Audio Transport over HDMI

How good do you want it to sound?

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High-Definition Multimedia Interface - history

- Developed by 7 companies in 2002/3 – Hitachi, MEI, Philips, Silicon Image, Sony, Thomson, Toshiba

- HDMI is based on DVI (Digital Visual Interface) for *RGB digital video*

- HDMI is backwards compatible with DVI and adds
  - Audio, LPCM to 8 channels or compressed
  - YCrCb digital video support (4:2:2 and 4:2:4)
  - Universal CEC (Consumer Electronics Control)
  - Auto configuration via E-EDID interrogation
  - Compact and sub-miniature connectors
  - A compliance program
High-Definition Multimedia Interface - history

- There have been 5 main versions in 8 years. The additions are all *optional*, for continued backwards support.

- HDMI 1.0 – uncompressed audio, plus SD and HD video, over a single cable at up to 5.1 Gb/s
- HDMI 1.1 – adds DVD-Audio support
- HDMI 1.2 – adds native SACD (DSD) support plus CEC
- HDMI 1.3 – doubles bandwidth to 10.2 Gb/s, adds HD codec support (Dolby and DTS)
- HDMI 1.4 – adds 3D video support, plus 100Mb/s Ethernet and ARC (audio return channel)
HDMI Connector vs DVI

**HDMI Connector**
- Single-link: Type A

**Dual-link**: Type B, 5mm wider than Type A.

**DVI1.0 Connector**

Type A is meant for CE devices
Type B is meant for PCs

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HDMI Payload (1.0 to 1.3)

- Video pixels, pixel clock and sync signals
- Video stream information (Aux. Video Information)
- Audio samples & information about audio clock
- Audio stream information (Audio InfoFrame)
- Control and auxiliary information

Back-channel Information (Source ← Sink)
- Sink-supported video formats
- Sink-supported audio formats
- Other Sink characteristics

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HDMI - typical system with a Repeater
HDMI Digital Link Capabilities

- Bandwidth up to 5.1/10.2 Gb/s
  - 24,30,36,48-bit video at 25 to 165/340 MHz clock
  - 1080p video plus 8ch audio at 24-bits, 192ks/s
  - Ethernet to 100Mb/s (HDMI 1.4 only)

- Range
  - Original specification says 5m
  - Depends on cable (thicker is better – skin effect)
  - Can be extended with equalisers
HDMI Range at 165MHz clock rate

Wire Gauge

32 AWG 30 AWG 28 AWG 26 AWG 24 AWG 22 AWG

Range

0m 10m 20m 30m 40m 50m 60m 70m

Equalised

Unequalised
HDMI Signal Coding

- Uses a DC-coupled TMDS link
  - 100 ohm balanced pairs with shields
  - 50 ohm termination
  - Nominal signal level 500mV p-p (10mA current switch)

- 1 clock channel and 3 data channels
  - 6 channels in type B (PC only)

- Coding is 8 to 10 in a transition minimised and DC-balanced sequence
Signals on the HDMI Cable

- 1 clock line, 3 data lines

- Non-coherent clock uses PLL in Tx and Rx to align
  - Clock typically 27, 74.25, 165 MHz
  - Pixel rate 1x, 2x, 5x or 10x clock rate
Data Layout in a Video Frame (example)
Data Island Payload

- Audio data and much auxiliary information are carried in Packets within Data Islands
- HSYNC, VSYNC are also carried during the Data Island Periods
- Packet Types:
  - Audio Samples and Audio Stream
  - Audio Clock Recovery data
  - InfoFrames: Auxiliary Video IF (AVI), Audio IF, Vendor-Specific IF (includes 4K and 3D video format info)
Auxiliary Video Info Frame

Sends video control data from source to sink:

- RGB/YCrCb and pixel encoding (4:4:4; 4:2:2)
- Quantisation range (full or limited)
- Colorimetry
- Aspect ratio
- Overscan
- Video Format ID code – 2D, 3D, 4K, additional frame rates
- Pixel repetition factor (SD video requires 2x or more pixel repetitions to carry enough audio data and be >25MHz)
- Content type (video, photo, graphics, game)
Audio Info Frame

Sends audio control data from source to sink,
(to supplement IEC 60958 Channel Status bits and
IEC 61937 Burst Info and/or stream data embedded
in the audio packets)

- Channel count
- Sample Frequency or presence of DSD stream
- Channel/speaker allocations
- Level Shift Value (for downmixing)
- LFE channel playback level (0 or +10dB)
HDMI – Supported Audio Formats

- **HDMI 1.0** 2ch 24-bit, 32, 44.1, 48 kHz; DD, DTS
- **HDMI 1.1** adds 8ch 24-bit, 32 - 96kHz (DVD-A)
- **HDMI 1.2** adds native and compressed DSD
- **HDMI 1.3** adds 8ch 24/192; Dolby True HD, Dolby Digital+, DTS-HD and DTS Master Audio (HD-DVD and BD formats)
- **HDMI 1.4** adds HEAC (Ethernet 100-base TX and Audio Return Channel). ARC must support IEC 60958-1 (6.144MHz clock, 2 ch 16-bit LPCM at 32, 44.1, 48 kHz). Compressed audio support is optional.
HDMI – DDC Channel

- Allows source to interrogate the capabilities of the sink
- I2C signalling with 100kHz clock
- E-EDID data structure according to:
  - EIA/CEA-861B
  - VESA Enhanced EDID
HDMI – DDC Connection

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HDMI – Audio Processor Repeater

Source → Audio Sink → Video Sink

EDID → DDR → EDID
HDMI – CEC Channel

- Uses the industry standard AV link protocol, originally used in analogue TVs, VCRs etc
- Used for remote control functions – 1 device to control everything
- One-wire bidirectional serial bus
- Mostly defined in HDMI Specification 1.2a
- *Additions in HDMI 1.3a included a method for improved audio clock recovery for a compatible source and sink/repeater*
Audio Clock Regeneration at an HDMI sink

- There is no audio sample clock transmitted in HDMI – the TDMS clock is video related
- HDMI does not in general specify how to do ACR
- ACR is usually carried out in the sink’s HDMI receiver IC - an electrically very noisy environment
- If there is any jitter on the recovered audio clock and it is applied to the audio DACs in the sink, then this will affect the final audio quality
- Buffering of the audio data cannot fix this
Audio Clock Regeneration at an HDMI sink (2)

- HDMI does specify one possible way which works quite well when the sink has coherent audio and video clocks:
  - Source transmits the ratio of TMDS clock to audio clock as a fraction with integers N and CTS where
    \[ N = \text{Numerator} \text{ and } CTS = \text{Cycle Time Stamp} \]

\[
128 \times F_s = Ftmds\_clock \times \frac{N}{CTS} \\
\text{and} \\
N \text{ is around } 128 \times F_s/1000
\]
ACR architecture - source

Figure 7-1 Audio Clock Regeneration model

Note: N and CTS values are transmitted using the "Audio Clock Regeneration" packet. Video Clock is transmitted on TMDS Clock Channel.
ACR architecture – sink or repeater

Figure 7-2 Optional Implementation: Audio Sink
ACR architecture – N and CTS at 48kHz

<table>
<thead>
<tr>
<th>TMDS Clock (MHz)</th>
<th>48 kHz</th>
<th>96 kHz</th>
<th>192 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>CTS</td>
<td>N</td>
</tr>
<tr>
<td>25.2 / 1.001</td>
<td>6604</td>
<td>26125</td>
<td>13720</td>
</tr>
<tr>
<td>25.2</td>
<td>6144</td>
<td>25200</td>
<td>12286</td>
</tr>
<tr>
<td>27</td>
<td>6144</td>
<td>27000</td>
<td>12286</td>
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<tr>
<td>27 x 1.001</td>
<td>6144</td>
<td>27027</td>
<td>12286</td>
</tr>
<tr>
<td>54</td>
<td>6144</td>
<td>54000</td>
<td>12286</td>
</tr>
<tr>
<td>54 x 1.001</td>
<td>6144</td>
<td>54054</td>
<td>12286</td>
</tr>
<tr>
<td>74.25 / 1.001</td>
<td>11648</td>
<td>140625</td>
<td>23296</td>
</tr>
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<td>74.25</td>
<td>6144</td>
<td>74250</td>
<td>12286</td>
</tr>
<tr>
<td>148.5 / 1.001</td>
<td>5824</td>
<td>140625</td>
<td>11648</td>
</tr>
<tr>
<td>148.5</td>
<td>6144</td>
<td>148500</td>
<td>12286</td>
</tr>
<tr>
<td>297 / 1.001</td>
<td>5824</td>
<td>281250</td>
<td>11648</td>
</tr>
<tr>
<td>297</td>
<td>5120</td>
<td>247500</td>
<td>10240</td>
</tr>
<tr>
<td>Other</td>
<td>6144</td>
<td>measured</td>
<td>12286</td>
</tr>
</tbody>
</table>

Table 7-3 Recommended N and Expected CTS for 48kHz and Multiples

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Using CEC for ARC (Audio Rate Control)

- Since HDMI 1.3 a CEC command called <set audio rate> allows a sink or repeater to instruct a *compatible* source slightly and continuously to vary its audio clock to track a stable master clock in the sink.

- Has been used by several large CE vendors, e.g.
  - Pioneer PQLS
  - Sony HATS
  - Denon Link (uses CAT5 for control)

- BUT - all proprietary – need BD player /AVR from the same brand – *cannot mix and match!*
Examples of audio jitter over S/PDIF & HDMI

Jitter at 96kHz/24bit

< JITTER FREQUENCY >

Total correlated jitter (re. -3dBFs into 47kohm) =
851psec (Left Channel)
647psec (Right Channel)

HDMI Jitter at 96kHz/24bit

< JITTER FREQUENCY >

Total correlated jitter (re. -2.87dBV into 47kohm) =
390psec (Left Channel)
362psec (Right Channel)

Denon AVR-3808A – Hi-Fi News Feb 2009

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Examples of audio jitter over S/PDIF & HDMI (2)

Onkyo TX-NR906 - Hi-fi News Feb 2009

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Examples of audio jitter over S/PDIF & HDMI (3)

Pioneer SC-LX83 - Hi-fi News Sept 2010

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Examples of audio jitter over HDMI with ARC

Pioneer SC-LX83 - Hi-fi News Sept 2010

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And finally – jitter using analogue interface from DVD at 48 and 96 kHz (Arcam DV139)

Audio output at 48 kHz
Total correlated jitter = 57ps

Audio output at 96 kHz
Total correlated jitter = 47ps

AES European Conference 2006
Examples of audio jitter over S/PDIF & HDMI (4)

48kHz/24-bit Jitter  PASS

HDMI - Jitter at 48kHz  PASS

Total correlated Jitter (re: -3dBFS into 60000ohm) =
51ps (Left Channel)
54ps (Right Channel)

Arcam AVR600 - Hi-fi News July 2009

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Audio Transport over HDMI - conclusions

- In CE space HDMI is here to stay. It supports all SD and HD audio formats to 8 channels and now includes an (SD) Audio Return Channel.

- Many more channels than 8 with BD audio formats.

- **But**….the audio clock is only loosely related to the dominant TMDS (video) clock.

- Most CE companies still implement ACR poorly.
The End!

Thank you for your time and attention!

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