High Definition Multimedia Interface (HDMI®)

Rob Tobias, Jim Chase, Jeff Park, and Brad Bramy

Contents

R. Tobias (✉) • J. Chase • J. Park • B. Bramy
HDMI Licensing, LLC, San Jose, CA, USA
e-mail: admin@hdmi.org; jchase@hdmi.org

J. Chen et al. (eds.), *Handbook of Visual Display Technology*,
DOI 10.1007/978-3-319-14346-0_37

Abstract

HDMI® technology has become ubiquitous in connecting high-definition and emerging 4K/ultra high-definition digital devices. The HDMI specification combines uncompressed high-definition video, multichannel audio, and data in a single digital interface to provide crystal-clear digital quality over a single cable. With its robust performance, broad feature support, ease of use, low cost, and worldwide adoption in the industry, HDMI-enabled devices now extend beyond the original consumer electronics applications to include portable, automotive, and commercial applications. The specification development history, an overview of the technology features and capabilities, its applications, and licensing requirements for HDMI-compliant products are covered in this chapter.

Terms

1080p	1920 × 1080 progressive scan display resolution
2160p	3840 × 2160 or 4096 × 2160 progressive scan display resolution
3DTV	3D digital televisions
4K	Ultra HD resolution four times the resolution of 1080p (2160p)
4K@50/60	4K ultra HD resolution video with 50/60 Hz refresh rate
4KTV	TV capable of displaying 4K resolution
ARC	Audio return channel
AV	Audio/video
CEC	Consumer electronics control
DDC	Display data channel
DVI	Digital visual interface
EDID	Extended display identification data
Gbps	Gigabits per second
HDCP	High-bandwidth digital content protection
HDMI	High-definition multimedia interface
HDR	High dynamic range
Mbps	Megabits per second
OTT	Over the top (transmission)
sRGB	Standard RGB color space (used by PC monitors)
TMDS	Transition minimized differential signaling
x.v.Color	xvYCC colorimetry

Introduction and Overview

HDMI, or high-definition multimedia interface, technology was introduced publicly at the 2003 consumer electronics show (CES) as a single cable solution to allow devices to share uncompressed high-definition video along with multichannel audio. Built on the same transition minimized differential signaling (TMDS) technology as its predecessor, DVI (see chapter "▶ Serial Display Interfaces"), HDMI technology has quickly grown to become the de facto standard of audio-

video (AV) connectivity in the home. The over 1,700 licensed HDMI adopters are expected to ship more than 800 million HDMI-compliant products in 2016 according to market research firm IHS Technology. This translates into an installed base of over four billion HDMI products deployed worldwide, nearly two billion of those products coming into the market since 2012 (IHS Technology 2014).

The HDMI founders – Hitachi Maxell, Ltd; Panasonic Corporation; Koninklijke Philips Electronics N.V.; Silicon Image, Inc.(a Lattice Semiconductor Company); Sony Corporation; Technicolor S.A.; and Toshiba Corporation– began work on HDMI in 2002 in an effort to improve on the DVI interface standard, specifically for consumer applications. In addition to native support for uncompressed high-definition video, additional capabilities including up to eight channels of digital audio, standard device control (CEC), and optional copy protection (via HDCP) were added to the protocol and small, consumer-friendly 19-pin connectors were defined. Support for interfacing to existing DVI-enabled devices via a passive adapter was also specified. The HDMI Specification Version 1.0 was released in December 2002, with several updates announced since. As of May 2016, HDMI Specification Version 2.0b, which among other features, added support for broadcast 4K@50/60 formats with High Dynamic Range (HDR), is the most current release.

The HDMI specification is available for licensing to HDMI adopters. The adopter agreement also gives access to the testing requirements and allows potential products to be tested at HDMI authorized test centers (ATC). Adopter fees include an annual license fee and a per-unit product royalty. Per-unit royalty discounts are also offered for compliant products that implement copy protection and follow HDMI trademark and logo guidelines. Licensing of the HDMI specification, which is confidential and restricted to adopters, is managed through HDMI licensing, LLC.

Applications and Benefits

As a high-performance alternative to analog interfaces such as composite video, S-video, coaxial cable, SCART, and component video, HDMI technology has found its way into the vast majority of home entertainment products. The combination of reduced cable complexity, uncompressed audio/video transmission, enhanced device control for consumers, lower cost for device makers, and high quality content distribution and protection for content owners have all contributed to the high adoption rate of HDMI technology.

HDMI technology currently has 100 % penetration in 4KTVs/HDTVs and Blu-ray Disc™ players (IHS Technology 2014). The latest generation of 4KTVs includes HDMI inputs to support up to 4K@50/60 content with HDR, and the new generation of UltraHD Blu-ray Disc™ players and other 4K HDR source devices using HDMI technology allow for delivery of premium 4K UltraHD HDR experience in the home today.

The success of HDMI technology in the home entertainment ecosystem has impacted related markets where the convenience of single cable connectivity brings ease of use to consumers. PC makers are increasingly adding HDMI connections to media center PCs to allow content to be viewed on larger cinema-style displays. In addition, HDMI adoption in the notebook PC and tablet segments continues to grow, enabling connectivity to an ever-increasing number of HDMI-enabled displays. More recently, over-the-top (OTT) video devices, or IPTV boxes, such as the Roku player, Apple TV, and Google Chromecast, Amazon Fire TV, which are essentially embedded STB systems enabling streaming media services and apps, have come to market with HDMI connectors.

Smaller form factor type C and type D HDMI connectors have specifically been introduced by the HDMI Consortium to support low power portable devices such as HD digital camcorders, digital still cameras, and mobile phones. The HDMI automotive connection system was introduced in HDMI Specification Version 1.4 and is currently available on many models from brands such as Honda and Dodge. For example, Honda Odyssey minivans allow external HDMI source devices to be connected to the Odyssey's entertainment system to be viewed on its integrated display/speaker system.

Content owners benefit from HDMI connectivity by providing a robust, uncompressed connection for high-definition content to be delivered from broadcast, locally stored, and streaming sources. Support for HDCP 1.4 and 2.2 offers improved copy protection over those offered in legacy analog distribution techniques.

Commercial and industrial applications for HDMI technology have grown recently as a result of a variety of adapter products introduced for application specific uses. Long distance connections between HDMI-enabled devices have been made possible by adapter products than allow HDMI signals to be sent over a variety of media, including fiber optic, wireless, and category 5/6 networking cable.

The success of HDMI technology within the home entertainment market and beyond to related segments is due to its robustness and ease of use. Figure 1 shows HDMI adoption by product type from 2012 to 2018, with strong growth through most of the categories.

Capabilities and Specifications

The HDMI specification defines a set of capabilities and performance specifications for four types of licensed products: source, sinks, repeaters, and cables. Source devices are designed to output video (and audio): examples include Blu-ray Disc players, desktop PCs, and set top boxes. Sink devices such as HDTV displays and PC monitors are capable of rendering compliant HDMI signals to decode and display audio and video, as well as respond to any CEC commands. Repeaters must act as both source and sink, passing through commands and signals as required by the upstream and downstream devices.

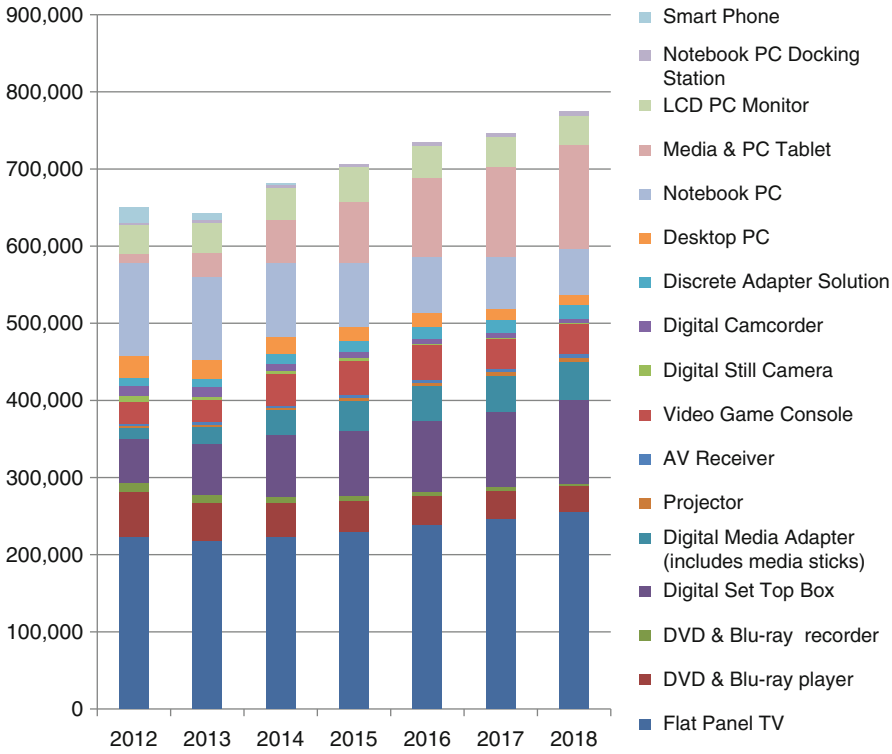

Fig. 1 HDMI device growth: 2012–2018 (Source: IHS Technology, Display Electronics Report 2014)

The HDMI system diagram is shown in Fig. 2. The HDMI interface includes four differential pairs (with shields) that carry the TMDS clock and data channels. These pairs carry audio, video, and supplemental data. The DDC channels manage configuration and control, while the CEC line enables optional consumer electronics control between devices connected in the same cluster. The optional HDMI Ethernet and audio return channel (HEAC) lines enable bidirectional Ethernet-compatible networking and two channel audio in the opposite direction from the TMDS lines. The hot plug detect line validates the presence of two directly connected devices

There are a total of 19 pins on each HDMI connector. While pin number conventions vary among the five connector types, common functional names and descriptions are as follows:

- TMDS data2+
- TMDS data2 shield
- TMDS data2−

- TMDS data1+

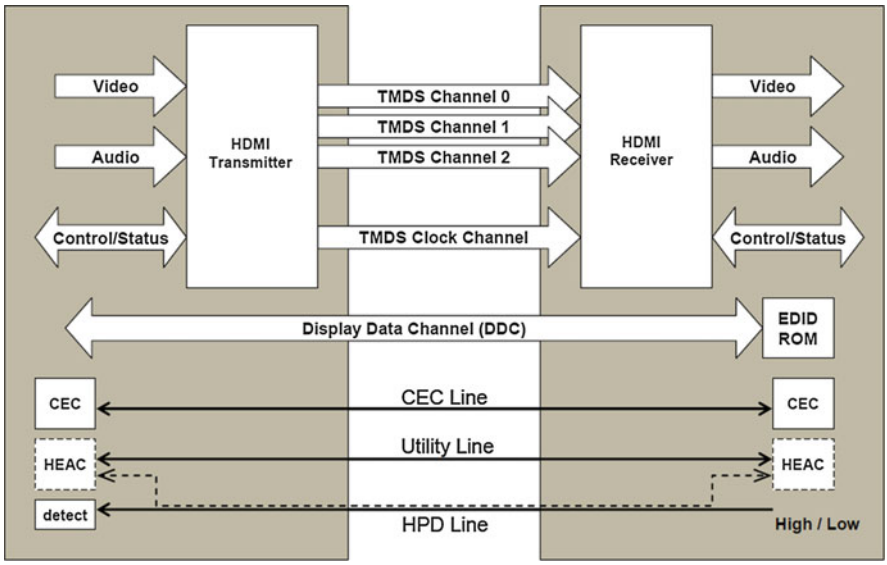

Fig. 2 HDMI system architecture overview (HDMI Licensing 2011)

- TMDS data1 shield
- TMDS data1−

- TMDS data0+
- TMDS data0 shield
- TMDS data0−

- TMDS clock+
- TMDS clock shield
- TMDS clock−

CEC	
SCL	I^2C serial clock for DDC
SDA	I^2C serial data line for DDC
DDC/CEC/HEC ground	
HEC data	HEC optionally used from HDMI 1.4 with Ethernet
Hot plug detect/HEC data+	HEC optionally used from HDMI 1.4 with Ethernet
+5 V power (max 50 mA)	Used with hot plug detect

Cables must be able to transmit all signals between the other device types; cable construction must be controlled to meet the strict timing requirements for transmitting high-speed uncompressed video over three pairs of differential TMDS lines

and the TMDS clock lines. Since HDMI Specification Version 1.4b, there have been five different cable types; each supports all mandatory features while higher video resolutions and the optional HDMI Ethernet channel are only supported in two. The new system identifies cables by features in an effort to make the capabilities of each cable clear; the cable type convention is no longer used. The new cable types are:

	HDMI standard cable (formerly known as HDMI 1.3 type 1) supports video resolutions up to 1080i at 60 frames per second (fps) with a 75 MHz TMDS clock frequency (up to 2.25 Gbps data rate for all three TMDS channels combined)
	HDMI standard with Ethernet cable, which supports up to 1080i/60 as above plus the optional HDMI Ethernet channel
	HDMI high-speed cable (formerly known as HDMI 1.3 type 2) supports 2D video resolutions up to 4K@60Hz, (up to 10.2 Gbps data rate for HDMI 1.4b based products and up to 18 Gbps data rate for HDMI 2.0 based devices). All HDMI 1.4b and HDMI 2.0 3D and 4KTV formats are also supported
	HDMI high speed with Ethernet cable support the same feature set ash HDMI high-speed cables plus the optional HDMI Ethernet channel
	HDMI standard automotive cable and type E connector supports the enhanced environmental requirements of the HDMI automotive connection system

Each of the four HDMI licensed product types has general capabilities that allow it to interoperate with other devices in a consistent way. Sources are connected to sinks or repeaters (which must act like a sink at one end) through a cable and vice versa. HDMI functionality can be broken down into several broad categories. Each will be covered in subsequent subsections.

Premium HDMI Cable Certification Program

On October 2015, the Premium HDMI Cable Certification Program was announced. The Program includes a best-practices design note and an expanded set of cable testing requirements. Under this program, Participants will test their HDMI cables at an HDMI Authorized Testing Center (ATC) to certify that their HDMI cables can reliably support the full 18 Gbps bandwidth of the HDMI 2.0 Specification, which is what is typically needed for the most advanced video formats such as 4K UltraHD, a wide color gamut, and High Dynamic Range (HDR). The Program also incorporates new testing guidelines for EMI levels to minimize unwanted interference with wireless signals in today's connected devices.

Once the cables have passed the testing requirements at an HDMI Authorized Testing Center (ATC) and are registered with HDMI Licensing, LLC, Participants can brand and promote their cables as Premium High Speed HDMI Cables or Premium High Speed HDMI Cables with Ethernet.

These cables will carry a tamper-proof, anti-counterfeit label to differentiate them from other HDMI cables. A mobile app that scans the label will allow manufacturers, distributors, retailers, and consumers to confirm the authenticity of Premium High Speed HDMI Cables.

Power Up and Device Discovery

When two active devices are connected and powered on, the hot plug detect signal is asserted in the sink and the sink responds with extended display identification data (EDID), which is sent over the DDC lines, to allow the source to discover the sink's capabilities. This in turn enables the source to supply content matching the configuration of the sink.

Content Transmission

Video, audio, and auxiliary data are transmitted across the three TMDS data channels. The TMDS clock, which runs at the video pixel rate, is transmitted across the TMDS clock line. Data is encoded as an equalized 10-bit sequence with data rate correspondingly equal to 10X the clock rate. A variety of video formats are supported with color depths ranging from 24 to 48 bits per pixel. Video encoding schemes include sRGB, YCbCr 4:4:4 or YCbCr 4:2:2 or YCbCr 4:2:0.

Stereo LPCM audio at 32, 44.1, or 48 kHz is the minimum requirement for HDMI compliance; optional audio formats up to 32 channels of audio and up to 1,536 kHz audio sampling rate are specified. Support for compressed surround sound and One-bit-audio formats is also specified, including lossless HD audio formats such as Dolby TrueHD and DTS-HD MA.

Content Protection

The HDMI Specification itself does not mandate, though it recommends, copy protection of protected content. The only requirement is that if HDCP is used, it shall adhere to HDCP Specification Version 1.4. Other content protection schemes are not referenced. HDCP 2.2 is optional.

Downstream Device Control via Consumer Electronics Channel (CEC)

The consumer electronics control (CEC) line is a bidirectional serial line using the AV. link protocol to perform remote control functions. CEC allows the remote of one HDMI-compliant product to control functions of other HDMI-compliant products connected to it. While physical CEC wiring is required in all HDMI licensed products, the use of CEC in a product is optional. If CEC is implemented, the two functions “one touch play” and “system standby” must be implemented; others are defined in the specification and are optional.

With HDMI 2.0, CEC functionality has been enhanced with CEC 2.0. CEC 2.0 provides expanded command and control for devices that implement CEC

HDMI 2.0 devices that implement CEC 2.0 must implement the existing CEC to support the following end-user CEC features:

- One touch play
- Standby
- Remote control pass through
- System audio control
- One touch record

Optional Features

Since the introduction of HDMI Specification Version 1.3, many new features have been added to address new product categories, features, and performance capabilities. These include extended color depths, 3D video display, audio return channel (ARC), HDMI Ethernet channel (HEC), and new color spaces for digital cameras. It should be noted that implementing any or all of these features is optional on a per-product basis. If implemented, these features must be clearly documented when the device is certified and must meet the performance requirements detailed in the HDMI specification.

Version History

The HDMI specification has undergone several enhancements since its first release as Rev 1.0 in December 2002. Subsequent releases have targeted higher data rates for higher resolution video (up to and including 4K@50/60), enhanced color fidelity, higher quality audio, support for expanded device types, additional audio and video formats, and more. Below is a brief chronology of each key version release, with a description of the main enhancements introduced.

HDMI Specification Version 1.0 (December 2002)

The initial release of the HDMI specification, prior to CES 2003, supported a maximum clock rate of 165 MHz which correlates to a total TMDS bandwidth (three TMDS data channels combined) of 4.95 Gbps. Maximum video resolution support was 1080p at 60Hz at 24-bit color depth, which utilizes 3.96 Gbps of throughput. Audio was specified at eight channels of LPCM at up to 192 kHz, 24-bit resolution.

HDMI Specification Version 1.1 (May 2004)

The primary change to HDMI Specification Version1.1 was the addition of support for DVD-audio and its multichannel encrypted content.

HDMI Specification Version 1.2 (August 2005)

This version, in addition to adding support for one-bit-audio formats used by super audio CD (SACD) – the primary alternative to DVD-audio – featured a series of enhancements designed to support PC applications as an improvement to DVI. These improvements included: (a) the allowed use of type A connectors in PC sources and displays with full support of PC video resolutions, (b) the option to use

native PC sRGB color spaces in addition to the YCbCr color space defined for CE applications, and (c) support for low voltage/AC coupled sourced in new displays to allow notebook PCs to connect to larger screen displays.

HDMI Specification Version 1.2a (December 2005)

CEC features and command sets were fully specified in HDMI Specification Version 1.2a. CEC compliance tests were also established.

HDMI Specification Version 1.3 (June 2006)

HDMI Specification Version 1.3 marked a major improvement in performance in many areas of the feature set. Most notably, the clock rate was increased to 340 MHz, which corresponds to a combined channel throughput of 10.2 Gbps. Color depth was increased as "Deep Color" and was introduced allowing for an increase in the 8-bit color-bit depth to 10-, 12-, and up to 16-bits per color. Deep color provides an increase in the shades of colors for more precise image representation. x.v.Color was also added, which allows for the representation of more colors in the color palette than are defined in the RGB color space.

Audio enhancements included support for output of the Dolby TrueHD and DTS-HD master audio lossless formats, as well as an automatic AV synchronization protocol to allow for different processing delays in decoding audio and video data streams inside ICs and devices.

Two classes of HDMI cables were defined; Category 1 cables were specified to work up to 75 MHz clock rate while category 2 cables supported the full 340 MHz clock rate. In addition, the HDMI type C "mini" connector was defined for use in portable devices.

HDMI Specification Version 1.3a (November 2006)

Several modifications for Type C connections and source termination recommendations were made in HDMI Specification Version 1.3a. It also modified CEC capacitance limits, provided quantization details for sRGB color space, and broadened SACD audio format support. CEC commands were further enhanced.

HDMI Specification Versions 1.3b (March 2007), 1.3b1 (November 2007), and 1.3c (August 2008)

Each of these versions provides enhancements to the testing requirements for compliance. No new features or performance specifications were introduced.

HDMI Specification Version 1.4 (June 2009)

HDMI Specification Version 1.4 added support for several substantial new features. The higher bandwidth of HDMI Specification Version 1.3 was leveraged by adding definition of new video display formats for 3D resolutions for cinema and gaming applications as well as ultra high definition (UHD)/4KTV (3840 × 2160p at 24/25/30 Hz and 4096 × 2160p at 24 Hz). To support the emergence of Internet accessible content in CE devices, support for 100 Mbps Ethernet was added, and two new cable types were defined to support this feature. Audio return channel (ARC) allows display devices to send audio information back to a receiver for decoding. New color spaces were defined to support for digital still cameras. Content type was defined, which provided the capacity for source devices to define the type of content in real time so that a display can be configured based on the content type to provide an optimized viewing experience. Finally, two new connection options, the micro-connector (type D) and the type E connection system for embedded automotive distribution were defined.

HDMI Specification Version 1.4a (March 2010)

3D broadcast formats were defined in the HDMI Specification Version1.4a. Further details were provided on mandatory, optional, and informative 3D formats for all media types.

HDMI Specification Version 1.4b (Nov. 2011)

Minor editorial update.

HDMI Specification Version 2.0 (September 2013)

HDMI Specification Version 2.0, which is backward compatible with earlier versions of the HDMI specifications, significantly increases bandwidth up to 18 Gbps and adds key enhancements to support continuing market requirements for enhancing the consumer video and audio experience. New functionality includes:

- 4K@50/60, (2160p), which is four times the clarity of 1080p/60 video resolution
- Up to 32 audio channels for a multidimensional immersive audio experience
- Up to 1536 kHz audio sample frequency for the highest audio fidelity
- Simultaneous delivery of dual video streams to multiple users on the same screen
- Simultaneous delivery of multi-stream audio to multiple users (up to 4)
- Support for the wide angle theatrical 21:9 video aspect ratio
- Dynamic synchronization of video and audio streams

- CEC extensions provide expanded command and control of consumer electronics devices through a single control point (CEC 2.0)

HDMI 2.0 does not define new cables or new connectors. Current high-speed cables (Category 2 cables) are capable of carrying the increased bandwidth.

HDMI Specification Version 2.0a (March 2015)

Support for High Dynamic Range (HDR) feature was added by including HDR Static Metadata support through the following additions to the specification:

- Added reference to CEA-861.3
- Added EOTF to Section 4.3.2
- Added Dynamic Range and Mastering InfoFrame to Table 8 1: Packet Types
- Added Section 8.7: Dynamic Range and Mastering InfoFrame
- Added Section 10.3.4: HDR Static Metadata Data Block

Minor editorial updates which incorporated previously released erratas were also included in this update.

HDMI Specification Version 2.0b (March 2016)

Minor editorial updates and clarifications for BT.2020 and audio formats usage.

Licensing and Testing Requirements

All manufacturers interested in developing HDMI-compliant products (which include cables, sources, sinks, or repeaters) must sign the HDMI adopter agreement. This agreement requires adopters to develop products in accordance with the specification, certify the product in accordance with the latest released specification version and compliance test specification (CTS), and adhere to the approved trademark and logo usage guidelines (ATLUG).

The specification and CTS are developed to enable manufacturers to develop HDMI-enabled products. When an adopter develops a new HDMI-enabled product in one of the four licensed product categories, it must be tested for compliance at an HDMI authorized test center. (As of this writing there are 10 ATCs worldwide.) Once an adopter successfully completes ATC testing for a licensed product, subsequent products in the same category (with the exception of HDMI cables) may be self-tested. In addition, there are third-party companies that offer advanced interoperability testing of licensed HDMI products to further evaluate a specific device's performance with other products in the HDMI ecosystem. In all cases, the adopter is ultimately responsible to ensure their products are compliant.

HDMI adopters are required to pay annual license and royalty fees. The HDMI royalty structure is as follows:

- High volume manufacturers (more than 5,000 total units per year)
  - $0.15 per unit from the end-product manufacturer
  - $0.05 per unit if the product uses the HDMI logo in accordance with the ATLUG
  - $0.01 per unit discount if the end-product implements HDCP
- Low volume manufacturers (less than 5,000 total units per year)
  - Same per-product royalty schedule as the high volume manufacturer above
  - Additional $1.00 per unit from the end-product manufacturer administrative fee

In addition to per-unit royalties, HDMI licensing, LLC, the licensing agent for the HDMI specification, charges $5,000 (for low volume manufacturers) or $10,000 (for high volume manufacturers) as an annual licensing fee. More details on becoming an adopter can be obtained from the HDMI consortium website www.hdmi.org.

HDMI Forum, Inc

The HDMI Forum was formed to foster broader industry participation in the development of the next generation of the HDMI specification and to support an ecosystem of interoperable HDMI-enabled products. The organization brings together the world's leading manufacturers of consumer electronics, personal computers, mobile devices, cables, and components.

Chartered as a nonprofit, mutual benefit corporation, the mission of the HDMI Forum is to:

- Create and develop new versions of the HDMI specification and the compliance test specification, incorporating new and improved functionality
- Encourage and promote the adoption and widespread use of its specification worldwide
- Support an ecosystem of fully interoperable HDMI-enabled products
- Provide an open and nondiscriminatory licensing program with respect to its specifications

Membership is open to anyone wishing to make an active and material contribution to the development of future HDMI specifications. Members of the HDMI Forum are eligible to participate in the technical working group, where details of the new specifications will be developed, as well as in other working groups and general meetings of the forum. More information on the HDMI Forum can be found at www.hdmiforum.org.

Conclusion

The availability of high-definition video content and rise of 4K UltraHD HDR capabilities have generated unprecedented demand for low cost, powerful, easy-to-use consumer electronics devices. Consumer electronics makers continue to develop innovative products that offer increasing capabilities and an improved viewing experience, for their entire product line. The HDMI interface has helped to usher in this concept of "anytime, anywhere" content through its easy to implement, easy-to-use solution. HDMI technology continues to evolve to meet market needs for robust, feature-rich connections between digital media products, and is expanding to address new markets and applications where high-definition content can be shared easily and securely.

Further Reading

DDWG (4/1999) Digital visual interface, Revision 1.0 3. Digital Content Protection LLC, High-bandwidth Digital Content Protection System, Rev. 1.4, 2.2
HDMI Licensing (2011) LLC (11/2011) HDMI specification 1.4b
IHS Technology (2014) Display Electronics Report Interface Battleground
O'Donnell B (2006) IDC (12/2006) HDMI™: the digital display link