating speeds of 800 Mbps and beyond. These rates will exceed the transfer rates of the EIDE and SCSI parallel interfaces.

Because the pending 1394b standard provides data transfer rates higher than existing low cost interfaces, it is currently in the running to become the successor to EIDE for storage peripherals. As such, 1394 is receiving strong backing from technology leaders such as Microsoft, Intel, and Apple. Storage companies such as Western Digital, Seagate, Quantum, Maxtor and others have invested time and resources towards creating the necessary standards to enable attachment of storage peripherals via the 1394 interface. The hard drive companies have taken a leadership role in these efforts since the interface could become the standard for hard drive attachment in the PC industry.

The move from analog to digital functionality in consumer electronics will spur the move to IEEE 1394 in the near future. Confirming the industry consensus, 1999 has been the year that 1394 became established in consumer applications. Based on the initial success of the Sony camcorders, other audio/visual products have been introduced. These introductions include: DVD for television using the MPEG-2 format, DVD as a CD-ROM, desktop cameras and color printers.

Ultimately ATM (Asynchronous Transfer Mode) and IEEE 1394 will drive each other's markets. ATM will become the worldwide voice/video/data public switched networks. However, ATM is too expensive for devices such as hard disk drives, cameras and desktop computers. Therefore IEEE 1394 is a complementary device interface for ATM.

Built on a base of inexpensive implementations, IEEE 1394 will become a high volume consumer electronics interface. Consumer electronics interfaces tend to be long lived—plain old telephone service (POTS) is over 100 years old, and audio/video coaxial interfaces date from World War II. Therefore, with ability to span media and maintain software compatibility, IEEE 1394 should enjoy a very long life. If ATM, the next telephone system, lasts at least 100 years, then IEEE 1394 could be there as well.
Such a high volume interface will enable many new applications. Not only will audio/visual data be available for computers to manipulate, but a user-friendly command-and-control interface will span home, vehicle, office and factory products. Existing barriers will gradually be shattered by the expected growth of IEEE 1394.