Digital set-top boxes in IEEE 1394 home entertainment

Set-top boxes are evolving from fixed-function devices to a home networking system, allowing a new breed of interactive services. The paper describes layered architecture and firmware approaches in the high-speed serial bus standard.

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With the availability of commercial interface modules, the IEEE 1394 is ready for integration into home electronics and computer products. A bridge device is required for connecting the home audio/video systems to satellite, cable television and Internet services. The digital set-top box is the bridging device.

With the proliferation of the IEEE 1394 high-speed serial bus, digital home-entertainment systems are now being realized. A new era has dawned, one that distributes audio and video content to every room in homes, simplifies in-wall wiring and eliminates redundant device remote controls. The networked home entertainment system places new constraints, as well as provides new opportunities for set-top box manufacturers and silicon designers. The paper outlines such constraints and opportunities, along with an introduction to a popular system-on-a-chip (SOC) architecture used in the design of interoperable home entertainment devices.

Figure 1: A typical IEEE 1394 home-entertainment system.

A digital set-top box is a consumer electronics device that converts an incoming digital signal to audio/video formats interpreted by current televisions and audio devices. The set-top box is typically connected between a television and a content provider such as cable television or direct broadcast satellite (DBS) operator. A block diagram of a typical 1394 home entertainment system is shown in **Figure 1**.

The device provides digital audio and video sources after decoding the incoming digital signals. It then separates audio and video data streams for presenting them to respective display devices. To process Internet contents and other interactive services, set-top boxes have incorporated browser interface. These also serve as the Internet-bridge devices for system firmware updates and upgrades. Other video decoders can also be implemented for DVD, camcorders and game players. Set-top boxes also support electronic program guide (EPG) and other on-screen

Data type	Bandwidth/channel	Channels
16-bit, 44.1kHz audio	705.6Kbps	453
24-bit, 48kHz audio	1.152Mbps	277
Dolby Digital 5.1 channel audio	384Kbps	833
DTS 5.1 channel audio	384Kbps	833
30fps, 640x480, 24-bit video	221Mbps	1
15fps, 320x240, 16-bit video	18Mbps	17
MPEG-2, NTSC video	3Mbps	106
MPEG-2, PAL video	4Mbps	80
MPEG-2, complex image video	5-10Mbps	32-64
DV, compressed video	20Mbps	16

Table 1: Bandwidth requirements for popular audio and video formats.

display features through remote control.

IEEE 1394 interface

The consumer value of a digital set-top box can be greatly enhanced with the addition of an IEEE 1394 interface. The IEEE 1394 is a high-speed serial interconnect capable of carrying digital audio/video streams and device control commands at a date rate of 400Mbps. The primary protocols for audio, video and control are being standardized in working groups within the 1394 Trade Association, currently comprising of more than 160-member companies worldwide.

Set-top boxes, when connected to a television set, enable a closed and limited system for watching programs and accessing Internet services. However, a 1394-enabled set-top box powered by the appropriate silicon and system firmware can connect to and control an endless variety of consumer electronics devices. That includes camcorders, game players, DVD and DVD-audio players and bridge devices that connect the 1394 bus to other home networks such as Ethernet, X-10 and Bluetooth.

The 1394 interface is already a requirement in digital set-top boxes that comply with Cable Labs' OpenCable specification in North America. Nevertheless, the commercial and technical success of the 1394-enabled devices depends on its ability to work intelligently in an integrated home audio/video system.

There are three main considerations in this regard: the architectural design of 1394 node controller ICs; the availability of tested system and device firmware that implements the myriad international standards and protocols for home entertainment devices; and device certification. The latter serves as the final "seal of approval" telling the consumer that the digital set-top box device will work in harmony with other audio/video devices already present in their home entertainment system.

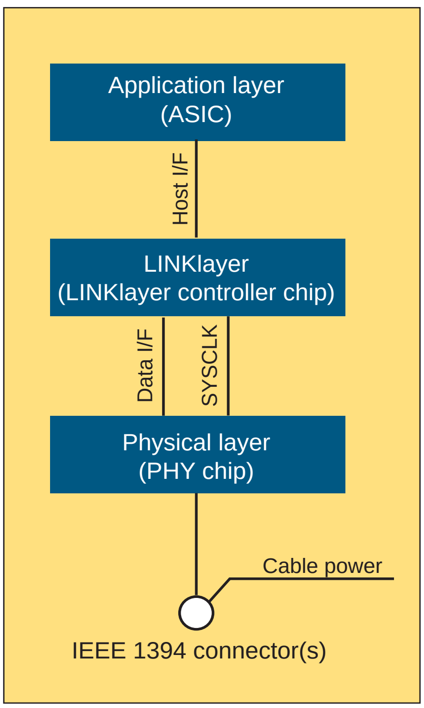

Figure 2: Traditional IEEE 1394 interface for peripheral, fixed-function devices.

What's Online

▶ **Designing 1394 in a digital set-top box**
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Basic system architecture

The topology of a 1394 home entertainment system can be a daisy chain, tree, star or a combination of these. Up to 63 devices may be connected in one bus, and up to 1,023 buses can be interconnected to create a very large network with over 64,000 devices. The extensibility is much needed in setting up audio/video networks for cruise ships, apartment buildings and large offices. During system initialization, each node in a 1394 bus carries out a process of bus initialization, tree identification and self-identification. These functions are carried out quickly and automatically without human intervention.

No master controller is required in a 1394 system, eliminating the communications bottleneck and single point of failure common to many other systems such as USB. Owing to integrated support for hot plugging,

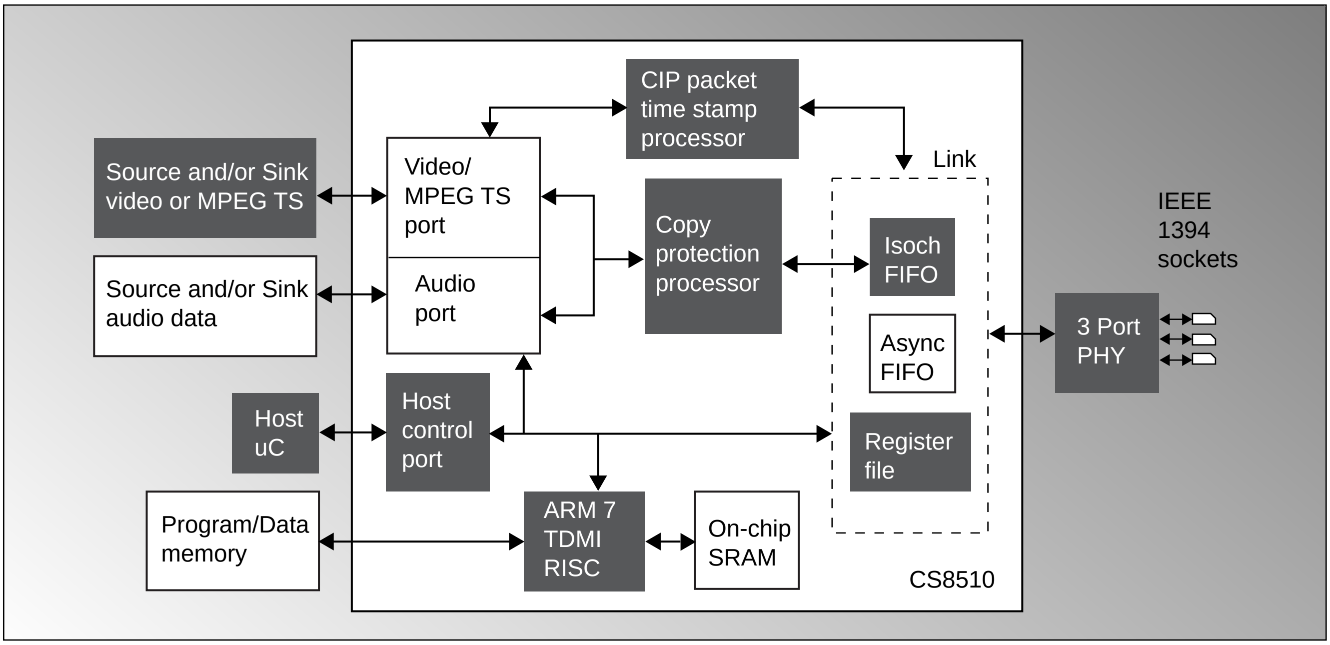

Figure 3: Block diagram of Cirrus Logic/Digital Harmony IEEE 1394 node controller.

devices may be added to or removed from the 1394 system without disrupting other nodes. The IEEE 1394 data rates are currently 98.304Mbps, 196.608Mbps, and 393.216Mbps, referred to as S100, S200 and S400, respectively. Devices with different data rates may be freely interconnected and communications will automatically be performed at the highest rate supported by the lower-rate devices.

The IEEE 1394 supports two primary means of transferring data — asynchronous and isochronous. Isochronous streams are transmitted with predictable latency, guaranteed bandwidth and on-time delivery. Each of 64 supported isochronous channels may contain an unlimited number of logical audio or video channels, limited only by the bus bandwidth. In a home entertainment system, for instance, one isochronous channel could carry a 5.1-channel surround-sound audio signal and a compressed digital video signal.

The IEEE 1394 standard allocates 80 percent of bus bandwidth to isochronous transactions. This enables data throughput of approximately 320Mbps for S400 interfaces. Ignoring overhead and bus arbitration inefficiencies, **Table 1** illustrates the ability of the 1394 bus to carry multiple audio and video streams throughout the home.

Asynchronous transfers used to transmit system and device control commands can take place any time the bus is free of isochronous traffic. The IEEE 1394 protocol guarantees that at least 20 percent of bus time is reserved for asynchronous data transfers. A short-acknowledge packet is returned to the sender for every asynchronous packet, providing a mechanism for guaranteeing delivery.

The IEEE 1394 asynchronous protocol allows one node to read from, or write to, memory in another node. The technique used to control and monitor device parameters is to simply read and write public variables. Several protocols have been devised for locating parameters and arbitrating "reads" and "writes" to them. The protocol most widely used in commercial 1394 devices is called function control protocol (FCP).

The actual commands are outside the scope of FCP, however. The primary command/transaction set used in 1394 devices is the AV/C digital interface command set. This command set has been designed for controlling typical consumer electronics devices such as camcorders, disk and tape recorders, tuners and still cameras.

IEEE 1394 layer hierarchy

There are two prevalent IEEE 1394 silicon strategies for set-top box designs. The traditional approach, used by most 1394 devices available today, is to employ discrete ICs for both the analog physical layer (PHY) and the mixed-signal link layer controller (LLC). **Figure 2** shows the layer hierarchy in this typical IEEE 1394 implementation for fixed-function devices, typically meant to be connected to a single device for a single application.

The physical layer provides low-level access to the 1394 bus. Cable power is typically extracted from the bus and used to power the PHY, maintaining the integrity of the bus while a device is turned off. The PHY chip exchanges data and system clock signals with the LLC.

The link layer is responsible for properly formatting isochronous and asynchronous packets for transmission, and buffering incoming packets for processing at the application-layer level. The IEEE 1394 standard allocates an undefined block of payload data to isochronous packets, and does not dictate specific audio or video data formats. Such formats are determined at the application layer. Asynchronous messages provide read/write access to shared memory on each node. Typical LLCs provide host interfaces compatible with common microprocessors, PCI buses and synchronous serial buses.

The application layer formats packets for specific audio, video and control applications. If the 1394 interface is intended for a computer, the application layer is often implemented in operating system drivers and application software. The application layer is not standardized presently and has been implemented differently in a variety of different devices.

Silicon, firmware strategies

In this design, the firmware that implements the relevant 1394 protocols runs on the device's host CPU, simultaneously with the application firmware. This technique has been successful in developing present fixed-function 1394 products that essentially act as a computer peripheral or slave device, as opposed to peer devices operating in a home entertainment system. Thus, consumers can buy a 1394 camcorder or hard-disk drive and plug it in to a 1394 laptop computer for running individual applications such as desktop video editing and MP3 file storage.

However, home entertainment systems are unlikely to contain a personal computer acting as a master device. Among the many challenges to this approach is synchronization. Each node must accurately recover audio stream's sample rate, and provides accurate time alignment between the appropriate audio and video data. Using timestamps, all audio and video signals on a 1394 bus can be synchronized within 40.69ns of each other, without an external synchronization clock. In addition, the isochronous nature of 1394 audio/video data requires a computer operating system to be interrupted every 125µs. If these interrupts are given a priority inconsistent with the presentation of sample-accurate audio and video, dropouts can occur, or at the very least, phasing will be misaligned. This scenario would be unacceptable to the consumer.

Finally, the sheer number of 1394 protocols and standards, including upcoming middleware technologies such as HAVi, has created a complex and exhausting task for device firmware programmers. Presented with these challenges, IC designers are adopting a "system-on-a-chip" approach, integrating an embedded processor with a customized LLC.

The processor acts as a dedicated "protocol engine," used only to run the 1394 protocol stack firmware. This approach frees up the host CPU for its original application. Furthermore, the dedicated node controller IC creates a higher likelihood that the resulting audio/video device will be interoperable with others, since the audio/video streams are processed on the bus without interrupting the host CPU or competing for services from the host real-time operating system.

Digital Harmony Technologies, in collaboration with ARM Design Services, was the first company to develop architecture available to semiconductor manufacturers through a non-exclusive licensing program. Other companies, including Texas Instruments and LSI Logic, are developing similar node-controller ICs. The first silicon device to comply with the Digital Harmony architecture is being designed under license by Cirrus Logic for its Crystal Semiconductor brand (**Figure 3**).

The interface to the IEEE 1394 bus is via a standard PHY/LLC port. An on-chip controller performs bus management tasks, freeing the host system CPU from any IEEE 1394-specific operations. A DTCP encryption/decryption processor is included. Host control is via a simple register based interface. The audio port can handle more than eight channels of digital audio data, while the video port supports multiple video formats, including MPEG2-TS and DV.

Set-top for transformation

Consumers are using digital set-top boxes to watch television programs, browse Web sites, send e-mails, and shop for goods and services. According to market research company Dataquest, sales of digital set-top boxes will reach 25.1 million units this year, worth an estimated US$6.3 billion.

By integrating low-cost, interoperable 1394 technology available today, manufacturers can transform the digital set-top box from a fixed-function device to a whole-house entertainment server and remote control. For a small investment in silicon and firmware, the IEEE 1394 interface adds considerable value to the digital set-top boxes by enhancing the consumer's entertainment experience.

This is accomplished through the elimination of redundant subsystems such as on-screen displays and MPEG decoders, the centralization of whole-house system remote control functions and the addition of new audio/video applications. Third-party providers of IEEE 1394 interface hardware and firmware, such as Digital Harmony, offer set-top box and IC manufacturers with a time-to-market advantage over in-house design and development. ●

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