HDMI Design and Initialization Sequence

Table of Contents

Glossary of Terms

4K Resolution - Approximately 4000 pixels wide used in the HDMI 1.4a specification, which is roughly 4 times the resolution of 1080p.

Audio Return Channel - The audio return path in HDMI 1.4a allows a TV to send audio data upstream to an A/V receiver, eliminating the need for a separate SPDIF audio connection. It supports the same audio formats as an SPDIF cable, which means it does not support high-definition audio or multi-channel PCM.

CEC - Consumer Electronics Control. One of the channels in an HDMI connection is dedicated to a set of advanced control functions, collectively known as CEC. When enabled by the manufacturer, CEC functionality allows connected devices to control each other in useful ways. For instance, a single command on a remote control can be used to play a DVD or to launch other complex activities across multiple devices in a home theater system.

DDC - The Display Data Channel, one of the channels in an HDMI connection. DDC allows devices to assess each others' capabilities and adjust themselves accordingly. For example, a DVD player can discover the maximum resolution of the monitor it is connected to by reading the monitor's EDID chip and optimize its signal output to match that monitor's display capabilities.

EDID - Extended Display Information Data, the data contained (in a small memory called EEPROM) on each DVI display or HDMI sink. The source device checks the display's DVI or HDMI port for the presence of an EDID PROM and uses the information inside to optimize the output video and/or audio format. All sink devices compliant to the HDMI specification must implement EDID.

HDCP - High-bandwidth Digital Content Protection, an authentication system developed by Intel designed to protect copyrighted audiovisual content. Most HDMI-enabled and DVI-enabled devices employ HDCP.

Hot Plug Detect - A pin on the HDMI connector that allows the source device to sense when a display device has been connected to it and its EDID is readable.

Source - A device that sends an HDMI signal, such as a DVD player or set-top box.

Sink - A device that receives an HDMI signal, such as an HDTV.

HDMI Repeater - A device that both receives and sends HDMI signals, such as an A/V receiver.

BCAPS Register - The source reads the sink's BCAPS register to determine whether the downstream device it is connected to is a display device or a repeater device.

Ro Value - Ro is a register value used to compare the source and sink and determine if the HDCP authentication has been completed successfully.

Ri Value - Ri value is the recalculation of the cipher between source and display.

V' Value - V' value is calculated when a repeater is involved in an installation. If the repeater is able to handle all of the downstream devices, it will calculate a V' value using all of the public key values of the downstream display devices. The source will calculate a similar value using the public keys. The V and V' values will be compared, and if they match, the authentication is successful.

Public Key(s) - The public keys (AKSV and BKSV, contained in the source and the sink respectively) are used to calculate the Ro value.

Scope

HDMI Design and Initialization Sequence is the second document in a series of HDMI whitepapers published by CEDIA. The first document, ***Introduction to HDMI Interface***, introduced HDMI standards and labeling guidelines. The objective of this document is to discuss the basic design of HDMI devices, the HDMI initialization sequence, and features in the HDMI 1.4a specification. A HDCP key limits guide is located in Appendix C.

Basic Design of HDMI

HDMI-compliant devices can be categorized into 3 types: sources, sinks and repeaters. Each device has one or more receiver(s) and/or transmitter(s), or it may contain both a receiver and a transmitter.

The source sends the content to be displayed. Examples of sources include set-top boxes, media servers, Blu-ray disc players, and computer graphic cards. A source only has an HDMI transmitter.

The sink receives the content from the source and provides it to the display so it can be viewed. Examples of a sink device include TVs and digital projectors. A sink can have one or more HDCP/HDMI receivers.

A repeater accepts content, decrypts it, then re-encrypts and finally retransmits the data [1]. A repeater may also perform some signal processing, such as up-converting video into a higher-resolution format, or splitting out the audio portion of the signal [1]. Repeaters have both HDMI inputs and outputs. Examples include A/V receivers that separate and amplify the audio signal while also retransmitting the video for display on a TV. A repeater can also transmit the protected content to multiple outputs for simultaneous display on several screens [1].

HDMI Initialization Sequence

During the authentication process, a source device and a sink device exchange their unique set of keys to determine the highest resolution (best possible format), correct audio outputs, and HDCP compliance. This process is depicted in figure 1 (see Appendix B for larger version).

The connection process begins when the source outputs a +5V signal on pin 18 to the sink, which sends back the +5V signal to the source on pin 19, which is the hot plug detect pin. If the hot plug is asserted, the source will read the capabilities of the sink device (see Figure 2). The capabilities are listed in the sink's EDID, which contains a multitude of information, including the acceptable video format(s), audio formats, and lip-sync delays. To learn more about EDID, see CEDIA's Introduction to HDMI whitepaper.

After the EDID is read properly, the source will send about 30 frames of unencrypted video to initialize the HDCP register of the sink device [5]. The source then typically reads the sink's HDCP BCAPS register to determine if the downstream device it is connected to is a display device or a repeater device [5]. Reading the BCAPS register is important because the repeater bit value is used in the calculation of the Ro value [5]. Ro is a register value used to compare the source and sink and determine whether the HDCP authentication has been completed successfully.

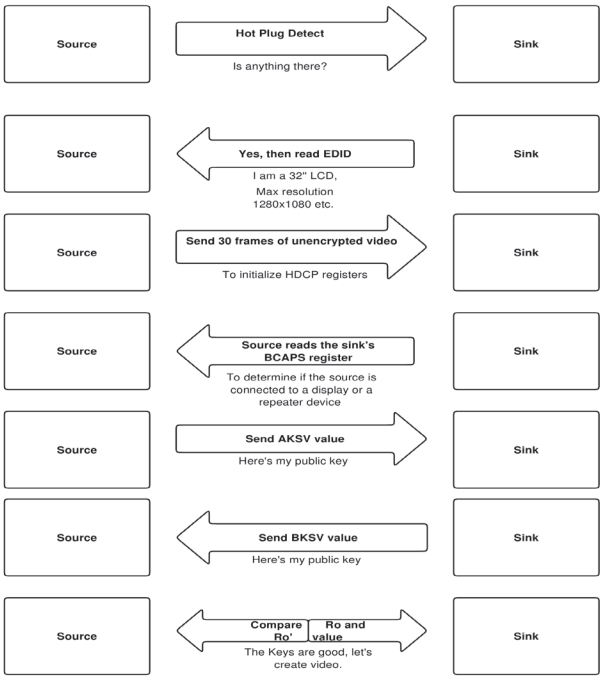


Figure 1: Visual Display of HDMI Initialization Sequence

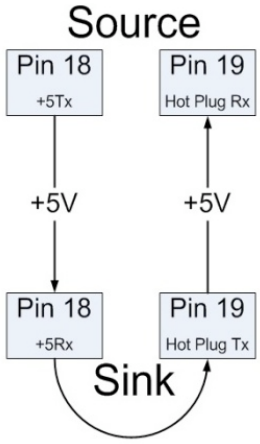


Figure 2: Visualizing Hot Plug Detect

The source will then send its public key (AKSV) and read the sink's public key (BKSV). In addition, specific timing requirements have to be met. For example, the source has to allow at least 100 milliseconds after writing the AKSV to the sink device before reading the Ro value [5]. **The first part of HDCP authentication is completed successfully when the source reads the Ro' value from the sink device and it matches the Ro value calculated by the source. If there is a mismatch between Ro of the source and Ro' of the display device, the source will repeat the first part of HDCP authentication [5]. The characteristic flashing seen in interoperability problems is the HDMI source sending the 30 frames of unencrypted video.** The HDMI source will then set the Encryption Enable and begin encrypting the content [5]. The source will continue to monitor encryption status using a periodic read of the Ri value.

When there is a repeater device involved in an installation, the initialization sequence and HDCP authentication is much more complex. The source has to ensure that all of the devices downstream from the repeater device are HDCP-compliant. The first part of the HDCP authentication process is the same, but the repeater device has to incorporate the public keys of all of the downstream devices into one register [5]. The repeater device has a maximum amount of time in which to collect the keys from the downstream devices, and some repeaters can handle only a limited number of downstream devices [5]. If the repeater is able to handle all of the devices, it will calculate a V' value using the public keys of those devices. The source will calculate a similar V value with the same public keys. The two values will be compared, and if they match, the authentication is successful [5].

HDCP's purpose is to prevent users from accessing high definition content during transmission from a source device to a sink device (i.e. from a set-top box to a TV). Each HDCP-capable device has 40 keys, and HDCP allows sources, sinks, and repeaters to be connected in a tree-shaped topology with up to seven levels and 127 devices [1]. HDCP can sometimes cause handshaking problems in which devices cannot establish a connection, especially with older high-definition displays. Problems are almost always in the source device, according to HDMI LLC, and tend to arise in one major area of implementation. **Sources have to support a function called "authenticate forever,"** which in layman's terms means the source must consistently send a signal inquiring whether its HDMI input is selected, even while another input is in use [2]. If a source device times out and stops inquiring, an HDCP authentication failure will most likely result.

Concluding Remarks

HDMI Initialization Sequence is a complex process, and it is important to have a good understanding of it. If one understands the initialization sequence, the ensuing troubleshooting of the system will be much easier. The technician or the system designer can diagnose based on the condition whether the source, sink, or repeater device is causing problems and needs replacement or a firmware upgrade. Troubleshooting will be the topic of a future whitepaper. In the next edition of this continuing series, we will cover the HDMI System Installation Best Practices.

References

1. Digital Content Protection. (2008, July). HDCP Deciphered. DCP.
2. HDMI LLC. (n.d.). HDMI for Installers. Retrieved June 19, 2010, from HDMI LLC: http://www.hdmi.org/installers/
3. Lu X. (2008, July 31). HDMI Demystified. AudioQuest
4. Quantum Data Corporation. (2009). Designing CEC into your next HDMI product
5. Quantum Data Corporation. (2010). HDMI Installer Workshop: Basic Troubleshooting Tips

Appendix A: HDMI 1.4a Features

HDMI 1.4a specification established protocols for a number of popular 3D display methods, including:

- Frame, line, or field alternative methods
- Side-by-side methods (full and half)
- 2D plus depth methods

3D video requires substantial data throughput, so a High Speed HDMI cable (with or without Ethernet) should be used, although standard HDMI cables will support the broadcast 3D formats (top and bottom, side by side).

The HDMI 1.4a specification has also added support for extremely high video resolutions that go far beyond today's 1080p displays. 4K is shorthand for 4,000 lines wide by 2,000 lines high, or roughly four times the resolution of a 1080p display [2]. Note that 4K resolution is 24p only, and therefore fits within the maximum data rate of a High Speed HDMI cable. Figure 2 shows the difference in quality between common display formats and 4K resolution.

Figure 2: A visual example of 4K Resolution Acquired from HDMI LLC

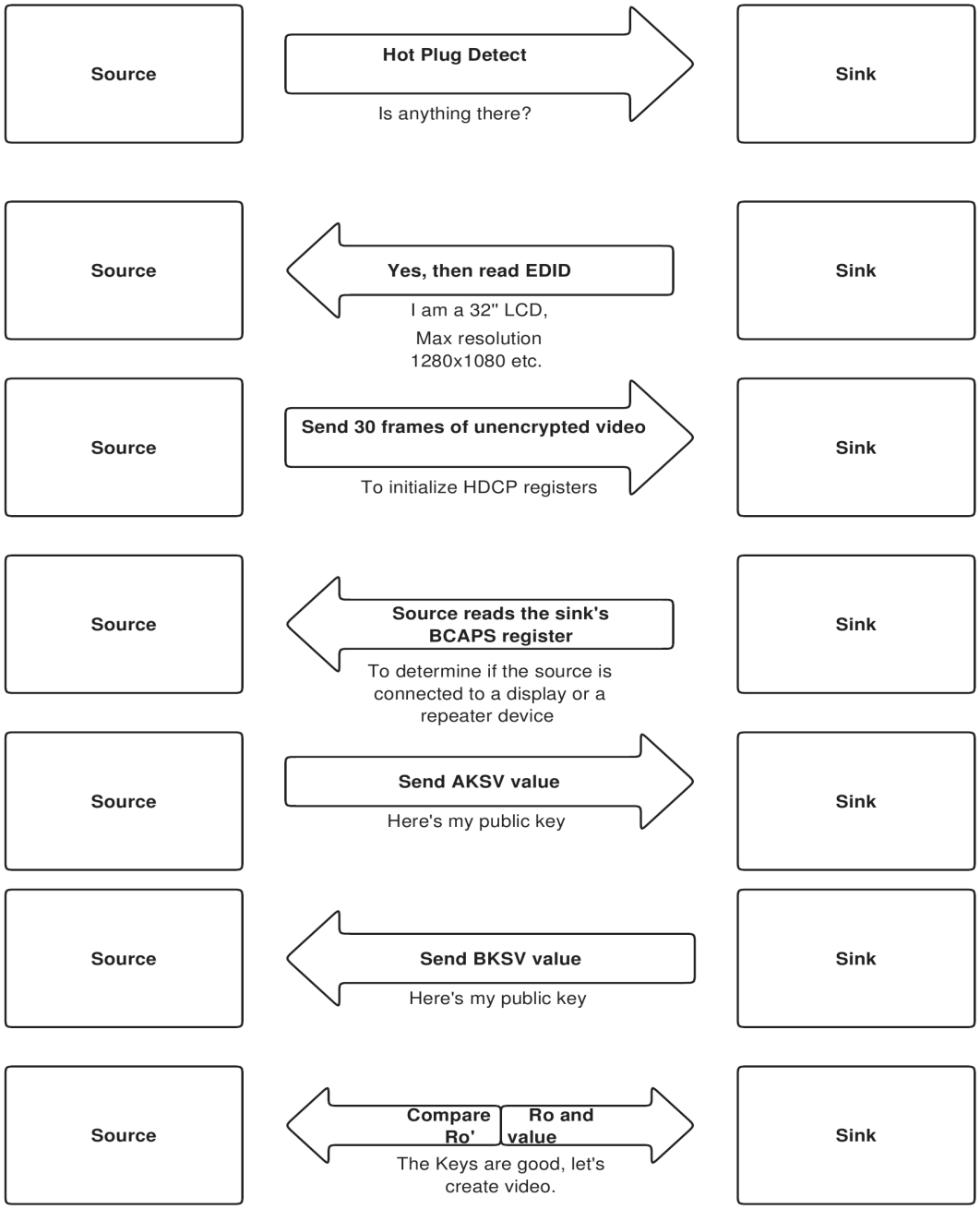
The Audio Return Channel in HDMI 1.4a enables a TV to send audio data "upstream" to an A/V receiver or surround audio controller, eliminating the need for any separate S/PDIF audio connection [2].

- An Audio Return Channel-enabled TV can either send or receive audio via HDMI, upstream or down stream, depending on system set-up and user preferences [2].
- LipSync functionality, introduced in HDMI 1.3, ensures that the audio stays matched to the video, auto matically compensating for any processor delays whether the audio is traveling upstream or downstream [2].

The HDMI Ethernet Channel allows internet-enabled HDMI devices to share an internet connection via the HDMI link, with no need for a separate Ethernet cable. It also provides the connection platform that will allow HDMI-enabled components to share content between devices with speeds up to 100 Mbps [2].

The CEC bus is a one-wire "party line" that connects up to 10 A/V devices through standard HDMI cabling [4]. CEC will automatically power on the appropriate products, route the DVD/Blu-ray's audio output through the A/V receiver to the attached speakers, and route the player's motion picture to the digital TV [4]. CEC enables automatic equipment discovery and simple "one touch" operation in HDMI interfaced systems. Most installers and designers prefer to turn off this functionality as it is usually not cross-brand compatible.

Appendix B: HDMI Initialization Sequence Diagram



Appendix C: HDCP Key Limits Guide

The following is a list of devices that Crestron has tested and the maximum number of devices each supports as of January 7, 2010.

High Definition Disc Players

Source Type	Manufacturer	Model	HDCP Keys
Blu-Ray	Denon	DVD-2500BT	3
Blu-Ray	Denon	DN-V500BD	3
Blu-Ray	Denon	BDP-1610	16
Blu-Ray	LG	BD-270	10
Blu-Ray	LG	Super Multi-Blue	16
Blu-Ray / HD-DVD	LG	LG-BD370	10
Blu-Ray / HD-DVD	LG	LG-BD390	16
Blu-Ray	Integra	DBS 6.9	3
Blu-Ray	Integra	DBS 30.1	3
Blu-Ray	Insignia	NS-2BRDVD	13
Blu-Ray	Magnavox	NB530MGX	3
Blu-Ray	Marantz	DV4001	9
Blu-Ray	Marantz	BD-7004	3
Blu-Ray	Marantz	BD-7003	3
Blu-Ray	Oppo	BDP-83	16
Blu-Ray	Panasonic	DMP-BD80	3
Blu-Ray	Panasonic	DMP-BD60	3
Blu-Ray	Panasonic	DMP-BD35	3
Blu-Ray	Panasonic	DMP-BD30	3
DVD (upscale 1080P)	Philips	DVP5990/12	9
DVD (upscale 1080i)	Philips	DVDR3475	3
Blu-Ray	Philips	BDP 7200	16
Blu-Ray	Pioneer	BD-LX80	16
Blu-Ray	Pioneer	BD-LX91	16
Blu-Ray	Pioneer Elite	BDP-05FD	16
Blu-Ray	Pioneer Elite	BDP-120	5
Blu-Ray	Pioneer	BDP-6000	16
Blu-Ray	Samsung	BD-P-3600	16
Blu-Ray	Samsung	BD-P-1600	7
Blu-Ray	Samsung	BD-P1500	7
Blu-Ray	Samsung	BD-P1000	16
Blu-Ray	Samsung	DBD-P1500	16
Blu-Ray	Samsung	BD-UP5000	10
Blu-Ray	Samsung	BD-T3600	16
Blu-Ray	Sharp	BD-HP21U	3

Blu-Ray	Sharp	BD-HP50	3
Blu-Ray	Sharp	BD-HP20	16
Blu-Ray	Sony	DVD-P DPX - 2380	9
Blu-Ray	Sony	BDZ-X100	8
Blu-Ray	Sony	BDP-S5000ES	16
Blu-Ray	Sony	BDP-S350	8
Blu-Ray	Sony	BDP-S360	8
Blu-Ray	Sony	BDP-S550	10

High Definition disc players (Continued)

Source Type	Manufacturer	Model	HDCP Keys
Blu-Ray	Sony	BDP-S2000ES	16
Blu-Ray	Sony	BDPS301	16
Upscaling DVD	Sony	DVP-NS71HP	16
Upscaling DVD	Sony	DVP-NS72HP	9
HD-DVD	Toshiba	HD-A3	16
HD-DVD	Toshiba	HD-A30	16
HD-DVD	Toshiba	HD-D3	16
HD-DVD	Toshiba	HD-E1	10
HD-DVD	Toshiba	HD-A20	10
HD-DVD	Toshiba	HD-A2KU	10
HD-DVD	Toshiba	HD-A35	16
Upscaling DVD	Yamaha	DV-S6160	9
Upscaling DVD	Zenith	DVB612	9

Cable, Tivo & Satellite Set Top Boxes

Source Type	Manufacturer	Model	HDCP Keys
IPTV Set Top Box	Advanced Digital Broadcast	ADB-3800W	16
Satellite receiver	DirecTV	HR21	NA
Dish Network Receiver	Dish Network	ViP-211	16
Satellite receiver	EchoStar Europe	Vi P211	16
Satellite receiver	Echostar STB	VIP-222	16
Hospitality Tuner	Enseo	HD2000	16
HD Set Top Box	Motorola	VIP 1200	16
Cable Box	Motorola	DCT-3200	1
Cable Box	Motorola	DCT-3412	1
Cable Box	Motorola	DCT-6412	1
Cable Box	Motorola	DCT-6416	1
Cable Box	Motorola	DCH-3416	1
Cable Box	Scientific Atlanta	Explorer 8300HD	16
Cable Box	Scientific Atlanta	Explorer 4250HD	16
Satellite receiver	Sky	Sky HD	16
HD Set Top Box	TivoHD	TivoHD	16

Media Servers, Game Systems / Other

Source Type	Manufacturer	Model	HDCP Keys
Video Processor	Anchor Bay	Edge 101	8
Media Server	Apple	Apple TV	16
Media Server	Crestron	ADMS	16
Media Player	DVICO	TViX HD M-6500A	none
Media Player	DVICO	EMM3211	10
Game System	Microsoft	XBOX 360	16
Media Server	Roku	N1000	16
Game System	Sony	PS3	16
Media Server	Vudu	VUDUBX100	16
Media Server	Western Digital	WDTV	0
Laptop	Haier	T628	16
Laptop	Sony	VGN-FW12G	16