NEW DEVELOPMENTS IN IEEE-1394 STANDARDS FOR THE CABLE SET-TOP BOX

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Abstract

In December 2002, consumer electronics manufacturers joined with cable MSOs in announcing an historic agreement on digital cable compatibility. Among the provisions identified in the agreement was a commitment on the part of cable operators to provide, by July 2005, IEEE-1394 interfaces on high-definition digital cable set-top boxes acquired for distribution to consumers. Two standards related to the 1394 interface were cited in the agreement, ANSI/SCTE 26 [1] and CEA-931-A [2]. This paper describes the agreed-upon functionality of this high-speed serial bus network interface, and provides an in-depth discussion of the new CEA-931-A protocol.

INTRODUCTION

As envisioned by the engineers and policy-makers who forged the December 2002 Agreement, the primary function of the 1394 interface is to enable consumer recording or time-shifting of compressed MPEG-2 audio/video content, and delivery on a peer-to-peer home network of that digital programming. While the High-Definition (HD) digital cable set-top box outputs digital video for viewing via an uncompressed Digital Visual Interface (DVI) or optionally a High Definition Multimedia Interface (HDMI) port, an IEEE-1394 high speed serial bus interface must also be present.

The memorandum of understanding in the December 2002 NCTA/CEA Agreement [3] requires High Definition cable set-top boxes to:

> "… comply with ANS/SCTE 26 (as of 10/29/03) with transmission of bit-mapped graphics (EIA-799) optional, and shall support the CEA-931-A PASS THROUGH control commands: tune function, mute function, and restore volume function. In addition these boxes shall support the POWER control commands (power on, power off, and status inquiry) defined in A/VC Digital Interface Command Set General Specification Version 4.0 (as referenced in ANSI/SCTE 26 2001)."

We start with a system-level overview of the Digital Cable Set-top Box (DCSB) as it fits into a typical home network environment. We then move to a detailed review of CEA-931-A [2], published this year by the Consumer Electronics Association (CEA). We include along the way a discussion of a typical "IR Blaster" application to show how use of CEA-931-A can overcome the inherent limitations of that technique. Next, a brief summary of ANSI/SCTE 26 [1], first published in 1999 and updated in 2001, is presented. We then summarize the various normative references cited in ANSI/SCTE 26 and in the primary CEA standard for the display side, EIA/CEA-849-A [4], and conclude with a discussion of two implementation issues that may be of interest to designers.

SYSTEM OVERVIEW

Figure 1 diagrams a Digital Cable Set-top Box (DCSB) at the upper left. The video output flows from its DVI/HDMI port to a High-Definition Display. Audio connections are not shown in the simplified diagram.

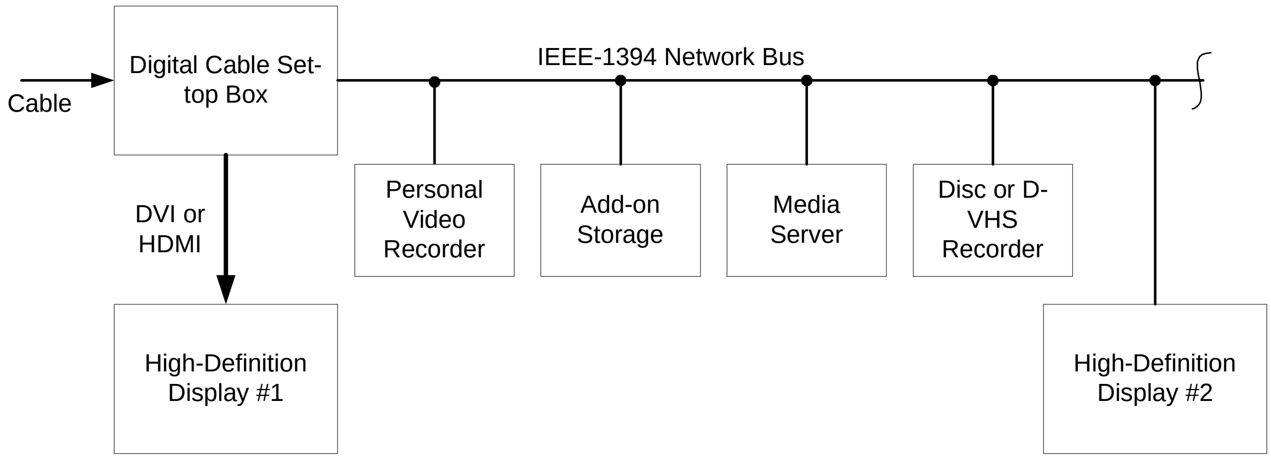

Figure 1. System Block Diagram

To the right of the DCSB in Figure 1, an IEEE 1394 Network Bus is shown interconnecting the set-top with a variety of audio/video devices. A hard-disk- based Personal Video Recorder (PVR) may have 100 GB or more of disk space available for temporary storage of audio-video programming. The PVR or DCSB may be able to make use of additional storage devices that may be present on the bus (represented here by the box labeled "Add-on Storage").

A Media Server is also shown in Figure 1. While similar in many ways to the functionality offered by the PVR, the Media Server might include extra features such as archived musical recordings, access to Internet-based content, ability to manage prerecorded packaged media such as CDs and DVDs, and ability to accept and catalog personal content such as digital photos and home videos.

At the far right side of Figure 1, a second display device is connected via the 1394 bus. Compatibility with the DCSB is guaranteed for DTV displays supporting EIA-775-A [5] and the "MPEG profile" of EIA/CEA-849-A [4]. These two protocols are complimentary to ANSI/SCTE 26 [1]. Whereas the DVI/HDMI port on the DCSB provides a high-bandwidth pathway for graphics as well as for HD video, the 1394 path offers HD video but only standard-resolution graphics and a graphics frame rate that is limited by hardware capacity in either the source or display.

Digital Recording Functionality

How might a viewer use a setup like that of Figure 1 to make recordings of digital content? Several scenarios are possible. One possibility is that the DCSB may discover the Add-on Storage device and may be able to use it as a disk-based cache for audio/video programs. In this scenario, the set-top manages files and offers a suitable user interface to access them and to organize and manage disk resources. In another scenario, the PVR maintains its own file system, provides its own user interface to stored programs, and performs attended and unattended recording from selected source devices. It is with this latter scenario in mind (among other considerations) that CEA-931-A was developed.

As noted, an HD digital cable set-top box built to comply with the NCTA/CEA Agreement implements ANSI/SCTE 26 and certain provisions from CEA-931-A. Using these protocols, the PVR (or any other device on the 1394 bus) can identify the set-top box as a source of digital video, can turn it on and can tune it to any given digital channel. The format of data on the bus, including aspects of physical, link layer, transport, link encryption for copy protection, and audio/video compression formats are all specified. The precision and completeness of these provisions enables the development of this new category of consumer digital recording devices.

CEA-931-A STANDARD

CEA-931-A [2], entitled *Remote Control Command Pass-through Standard for Home Networking*, defines a standard method for communication on the network of simple “user intents” such as those typically represented by keys on a consumer Remote Control Unit (RCU). Additionally, the protocol recognizes and supports applications such as unattended recording that typically, in the analog world, must rely on devices capable of emulating the infrared pulses emitted by a given device’s RCU. The new protocol offers a vast improvement in reliability and ease of use as compared with the analog techniques it replaces.

Remote Control Key Pass-through

Figure 2 illustrates in a simplified way the concept of remote-control key pass-through. The RCU in the figure is the unit sold with the DTV receiver. The format and carrier frequency of the infrared (IR) pulses it emits are recognized and accepted by that DTV receiver. Some of the commands, such as power on and off and picture controls (brightness, contrast, etc.) are directed at the DTV itself and are processed internally. Others, such as a “Record” key may not correspond to functions supplied by the display. Key presses such as these can be “passed through” the DTV and placed onto the 1394 bus. The function of the CEA-931-A [2] protocol is to define the standard method whereby these RCU keys are communicated across the network.

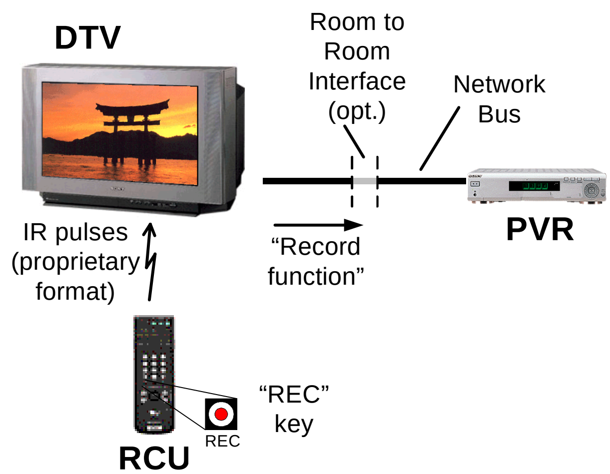

Figure 2. “Record” Key Example

Typically, the DTV will address the key commands not corresponding to internal functions to the specific network device currently selected as the current audio/video “input” or A/V source device. If several devices on the network could respond to a “Record” command, for example, the only one receiving the command will be the one currently selected as the A/V source.

A key feature of RCU key pass-through is that the IR pulses corresponding to the external function are proprietary to the manufacturer of the RCU itself, yet the functions themselves are mapped (in the device receiving the IR pulses) into standard key commands by the 931-A protocol.

What are the benefits of RCU key pass-through? The primary benefit is apparent if the device being controlled is not directly visible to the viewer who is holding the RCU. It may be in another room, for example, or simply inside a cabinet or behind a piece of furniture such that the RCU’s IR pulses cannot reach its front panel. In such cases, the DTV receiver, whose IR receiver is in full view of the user, acts as a relay agent to deliver the commands to the hidden unit.

Another benefit of RCU key pass-through is that the networked A/V devices (if they all support CEA-931-A) may be controlled by a single RCU, thus eliminating the clutter and confusion of several remotes on the coffee table. This statement comes with a caveat: certain devices may include functions associated with dedicated keys on their native RCUs. These may not be mappable in a straightforward way to CEA-931-A key codes. The "universal" RCU remains elusive, yet CEA-931-A is clearly a step in the right direction.

Infrared "Blasters"

As mentioned, CEA-931-A [2] was designed with a scenario beyond simple key pass-through in mind. Typically, it is the viewer who operates his or her audio/video equipment via IR remote control by pushing keys on the RCU. Certain equipment, however, may take the place of a human operator in order to control a piece of A/V equipment when, for example, the user is not present.

Until the advent of digital home network busses and protocols such as CEA-931-A, analog methods were the only option. One approach employed "IR Blasters," devices capable of emulating the IR pulses recognized by the piece of equipment to be controlled. The controlling device typically includes an IR emitter attached to the end of a cable; the emitter is affixed in a position near the front panel of the device to be controlled. This approach, while workable, is fraught with difficulties.

To appreciate how CEA-931-A [2] may be used to overcome the shortcomings of IR Blaster approaches, we take a look at a typical application. This scenario involves a PVR using a cable or satellite set-top box as a video source and an analog VCR for archival backup of disk-based material to videotape. This setup is diagrammed in Figure 3.

As shown, the user operates the system primarily from the PVR's native remote control unit. When a channel change is desired, the PVR creates the necessary IR pulses to effect the channel change in the cable set-top box. For archival recording, it emulates the VCR's RCU to start and stop recording.

Beyond the large number of cables needed to wire these pieces of equipment together, one must allow for the limited length of the cables supporting the infrared emitters. If either of these emitters slips out of position, IR commands will not be received reliably.

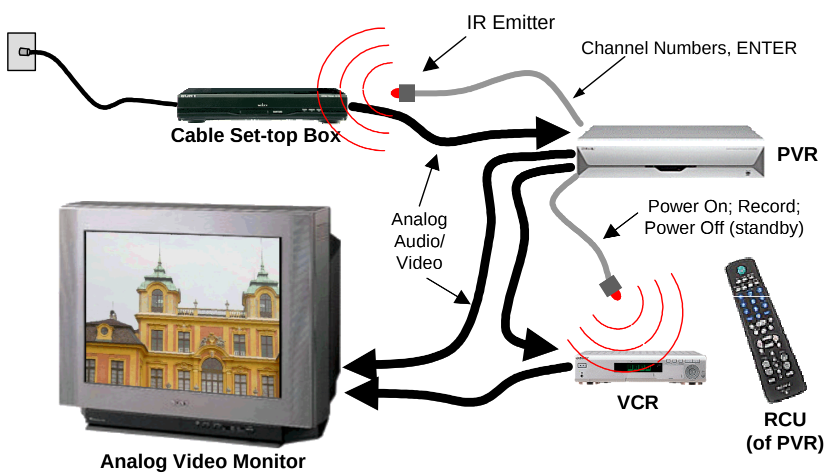

Figure 3. IR Blaster Example

Another reliability issue occurs because commands such as the one used to tune the DCSB to a given channel involve several key codes sent in sequence. If the codes are sent too close together, the set-top box may not recognize them. If they are sent too far apart, "channel surfing" is noticeably more sluggish.

Setting up the system in Figure 3 is a challenge by itself. The PVR must include a database covering as many models of audio/video equipment as possible. This database describes the modulation modes and infrared pulse formats corresponding to the needed commands for various models of various manufacturers' equipment, so that the PVR can control the user's specific set-top box and VCR. Typically, during the setup procedure the user will need to answer a series of questions such as "Does your set-top box require an ENTER key to terminate channel changes?" and "Does a channel number involve two digits or three?" With the setup procedure being time-consuming and prone to errors, it is no wonder many people are unwilling to attempt it.

Figure 4 shows the same application (PVR functionality with unattended recording and control of an A/V source device), but this time the devices handle digital audio/video on a 1394 bus and support standard protocols including CEA-931-A. 1394 cables interconnecting the pieces of equipment replace the bulky audio/video wiring.

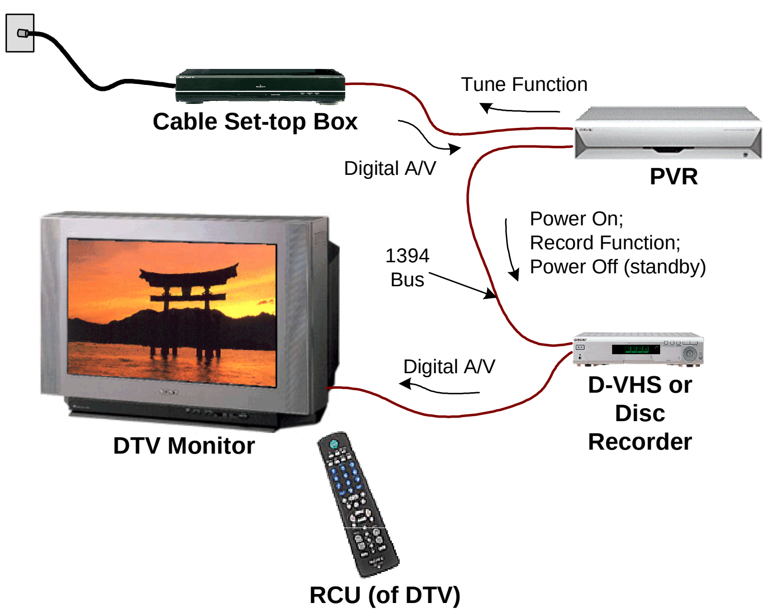

Figure 4. Using CEA-931-A for Unattended Recording

As soon as the equipment is powered on, each unit discovers the others on the network and can determine each device's type and function and what protocols are supported. No special setup is required at all!

The functions previously handled by the IR blasters are now handled by the CEA-931-A protocol. When the PVR wishes to tune the DCSB to a given channel, it may simply issue a "Tune Function" command providing the channel number to be tuned. Bus commands are acknowledged, so operation is reliable and predictable.

Whereas in the analog scenario the PVR's own RCU was used to control it, now the DTV's own RCU may be used to control the PVR, since the DTV is able to pass on to it key presses appropriate to its control.

When the PVR wishes to transfer a stored program to disc or tape, it can operate the recorder using other CEA-931-A functions. Power control is provided by commands defined in the *A/VC Command Set General Specification* [7], and the recording is initiated by a CEA-931-A "Record Function."

Now, when the viewer browses through the channel lineup to look for something entertaining, channel changes are fast: the time interval between channel number digits has been eliminated because the "Tune Function" involves a single command delivered on the home network bus.

CEA-931-A IN DETAIL

CEA-931-A [2] actually does not itself define or invent anything new. It is built on a portion of an existing industry standard developed by the 1394 Trade Association, called Panel Subunit 1.21 [6]. Whereas the Panel

Subunit document specifies both a "direct" mode and an "indirect" mode of operation, CEA-931-A uses only the simpler "indirect" mode. In this mode, whatever on-screen text or graphics constitutes the graphical user interface is either embedded into video or delivered via EIA-775-A bit-mapped graphics (defined in EIA-799 [8]).

The indirect mode of Panel Subunit was designed to allow a controller device to emulate the RCU of the device being controlled, hence its applicability to the needs identified by CEA for home networking.

The Panel Subunit command that conveys functions associated with RCU keys and "basic user intents" is called the PASS THROUGH control command. Each PASS THROUGH control command is carried within a standard AV/C Function Control Protocol (FCP) packet defined in [9], and identifies the particular RCU key or user intent by an "Operation ID" and (for some functions) one or more parameters.

Operation IDs

Table 1 lists the RCU keys and Deterministic Functions supported in Panel Subunit 1.21 and CEA-931-A. Those in the top portion of the table correspond to RCU keys, and have no accompanying parameters. Some of those in the lower portion labeled "Deterministic Functions" have associated data; these support applications like unattended recording and simple device control.

As can be seen by inspection of the top portion of the Table, all of the common RCU key functions are represented. Some are clearly aimed at specific types of devices. An example is the "Angle" key, used typically on DVD players to cycle among video tracks offering different viewing angles.

Each of the Operation ID types given in the top half of the table, when received by the target device, has exactly the same effect on the device as the corresponding key on its own RCU would have. That means that, for example, if repeated pressings of the PLAY key would cause the device to toggle between playing and pausing playback, reception of the

Tab1e 1. Defined Operation ID values.

Category	User operations
Navigation keys	Digits 0-9, Select, Up, Down, Left, Right, Right-up, Right-down, Left-up, Left-down
Menu selection	Root menu, Setup menu, Favorite menu, Exit
Media control	Play, Stop, Pause, Record, Rewind, Forward, Fast forward, Eject, Backward, Angle, Subpicture
Channel control	Channel up, Channel down, Previous channel
Miscellaneous	Power, Volume up, Volume down, Mute, Sound select, Input select

Deterministic Functions

Name	Function	Parameter
Play function	Start (or continue) playing content	Speed and direction of play
Record function	Start (or continue) recording	-
Pause-play, Pause-record	Pause playback or recording	-
Stop function	Stop playback or recording	-
Mute function	Mute audio	-
Restore volume function	Restore audio to previous volume level	-
Tune function	Tune to indicated channel (or virtual channel)	One- or two-part channel number
Select disk function	Select indicated physical media	Disk number (1-65,535)
Select A/V input function	Select indicated A/V input	A/V input (1-255)
Select audio input function	Select indicated audio input	Audio input (1-255)

"play" Operation ID would have the same toggling effect. Both "key down" and "key up" events are represented.

The Deterministic Functions listed in the lower half of Table 1, on the other hand, are defined such that the result of the command is entirely predictable. Toggling is not allowed. Accordingly, reception of the "Play Function" in the target device must result in playback either starting or continuing. Note that control of device power is not included here. CEA-931-A specifies that the POWER control command specified in [7] is to be used for deterministic control over device power state.

The benefit of Deterministic Functions is that the controller device no longer needs to try to keep track of the state of the device under control. With IR Blaster techniques, for example, the Power key on the RCU might toggle device power between "On" and "Standby." If the controlling device does not know the initial state, using the Power key might result in turning the unit off rather than on.

Deterministic Functions supported in Panel Subunit 1.21 and CEA-931-A include media control (Play, Record, Pause, and Stop), audio control (Mute, Restore volume), tuning control (Tune function), and functions to support selection of specific A/V inputs. The Play function is particularly powerful, in that it includes as a parameter the speed and direction of desired playback. All the trick modes are included, as well as fast-forward and rewind functions.

For reliability and error handling, the Panel Subunit specification describes methods any device on the network can use to determine whether a given target device supports the protocol. It also describes how a device issuing a PASS THROUGH command can determine whether or not the command is implemented in that device, and if implemented, whether it will be acted upon.

DTV 1394 INTERFACE

While the December 2002 Agreement does not cite specific requirements for a DTV receiver connected to the HD digital cable set-top via 1394, the applicable standards are well known in the industry. CEA has developed a logo program called "DTV Link" based on the "MPEG-2 profile" of EIA/CEA-849-A [4] (visit http://www.ce.org/dtvlink for details).

Any DTV display device that is compliant with the requirements of the EIA/CEA-849-A MPEG-2 profile is compatible with the HD digital cable set-top box. Simply put, "compatible" means the user will be able to interconnect the DCSB to the display and then view on-screen displays and program audio/video generated by the DCSB. In technical terms, this compatibility guarantees:

- The DTV display is able to discover and identify the cable DCSB on the 1394 bus as a compatible source (offering it up as a choice);
- The display is capable of decoding and displaying audio/video services including AC-3 audio and any of the allowed formats for compressed MPEG-2 video;
- The display is able to accept analog A/V output from the DCSB, and is able to switch between analog and digital DCSB outputs upon request by the DCSB (analog/digital source selection is discussed in more detail below);
- The display supports the MPEG-2 Transport Stream format delivered within an isochronous channel on the

1394 bus in accordance with IEC 61883-4 [10];

- The display determines which video program element to decode and display by examining the MPEG-2 Program Specific Information (PSI) tables: the Program Association Table (PAT) and the Program Map Table (PMT) it references. Whenever the DCSB includes a single program (service) in the PAT, the DTV display identifies the video component of that service and decodes it without need for viewer intervention. Likewise, it will find the appropriate audio track (perhaps based on its indicated language) and decode it without the need for user interaction.

For the same setup (DCSB connected to DTV), if CEA-931-A is supported by the DCSB, the DTV (or any other device on the network) can cause the DCSB to power on or go to standby power state, can cause audio outputs to be muted or un-muted, and can cause the DCSB to tune to any given analog or digital channel.

OTHER PROTOCOLS AND STANDARDS

CEA-931-A is the newest protocol applicable to home networking, but it is only part of the story. We provide a brief overview of protocols and standards relative to digital audio/video distributed by cable to an IEEE-1394-based home network. This discussion should not be confused with a 1394-based network primarily directed at A/V for the PC platform, as different video compression formats and protocols are involved there.

Figure 5 shows a digital cable set-top box on the left and a DTV display on the right. As mentioned, the primary standard defining requirements for the 1394 interface on the DCSB is ANSI/SCTE 26 [1]. The primary standard for the DTV receiver is EIA/CEA-849-A [4].

ANSI/SCTE 26

Entitled *Home Digital Network Interface with Copy Protection*, ANSI/SCTE 26 [1] specifies requirements for the 1394 interface on a digital cable set-top box. It states that a compliant cable set-top box must meet re-

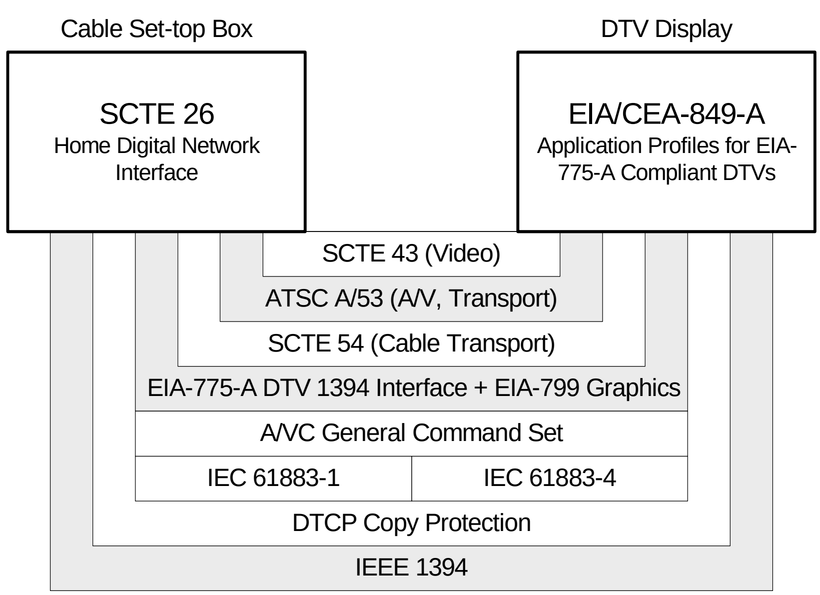

Figure 5. Protocol Dependencies

quirements for source devices given in EIA-775-A [5]. In addition, the set-top box must implement link encryption according to the "5C" method, also known as Digital Transmission Copy Protection (DTCP). The set-top box must indicate to the receiver whether to take its analog or digital output via the "analog digital source selection" method of EIA-775-A (discussed below).

EIA/CEA-849-A

Although EIA-775-A is an important element to 1394 compatibility between the set-top box and the DTV, it does not specify requirements for the higher protocol layers. For example, it does not state requirements for compatibility with various possible transport, or audio or video compression formats. EIA/CEA-849-A was written to address this need, defining a number of "application profiles" for EIA-775-A. The one relevant to our discussion here is called the "MPEG profile." If both a source device and a sink (display) device support a common EIA/CEA-849-A profile, 1394 interconnectivity (including the ability to decode audio and video) is assured.

Normative References

The ANSI/SCTE 26 [1] and EIA/CEA-849-A standards both cite a number of normative references, including:

- **ANSI/SCTE 43** [11], defining the allowable MPEG-2 video compression formats;
- **ATSC A/53** [12], the ATSC Digital Television Standard, defining audio, video, and transport aspects for sources originating from digital terrestrial broadcast;
- **SCTE 54** [13], defining transport-related characteristics for digital cable;
- **EIA-775-A** [5], defining how the IEEE-1394 protocol is used for discovery and connection management, delivery over isochronous channels of the MPEG-2 Transport Stream and over asynchronous channels of bit-mapped graphics defined in EIA-799 [8];
- **AV/C Command Set General Specification** [7], providing standard methods for device discovery and basic control, this document is the foundation for the family of AV/C protocols (learn more at http://www.1394ta.org/);
- **IEC 61883-1** [9], providing a robust foundation of lower-layer protocols, including common methods for encapsulating AV/C commands, and for formatting isochronous packets including timestamps;
- **IEC 61883-4** [10], specifying the standard method for carrying MPEG-2 Transport Streams on 1394;
- **Digital Transmission Copy Protection**, providing a standard method for link encryption to protect against unauthorized copying of high-value content (learn more at http://dtcp.com/); and
- **IEEE 1394** [14], the fundamental specification for the high-speed serial bus technology. The lower layers of the protocol stacks are defined here, including physical aspects of connectors and cabling.

IMPLEMENTATION ISSUES

We conclude with a couple of implementation issues for consideration by system designers.

Isochronous Channel Bit-Rates

Certain devices, such as for example disc or digital tape recorders, may not be able to handle the data rates as high as those delivered by a 256-QAM modulated carrier on cable. In 256-QAM mode, a given 6-MHz cable channel can deliver data at a rate exceeding 38 Mbps. A recorder capable of handling a maximum bit-rate of 20 Mbps, for example, would be able to record any single HD audio/video program, but would not be able to handle the rate of a full Transport Stream derived from a 256-QAM carrier on cable.

For this reason, and for the fact that from the user's perspective the desire is to record one program (not an arbitrary group of concurrently broadcast programs), the source device is expected to create a Single Program Transport Stream (SPTS). The process of creating a "partial" TS is straightforward, and is described in IEC 61883-4 [10].

Partial Transport Streams are structured like regular MPEG-2 Transport Streams except that not every 188-byte transport present in the original TS is present in the "partial" TS—only those corresponding to PID values of interest are included. For example, a partial TS may consist of TS packets carrying the Program Association Table (PID value 0), the Program Map Table section (PID value as identified in the PAT), and one audio and one video track (PID values identified in the PMT section). PIDs associated with Program and System Information Protocol (ATSC A/65) data may also be included.

The Common Isochronous Packet in [9] describes a time-stamp mechanism to enable the packet timing of the original partial Transport Stream to be accurately reconstructed at the receiving end of the isochronous channel. The important thing to note about partial Transport Streams is that the bus bandwidth needed to deliver them does not need to be any higher than the total data rate of the packets actually present. For example, a partial TS might include one standard-definition A/V programming service. While the full TS carrying that service might arrive in a 38.8 Mbps Transport Stream, the partial TS carrying the single program could be sent across a 1394 isochronous channel allocated with a much lower bandwidth (perhaps 6 or 8 Mbps).

Analog/Digital Source Selection

For the foreseeable future, HD digital cable set-top boxes will have analog outputs in addition to their digital ones. While it is possible (and becoming more practical every day) for the DCSB to digitally compress and encode services received via analog transmission channels, cost considerations may preclude this in the near-term. That means that when an analog channel is tuned, the digital video output from the set-top may cease. How is this situation handled?

ANSI/SCTE 26 requires the set-top to signal to the device connected to its digital output on the 1394 bus whether to take its digital or its analog output. This is described in Sec. 4.11 of [5], and it involves processing an AV/C CONNECT command identifying which output plug (analog or digital) should be taken as the current output from the box. Compliance with the MPEG-2 profile of EIA/CEA-849-A [4] (and hence DTV Link) also requires support for this analog/digital source selection mechanism.

A DTV display typically has several analog A/V inputs, perhaps labeled Video-1, Video-2, etc. In order for the AV/C CONNECT command to have the desired effect, the user must configure the DTV in a setup menu to identify which set of A/V inputs should be associated with a given set-top box.

CONCLUSION

This paper has explored the specifics of the historic December 2002 NCTA/CEA Agreement as it relates to the IEEE 1394 interface on the digital cable set-top box, and the ramifications of the provisions therein. The features and benefits of the CEA-931-A protocol published this year by the Consumer Electronics Association were outlined.

One hopes that the NCTA/CEA Agreement, along with the standardized protocols they reference, will spark a frenzy of creativity among manufacturers to bring the convenience and exceptional video quality of digital technology to a new family of home network-based Consumer Electronics products.

Acknowledgements

The author wishes to thank the members of the CEA R-7.5 Home Networking committee, chaired by James Williamson of Sony Electronics, for the development of the CEA-931-A protocol. The necessary extensions to the Panel Subunit specification were completed in the A/V Working Group of the 1394 Trade Association, chaired by Scott Smyers.

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