Fire on the Wire: The IEEE 1934 High Performance Serial Bus

The IEEE 1394-1995 standard for the High Performance Serial Bus, here abbreviated to 1394, defines a serial data transfer protocol and interconnection system that "provides the same services as modern IEEE-standard parallel busses, but at a much lower cost." 1394 incorporates quite advanced technology, but it's the "much lower cost" feature that assures 1394's adoption for the digital video and audio consumer markets of 1997 and beyond. The capabilities of the 1394 bus are sufficient to support a variety of high-end digital audio/video applications, such as consumer audio/video device control and signal routing, home networking, nonlinear DV editing, and 32-channel (or more) digital audio mixing. Sony's DCR-VX700 and DCR-VX1000 digital video (DV, formerly called DVC) camcorders, introduced in September 1995, were the first commercial products to implement 1394. Subsequently Sony introduced in late 1996 its DCR-PC7 micro-DV camcorder and Matsushita announced in early 1997 Japanese availability of the Panasonic NV-DE3 DV camcorder with a 1394 connector. As of fall 1998, there were about 30 consumer DV camcorder models from which to choose, ranging in street price from less than US$1,000 to about US$4,000, almost all of which have 1394 connectivity.

This objective of this paper is to describe the architecture of 1394 bus systems, typical consumer video and audio applications for 1394, initial implementations of 1394 connectivity on PCI adapter cards, and the commercial adapter card designs that currently are available for digital video editing applications. A brief comparison of the IEEE 1394 High Performance Serial Bus with the proposed Universal Serial Bus (USB) appears at the end of this paper. The orientation of this paper is toward consumer- and professional-grade DV products, because DV is the first application (and is likely to be the highest-volume application through 1999) for the High Performance Serial Bus.

> ***Note: You can obtain the final version of the IEEE 1394-1995 standard from the Institute of Electrical and Electronic Engineers, Inc., Customer Service, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, voice (800)678-IEEE or (908)981-0060, fax (908)981-9667, e-mail customer.service@ieee.org The USB 1.0 specification is available from the USB WebBoard. The Open Host Controller Interface (Open HCI) 1.0 specification, which applies to 1394 and USB hosts, is available from http://www.microsoft.com/hwdev/specs/busspecs.htm. A wide variety of information on 1394-related products and activities is available from The 1394 Trade Association, Adaptec Corp.'s site, and on Texas Instrument's IEEE 1934 Web pages.*** **FireWire System Architecture: IEEE 1934** ***by Don Anderson, the latest of Mindshare's PC System Architecture series (ISBN 0201694700), is a comprehensive overview of the IEEE 1394-1995 specification, updated for the 1394a amendments.***

The IEEE's Microcomputer Standards Committee commenced in 1986 a unification process for various serial bus implementations of the VME, Multibus II, and Future Bus standards. This effort resulted in the original development of what became the IEEE 1394-1995 standard in Fall 1995. 1394 is based on Apple Computer's original FireWire bus, which was intended as a low-cost replacement for or supplement to the SCSI bus that is a standard feature of Macintosh and PowerMac computers. Apple and SGS Thomson, which has an UK patent applicable to 1394, license their patents "on reasonable and non-discriminatory terms to anyone wishing to obtain a license." These licenses apply only to the point of first implementation, which means integrated circuits to implement 1394 connectivity, and thus are of no concern to most adapter card manufacturers or end users. Today's licensees primarily are 1394 chip manufacturers, such as Texas Instruments, Adaptec and Symbios Logic, plus consumer electronics firms like Sony that incorporate some of the 1394 technology within their own specialized processor chips. Apple also licenses use of its FireWire trademark to manufacturers; Adaptec Corp., as an example, has licensed use of the FireWire trademark and other 1394-related Apple technology for its AHA8940 and AHA8945 1394/FireWire PCI host adapter cards.

1394 Architecture

The 1394 standard defines two bus categories: backplane and cable. The backplane bus is designed to supplement parallel bus structures by providing an alternate serial communication path between devices plugged into the backplane. The cable bus, which is the subject of this paper, is a "non-cyclic network with finite branches," consisting of bus bridges and nodes (cable devices). *Non-cyclic* means that you can't plug devices together so as to create loops. 16-bit addressing provide for up to 64K nodes in a system. Up to 16 cable hops are allowed between nodes, thus the term *finite branches*. A bus bridge serves to connect busses of similar or different types; a 1394-to-PCI interface within a PC constitutes a bus bridge, which ordinarily serves as the root device and provides bus master (controller) capability. A bus bridge also would be used to interconnect a 1394 cable and a 1394 backplane bus. Six-bit Node_IDs allow up to 63 nodes to be connected to a single bus bridge; 10 bit Bus_IDs accommodate up to 1,023 bridges in a system. This means, as an example, that the limit is 63 devices connected to a conventional 1394 adapter card in a PC.

Each node usually has three connectors, although the standard provides for 1 to 27 connector per a device's physical layer or PHY. Up to 16 nodes can be daisy-chained through the connectors with standard cables up to 4.5 m in length for a total standard cable length of 72 m. (Using higher-quality "fatter" cables permits longer interconnections.) Additional devices can be connected in a leaf-node configuration, as shown in figure 1. All 1394 consumer electronic devices announced as of early 1997 have only a single connector; there are no currently are digital camcorders or VCRs that correspond to the devices with ID 3 or ID 5 shown in figure 1. Physical addresses are assigned on bridge power up (bus reset) and whenever a node is added or removed from the system, either by physical connection/disconnection or power up/down. No device ID switches are required and hot plugging of nodes is supported. Thus 1394 truly qualifies as a plug-and-play bus.

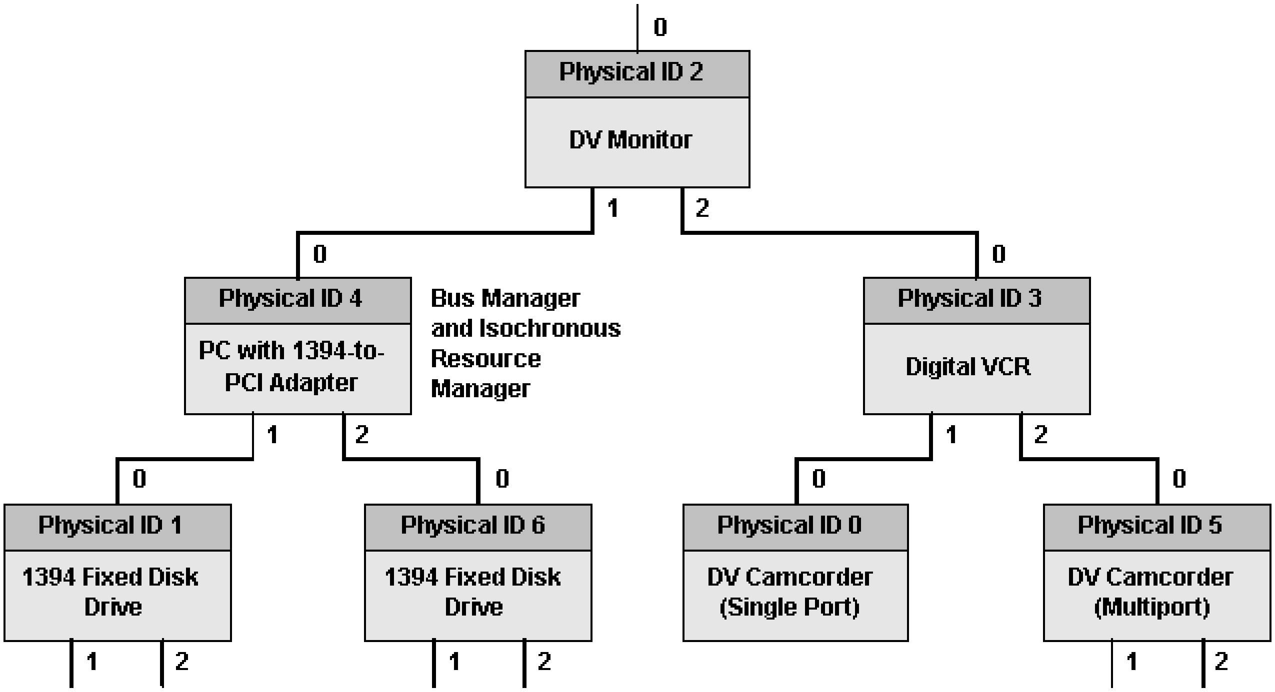

Fig. 1. Topology of a typical PC-based 1394 bus system for DV applications.

> ***Note: The topology shown in figure 1 assumes a common audio/video data format for all DV devices. For transmission on a single isochronous channel, devices must share the same data format. The Digital VCR Consortium (DVC) has prepared a standard for DV data formats and related control protocols for 1394, presently titled "General Specification for Consumer-Use Digital Interface." This standard is pending approval as International Electrotechnical Commission IEC1883, "Digital Interface for Consumer Electronics A/V."***

The 1394 cable standard defines three signaling rates: 98.304, 196.608, and 393.216 Mbps (megabits per second; MBps in this paper refers to megabytes per second.) These rates are rounded to 100, 200, and 400 Mbps, respectively, in this paper and are referred to in the 1394 standard as S100, S200 and S400. Consumer DV gear uses S100 speeds, but most 1394 PC adapter cards support the S200 rate. The signaling rate for the entire bus ordinarily is governed by the slowest active node; however, if a bus master (controller) implements a Topology_Map and a Speed_Map for specific node pairs, the bus can support multiple signaling speeds between individual pairs. The 1394 Trade Association's 1394.1 working group presently are refining and clarifying the setup requirements for handling interconnected devices with multiple signaling speeds.

Physical, Link, and Transaction Layers

The 1394 protocol is implemented by the three stacked layers shown in figure 2. The three layers perform the following functions:

- **The transaction layer implements the request-response protocol required to conform to the ISO/IEC 13213:1994 [ANSI/IEEE Std 1212, 1994 Edition] standard Control and Status Register (CSR) Architecture for Microcomputer Buses (read, write and lock). Conformance to ISO/IEC 13213:1994 minimizes the amount of circuitry required by 1394 ICs to**

interconnect with standard parallel buses.

- **The link layer supplies an acknowledged datagram to the transaction layer. (A *datagram* is a one-way data transfer with request confirmation.) The link layer handles all packet transmission and reception responsibilities, plus the provision of cycle control for isochronous channels.**

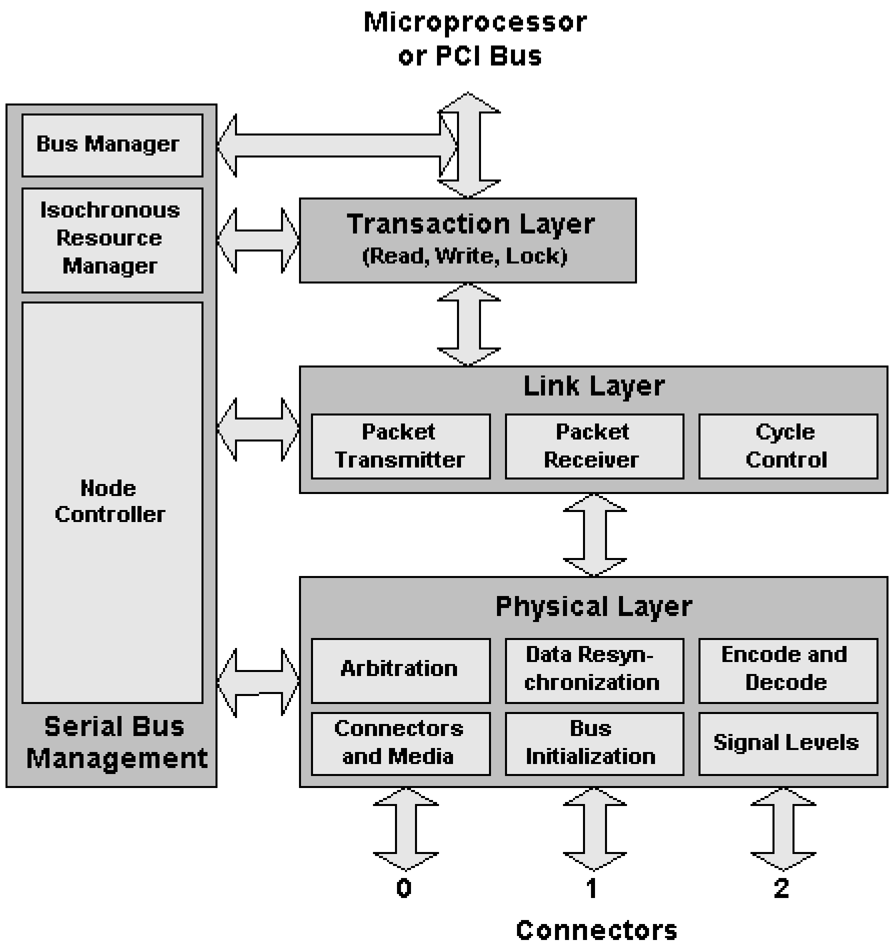

Fig. 2. The 1394 Protocol Stack and Serial Bus Management Controller.

- **The physical layer provides the initialization and arbitration services necessary to assure that only one node at a time is sending data and to translate the serial bus data stream and signal levels to those required by the link layer. Galvanic isolation may be implemented between the physical layer and the link layer using optical isolators; with isolation, the chip implementing the physical layer is powered by the bus conductors. Isolation should be provided where three-wire power cords are used to prevent ground loops through the green-wire ground; consumer devices, which use two-wire power cords or wall-wart power supplies, ordinarily don't require galvanic isolation.**

Note: The physical (PHY) layer is the bottleneck in 1394 systems. Historically, commercial PHY chips operated at half the potential data rate of link layer (LINK) chips (100 Mbps vs. 200 Mbps, later 200 Mbps vs. 400 Mbps.) Texas Instruments announced in fall 1998 a set of 400-Mbps PHY chips which conform to the updated 1394a tentative specification and support the Open Host Controller Interface (OHCI) in conjunction with an OHCI-compliant LINK chip.

Cables and Connectors

Standard bus interconnections are made with a 6-conductor cable containing two separately-shielded twisted pair transmission lines for signaling, two power conductors, and an overall shield (see figure 3). The two twisted pairs are crossed in each cable assembly to create a transmit-receive connection. The power conductors (8 to 40 v, 1.5 a max.) supply power to the physical layer in isolated devices. Transformer or capacitative coupling is used to provide galvanic isolation; transformer coupling provides 500 volts and lower-cost capacitative coupling offers 60 volts of ground potential difference isolation. Connectors are derived from the GameBoy design and use either a friction detent (standard) or the special side-locking tab restraints shown in figure 3.* (You squeeze the sides of the connectors for removal.) 1394 connectors are available from Molex and several other firms.

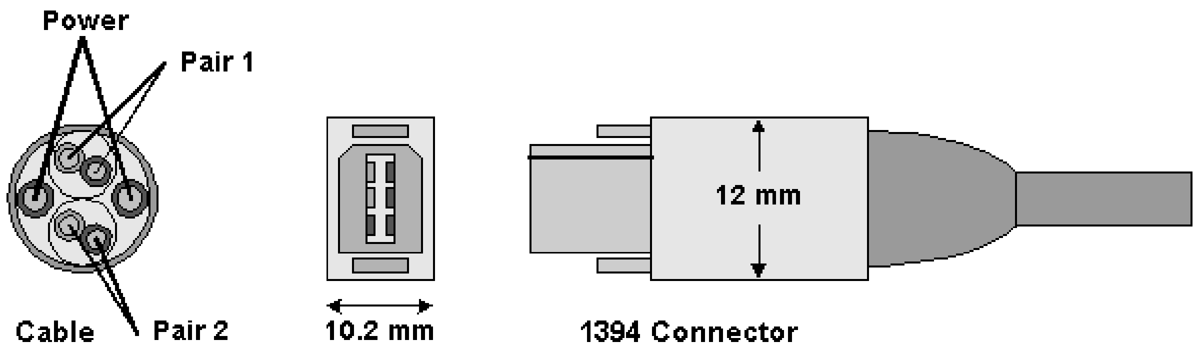

Fig. 3. 1394 cables and connectors.

> ***The Sony DCR-VX700 and DCR-VX1000 camcorders and the DHR-1000 DVCR have only a single, non-standard 1394 connector to support DV input/output (output only in European versions). The four-conductor Sony connector, which is smaller than the standard 1394 connector and has only the signaling pairs (no power conductors), is defined in Part 1 of the draft of the proposed IEC standard and a forthcoming IEEE draft standard P1394.1. The Sony VMC-20V DV cable can interconnect two camcorders, but cannot connect to standard 1394 sockets without an adapter cable. These Sony camcorders act as terminating nodes and require a yet-undefined adapter for insertion as a leaf in a standard 1394 chain. DVCRs and other non-miniaturized consumer devices also use P1394.1 connectors.***

1394 Bus Management

1394 provides a flexible bus management system that provides connectivity between a wide range of devices, which need not include a PC or other bus controller. Bus management involves the following three services:

- **A cycle master that broadcasts cycle start packets (required for isochronous operation)**
- **An isochronous resource manager, if any nodes support isochronous communication (required for DV and DA applications)**
- **An optional bus master (usually a PC adapter, but an editing DVCR might act as a bus master)**

On bus reset, the structure of the bus is determined, node IDs (physical addresses) are assigned to

each node, and arbitration for cycle master, isochronous resource manager, and bus master nodes occurs. Figure 4 illustrates on a timeline the identification and arbitration processes that occur on bus reset. Note that during the 1-second delay isochronous resources that had been allocated before the reset are to be reallocated. Any resources that are not reclaimed will become available for future use. After that delay new resources may be allocated.

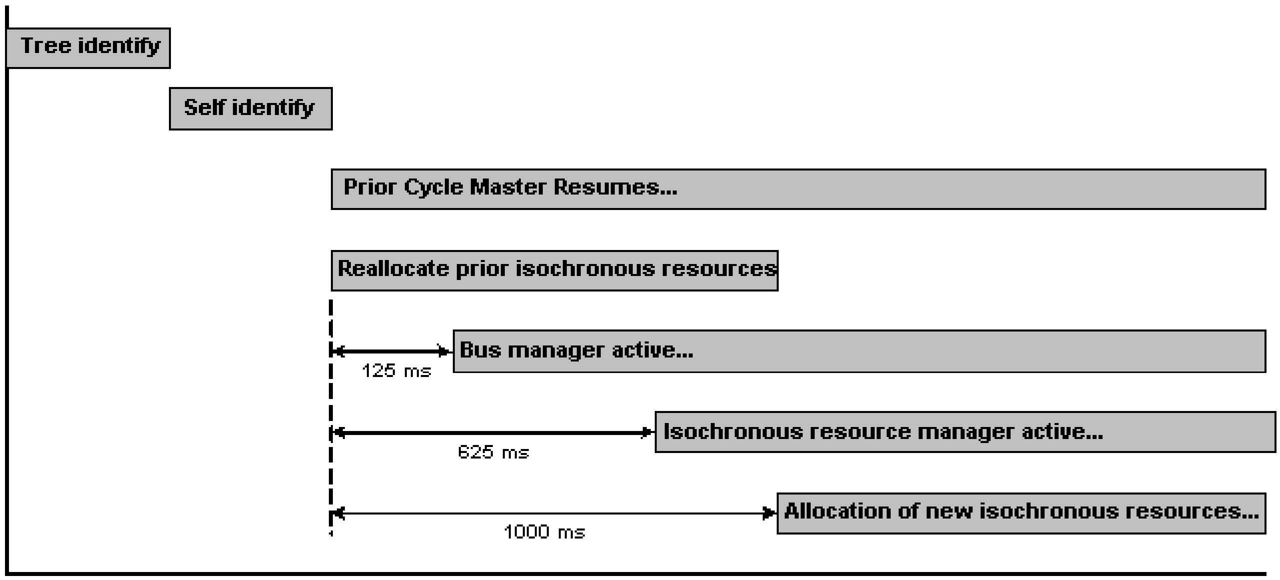

Fig. 4. Bus reset timeline.

Isochronous Data Transport

The isochronous data transport of the 1394 bus provides the guaranteed bandwidth and latency required for high-speed data transfer over multiple channels. The isochronous resource manager includes a BANDWIDTH_AVAILABLE register that specifies the remaining bandwidth available to all nodes with isochronous capability. On bus reset or when an isochronous node is added to the bus, the node requests a bandwidth allocation. As an example, a DV device would request approximately 30 Mbps of bandwidth, representing the 25+ Mbps DV data rate plus 3-4 Mbps for digital audio, time code, and packet overhead. Bandwidth is measured in bandwidth allocation units, 6,144 in a 125 m s cycle. (A unit is about 20 ns, the time required to send one data quadlet at 1,600 Mbps, called the S1600 data rate; the S1600 data rate is unlikely be supported in future implementations. A *quadlet* is a 32-bit word; all bus data is transmitted in quadlets.) 25 m s of the cycle is reserved for asynchronous traffic on the bus, so the default value of the BANDWIDTH_AVAILABLE register on bus reset is 4915 units. In a 100-Mbps system, a DV device would request about 1,800 units; in a 200-Mbps system, about 900 units would be sufficient. If adequate bandwidth is not available, the requesting device is expected to repeat its request periodically.

The isochronous resource manager assigns a channel number (0 to 63) to nodes that request isochronous bandwidth based on values in the manager's CHANNELS_AVAILABLE register. All isochronous packets are identified by the assigned channel number. When a node no longer requires isochronous resources, it is expected to release its bandwidth and channel number. As an example, the bus manager sends signals to cause a camcorder to commence talking on its channel and a record deck to commence listening on its channel for video data from the bus manager application. Device control is managed by asynchronous communication. Video acquisition for

non-linear digital editing is simpler than the camcorder-DVCR example, because it requires only a single isochronous channel, plus an asynchronous path for device control. Timecode is built into the DV data, but asynchronous timecode transmission over the bus is useful when in camcorder or DVCR shuttle mode.

Consumer Electronics Applications for 1394

The majority of the informative illustrations in the 1394 standard show interconnections between consumer video devices, with and without attached PCs. Based on the draft standard, 1394 Trade Association documents, and conversations with members of the Association, following are the primary consumer electronics applications anticipated for the High Performance Serial Bus. The products are listed in the author's forecast order of their introduction to the retail market.

- **Digital camcorders and DVCRs (Sony DCR-VX700, DCR-VX1000, and DCR-PC7 camcorders, Sony DHR-1000 DVCR, Sony DSR-30 DVCAM DVTR, and new Panasonic DV camcorders)**
- **Direct-to-home (DTH) satellite video and audio MPEG-2 data streams***
- **Musical synthesizers with MIDI and digital audio capabilities, initially from Yamaha using the Music LAN (mLAN) architecture**
- **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**
- **Digital Cable TV and MMDS ("wireless cable") set-top boxes****
- **DVD video and audio drives**

****Thomson/RCA receivers for DirecTV and USSB DSS satellite programming presently have an unused high-speed parallel data port intended to transmit MPEG-encoded video and audio to a digital tape recorder for time-shift recording. A Thomson/Hitachi digital VCR using JVC's D-VHS 1/2-inch bitstream recording format was announced in 1994 for availability in early 1996, together with an upgraded version of the Thomson/RCA DBS receiver. Despite the press releases, this combination didn't arrive. At the 1997 Winter Consumer Electronics show, Hitachi exhibited a prototype of its DX815 D-VHS recorder, which uses a non-standard implementation of 1394 to connect the recorder to a Hitachi DSS set-top box. Thomson did not display a D-VHS deck, but is expected to announce a similar product later in 1997. The R-4.1 ATV Receiver Interface Subcommittee of the Consumer Electronics Manufacturers Association (CEMA, formerly the Consumer Electronics Group) of the Electronic Industries Association is supporting a proposal to the IEC TC84 committee for a transport layer over fully-compliant 1394 to handle MPEG-2 and other digital data streams associated with Digital (Standard- and High-Definition) TV.***

*****CableLabs, a cable-TV industry technical group, has established IEEE 1934 as the OpenCable interconnect between digital cable set-top boxes for HDTV and DTV receivers. On May 4, 1998, Scientific Atlanta and Mitsubishi Electric demonstrated a 1394-compliant version of the Explorer 2000 set-top box at the National Cable Television Association (NCTA) Cable '98 show in Atlanta. According to a story by Junko Yoshida and George Leopold in the September 1, 1998 edition of*** **EE Times** ***magazine, "Cable Not Ready For Digital TV," the first-generation DTV sets won't be able to receive HDTV (or even plain DTV) broadcasts via cable. Bill Wall, Scientific-Atlanta's chief scientist, says***

the problem is due to lack of IEEE 1394 interfaces in 1999 DTV sets. Another problem is the lack of spare channel capacity (bandwidth) on the cable-TV infrastructure.

A principal advantage of the use of 1394 to interconnect DV and digital audio (DA) gear is that the 1394 bus is operable without a bus manager, and any "talker" device can arbitrate for assignment as the isochronous resource manager. Thus a DV camcorder, simple DVCR, printer, and DTV set can be connected without the need for a PC or other device to act as a bus manager. Assuming the camcorder is the "talker" and all other devices are "listeners," only a single, fixed isochronous channel is required. The camcorder starts talking in response to a local or remote control device, and the other DV devices listen or not, depending on their control status. One also could create a low-end equivalent of the $60,000+ Avid/Ikegami fixed-disk camcorder (CamCutter) with a battery-powered 1394 fixed or removable disk drive in a belt-pack, assuming the disk drive has enough built-in "smarts" to handle disk I/O chores and generate unique file names for successively-recorded bitstreams. Such a device would eliminate the need to copy video and audio data from tape to disk in the editing studio, the original objective of the CamCutter. High-capacity fixed disk drives are required; DV content at 3.5 MBps fills 1G in less than 5 minutes.

> ***Note: Part 1 of the "General Specifications for Consumer-Use Digital Interface" (Specifications) defines packet formats, data flow management, and connection management for DV and DA data over the 1394 bus, plus "general transmission rules" for control commands, which are "vendor-unique." The Specifications define the concept of a logical input or output plug that corresponds to a single physical connector (or set of audio and video connectors) on a camcorder, VCR or related device. Input and output plug control registers determine the properties of plugs. As an example, a DV camcorder could have two logical output plugs, one for camera out and one for tape out, plus a logical input plug for DV dubbing, but only one physical connector. The Specifications also define a broadcast mode, over which an output plug continuously transmits "in the blind" on one channel, rather than to a particular input plug. Part 2 of the Specifications defines the SD-DVCR data stream for 525/60 and 625/50 systems, and Part 3 covers HD-DVCR streams for 1125/60 and 1250/50 high-definition formats. The DV recording format is defined by "Proposal for Digital Interface for Consumer Electronic Audio/Video Equipment," authored by Philips, Matsushita, Thomson Multimedia, and Sony (sometimes called the "Big Four" of the DV standard), and presented at the 1394 Trade Association meeting in October 1995. Implementation of the consumer electronics device control protocol is the subject of "Specifications of AV/C Command and Transaction Set for Digital Interface," by Sony Corp. and Matsushita Electric Industry Co., Ltd., presented to the January 1996 meeting of the 1394 Trade Association. This specification defines VCR-like commands, such as Play, Record, Rewind, etc.***

Microsoft PC97+ Requirements for 1394 Connector(s)

Microsoft published in late 1996 the *PC 97 Hardware Design Guide*, a set of requirements and specifications that form the basis for PC manufacturers' qualification to apply Microsoft's "Designed for Microsoft Windows" logo to their products on and after July 1, 1997. The *Guide* was based on Microsoft's Simply Interactive PC (SIPC) initiative launched at the April, 1996 Windows Hardware Engineering Conference (WinHEC '96.) PC 97 defined the following three classes of PCs running 32-bit Windows on Pentium processors:

- ***Basic PC*** **for general-purpose desktop or mobile use, including low-end Multimedia PCs**

(MPCs), running Windows 9x.

- ***Workstation PC*** **for networked applications, engineering or scientific applications, media-authoring or software development, running Windows NT Workstation.**
- ***Entertainment PC*** **for "home entertainment centers," running Windows 9x, with enhanced graphics, game, audio, Internet, and consumer-electronic connectivity capabilities. The Entertainment PC requires a DVD-ROM drive and the capability to display MPEG-1 and MPEG-2 video, plus delivery of "advanced audio." Entertainment PCs are expected (but not required) to include a large-screen (27-inch or larger) RGB monitor.**

Each of the above classes requires a USB connector (the Entertainment PC requires two USB connectors), use of 32-bit Windows Driver Model (WDM) device drivers, and automatic power management capabilities (Advanced Configuration and Power Management, ACPM, and OnNow). A single, front-panel 1394 connector is required for the Entertainment PC. (Two 1394 connectors are recommended, with the second on the back panel of the PC.)

The *Guide* stated that the Entertainment PC is optimized for "fast and easy capture, editing, and playback of personal video," and that one of the "key design issues" is "[e]nabling PC connections via USB and IEEE 1394 to consumer electronic devices such as camcorders, VCRs, and home theater stereo systems." These statements imply the ability of the Entertainment PC's fixed-disk drive to sustain the 3.5-MBps (Megabytes per second) data rate of the DV format and to provide sufficient storage capacity to edit "personal video" productions. Version 1.0 of the *Guide* didn't require fixed-disk data rates and capacities that are adequate to handle DV capture and editing. The PC 98 and PC 99 specs require fixed-disk data rates that support DV capture and playback. According to Texas Instrument's James Snider in his "Barriers are Falling for 1394" presentation at the 1394 Trade Association's July 1998 Developers Conference,, the "next service release" for Windows 98 will include support for 1394-compliant consumer electronic gear (presumably DV camcorders and DVTRs) and storage devices (Ultra-DMA EIDE drives with IEEE 1394 adapters and Device Bay.)

> ***Note: Microsoft appears to have abandoned its original 1394 "FlexiBUS" proposal, described in general terms at WinHEC '96 as the consumer electronics Control Bus Abstraction component of SIPC. An early draft of the specification referred to FlexiBUS as "part of a layered architecture that routes user commands from a handheld remote controller or computer application interface to the appropriate consumer electronic device in the user's home environment." The first draft FlexiBUS specification proposed a standard set of Registry entries and a simple Windows user interface with buttons and sliders for activities like "Watch Home Movies."***

The two later version of the Microsoft guidelines, PC98 and PC99, appeared with recommendations (no longer requirements) for IEEE 1934 connectors and recommendations for inclusion of Device Bay compatibility by 1999. Yet there were no products meeting the PC97 or PC98 guidelines for the Entertainment PC as of Fall, 1998, and PC pricing pressures have just about eliminated any chance of Device Bay becoming a reality. Although Intel Corp. had committed to including a 1394 LINK layer in its 440BX core-logic chipset for Pentium II PCs by the end of 1998, on-board 1394 connectivity will be missing from the 440BX, reportedly due to concerns on the part of PC assemblers about the $20 to $30 cost of full IEEE 1934 support.

The 1394 Trade Association's press release for it's Second Annual 1394 Developer's Conference held June 29 - July 1, 1998 in San Jose says about Microsoft's half-hearted support for 1394: "Microsoft's Stork sounded a 'go-slow' theme, citing significant design challenges while reasserting the company's commitment to the standard ('we at Microsoft are making a major bet

on 1394') and calling 2001 the breakout year for significant PC penetration. Another Stork-identified obstacle: the cost added to each system for 1394's inclusion, which has thus far deterred some major OEMs from asking for it. This conclusion strikes the same chord as Intel's Gelsinger noted as one reason the IC leader moved its 1394-enabled chipset plans out a couple quarters. But Intel, in general, adopted the "1394 is Inevitable" theme, and has promised to continue to support the standard completely as it is enhanced and extended. Its lead sponsorship (with TI) of the second Developers' Conference helped the effort to a successful start when the initial plans were beginning in February."

DeviceBay, a specification developed by the Microsoft-Intel-Compaq axis for removable PC peripherals, such as fixed disk, tape backup, and DVD drives, proposes to make "adding a peripheral as easy as inserting a video cassette in a VCR." DeviceBay incorporates both IEEE-1394 and USB connectors to support a wide range of data rates. DeviceBay appears to have fallen victim to "under $1,000 PC syndrome," in which any improvement that costs more than a dollar or two to implement gets "Don't even *think* about it" responses from high-volume PC assemblers. Bob O'Donnell of *InfoWorld* magazine wrote an October 5, 1998 "Plugged In" column, "Whatever happened to 1394 and DeviceBay," that laments the failed promises of Microsoft and Intel to deliver on promised support for IEEE-1394 in their operating systems and chipsets, respectively.

The Home Audio Video Interoperability (HAVi) Specification

Sony, Philips, Hitachi, Sharp, Matsushita, Thomson, Toshiba, and Grundig have joined to create a draft core software specification for Home Audio Video Interoperability (HAVi) for consumer electronic devices having IEEE 1934 connectivity. The 200-page draft version (1.0 Beta), which defines a set of application programming interfaces (APIs), is available in Adobe Acrobat format from the new HAVi web site (requires registration.) The purported requirements of the HAVi specification are:

> **"[A]n open, light-weight, platform-independent and architecturally neutral specification that allows consumer electronics manufacturers [to] develop interoperable devices and independent application developers to write applications for these devices. It can be implemented on different hardware/software platforms and does not include features that are unique to any one platform."**

HAVi is implemented by a "write-once, run-everywhere language called HAVi *bytecode*," which is vaguely reminiscent of claims for the Java language. A HAVi "Full AV Device" (FAV) requires "the presence of a runtime environment for HAVi bytecode." The HAVi authors envision FAV devices to include set-top boxes, DTV receivers, home control devices (presumably modeled on the X-10 specification), and "even Home PCs," which would appear to require a HAVi "virtual machine." The HAVi consortium states: "Public demonstrations [of HAVi] can be expected in 1999 and first products can be expected in late 1999 or early 2000."

According to industry sources, the objective of the HAVi cabal is to prevent Microsoft from controlling the APIs for 1394 and home networking. (Support for a two-computer network using 1394 was included in beta versions of Windows 98.) Instead, the Sony-Philips axis, which brought the world audio CDs, CD-ROMs and recently fractious DVD specifications, wants to control the APIs. Microsoft, however, recently purchased a significant ownership in France's Thomson Multimedia, one of the co-authors of the specification. It remains to be seen whether consumers are better off having Microsoft control the PC side of consumer digital audio/video systems or

trusting a cabal of Japanese, Dutch, French and German consumer-electronic conglomerates to define a set of universal "convergence APIs."

Content Protection for Consumer Electronics 1394 Implementations

One of the primary stumbling blocks to widespread use of 1394 in consumer electronics devices is the recording and motion picture industry's objection to digital interconnects that permit unlimited duplication of perfect copies of digital content on CDs, DVDs, and Audio-DVDs. The Recording Industry Association of America (RIAA) and Motion Picture Association of America (MPAA) have consistently attempted to block any digital interchange method for consumer electronics devices. RIAA hasn't been able to stop CD-ROM drive manufacturers from providing direct digital outputs of Red Book audio data, which has given rise to transcoding recorded music from standard waveform audio format to MP3. Both the MPAA and RIAA have heavyweight Washington lobbyists who promote the organizations' legislative interests against those of the Home Recording Rights Coalition (HRRC) and the Digital Future Coalition (DFC). MPAA is particularly concerned about the ability of consumers to make perfect MPEG-2 copies of feature films from DVDs and, particularly, HDTV broadcasts. MPAA is concerned about off-air duplication because of the adoption of IEEE 1394 by CableLabs as the digital cable box (and presumably DTV tuner) interconnect to high-end HDTV monitors. The result of RIAA and MPAA legislative pressure was congressional passage on October 12, 1998, of the "Digital Millenium Copyright Act," which tightens the screws on digital content duplication, *inter alia*. You can read a complete analysis of the Act by Jonathan Band of Morrison & Foester's Washington office at the HRRC Web site.

In an attempt to satisfy the MPAA and RIAA objections, Hitachi, Intel, Matsushita (Panasonic), Sony, and Toshiba joined forces to create the Digital Transmission Licensing Authority, which has Japan's Ministry of International Trade and Industry (MITI) approval to license the Digital Transmission Content Protection (DTCP) system. DTLA describes DTCP as "... a cryptographic protocol for protecting audio/video entertainment content from illegal copying, intercepting and tampering as it traverses high performance digital buses, such as the IEEE 1394 standard. Only legitimate entertainment content delivered to a source device via another approved copy protection system (such as the DVD Content Scrambling System) will be protected by this copy protection system." You can read the "5C Digital Transmission Content Protection White Paper," which describes the basic features of DTCP for IEEE-1394 at the 5C coalition's DTLA Web site.

General-Purpose 1394-to-PCI Bus Implementations

When this paper was updated in January 1997, there were no PCs available with 1394 built-in connectivity; announcements of PC systems with on-board 1394 connector(s) were expected at 1997 Spring Comdex, with deliveries to begin in 1997Q3 to meet Microsoft's Entertainment PC deadline for application of the "Designed for Microsoft Windows" logo. The 1394 requirement of the PC 97 specification can be met by implementing the bus on the motherboard or with a 1394-to-PCI hose adapter (bus bridge) card. Microsoft intended to include support for basic 1394 device classes.

In early 1998, Apple Computer was the only firm to offer an IEEE 1934 adapter as a $300 "standard option," but only on its high-end G3 Macintoshes. Compaq later announced its Presario 5600 series Pentium II PCs with a single IEEE-1394 connector to support its "Digital Creativity Imaging Center." List prices start at US$1,699 for the 350-MHz Presario 5610 with an 8-GB UltraDMA33 IDE drive and escalate to US$2,499 (US$2,150 lowest street) for the Presario

5660 with a 450-MHz processor and 12-GB drive, sans monitor. Sony's VAIO 505GX "SuperSlim" was the first notebook computer to offer a built-in i.LINK (IEEE-1394) port for "Digital Video capture." Sony announced in early October 1998 the VAIO PCV-E302DS (US$1,499) and PCV-E308DS (US$2,299, both less monitor) mini-tower PCs with Sony DVgate DV editing software. (Sony implements i.LINK with a PCI adapter, probably from Adaptec.) As of October 1998, Compaq and Sony were the only name-brand Wintel-based PC suppliers offering IEEE-1394 as a standard, built-in feature.

Two U.S. firms offer general-purpose 1394-to-PCI adapters:

- ***Texas Instruments* offers a series of 1394 Evaluation Modules with TI 200-Mbps PHY layer, 400-Mbps PCILynx chips, and Windows 95 drivers. TI's Evaluation Modules are intended for designers of adapter cards and PC motherboards using TI PHY and LINK layer chips, not as commercial products. TI supplies the single-connector PHY chip used in Sony's camcorders and a single-chip PHY, LINK, and DV packetizer for the Panasonic NV-DE3. TI is the major commercial force behind the promotion of 1394.**
- ***Adaptec Corp.* announced its AHA-8940 PCI-to-1394 Host Adapter card and 1394 FireWire Developer's Kit for Windows NT in August 1996 and for Windows 95 (the OSR 2.1 version supporting WDM) in January 1997. The AHA-8940 has one internal and two external 1394 connectors; the internal connector provides for cabling to the front-panel connector required by the Entertainment PC specification. An IBM PHY chip provides a 200-Mbps maximum signaling rate; Adaptec's own LINK layer controller chip can run at 400 Mbps when higher-speed PHY chips become available. PC manufacturers with a USB host controller on the motherboard can use the AHA-8940 to qualify existing designs for Entertainment PC status. Adaptec sells its AHA-8945 adapter card, which includes an UltraWide SCSI controller, as the HotConnect™ Ultra 8945. The Developer's Kit no longer is available.**

Widespread availability of conventional 1394 PC peripherals, such as disk drives with the 1394 implementation of the SCSI Serial Bus Protocol (SBP-2), isn't expected until a critical mass of 1394-compliant PC systems occurs, possibly by 2000. Proposed sealed-case NetPCs, for which a 1394 interface to external disk drives and other peripherals was optional in Microsoft's preliminary NetPC specification, met with little interest.

1394 Adapters for Digital Video Applications

Camcorders and VCRs using the Digital Video (DV) format were the first to implement 1394 I/O and continue to be the only consumer or professional 1394-compliant products in widespread distribution. Thus the only application for 1394 adapter cards, as of early 1997, was capturing and editing DV material. The following DV-related 1394 adapter cards were available in Fall 1998:

- ***Adaptec Corp.* and *Digital Processing Systems, Inc.* (DPS) have teamed up to deliver a complete non-linear editing (NLE) system based on the Adaptec AHA-8940 Host Controller, Adobe Premier 4.2, and DPS video capture software. DPS is a highly-regarded supplier of analog video capture and playback cards for professional use, as well as analog video time base correctors (TBCs) and waveform/vectorscope test devices. The US$695 ($400 street price) DPS Spark product uses a software DV codec (coder-decoder) developed by Adaptec and is available for both Intel PCs and Apple PowerMacs. The AHA-8940 is a general-purpose 1394 host controller card, so it also can accommodate other 1394 peripherals as they become available. The AHA-8945 includes an UltraWide SCSI controller; DPS's Spark**

Plus is based on the AHA-8945 and has a street price of US$750.

- ***miro Computer Products, Inc.*** **originally licensed the Sony software DV codec and used a 1394-to-PCI adapter card from Skipstone, Inc. to provide the DV-100 with capture-only capability for US$995. Pinnacle Systems, Inc. purchased miro's analog and digital video product lines in 1997. The Pinnacle miroVIDEO DV300 uses the Adaptec AHA-8945 adapter and has a street price of about US$650.**
- ***FAST Multimedia, Inc.*** **uses the Sony DVBK-1 hardware DV codec to produce its DVMaster a dedicated DV editing card scheduled for release in 1997Q2. FAST is a German firm best known for its Video Machine PC-based editing systems and AVMaster analog video capture and playback cards. The DVMaster, priced in the $4,000 range, offers composite and S-video inputs and outputs, plus analog component (YCrCb) output for BetacamSP and MII recording.**
- ***Truevision, Inc.*** **joined with Matsushita to create a DV version of its Targa 2000RTX, a dual-channel video capture card that provides real-time rendering of digital effects, such as dissolves. The Targa DV2000RTX uses a pair of Matsushita DV hardware codecs that provide interpolated 4:2:2 digital component processing. The low-end Bravado DV2000 adapter offers the full version of Adobe Premier 5.0 at a street price of US$475.**
- **Canopus Corp.'s DVRaptor capture card is the latest variation on the moderately-priced 1394 adapter scene. The $699 (MSRP) DVRaptor offers composite and Y/C video inputs and outputs; the input connects to the video output of the camcorder to provide a high-quality overlay images. DVRaptor eliminates the 2G AVI file size barrier and permits "seamless capture" of long video clips across multiple drive volumes.**

Adapter cards that employ software DV codecs use the digital-to-analog conversion circuitry in the camcorder or DVCR to provide composite or S-video NTSC/PAL output to video monitors via the 1394 connection. (The current miro DV-100 product is an exception.) Eliminating analog video circuitry from the adapter card makes the US$500 and below price point feasible. Today's software DV codecs require a substantial amount of PC processing power and take a relatively long time to render (process) digital video transitions (e.g., fades, cross-dissolves, wipes) and titles. The current generation of software DV codecs that take full advantage of Intel's MMX technology and greatly reduce the rendering time penalty compared with low-cost hardware DV codecs. Software video and audio codecs gain more from MMX than any other PC application class. In the meantime, companies such as Divio are developing low-cost hardware codecs for DV and DVCPRO-50 formats. On the high-end, C-Cube Microsystems' new DVXpress hardware codec, introduced in September 1998, offers DV and MPEG-II capture and transcoding capability in a single, very high-power chip (plus 8 MB of SDRAM and glue chips).

> ***Note: A companion paper, "Consumer and Professional Digital Video Recording and Data Formats," describes the DV recording format, hardware DV codecs, and the DV data format for transmission via 1394 (DVover1394). The Divio and C-Cube hardware codecs are discussed in the DV paper.***

On the conspicuous-consumption consumer front, Snell & Wilcox (a UK manufacturer of video broadcast, studio signal processing and test equipment) displayed the Interpolator at the 1997 Winter Consumer Electronics Show. The Interpolator, a $27,000 digital signal interpolator for optimizing home-theater projection video, is Snell & Wilcox's first consumer product. The Interpolator is equipped with a 1394 connector for DV gear; S-video, analog component (Betacam), and serial D-1 inputs also are provided. The Interpolator's output is in the RGB format used by PC monitors and high-end video projection systems.

Variations on the 1394 Theme

Not content to wait for widespread commercial adoption of products adhering to the IEEE 1394-1995 standard, members of the 1394 Trade Association are working on the following three initiatives to improve or alter the 1394 specification:

- ***1394a* is considered a "cleanup" document that fills a few holes in the original standard and reflects some minor changes, such as faster bus reset operations. 1394a-conformant products are backwardly compatible even with products (primarily Sony camcorders) that predate the original 1394 standard. 1394a originally was intended to cover increasing the signaling speed of 1394 to 800-Mbps and higher in order to attract fixed-disk manufacturers to the 1394 camp. To avoid a delay in publishing the 1394a update, higher speed 1394 versions were take up by a 1394b working group, spearheaded by Zayante Corp.'s Michael Johas Teener, formerly Apple Computer's FireWire architect. The working group's meeting minutes and proposed 1394b specification, now in draft version 0.14, are hosted by Zayante.**
- **1394.1 covers the four-wire consumer connector used by Sony in its DCR-series DV camcorders and DHR-1000 DVCR, and establishes standards for 1394 bridges. Bridges extend the allowable distance between 1394 devices (presently a maximum of 4.5 m) and are critical components for home networking with 1394. Bridges also can segment isochronous bus traffic to improve performance in some high-end audio/video applications.**
- **1394.2 is a proposed standard for an incompatible variant of 1394 designed to interconnect clusters of workstations at signaling rates of 1Gbps or higher. 1394.2 is loosely based on the IEEE 1596 Scalable Coherent Interface (SCI) standard for supercomputers and often is referred to as "Serial Express" or "SCSILite." 1394.2 uses a signaling interface similar to Fiber Channel Arbitrated Loop (FCAL.) 1394.2 requires a loop architecture; 1394 expressly prohibits looped connections.**

The 1394.2 proposal has stirred widespread controversy among 1394 proponents. 1394.2 has little in common with 1394 and its supporters appear to be at cross-purposes with the 1394 Trade Association's attempt to gain widespread adoption of 1394 in the consumer electronics and PC industries. Apple, Sun, and Intel are the primary supporters of 1394.2. Some observers have surmised that Intel joined the 1394.2 cabal in order to muddy the 1394 waters and minimize a perceived competitive threat by 1394 to USB's hegemony. The only common element between 1394 and 1394.2 is the computer-based software architecture; 1394.2 is designed primarily to interconnect computers, not peripheral devices. As of late 1998, it appears that 1394.2 has been subsumed by the 1394b activity.

Comparing 1394 and the Universal Serial Bus

The Universal Serial Bus (USB) is defined by two specifications, USB Specification 1.0 and USB Device Class Specification 1.0, created by a PC industry consortium consisting of Compaq, DEC, IBM PC Company, Intel, Microsoft, NEC, and Northern Telecom. The final version of the USB Specification 1.0 was released at 1995 Fall Comdex. The specifications define the architecture, communication protocol, device types, and connector for the USB. A separate triumvirate of Compaq, National Semiconductor, and Microsoft has developed an Open Host Controller Interface (OpenHCI) specification that defines the software and hardware for implementing the OpenHCI on Intel-based PCs. Intel has a similar specification, called Universal HCI, that applies to its USB controllers and motherboards. Intel motherboards with on-board USB connectors became available in mid-1996, unaccompanied by commercial USB peripherals.

> ***Note: The OpenHCI Specification 1.0 also applies to 1394 adapter cards and motherboard subsystems. Microsoft says it is "working with Texas Instruments and***

Adaptec to implement support for devices that predate the OpenHCI specification. However, to take advantage of future built-in driver support in Windows and to minimize the size of the IEEE 1394 test matrix, subsequent designs are strongly encouraged to adopt OpenHCI."

1997 Sony and Toshiba consumer PCs included USB connectors on the motherboard, but only Toshiba made use of the USB port with a proprietary software implementation for its monitor-based LCD display and control panel. Specifications for Sony's VAIO (Video Audio Integrated Operation) PCs carry the following footnote: "USB ports are included to provide state-of-the-art technology. Full utilization of the capability of the USB standards requires a version of the Microsoft operating system that supports USB at the operating system level. Upgrading to this operating system when it becomes available will allow full utilization of the USB ports included on these models." USB support is included in Windows 95 OSR2 (OEM Service Release 2), but wasn't simultaneously available for Windows NT 4.0.

Sony might well have added "... and when USB peripherals appear" to its VAIO footnote. Unlike 1394, USB connectors on PCs arrived considerably before connectable peripherals. All classes of PC 97 computers now must support both USB Specifications and either OpenHCI or UHCI, so production quantities of at least a few USB peripherals are likely to appear in retail channels about mid-1997.

USB is designed to eliminate the multiple peripheral connectors and tangled cables behind today's PCs, while freeing PC users from the limited number of free interrupts available for external peripheral devices. USB is intended to connect keyboards, mice, tablets, modems, telephones, CD-ROM drives, printers, and other low- to moderate speed external peripherals in a tiered star technology (see figure 5). The primary objective of USB is low implementation cost to minimize the premium for USB-compliant peripherals. USB uses a four-wire connector with a single twisted pair for signaling, plus 5-volt power and ground conductors. The data transfer rate is limited to 12 Mbps, with a 1.5 Mbps subchannel available for low-data-rate devices, such as mice. The purpose of the low-speed subchannel is to minimize chip costs and EMI protection requirements. Isochronous communication is available for higher bandwidth devices, including CD-ROM drives, ISDN modems, and digital telephony.

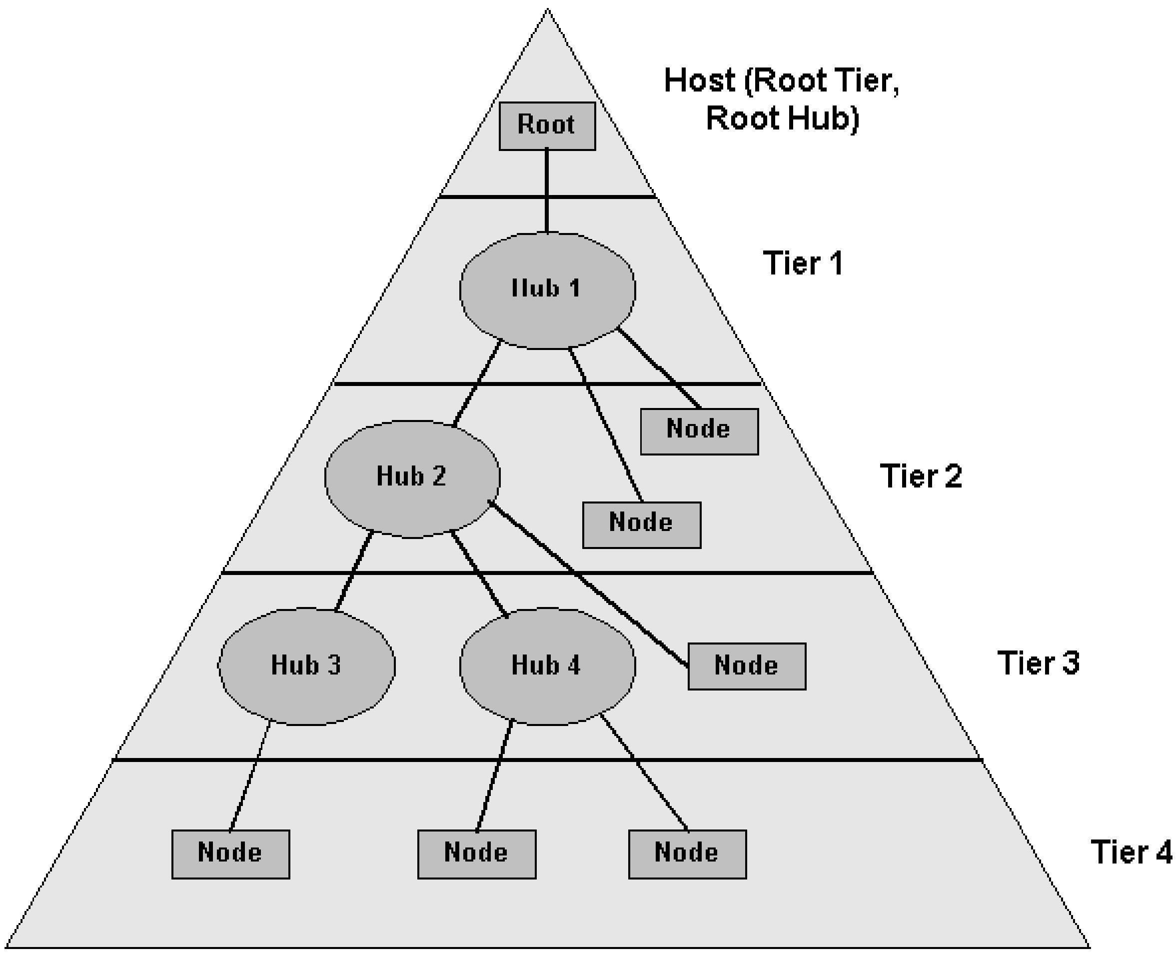

Fig. 5. USB Topology (from USB Specification 1.0)

Unlike 1394, hubs are required for multiple connections to the host (root) connector. Hubs notify the host when nodes (called functions) attach or detach from the hub to provide the dynamic reconfiguration and device identification required by the Windows 95 Plug and Play specification. Biased termination at each end of the cable provides attach/detach notification and identification of low-speed devices. All devices have an upstream connection; hubs include downstream connections. Upstream and downstream connectors are polarized to prevent loopback. Hubs can have up to seven connectors to nodes or other hubs, and may be self-powered or powered by the host. Although 1394's bus bridge might be compared to a USB hub, 1394 allows up to 63 devices to be connected in leaf/node configurations before a bus bridge is required.

A USB keyboard might include both node and unpowered hub functionality so a mouse and tablet could plug into the keyboard. Monitors also are a logical location for USB hubs. High-end USB peripherals, such as CD-ROM drives and ISDN modems, also would be expected to include hub capability, eliminating the need to purchase standalone USB hubs. Another potential for the USB are cablemodems, which presently require connection to an Ethernet adapter; 12 Mbps should be plenty of bandwidth for cablemodems produced in 1996 and 1997. Demand for cablemodems is expected to increase as cable MSOs abandon their gamble on interactive TV for more of a "sure thing" as purveyors of high-speed Internet connectivity, at least in the downstream direction.

> ***Note: The Video Electronic Standards Association (VESA) has established a Enhanced Video Connector (EVC) standard for connecting monitors to PCs. The EVC includes***

conductors for implementing USB and 1394 ports on the front or in the base of the monitor. PCs and monitors with EVCs are slated for retail distribution in 1997Q3.

The 12 Mbps signaling rate of the of the USB is capable of handling MPEG-1, DVD's nominal 3.5 Mbps data rate, and MP@ML MPEG-2 compressed video and audio at 6+ Mbps. Like 1394, USB provides for isochronous signaling, but at a much lower bandwidth. Thus initial multimedia applications for USB peripherals are more likely to be in the audio and still-image realm. As an example, Altec-Lansing announced in early 1997 a set of powered speakers that accept digital audio signals from a USB port and Northern Telecom promises a USB-connected telephone. The requirement for a PC host controller, however, limits USB to PC-only peripherals. The primary advantage of 1394, aside from its much higher bandwidth, is that consumers can use 1394 devices in simple setups, such as dubbing DV tapes from a camcorder to a DVCR, without the need to connect a PC or another microprocessor-based controller as an intermediary.

Summary

The Digital VCR Consortium, consisting of more than 50 manufacturers of consumer electronics firms has adopted the IEEE 1934 High Performance Serial Bus as the standard digital interface between consumer DV products. Sony's release of three moderately-priced (by professional standards) DV camcorders with 1394 digital audio/video input/output and device control is a major step in the widespread adoption of the High Performance Serial Bus for digital audio/video interconnection. Matsushita recently joined the 1394 coalition with the Panasonic NV-DE3 DV camcorder. Other Japanese camcorder and VCR manufacturers are certain to follow the Sony and Matsushita lead. The Digital Audio/Video Interoperability Council (DAVIC) and Europe's Digital Video Broadcast (DVB) consortium have adopted the 1394 bus for set-top box and other broadcast-related applications. DBS set-top box manufacturers for the U.S. market appear poised to adopt 1394 (or a "dumbed-down" variant thereof) in third-generation satellite TV receivers to connect dedicated digital time-shift VCRs that use JVC's D-VHS format.

IEEE 1934 proponents hoped that Microsoft's support for 1394 in Active Movie 2.0 and the Entertainment PC specification would give 1394 additional consumer visibility during the Christmas 1997 selling season. Apple Computer promised that at least some 1997 PowerMac models finally would sport FireWire connectors. One of the major benefits of adding 1394 connectivity was perceived as allaying consumers' fears of PC "obsolescence at purchase," one of the causes of diminished home PC sales during the 1996 and 1997 Christmas seasons. The advent in 1998 of the sub-$1,000 home and business PC reduced the gross margins of mainstream consumer PCs to the point where products include only "absolutely necessary" features in order to compete. Sony's October 1998 introduction of competitively-priced mini-tower for the midrange PC market, however, might force other PC assemblers for the consumer market to bite the IEEE-1394 bullet in 1999.

Only when FireWire adds $10 or less to the retail price of a sub-$1,000 PC, will 1394 become a ubiquitous PC peripheral interconnect, as opposed to a consumer-electronics controller and DV editing enabler. Mark Kristen, an industry analyst for market reasearcher In-Stat, estimated at the 1394 Trade Association's Developer Conference in July 1998 that 450 million 1394 chipsets will ship in 2002. The vast majority of these chipsets will be installed in DV camcorders and DVTRs; cable, satellite and off-air (UHF) DTV set-top boxes; and other consumer electronics devices, not Entertainment PCs.

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