BEHIND THE SCENES OF DVI, HDMI & DISPLAYPORT

BASICS
Video signals
The trick

Viewing experience

- Resolution
- Framerate
- Dynamic range
  - black level, luminance
- Color gamut
- Color depth
Video signals

Frames

Pixels

Subpixels
(Red, Green, Blue)

Video signals

Resolution

2 megapixels / 1920 x 1080 / Full HD
Behind the Scenes of DVI, HDMI and DisplayPort

**Video signals**

<table>
<thead>
<tr>
<th>Refresh rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 Hz</td>
</tr>
<tr>
<td>120 Hz</td>
</tr>
</tbody>
</table>

**Video signals**

**Color depth**
Behind the Scenes of DVI, HDMI and DisplayPort

Color space

Video signals

Video interfaces
DVI
Digital Visual Interface
Behind the Scenes of DVI, HDMI and DisplayPort

DVI pins

DVI full frame

Active video area
Active columns
Active lines

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DVI full frame

Blanking interval: Control data
- VSync (new frame)
- HSync (new line)

Active video area: RGB pixels

Active lines: 2200 pixels
Active columns: 1920 pixels
Active video area: 41 lines

Typical HSYNC values: 25 – 90 kHz
Typical VSYNC values: 24 – 120 Hz

VSync = Frame Rate (FPS)

Pixel clock frequency (f_{PCLK})

\[ f_{PCLK} = \frac{X_{FULL} \times Y_{FULL} \times fps}{240} \]

X_{FULL}: total number of columns
Y_{FULL}: total number of lines
fps: frame rate

X_{FULL}: 2200 pixels
Y_{FULL}: 1125 lines
fps: 60

\[ f_{PCLK} = 2200 \times 1125 \times 60 \]

f_{PCLK} = 148.5 MHz
Example: 1920×1080@60Hz

- Frame rate (VSync): 60 frames per sec
- Pixel clock: 148.5 MHz
- Data rate: 1.485 Gb / s / color
- Total data rate: 4.455 Gb/s

Worst case DVI signal?

- Pixel clock: 2080 × 1235 × 60 = 154 MHz
- Pixel clock: 2160 × 1250 × 60 = 162 MHz

1600×1200@60 has smaller active video area, but higher pixel clock and data rate!
Digital video representation

DVI → 24 bits/pixel
8 bits/color
8 bit = 2^8 = 256 levels

3 components (R,G,B):
256 × 256 × 256
= 16.7 million colors

Digital video representation

3×8 bits/pixel

3×10 bits/pixel

Binary representation  Electrical representation  Minimizing transitions

The two extra bits carry coding information.

T.M.D.S. = Transition Minimized Differential Signaling
Why minimize transitions?

Electromagnetic noise

Transition minimizing

10 bit TMDS = 8 bit + 2 bit (encoding)
T.M.D.S. – Single ended vs. differential signals

Noise affects both wires the same way.

Difference:
Digital video transmission

T.M.D.S. = Transition Minimized Differential Signaling

Issue 1 – Attenuation

Depends on:
- Length of cable
- Diameter of wires
- Frequency

Attenuation

Attenuation

Attenuation
Issue 1 – Attenuation

What can you do?

1. Decrease the frequency
   → lower resolution
   → lower refresh rate
   → reduced blanking signal
2. Use thicker cables
3. Use shorter cables (optimize cable path)
4. Use equalization (EQ)

What is EQ?

1. Amplify
2. Shape
Issue 2 – Crosstalk between pairs

What can you do?
Use shielding

Source

Sink

Issue 3 – Intra-pair skew

What can you do?
Use reclocking

Source

Sink
Understanding jitter

000

001

010

011

100

101

110

111

Millions of samples drawn on top of each other

It’s called ‘Eye pattern’
Understanding jitter

Can’t touch this!

Timing problems

Ideal transition time
Behind the Scenes of DVI, HDMI and DisplayPort

Timing problems

Must reclock the signal!

Why does jitter matter?

Don’t care

Eliminate
Timing problems

Samples are taken at this moment

Amplitude problems

Samples are taken at this moment
Amplitude problems

Attenuation

Must use equalization!

Issue 4 – Inter-pair skew

What can you do?

Use reclocking
Behind the Scenes of DVI, HDMI and DisplayPort

TMDS reclocking

Re-aligning max. 1 bit

Pixel Accurate Reclocking

Re-aligning the pixels
Transmission errors

Errors are aggregated when using multiple non-reclocking DVI repeaters.

Noise
Random red, green or blue dots

“Jaggies”
Flashing horizontal lines

Loss of sync
Unstable picture

Pixel Accurate Reclocking repairs all of these errors.

EDID
Extended Display Identification Data
EDID: the passport of the display

The source needs to determine the appropriate formats:
Resolution, frame rate, HDMI/DVI mode, color space, color depth, audio format...

EDID – Extended Display Identification Data
VESA defined standard, 128-byte descriptor structure

Optional 128-byte extensions
A common extension in DTVs: CEA extension

Basic handshaking at startup

I'm present → Power 5V → I'm ready
Read EDID → Hotplug → Send EDID
HDCP handshaking → Display Data Channel → HDCP handshaking
Send video and audio → TMDS lanes
An EDID example

**EDID header**

Manufacturer PN PID: GSM (Goldstar Company)
Product code: 6676
Serial number: 16843009
Date: 01/2009
Screen size: 70 cm × 39 cm (27.6" × 15.4")

Standby: supported
Suspend: supported
Active off: supported

**Preferred timing mode** (most likely signal to be displayed)

- **Pixel clock:** 148.5 MHz
- **Active resolution:** 1920×1080p60
- **Horizontal blanking:** 160 pixels
- **Vertical blanking:** 31 lines
- **Horizontal Sync offset:** 48 pixels
- **Vertical Sync offset:** 3 lines
- **HSync pulse width:** 32 pixels
- **VSync pulse width:** 5 lines
- **HSync polarity:** positive
- **VSync polarity:** negative
- **Scan mode:** progressive
- **Border size:** 0 mm × 0 mm
Behind the Scenes of DVI, HDMI and DisplayPort

An EDID example

2nd detailed timing descriptor (2nd most likely signal)

- **Pixel clock:** 84.75 MHz
- **Active resolution:** 1360×768p60
- **Horizontal blanking:** 416 pixels
- **Vertical blanking:** 30 lines
- **Horizontal Sync offset:** 72 pixels
- **Vertical Sync offset:** 3 lines
- **HSync pulse width:** 136 pixels
- **VSync pulse width:** 5 lines
- **HSync polarity:** negative
- **VSync polarity:** positive
- **Scan mode:** progressive
- **Border size:** 0 mm × 0 mm

Chromacity information

Established and standard timings:

- 720×400@70
- 640×480@60
- 640×480@75
- 800×600@60
- 800×600@75
- 832×624@75
- 1024×768@60
- 1024×768@70
- 1024×768@75
An EDID example

- **Display range limits descriptor**
  - VSync frequency: 57 – 75 Hz
  - HSync frequency: 31 - 84 kHz
  - Maximum pixel clock: 180 MHz

- **Product name:** 32LG5700
- **Number of extensions:** 1 (128-byte CEA extension fields)
- **Checksum:** 0x3F

CEA extension fields

- **Supported colorspace**
- **Short video descriptors**
  - 59 CEA-defined DTV standard resolutions
- **Supported audio formats**
- **Available speakers**
- **HDMI compatibility, Deep Color**
- **Additional detailed timing descriptors**
A CEA extension example

CEA revision number: 3
Audio support: Yes
YCbCr 4:4:4 support: Yes
YCbCr 4:2:2 support: Yes
Short video descriptors:
- 1920×1080 p60
- 1280×720 p60
- 1920×1080 p50
- 1280×720 p50
- 1920×1080 p25
- 720×576p60
- 1920×1080 p24
- 720×576p50
- 1920×1080 i60
- 640×480p60

Supported audio formats: 2ch-PCM
48 kHz, 44.1 kHz, 32 kHz
16 bit, 20 bit, 24 bit
Available speakers: FL and FR
HDMI support: Yes
30 bits/pixel support: Yes
36 bits/pixel support: Yes
Max. TMDS clock: 225 MHz
Additional 5 detailed timings blocks
Checksum: 0x34
Lightware factory EDIDs vs. display EDIDs

<table>
<thead>
<tr>
<th>Lightware factory EDID</th>
<th>Display EDID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preferred timing mode:</td>
<td>1920×1080p60</td>
</tr>
<tr>
<td>2nd detailed timing:</td>
<td>-</td>
</tr>
<tr>
<td>Established and std. timings:</td>
<td>-</td>
</tr>
</tbody>
</table>

EDID resolution issues

720p 50Hz

NO SIGNAL

720p 50Hz
The same resolution doesn’t mean the same full frame size.

Lightware’s Frame Detector feature can measure the size of the blanking interval and offsets.
EDID vs. chip capabilities

What can be different?

• Blanking size (reduced blanking or standard)
• Frame rate (60 Hz vs. 59.94 Hz)
• HSync & VSync polarities
• HSync & VSync pulse width
• Audio sampling frequency, sample size
• Color space

VESA and CEA resolutions

VESA standard resolutions (basic EDID):
• 1920×1200 (16:10)
• 1600×1200 (4:3)

CEA standard resolutions (CEA extension):
• 1920×1080 (16:9)
• 1280×720 (16:9)
Sync polarities

Positive
Normally low

Negative
Normally high

EDID vs. chip capabilities

Display 1

\[ HSync + VSync - \neq HSync - VSync - \]

Display 2
EDID vs. chip capabilities

Create a new EDID!

Color spaces

Some HDMI devices cannot convert color spaces!
Requesting the correct color space from the source is essential!

<table>
<thead>
<tr>
<th>Device Description</th>
<th>Capabilities reported in the EDID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Win 7 PC (AMD 6670)</td>
<td>RGB Only</td>
</tr>
<tr>
<td></td>
<td>RGB</td>
</tr>
<tr>
<td></td>
<td>YCbCr 4:4:4</td>
</tr>
<tr>
<td>Asrock ION 3D 1.A (NVIDIA GT218-ION)</td>
<td>RGB</td>
</tr>
<tr>
<td></td>
<td>RGB</td>
</tr>
<tr>
<td>Pioneer BDP-150 BluRay</td>
<td>RGB</td>
</tr>
<tr>
<td></td>
<td>RGB and YCbCr 4:2:2</td>
</tr>
</tbody>
</table>
EDID Management

EDID Management approach #1

- EDID is taken from the input port
- Doesn’t care about the capabilities of the displays
EDID Management approach #2

- EDID is taken from Output #1
- The user must consider the order of the displays

Cheap Distribution Amplifier

HDMI, 1080p, deep color, PCM
EDID Management approach #3

- EDID is mixed from all outputs
- Hard to implement properly (automatic systems may not always work as expected)

Operation of EDID Manager V4

60 m DVI cable (200')

Emulated EDID:

27
Factory preset / valid
Behind the Scenes of DVI, HDMI and DisplayPort

Conference room example

1920×1200

Advanced EDID Management

Emulating the proper EDID to the sources is an essential part of system setup!
Advanced EDID Management

Static EDID emulation
- From Factory Preset or User programmable memory.

Dynamic EDID emulation
- Copy EDIDs from any display to any input. The emulated EDID changes if the display is replaced.

EDID storing
- Store EDID from any display.

EDID editing functions
- Edit EDIDs with the Advanced EDID Editor.

EDID transfer into/from the router
- Upload/download EDID files through any of the control ports.

Custom EDID creation
- Custom EDID creation with Lightware Easy EDID Creator.

Static EDID emulation
Static EDID emulation in LDC

Dynamic EDID emulation

HDMI/DVI matrix switcher

Factory EDIDs

User memory

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When to use Dynamic emulation

Transmitter

Transmitter

Transmitter

HDMI/DVI matrix switcher

Factory EDIDs

User memory

Store EDIDs

<table>
<thead>
<tr>
<th>EDID Index</th>
<th>Type</th>
<th>Vendor</th>
<th>Model</th>
<th>EDID Code</th>
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<td>YMVID001</td>
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<td>27</td>
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<td>Zebron</td>
<td>HDMI</td>
<td>ZEBVID001</td>
</tr>
</tbody>
</table>

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Behind the Scenes of DVI, HDMI and DisplayPort

Edit EDIDs

Upload/download EDIDs
Behind the Scenes of DVI, HDMI and DisplayPort

Upload/download EDIDs

Create new EDIDs
Create new EDIDs

DVI or HDMI

Please specify whether your sink device supports the High Definition Multimedia Interface or not. If you want to feed audio, then you have to enable the HDMI mode. Only 24bit RGB support will be indicated as default, but you will be able to add other color depths and spaces with the EDID editor later.

Please note that most DVI computer displays are not able to show HDMI signals. If you want to use DVI signals, then choose the checkbox empty.

If you want create an EDID for an analog source, then select the analog option. In this case, you won’t be able to use HDMI signals, due to an EDID cannot be analog and digital at the same time.

- Analog signal
  - DVI
  - HDMI

Create new EDIDs

Select Audio

Specify the audio format that you want to use. Please note that 32kHz 44.1kHz and 48kHz stereo PCM will be supported in all cases according to the specification. If your source sends PCM instead of the desired format, you have to set the digital audio output to bytstream in your player’s menu. Select the “All audio” option if your AV receiver is capable of decoding every compressed content.

Just the most common formats are listed here. The EDID editor software is able to handle much more settings and details.

Preferred audio format:
- stereo 48kHz PCM
- stereo 44.1kHz PCM
- stereo 32kHz PCM
- stereo 22kHz PCM
- stereo 16kHz PCM
- stereo 15kHz PCM
Create new EDIDs

Advanced EDID Management

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- **Custom EDID creation**
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HDMI
High Definition Multimedia Interface
Behind the Scenes of DVI, HDMI and DisplayPort

Evolution of HDMI

<table>
<thead>
<tr>
<th>Version</th>
<th>Added Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDMI 1.0</td>
<td>PCM, Dolby, DTS, YCbCr 4:4:4 and 4:2:2, CEC</td>
</tr>
<tr>
<td>HDMI 1.1</td>
<td>DVD audio support</td>
</tr>
<tr>
<td>HDMI 1.2</td>
<td>Super Audio CD</td>
</tr>
<tr>
<td>HDMI 1.3</td>
<td>Dolby TrueHD, DTS-HD, Deep Color</td>
</tr>
<tr>
<td>HDMI 1.4</td>
<td>3D, ARC, Ethernet</td>
</tr>
<tr>
<td>HDMI 2.0</td>
<td>YCbCr 4:2:0, Rec. 2020, 4 audio streams, 32 channel audio</td>
</tr>
<tr>
<td>HDMI 2.0a</td>
<td>HDR 10</td>
</tr>
<tr>
<td>HDMI 2.0b</td>
<td>HLG</td>
</tr>
</tbody>
</table>

DVI
- no audio
- RGB only, 24 bits per pixel

DVI cables CAN carry HDMI signals with audio!!!

Backwards compatible
Typical VSYNC values: 24 – 120 Hz
Typical HSYNC values: 25 – 90 kHz

Audio is EMBEDDED
There is no separate wire for audio!

Infoframes over HDMI

Infoframes cannot be embedded in DVI signals

AVI Infoframe
- Colorspace (RGB, YCbCr 4:4:4 or 4:2:2)
- Pixel repetition factor
- Bar info
- Aspect ratio
- Video mode, resolution

Audio Infoframe
- Applied audio codec
- Channel count
- Sampling frequency
- Sample size
- Speaker allocation
Color spaces

R

G

B

Y

Cb

Cr

YCbCr

Y

Luma (brightness)

Cb

Blue – Luma

Cr

Red – Luma

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Behind the Scenes of DVI, HDMI and DisplayPort
Behind the Scenes of DVI, HDMI and DisplayPort

What color is the bedsheets?

<table>
<thead>
<tr>
<th>YCbCr sampling methods</th>
<th>4:4:4</th>
<th>4:2:2</th>
<th>4:2:0</th>
<th>4:1:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td><img src="image" alt="4:4:4_Y" /></td>
<td><img src="image" alt="4:2:2_Y" /></td>
<td><img src="image" alt="4:2:0_Y" /></td>
<td><img src="image" alt="4:1:1_Y" /></td>
</tr>
<tr>
<td>Cb</td>
<td><img src="image" alt="4:4:4_Cb" /></td>
<td><img src="image" alt="4:2:2_Cb" /></td>
<td><img src="image" alt="4:2:0_Cb" /></td>
<td><img src="image" alt="4:1:1_Cb" /></td>
</tr>
<tr>
<td>Cr</td>
<td><img src="image" alt="4:4:4_Cr" /></td>
<td><img src="image" alt="4:2:2_Cr" /></td>
<td><img src="image" alt="4:2:0_Cr" /></td>
<td><img src="image" alt="4:1:1_Cr" /></td>
</tr>
</tbody>
</table>

- 4:4:4 = RGB (best quality)
- 4:2:2 = SDI
- 4:2:0 = H.262 / H.264
- 4:1:1 = DVD, BluRay, JPEG
- DV

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Infoframes – Color space conversion

PC monitor (DVI)  
HDMI/DVI repeater

HDTV (HDMI)

It must be RGB!

Oh, it’s YCbCr!

Deep Color modes – HDMI 1.3

HDMI 1.3 – Optional 30 bpp, 36 bpp and 48 bpp support

36 bpp = $2^{36}$ colors = 68,719,476,736 shade

In Deep Color modes TMDS clock frequency is the multiple of pixel clock frequency (1.25×, 1.5×, 2×) → Higher bandwidth needed

Example: 1920×1080p60 at 36bpp  
TMDS clock 223MHz, Pixel clock 148.5MHz
HDMI 1.4

- 10.2 Gbps bandwidth
- 4K resolution support (30 Hz 4:4:4)
- HDMI Ethernet Channel (HEC)
- Audio Return Channel (ARC)
- 3D support
Behind the Scenes of DVI, HDMI and DisplayPort

HDMI 1.4 Audio Return Channel

- Video
- Audio
- HDMI (embedded audio)

HDMI 1.3 scenario

HDMI 1.4 with ARC

HDMI 1.4 Audio Return Channel

- Video
- Audio
- HDMI (embedded audio)

HDMI 1.4 with ARC

5.1 audio

2.0 audio
HDMI 1.4 Ethernet

- 18 Gbps bandwidth
- True 4K @ 60Hz 4:4:4 support
- YCbCr 4:2:0
- Rec. 2020 color space
- 32-channel audio
- 4 audio streams, 2 video streams
- 21:9 aspect ratio

HDMI 2.0 – The newest standard
Definition and usage

4K
- Also known as 4K×2K (4096×2160)
- DCI (Digital Cinema Initiative) standard

UHD
- 3840×2160
- "Consumer 4K"
- Aspect ratio must be 16:9
Resolution and distance matters

Average vision limit:
60 pixels per 1 degree

Distance from screen

All resolution appear similar
720p visible
1080p visible
4K visible

Screen size
Viewing distance – rule of thumb

40” TV
1080p → ~2 meters (6’)
4K → ~1 meter (3’)

1,5x screen height

Interface limitations

<table>
<thead>
<tr>
<th>Interface</th>
<th>Bandwidth (Gbps)</th>
<th>With overhead</th>
<th>Net</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDBaseT</td>
<td>10</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>HDMI 1.4</td>
<td>10.2</td>
<td>8.2</td>
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<tr>
<td>DisplayPort 1.1</td>
<td>10.8</td>
<td>8.6</td>
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<tr>
<td>HDMI 2.0</td>
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<tr>
<td>DisplayPort 1.2</td>
<td>21.6</td>
<td>17.3</td>
<td></td>
</tr>
</tbody>
</table>
The budget decision

Today’s technologies don’t have the necessary bandwidth to support true 4K 60Hz 4:4:4.

- 60Hz + 4:2:0 subsampling
  - Visual artifacts

- 4:4:4/RGB + 30Hz frame rate
  - Jittery movement

Chroma subsampling

- **4:4:4**
  - Y: RGB (best quality)
  - Cb: SDI
  - Cr: H.262 / H.264

- **4:2:2**
  - Y: SDI
  - Cb: DVD, BluRay, JPEG

- **4:2:0**
  - Y: H.262 / H.264
  - Cb: DVD, BluRay, JPEG

- **4:1:1**
  - Y: DV
Bandwidth

4:4:4

Y  Cb  Cr

33% lower bandwidth

4:2:2

Y  Cb  Cr

50% lower bandwidth

4:2:0

Y  Cb  Cr

50% lower bandwidth

4:1:1

Y  Cb  Cr

50% lower bandwidth

Bandwidth

4:2:0

Y  Cb  Cr

50% lower bandwidth
4K YCbCr 4:2:0

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.
Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.
White-gray-black (Y) is not affected

Contrasting colors (Cb, Cr) are blurred
Behind the Scenes of DVI, HDMI and DisplayPort
Subsampling

4:4:4  4:2:0
Behind the Scenes of DVI, HDMI and DisplayPort

1. **Photo editing**
   - Graphics Design
   - CAD
   - Y'CbCr 4:4:4 30 Hz 8-bit

2. **Programming**
   - General video
   - Presentation
   - PC gaming
   - Y'CbCr 4:2:0 60 Hz 8-bit

3. **Post-production**
   - Rental & Staging
   - RGB

4. **Professional broadcast**
   - Video editing
   - Rental & Live
   - Y'CbCr 4:2:2 50/60 Hz 10-bit

5. **Digital Cinema**
   - Y'CbCr 4:2:2 24 Hz 12-bit

**Applications**

- **HDMI 1.4**
  - DP 1.1
  - HDBaseT

- **HDMI 2.0**
  - DP 1.2

- **Quad link 3GSDI**

**HDR**

High Dynamic Range
What's the point of these improvements?

To re-create what we see in real life
Behind the Scenes of DVI, HDMI and DisplayPort

Viewing experience

- Resolution
- Framerate
- Dynamic range
- Color gamut
- Bit depth

HDR

- Dynamic range
- Color gamut
- Bit depth
Dynamic range

Provide extended detail within brighter highlights
Behind the Scenes of DVI, HDMI and DisplayPort
Real world dynamic range

Source: Dolby Laboratories
Behind the Scenes of DVI, HDMI and DisplayPort

Real world vs. Displays: dynamic range

<table>
<thead>
<tr>
<th>Luminosity nits</th>
<th>Human vision</th>
<th>CRT</th>
<th>iPad</th>
<th>Average LCD Display</th>
<th>Average HDR Display</th>
<th>Viewers preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-6}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-5}$</td>
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<tr>
<td>$10^{-4}$</td>
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<tr>
<td>$10^{-3}$</td>
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<td>$10^{-1}$</td>
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<tr>
<td>$10^0$</td>
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<td>$10^1$</td>
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<td>$10^2$</td>
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<td>$10^3$</td>
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<tr>
<td>$10^6$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Current SDR standards

HDR standards
Color gamut
Color gamut

**Pointer’s gamut:**
Colors reflected by any natural or man-made object

46% of CIE $u'v'$

**Rec. 709 (sRGB)**

70% of Pointer’s gamut
Rec. 2020

99.7% of Pointer’s gamut

Bit depth
Behind the Scenes of DVI, HDMI and DisplayPort

Bit depth

- 8 bits = 256 steps
- 10 bits = 1024 steps
- 12 bits = 4096 steps
- 16 bits = 65536 steps
Bit depth

Recipe for HDR

More contrast + More colors + Higher bit depth = New set of standards
Behind the Scenes of DVI, HDMI and DisplayPort

Color volume

Dynamic range

Bit depth

Color gamut

Competing standards

DOLBY VISION

HDR 10

HLG

Hybrid Log Gamma

SL-HDR1

Consumer Technology Association

BBC

PHILIPS

technicolor

CableLabs
A1  A HLG is maradjon benne
Author; 2018. 03. 27.

A2  Open standard
Backwards compatible with SDR
10-bit
Author; 2018. 03. 27.
Competing standards

- **Dolby Vision**
  - Proprietary ($3/unit)
  - 12 bit
  - 10,000 nits
  - Dynamic metadata

- **HDR 10**
  - Open standard
  - 10 bit
  - 1,000 nits
  - Dynamic metadata

- **HLG (Hybrid Log Gamma)**
  - Open standard
  - 10 bit
  - 1,000 nits
  - No metadata (backwards compatible)

Source manufacturer support

- **VUDU**
- **Apple**
- **Roku**
- **Netflix**
- **Amazon**
- **Xbox**
- **PS4 Pro**
Display manufacturer support

- Dolby Vision HDR 10
- SONY
- Samsung
- Hisense
- Sharp
- TCL
- LG
- Vizio
- Blu-ray Disc

HLG Hybrid Log Gamma

HDR capabilities in EDID

- Dynamic range - black level, luminance -
- Bit depth
- Color gamut

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HDR capabilities in EDID

HDR capabilities in EDID
HDR capabilities in EDID

CEA HDMI Options

- 30 bits / color Deep Color mode supported
- 36 bits / color Deep Color mode supported
- 40 bits / color Deep Color mode supported
- YUV444 is supported in Deep Color modes
- DVI dual link operation is supported

Max. TMDS clock: 100 MHz

HDR capabilities in EDID

CEA HDMI Forum Vendor Specific Data Block

Max. TMDS clock: 100 MHz

HDMI Forum Support Flags
- 3D OSD Disparity
- Dual View
- Independent View
- Less than or equal to 340 Msec Scramble
- SCDC Read Request Capable
- SCDC Present
- 10 bits/component Deep Color 4:2:0
- 12 bits/component Deep Color 4:2:0
- 16 bits/component Deep Color 4:2:0
HDR capabilities in EDID

4K60 bandwidth requirements
Extension

HDMI20-OPTJ-TX/RX

HDMI20-OPTC-TX/RX

Switching

MX2-8x8HDMI20-Audio
Scaling and compressing

HDR
High dynamic range

Dolby Vision

HDCP
High-bandwidth Digital Content Protection
Protection for the cable

Encryption between two endpoints

Encrypt

Decrypt

Three pillars

Authentication

Encryption

Revocation
HDCP – Legal stuff

- Manufacturers must obtain a licence from Digital Content Protection LLC
- ... and pay an annual fee.
- A set of unique public and secret keys is required, which is generated by DCP LLC using a master key matrix.
- Making a secret key public is a huge violation. Not even device manufacturers have access to the secret keys in the chips.
- DCP LLC knows which key set has been sold to which manufacturer so that they can be revoked.

HDCP vs. EDID

- EDID and HDCP are communicated using different DDC addresses
- EDID is stored in a memory chip (may be implemented in Receiver chip)
- HDCP is a complicated handshaking process between Source and Receiver chip
- EDID does not contain HDCP related information
HDCP – A rule of thumb

HDCP protected content can ONLY be viewed on an HDCP compliant device!!!

There is no legal way to remove HDCP protection.

HDCP compliancy is optional for DVI, recommended for HDMI.

The public keys of the HDCP breaker devices will be revoked in the future and they won’t operate anymore.

HDCP handshake with end devices

Initialize session, exchange public keys

Verify the connection

Sending encrypted stream

Link integrity verification in every 2 sec

Number of possible keys = 670 442 572 800
Behind the Scenes of DVI, HDMI and DisplayPort

Every device has a Public Key, also known as KSV (Key Selection Vector)

```
0110001011
1001100101
0011110100
1101001100
```

40 bits = 20 ones + 20 zeros

And every device has 40 Secret Keys

```
0110101011
0101101111
1011010101
0101001100
0110011010
100110
1001011001
1110101011
0100101101
1101010010
1101010011
1001010010
0010110110
1010100110
1010100110
001001
```

40 × 56 bits

HDCP handshake with end devices

The source’s Key Selection Vector chooses 20 of the display’s secret keys

```
0110001011
1001100101
0011110100
1101001100
```

40 bits = 20 ones + 20 zeros

Add them together

Common secret, Km’

Use a random number (An) to encode Km’ to get R0’
HDCP handshake with end devices

AKSV
(public key)

Secret keys

BKSV
(public key)

Secret keys

Km = Km’

HDCP handshake with end devices

Generate An

Calculate R0

Verify R0=R0’

Not a repeater?

Verify R=R’

Read BKSV

Write AKSV, An

Read R0’

Read BCAPS

Read R’ after every 128 frames
BCAPS and repeaters

- BCAPS = B device capabilities, 8-bit register
- Can B device communicate at 400 kbit/s?
- Is B device a repeater? (1 bit, called repeater bit)
- If repeater, is the KSV list ready?

A Repeater is a device that decodes and re-encodes an HDCP encrypted signal and sends it to one or multiple destinations. For example matrices, distribution amplifiers, switchers, signal processors, etc.

Cable extenders are not always repeaters!

HDCP snowing

- K and K’ are re-calculated after each frame.
- If one of the devices makes an calculation error, then the common secrets won’t match, which means the signal cannot be decoded, this is when you see snowing.
- The source reads R’ after every 128th frame.
- The snowing should disappear after 128 frames.
Behind the Scenes of DVI, HDMI and DisplayPort

HDCP handshake with repeaters

- Initialize session, exchange public keys
- Verify the connection
- Send KSV list and topology
- Sending encrypted stream
- Link integrity verification in every 2 sec

HDCP handshake – Repeaters

- Generate An
- Calculate R0
- Verify R0=R0'
- Repeater?
- Verify R=R'
- Read BKSV
- Write AKSV, An
- Read R0'
- Read BCAPS
- Poll BCAPS, is KSV list ready?
- Read KSV list and system topology
- Read R' after every 128 frames
- Collect KSV list
- 5 sec max.
HDCP issues – Repeater limits

The HDCP standard allows a maximum of 127 attached sinks.

Examples:
- Sony Playstation 3 max. 14 devices
- XBOX 360 max. 16 devices
- Panasonic DMP-BD30 max. 3 devices

HDCP issues – Cascading limits

HDCP protected signals can only be routed through seven repeaters.

Cable extenders are usually not repeaters!
HDCP issues – Revoking list

A compromised device affects the whole system.

Revocation list is distributed on DVD and BluRay discs.

HDCP and Mac

The Mac tries to use HDCP whenever possible.

Encryption ON

Encryption OFF

Not HDCP compliant
Behind the Scenes of DVI, HDMI and DisplayPort

HDCP and Mac

The Mac tries to use HDCP whenever possible.

Encryption ON
Encryption OFF

HDCP compliant

Not HDCP compliant

HDCP compliant
Behind the Scenes of DVI, HDMI and DisplayPort

**HDCP and Mac**

- Encryption ON
- Encryption OFF

Not HDCP compliant

HDCP compliant

**Input port**

HDCP enable

**Operation of EDID Manager V4 (HDCP disabled)**

- 60 m DVI cable (200')
- A/V System HDCP compliant
- Non-HDCP display
Most common HDCP problems and possible reasons

<table>
<thead>
<tr>
<th>Problem</th>
<th>Possible reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>No image</td>
<td>Non-compliant display</td>
</tr>
<tr>
<td></td>
<td>Non-compliant device in the signal chain</td>
</tr>
<tr>
<td></td>
<td>Compromised device in the signal chain</td>
</tr>
<tr>
<td></td>
<td>Too many KSVs are reported to the source</td>
</tr>
<tr>
<td></td>
<td>Too many levels in the HDCP device tree</td>
</tr>
<tr>
<td>Periodic Snowy Image</td>
<td>Unstable DDC connection</td>
</tr>
<tr>
<td></td>
<td>Too long or too low quality cable</td>
</tr>
<tr>
<td></td>
<td>UTP cable and ambient electromagnetic noise</td>
</tr>
<tr>
<td>Red (or any color) image</td>
<td>Intelligent repeater indicating HDCP error (non-compliant display or failed authentication)</td>
</tr>
</tbody>
</table>

HDCP 1.4 master key published

In 2010 the HDCP Master Key was published

- Leaked or reverse engineered (theoretically possible).
- Intel confirmed that it is the real Master Key, but says it’s irrelevant.
- Anyone can create their own HDCP keys.
- Revocation list is neutralized.
HDCP 2.2

What's changed?

1. XOR stream cipher
   56-bit key
   Standard

2. RSA + AES
   algorythms

31. Max. devices

4. Max. levels

Locality check

Content types
Locality check

Here’s a random number. Send it back to me in 20 msec.

16846435

Content types

HDCP 1.4
HDCP 2.0
HDCP 2.1
HDCP 2.2

Content providers demand a solution to disallow compromised versions.
Content types

Type 0
- Any type of HDCP encryption can be used.
- The strongest possible encryption will be used.

Type 1
- ‘High Value’
- HDCP 2.2 must be used.
- Only applies to UHD content.
- 1080p is not affected.
Content types

Type 1

4K 4K

HDCP 2.2

HDCP 2.2

1080p

HDCP 1.4

2.2

1.4

Content types

Type 1

4K 4K

HDCP 2.2

HDCP 2.2

4K

HDCP 2.2

HDCP 1.4

2.2

1.4

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Content types

1080p

2.2

1080p

2.2

4K

Type 1

HDPC 2.2

HDPC 2.2

No signal

MX2 HDCP options

Type 1

HDPC 2.2

HDPC 2.2

HDPC 1.x

Disable HDCP

No signal

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MX2 HDCP options

Type 1

Enable only

HDCP 1.4

1080p

2.2

Type 1

Enable both

HDCP 1.4

and

HDCP 2.2

1080p

2.2

MX2 HDCP options

Type 1

Enable only

HDCP 1.4

1080p

2.2

Type 1

Enable both

HDCP 1.4

and

HDCP 2.2

1080p

2.2

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Content types

HDMI 2.0 ≠ HDCP 2.2

Some early* UHD displays are not HDCP 2.2 compliant.

*mostly manufactured before 2014

These might not work with Type 1 content.
Why disable HDCP 2.2?

HDCP 2.2
Max. devices: 31
Max. levels: 4

Why disable HDCP 2.2?

HDCP 1.4
Max. devices: 127
Max. levels: 7
Cables & Connectors

DVI & HDMI connectors

- **DVI-D (single link)**
  - 3 data + 1 clock TMDS

- **DVI-D (dual link)**
  - 6 data + 1 clock TMDS
  - Analog RGBHV pins

- **DVI-I (single link)**
  - 3 data + 1 clock TMDS
  - Analog RGBHV pins

- **DVI-I (dual link)**
  - 6 data + 1 clock TMDS
  - Analog RGBHV pins

- **DVI-A (analog)**
  - Analog pins only
  - (rarely used)

- **HDMI type A**
  - 3 data + 1 clock TMDS
  - CEC line

- **HDMI type C „Mini“**
  - 3 data + 1 clock TMDS
  - CEC line

- **HDMI type D „Micro“**
  - 3 data + 1 clock TMDS
  - CEC line
### Single vs. Dual Link DVI

#### DVI-D (single link)
- 3 data + 1 clock TMDS
- Dual link pins are not connected
- Up to $3 \times 1.65 = 4.95$ Gbps

#### DVI-D (dual link)
- 6 data + 1 clock TMDS
- Up to $6 \times 1.65 = 9.9$ Gbps

#### Resolution examples
<table>
<thead>
<tr>
<th>Resolution</th>
<th>Data Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1920 \times 1080 @ 60$</td>
<td>4.44 Gbps</td>
</tr>
<tr>
<td>$1600 \times 1200 @ 60$</td>
<td>4.86 Gbps</td>
</tr>
<tr>
<td>$3840 \times 2400 @ 17$</td>
<td>4.77 Gbps</td>
</tr>
<tr>
<td>$2560 \times 1600 @ 60$</td>
<td>8.04 Gbps</td>
</tr>
<tr>
<td>$3840 \times 2400 @ 30$</td>
<td>8.46 Gbps</td>
</tr>
<tr>
<td>$1920 \times 1080 @ 120$</td>
<td>8.88 Gbps</td>
</tr>
</tbody>
</table>

The only limitation is the data rate!

### Single vs. Dual Link DVI

#### Example: $1600\times1200@60$ Hz
- $X_{\text{FULL}}$: 2160 pixels
- $Y_{\text{FULL}}$: 1250 lines
- $f_{\text{SYNC}}$: 60 Hz
- $f_{\text{PCLK}}$: 162 MHz
- Data rate: 1.62 Gbps

#### Example: $2560\times1600@60$ Hz
- $X_{\text{FULL}}$: 2720 pixels
- $Y_{\text{FULL}}$: 1646 lines
- $f_{\text{SYNC}}$: 60 Hz
- $f_{\text{PCLK}}$: 268 MHz
- Data rate: 1.34 Gbps

Max (DVI): 1.65 Gbps/color
Dual Link transmission

- Doubles the number of wire pairs to double the maximum bandwidth
- 6 TMDS wire pairs carry color information, 1 TMDS wire pair carries the clock
- The “Single Link” wire pairs carry the odd pixels
- The “Dual Link” wire pairs carry the even pixels

DVI & HDMI cables

- Consumer Electronics Control
- HDMI only!
- Shield
- Power5V and Hotplug Handshake signals
- 4 TMDS lanes (twisted pair)
  - High speed, unidirectional
  - Reserved/Ethernet
- 2 wire Display Data Channel bus
  - Low speed, bidirectional
  - EDID, HDCP communications
- Ground
- AWG: American Wire Gauge
  - Lower is thicker
  - Thicker is better
  - Typical values:
    - 24 AWG
    - 22 AWG

There is no separate wire for audio! Audio is EMBEDDED.
CATx cable structures

UTP (Unshielded Twisted Pair)
- Sheath
- Twisted pair
- Insulation
- Conductor

FTP (Foiled Twisted Pair)
- Sheath
- Cable shield
- Twisted pair
- Insulation
- Conductor

SFTP (Screened and Foiled Twisted Pair)
- Sheath
- Cable shield
- Twisted pair
- Pair shield
- Insulation
- Conductor

UTP cables and noise

Electromagnetic signals cannot penetrate metal
### CATx categories

<table>
<thead>
<tr>
<th>Specification</th>
<th>Cat5</th>
<th>Cat5e</th>
<th>Cat6</th>
<th>Cat6a</th>
<th>Cat7</th>
<th>Cat7a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>UTP / FTP</td>
<td>UTP / FTP</td>
<td>UTP / FTP / SFTP</td>
<td>FTP / SFTP</td>
<td>SFTP</td>
<td>SFTP</td>
</tr>
<tr>
<td>Frequency</td>
<td>100 MHz</td>
<td>100 MHz</td>
<td>250 MHz</td>
<td>500 MHz</td>
<td>600 MHz</td>
<td>1000 MHz</td>
</tr>
<tr>
<td>Attenuation (at 100 MHz)</td>
<td>24 dB</td>
<td>24 dB</td>
<td>21.7 dB</td>
<td>18.4 dB</td>
<td>18.4 dB</td>
<td>17 dB</td>
</tr>
<tr>
<td>Far end crosstalk</td>
<td>N/A</td>
<td>-27.1 dB</td>
<td>-42.3 dB</td>
<td>-59.1 dB</td>
<td>-59.1 dB</td>
<td>-70 dB</td>
</tr>
<tr>
<td>Max delay / skew (on 100 m)</td>
<td>50 ns</td>
<td>45 ns</td>
<td>45 ns</td>
<td>45 ns</td>
<td>20 ns</td>
<td>20 ns</td>
</tr>
</tbody>
</table>

### Maximum achievable cable lengths

<table>
<thead>
<tr>
<th>Resolution</th>
<th>f_{VCLK}</th>
<th>Cat5e UTP</th>
<th>Cat5e FTP</th>
<th>CAT5 UTP</th>
<th>CAT5 FTP</th>
<th>CAT5 SFTP</th>
<th>CAT6 UTP</th>
<th>CAT6 FTP</th>
<th>CAT6 SFTP</th>
<th>CAT7 SFTP</th>
<th>24 AWG</th>
<th>22 AWG</th>
</tr>
</thead>
<tbody>
<tr>
<td>640×480p60</td>
<td>25.2 MHz</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>66 m</td>
<td>70 m</td>
<td>70 m</td>
<td>80 m</td>
<td>100 m</td>
<td>120 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>800×600p60</td>
<td>40.0 MHz</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>65 m</td>
<td>65 m</td>
<td>65 m</td>
<td>75 m</td>
<td>84 m</td>
<td>100 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1024×768p60</td>
<td>65.0 MHz</td>
<td>55 m</td>
<td>55 m</td>
<td>55 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>75 m</td>
<td>62 m</td>
</tr>
<tr>
<td>1280×720p60</td>
<td>74.2 MHz</td>
<td>55 m</td>
<td>55 m</td>
<td>55 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>75 m</td>
<td>62 m</td>
</tr>
<tr>
<td>1280×1024p60</td>
<td>108.0 MHz</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>55 m</td>
<td>55 m</td>
<td>55 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
</tr>
<tr>
<td>1400×1050p60</td>
<td>121.8 MHz</td>
<td>45 m</td>
<td>45 m</td>
<td>45 m</td>
<td>55 m</td>
<td>55 m</td>
<td>55 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
<td>60 m</td>
</tr>
<tr>
<td><strong>1920×1080p60</strong></td>
<td><strong>148.5 MHz</strong></td>
<td><strong>30 m</strong></td>
<td><strong>35 m</strong></td>
<td><strong>35 m</strong></td>
<td><strong>45 m</strong></td>
<td><strong>45 m</strong></td>
<td><strong>50 m</strong></td>
<td><strong>50 m</strong></td>
<td><strong>50 m</strong></td>
<td><strong>60 m</strong></td>
<td><strong>75 m</strong></td>
<td><strong>60 m</strong></td>
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<tr>
<td>1920×1200p60</td>
<td>153.0 MHz</td>
<td>30 m</td>
<td>35 m</td>
<td>35 m</td>
<td>45 m</td>
<td>45 m</td>
<td>45 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>60 m</td>
<td>60 m</td>
</tr>
<tr>
<td>1600×1200p60</td>
<td>162.0 MHz</td>
<td>30 m</td>
<td>35 m</td>
<td>35 m</td>
<td>45 m</td>
<td>45 m</td>
<td>45 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>60 m</td>
<td>60 m</td>
</tr>
</tbody>
</table>
CATx cables for DVI and HDMI

**Advantages**
- Thin, flexible, easy to string
- Easy to crimp
- Cost effective
- Already in the building

**Disadvantages**
- Unreliable
- High attenuation
- Noise sensitive (no shield)
- Different twist ratio
  - Decreases crosstalk
  - Increases inter-pair skew

CATx cables for DVI and HDMI

- 100 EDID memory (50 programmable)
- One cable without HDCP
- Two cables with HDCP
- Up to 50 meters (165') at 1080p60

Main applications:
- Digital Signage
- Fixed installations
- Conference room
- Classrooms

Lightware CATx solutions

Transmit DVI and HDMI over CATx

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Lightware CATx solutions

8× TMDS

+12V (remote power in either direction)
GND
DDC (EDID & HDCP)
RS-232
HotPlug

HDBaseT
Single CAT transmission for up to 170m
Behind the Scenes of DVI, HDMI and DisplayPort

HDBaseT alliance founders

Valens
LG
SONY
PICS
SAMSUNG

Forget cable clutters

HDMI
Audio
RS-232
Power
Extension up to 170 meters (550’) *

* with Long Reach firmware and AWG 23 CAT7 cable

HDBaseT source

170 meters

550 feet

HDBaseT sink
HDMI vs. HDBaseT

HDMI Source

HDBaseT Transmitter

HDMI Display

HDBaseT Receiver

Where is HDMI?
Structure of HDBaseT devices

Valens chips do the format conversion between HDMI and HDBaseT
HDBaseT wouldn’t exist without HDMI

HDMI over HDBaseT
No compression, no frame delay, no loss of information
HDMI over HDBaseT
HDMI 1.4, UHD, 3D, Various color spaces, Multichannel audio

Basic handshaking at startup
- I'm present
- Read EDID
- HDCP handshaking
- Send video and audio
- Power 5V
- Hotplug
- Display Data Channel
- I'm ready
- Send EDID
- HDCP handshaking
- TMDS lanes

Behind the Scenes of DVI, HDMI and DisplayPort
EDID and video over HDBaseT
No dedicated DDC or TMDS wires at HDBaseT connection

HDBaseT latency:
~1 microsec

Ethernet over HDBaseT

No need Ethernet Ethernet

Internet

No need Ethernet Ethernet

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Meeting room example

Control over HDBaseT – Ethernet
Behind the Scenes of DVI, HDMI and DisplayPort

Control over HDBaseT – RS-232

Data over HDBaseT

Full duplex transmission over four wire pairs
Behind the Scenes of DVI, HDMI and DisplayPort

Full duplex transmission over 4 pairs

- DOWNSTREAM SUB-LINK
- UPSTREAM SUB-LINK

HDBaseT Transmitter to HDBaseT Receiver

- Video
- Audio
- AV Control
- Ethernet
- RS-232
- IR

4 differential wire pairs
- PAM modulated
- Packet based
- 500 Msymb/sec
- 8Gbps net bandwidth

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Full duplex transmission over 4 pairs

AV control
Ethernet
RS-232
IR

4 differential wire pairs
PAM modulated Packet based
12.5 Msymb/sec
150 Mbps net bandwidth

HDBaseT Transmitter

UPSTREAM SUB-LINK

HDBaseT Receiver

Power over HDBaseT – PoH*

100 watts of power can be transmitted over the 4 wire pairs

• 1st generation Lightware TPS products deliver remote power over CATx cable in both directions. This method does not conform to the PoH standard, and it is not compatible with PoH or PoE.
Behind the Scenes of DVI, HDMI and DisplayPort

Power over HDBaseT – PoH*
100 watts of power can be transmitted over the 4 wire pairs

- 1st generation Lightware TPS products deliver remote power over CATx cable in both directions. This method does not conform to the PoH standard, and it is not compatible with PoH or PoE.
Packet based transmission

There are no dedicated wires for the different datatypes.
HDBaseT link - Packet based architecture

- HEADER: Contains the type of the packet
- DATA: Contains the payload
- CRC: Cyclic Redundancy Check for error detection

Difficulties of CATx extension

- Attenuation – depends on data rate
- Reflection adds noise – patch panels
- Different twist ratio – inter pair skew!!!
HDBaseT – Physical layer: 10GbE

- Error rate measurements
- Reflection compensation
- Compensation for different twist ratios
- Compensation for attenuation by measuring cable length and data rate
- Pulse Amplitude Modulation - PAM
- Point-to-point – no extra overhead coming from addressing

Start-up period

Silent mode – no connection
Start-up period

Startup period – sending training pattern

Start-up period

Normal operation – sending data
Start-up period – Set EQ level

The receiver sets the appropriate compensation level for each pair.

Start-up period – Symbol lock

The transmitter and the receiver sync to each other in order to find the symbol borders.
Start-up period – Twist ratio compensation

The receiver compensates for the length difference between the wire pairs.

Pulse Amplitude Modulation (PAM)

Two levels to represent binary ones and zeros

PAM uses multiple voltage levels to represent digital data.
Example – PAM2

2 voltage levels, each level representing 1 bit

Example – PAM4

4 voltage levels, each level representing 2 bits
Behind the Scenes of DVI, HDMI and DisplayPort

Example – PAM8

8 voltage levels, each level representing 3 bits

Example – PAM16

16 voltage levels, each level representing 4 bits
Behind the Scenes of DVI, HDMI and DisplayPort

PAM4 vs. PAM16

Neighbouring values have closer voltage levels with PAM16, which makes it more sensitive to noise.

Variable bitrate / Protection level

Least important data is modulated with the highest grade PAM modulation.

- **PAM2**: HDBaseT, Training Symbols
- **PAM4**: Header and CRC
- **PAM8**: Audio, Ethernet
- **PAM16**: Active pixels

VIPS, Executives, Middle class, Lower class
Installation recommendations

- Use high quality cables
- Cables should be laid in a straight manner
- Avoid noise sources in the cable’s environment
- Use maximum of two patch panels
- Max number of cables in a bundle (for 100m, 330’):
  - Six for Cat6a/7
  - Only one for Cat5e/6

HDBaseT 2.0

- Backwards compatible with HDBaseT 1.x (5Play™), new feature set: HomePlay
- Audio Return Channel
- USB 2.0 support at up to 190 Mb/s and max. 22 endpoints (practically 7 devices)
- Upstream sublink’s BW was increased from 150 Mbps to 300 Mbps
- Downstream sublink’s BW is unchanged (8 Gbps)
- Multistreaming support - HDBaseT hubs, and daisy chainable devices
HDBaseT summary

- Designed to complement HDMI, not to replace it
- 5Play™: Video + Audio + Control + Ethernet + Power
- Proprietary coding scheme (PAM16)
- Similar to 10GBaseT, but doesn’t use IP protocol
- Less sensitive to CATx cable problems (skew, crosstalk, attenuation)

Lightware TPS solutions

How Lightware enhances HDBaseT:

- 15 kV ESD protection
- Steel enclosure for EMI protection
- Two modes (HDBaseT and Long Reach)
- Cable diagnostics
- EDID Management
- Hybrid signal conversion
- Audio embedding/de-embedding
- Event Manager
Behind the Scenes of DVI, HDMI and DisplayPort

Lightware TPS solutions

MMX6x2-HT220

MX-TPS-IB/OB

TPS-TX95/RX95

WP-UMX-TPS-TX

UMX-TPS-TX

Fiber optical transmission
Behind the Scenes of DVI, HDMI and DisplayPort

Optical fiber

Advantages
- Not sensitive to EM noise
- No crosstalk
- No skew
- Less attenuation than copper cables
- Galvanic isolation

Higher distances are possible

Singlemode and Multimode

Multimode

Singlemode
Singlemode and Multimode

Multimode

50 - 65 μm

300 m - 2.6 km

0.2 - 1.6 miles

Singlemode

8 - 10 μm

<< 10 km

<< 6 miles

The difference

Core

The difference

Basics – Refraction

Air

Refraction index: n₂

Water

Refraction index: n₁
Basics – Refraction

Air

Refraction index: $n_2$

Total internal reflection

Water

Refraction index: $n_1$

Refraction examples
Basics – Refraction

Multi-mode step index fiber
• Multiple paths with different length
• Increased amount of dispersion

Multi-mode graded index fiber
• Lower modal dispersion

Optical fiber types
Behind the Scenes of DVI, HDMI and DisplayPort

Optical fiber types

- **Multi-mode step index fiber**
  - Multiple paths with different length
  - Increased amount of dispersion

- **Multi-mode grade index fiber**
  - Lower modal dispersion

- **Single-mode fiber**
  - Light can enter in one angle only
  - Greater distances are possible

Modal dispersion

- Path differences cause skew between modes.
Multimode fiber types

<table>
<thead>
<tr>
<th>Transmission properties</th>
<th>Fibertype L (OM1)</th>
<th>Fibertype F (OM2)</th>
<th>Fibertype I (OM3)</th>
<th>Fibertype OM3e</th>
<th>Fibertype J (OM4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>850</td>
<td>1300</td>
<td>850</td>
<td>1300</td>
<td>850</td>
</tr>
<tr>
<td>Attenuation</td>
<td>3.2</td>
<td>0.9</td>
<td>3.0</td>
<td>1.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Bandwidth (MHz km)</td>
<td>200</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>1500</td>
</tr>
<tr>
<td>Numerical aperture</td>
<td>0.275 ± 0.015</td>
<td>0.2 ± 0.02</td>
<td>0.2 ± 0.015</td>
<td>0.2 ± 0.015</td>
<td>0.2 ± 0.015</td>
</tr>
</tbody>
</table>

Misalignment

- Reduced light power
- Cancelled light
Dirt

Reduced light power

Cancelled light

Optical connector types

Neutrik connector (NT)
- Two fibers per cable
- Very reliable connection
- Compatible with 2×LC fibers
OPT series
DVI-OPT and HDMI-OPT

Light spectrum

- IR
- Red
- Green
- Blue
- UV

Visible for humans

Sun
**Spectrum of the Sun**

- **Continuous spectrum**

**Spectrum of an RGB display**

- **Non-continuous spectrum**
Behind the Scenes of DVI, HDMI and DisplayPort

Spectrum of OPT series

Coarse Wavelength Division Multiplexing

Non-continuous spectrum

Intensity

Wavelength

OPT series

Fiber optical cable

Laser diodes

Lens

Photo diodes

Fiber optical cable

CWDM – Coarse Wavelength Division Multiplexing
Lightware OPT technology

- One multimode Fiber
- Zero frame delay
- No compression
- DVI, HDMI and DisplayPort
- Up to 2600 meters (1.6 miles)

Lightware OPT technology

- Input and Output cards
- NT, SC, ST and LC connectors
- DVI and HDMI compliant
- With or without Pixel Accurate Reclocking
- Can be mixed with any other card
OPTM/OPTS series

Spectrum of OPTM/OPTS series
Behind the Scenes of DVI, HDMI and DisplayPort

Modular System Structure (2007)
- Single Link DVI
- Dual Link DVI
- HDMI
- DVI-I
- 3G-SDI
- Fiber
- CATx (TP and TPS)

---

Hybrid router concept example
Industry needs for DisplayPort

- Common standard for internal and external display connections.
- Simplify cabling.
- Reduce cost and complexity.
- Enable digital audio transmission.
- Enable content protection.
- Higher bandwidth on fewer wires.
- Apply embedded clock to reduce EMI.
- Provide a small form factor and latching connector.
- Create an open and extensible standard.
- Provide legacy support.

Features of DisplayPort

- Standard by VESA
- 1, 2 or 4 data pairs
- 8B/10B Encoding
- Up to 21.6 Gbps (DP v1.2)
- RGB, YCbCr and xvYCC (only in v1.2)
- Deep color
- Supports all HDMI resolutions
- 8 channel audio
- Content protection (HDCP, DPCP)
Behind the Scenes of DVI, HDMI and DisplayPort

Digital video representation

- **DVI and HDMI**
  - Pixel 0: Red / Cb: 01001010, Green / Y: 01101011, Blue / Cr: 01011101, Clock: 01001010
  - Pixel 1: Red / Cb: 10010101, Green / Y: 10010100, Blue / Cr: 10110110, Clock: 10010100

- **DisplayPort**
  - Pixel 0: Red / Cb: 01001010, Green / Y: 01101011, Blue / Cr: 01011101, Clock: 01001010
  - Pixel 4: Red / Cb: 10010101, Green / Y: 10010100, Blue / Cr: 10110110, Clock: 10010100

- **DVI and HDMI**
  - TMDS architecture
  - Dedicated color channels
  - Dedicated clock channel
  - The 4 wire pairs are always used

- **DisplayPort**
  - Packet based architecture
  - Non-dedicated wire pairs
  - Embedded clock
  - Wire pairs can be turned off

DisplayPort connection

- **Source**
  - Pin #1: Lane0+, Lane0- GND, Lane1+, Lane1- GND, Lane2+, Lane2- GND, Lane3+, Lane3- GND
  - Config1, Config2, AUX+, AUX- GND, Hot Plug, Return PWR, DP_PWR

- **Sink**
  - Pin #1: Lane3+, Lane3- GND, Lane2+, Lane2- GND, Lane1+, Lane1- GND, Lane0+, Lane0- GND
  - Config1, Config2, AUX+, AUX- GND, Hot Plug, Return PWR, DP_PWR

For recognizing adapters
Active/Passive DP converters

Active Converter

Format conversion

Dual-mode GFX chip

DisplayPort signal

TMDS signal

Passive Converter

Format conversion

Level shifting

Dual-mode GFX chip

TMDS* signal

TMDS signal

TMDS*: non-standard voltage levels
Active/Passive DP converters

- Small form factor
- One-chip solution
- Low power consumption
- Bigger size (more chips)
- Active converter
- Expensive converter chips
- High power consumption

Passive or active DP to DVI/HDMI

DP to VGA

DP to Dual Link DVI

Dual-mode pin mapping

<table>
<thead>
<tr>
<th>DisplayPort</th>
<th>DP++ to DVI/HDMI Passive Adapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Link Lane 0</td>
<td>TMDS Channel 2</td>
</tr>
<tr>
<td>Main Link Lane 1</td>
<td>TMDS Channel 1</td>
</tr>
<tr>
<td>Main Link Lane 2</td>
<td>TMDS Channel 0</td>
</tr>
<tr>
<td>Main Link Lane 3</td>
<td>TMDS Clock</td>
</tr>
<tr>
<td>AUX Ch+</td>
<td>DDC Clock</td>
</tr>
<tr>
<td>AUX Ch-</td>
<td>DDC Data</td>
</tr>
<tr>
<td>DP_PWR (+3.3V)</td>
<td>DP_PWR (source for DVI 5V)</td>
</tr>
<tr>
<td>Hot Plug Detect</td>
<td>Hot Plug Detect</td>
</tr>
<tr>
<td>Config 1</td>
<td>Video Adapter Detect</td>
</tr>
<tr>
<td>Config 2</td>
<td>CEC (HDMI only)</td>
</tr>
</tbody>
</table>
DisplayPort extension

DP source → DP over Fiber TX → DisplayPort Converter → DVI over Fiber RX → DVI display

Fixed bandwidth

- DVI and HDMI: Used Bandwidth = Bandwidth requirement
- DisplayPort: Used Bandwidth ≠ Bandwidth requirement
Behind the Scenes of DVI, HDMI and DisplayPort

Link training

- Hotplug Event
- Read EDID
- Read DPCD
- Send Training Pattern
- Read result
- Send video and audio
- AUX Channel
- Main Link Lanes, 1.62 Gbps/lane
- DPCD: DisplayPort Configuration Data

Micro-packets and lane count

- All lanes use embedded clock.
- Control data is always sent 4 times.
- The highest possible bitrate and lowest number of lanes are used.
- Pixel information is put into packets.
- Packets are carried by the assigned Main Link lane.

Lane 0 | Lane 1 | Lane 2 | Lane 3
------|--------|--------|--------
Pixel 0 | Pixel 1 | Pixel 2 | Pixel 3
Pixel 4 | Pixel 5 | Pixel 6 | Pixel 7
CTRL | CTRL | CTRL | CTRL

Lane 0 | Lane 1
------|--------
Pixel 0 | Pixel 1
Pixel 2 | Pixel 3
Pixel 4 | Pixel 5
Pixel 6 | Pixel 7
CTRL | CTRL
CTRL | CTRL

All pixels
Requirements and lane count

1280×720p@60Hz → 2.23 Gbps total
1920×1080p@60Hz → 4.46 Gbps total

DVI/HDMI

DisplayPort

Inter-lane skewing

- Control data must not become corrupted by external noise.
- The lanes are skewed by 20 unit intervals relative to each other.

BE = Blanking End
BS = Blanking Start
DisplayPort v1.2

- Backwards compatible with v1.1a
- Maximum data rate: 21.6 Gbps with multi-streaming
- 720 Mbps bi-directional AUX channel
- Audio Copy Protection, support for new audio formats

4 Full HD signals with audio or 2560×1600@120Hz or 4K60
High-speed USB 2.0, ethernet
New and exciting problems 😊

Multistreaming

TX
4 IN 1 OUT

RX
1 IN 4 OUT

313/xxx

314/xxx
Behind the Scenes of DVI, HDMI and DisplayPort

Multistreaming

Future of DisplayPort

<table>
<thead>
<tr>
<th>PC Market</th>
<th>Consumer Market</th>
<th>Professional Manufacturers</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Performance demand</td>
<td>• Millions of HDMI devices have been sold</td>
<td>• Serving both markets</td>
</tr>
<tr>
<td>• High resolution gaming and</td>
<td>• No need for higher resolutions</td>
<td></td>
</tr>
<tr>
<td>graphics work</td>
<td></td>
<td></td>
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</table>

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# Behind the Scenes of DVI, HDMI and DisplayPort

## Comparison

<table>
<thead>
<tr>
<th></th>
<th>Max. Bandwidth (Gbps)</th>
<th>Max. Resolution (@60Hz)</th>
<th>Deep Color</th>
<th>Audio</th>
<th>Ethernet</th>
<th>USB</th>
<th>Audio Return Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Link DVI</td>
<td>4.95</td>
<td>1920×1200 or 2K</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dual Link DVI</td>
<td>9.9</td>
<td>2560×1600</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HDMI 1.3</td>
<td>6.75</td>
<td>1920×1200 or 2K</td>
<td>Yes</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HDMI 1.4</td>
<td>10.2</td>
<td>2560×1600</td>
<td>Yes</td>
<td>Yes</td>
<td>10/100</td>
<td>-</td>
<td>Yes</td>
</tr>
<tr>
<td>HDMI 2.0</td>
<td>18</td>
<td>4K</td>
<td>Yes</td>
<td>Yes</td>
<td>10/100</td>
<td>-</td>
<td>Yes</td>
</tr>
<tr>
<td>DisplayPort v1.1a</td>
<td>10.8</td>
<td>2560×1600</td>
<td>Yes</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DisplayPort v1.2</td>
<td>21.6</td>
<td>4K</td>
<td>Yes</td>
<td>Yes</td>
<td>10/100</td>
<td>Yes</td>
<td>-</td>
</tr>
</tbody>
</table>
Behind the Scenes of DVI, HDMI and DisplayPort

Apple Thunderbolt

Thunderbolt vs. DisplayPort

DisplayPort

Thunderbolt
Thunderbolt

- Created by Intel (codenamed Light Peak)
- First introduction: Apple MacBook Pro, February 24, 2011
- Uses the same connector as Mini DisplayPort (Apple’s standard)
- Backwards compatible with DisplayPort architecture
- Existing DP-to-VGA, -DVI and -HDMI converters can be used

Technical details

- Multiplexes PCI Express data and DisplayPort data
- Two 10 Gbps bi-directional channels, allowing a total throughput of 40 Gbps
- 10 W power over copper cable
- Thunderbolt uses an active cable, which has 5 wires:
  - 1 for maintenance
  - 2 uni-directional pairs, one for incoming, one for outgoing data
DP vs. Thunderbolt pinout

<table>
<thead>
<tr>
<th>Pin #</th>
<th>DisplayPort</th>
<th>Thunderbolt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lane0+</td>
<td>GND</td>
</tr>
<tr>
<td>2</td>
<td>GND</td>
<td>Hot Plug</td>
</tr>
<tr>
<td>3</td>
<td>Lane0-</td>
<td>High Speed 0 TX+</td>
</tr>
<tr>
<td>4</td>
<td>Lane1+</td>
<td>High Speed 0 RX+</td>
</tr>
<tr>
<td>5</td>
<td>GND</td>
<td>High Speed 0 TX-</td>
</tr>
<tr>
<td>6</td>
<td>Lane1-</td>
<td>High Speed 0 RX-</td>
</tr>
<tr>
<td>7</td>
<td>Lane2+</td>
<td>GND</td>
</tr>
<tr>
<td>8</td>
<td>GND</td>
<td>GND</td>
</tr>
<tr>
<td>9</td>
<td>Lane2-</td>
<td>Low Speed TX</td>
</tr>
<tr>
<td>10</td>
<td>GND</td>
<td>GND</td>
</tr>
<tr>
<td>11</td>
<td>Lane3+</td>
<td>Low Speed RX</td>
</tr>
<tr>
<td>12</td>
<td>GND</td>
<td>GND</td>
</tr>
<tr>
<td>13</td>
<td>Lane3-</td>
<td>Low Speed RX</td>
</tr>
<tr>
<td>14</td>
<td>Config1</td>
<td>GND</td>
</tr>
<tr>
<td>15</td>
<td>Config2</td>
<td>GND</td>
</tr>
<tr>
<td>16</td>
<td>AUX+</td>
<td>High Speed 1 TX+</td>
</tr>
<tr>
<td>17</td>
<td>AUX-</td>
<td>High Speed 1 RX+</td>
</tr>
<tr>
<td>18</td>
<td>Hot Plug</td>
<td>High Speed 1 TX-</td>
</tr>
<tr>
<td>19</td>
<td>Return PWR</td>
<td>High Speed 1 RX-</td>
</tr>
<tr>
<td>20</td>
<td>DP_PWR</td>
<td>DP_PWR</td>
</tr>
</tbody>
</table>

Apple Thunderbolt

Host side Thunderbolt controller chip  

Thunderbolt  

Thunderbolt controller chip

PCle  

DisplayPort  

PCle  

DisplayPort
Behind the Scenes of DVI, HDMI and DisplayPort

Apple Thunderbolt

- Host side Thunderbolt controller chip
- PCIe
- DisplayPort

Daisychaining Thunderbolt devices

- 6 peripherals can be daisychained
- The display could theoretically be anywhere in the chain (but the end of the chain is recommended).
Future of Thunderbolt

• Very good for data intensive work (video editing, video capturing).
• USB is a big competitor, the speed of USB 3.0 is enough for the majority of applications in the PC Market.
• Probably not a big hit in the Pro A/V world.
• SDI, HDMI and DisplayPort are more likely to rule.

System level issues
Behind the Scenes of DVI, HDMI and DisplayPort

Compatibility

Will it work?

Manufacturer 1  Manufacturer 2

Compatibility – Powering

Huge violation of the standard

Source device  +16V  Hotplug  Sink device

“Phantom power”
Ground loop – Faraday’s law

Changing Electromagnetic field

Conductor

Current

Ground loop

Hum noise

Audio Source

Amplifier

Loop

training@lightware.com
Ground loop

HDCP compliant fiber optical cable with copper wires

Ground loop

Fiber + UTP

TX

RX

Loop
### Solution

- **Cut** – cut the ground connection between two points, but consider safety.

- **Isolate** – Use devices with isolated power supplies or isolated signal paths. (e.g. Lightware Single Fiber extenders)

- **Reduce** – Reduce the area of the ground loop.

### Digital audio “pop”

Correct: soft mute
Problem finding

The ultimate solution

Have you tried turning it OFF and ON again?

Chris O’Dowd – IT Crowd
Start-up sequence

- Sources
- Transmission system
- Distribution system
- Displays
- Event controller

Asking for technical support

- If you have a problem, try to reproduce it.
  - Problems that cannot be reproduced in the manufacturer’s lab are extremely hard to solve.
- Document the circumstances, used devices (serial numbers, firmware versions), order of steps that lead to the problem.
- Document the symptoms by photo or video.
- Send a schematic! A hand drawing can be sufficient.
- Every little detail counts (patch panels, gender changers, cable lengths, resolution, refresh rate).
Systematic problem finding

The rule of problem finding: only change one thing at a time!

You can use different methods:

1. Start at the source side and go towards the displays.
2. Start at the display side and go backwards.
3. Cut the system in half and see which half the problem moves with.
4. Based on past experience and intuition you can start anywhere. If that doesn’t work, choose one from the above.

Systematic problem finding – Hardware issue
Behind the Scenes of DVI, HDMI and DisplayPort

Systematic problem finding – Hardware issue

Source 1  →  Matrix  →  DVI In  →  Fiber  →  Fiber RX 2  →  LCD 1
Source 2  →  Matrix  →  DVI In  →  Fiber  →  Fiber RX 1

Systematic problem finding – Setting issue

Laptop
- DSUB
- HDMI

BluRay
- HDMI

Projector 1
- HDMI
- DSUB

Projector 2
- HDMI
- DSUB
Systematic problem finding – Setting issue

Solution 1: EDID Management
Solution 2: Signal Conversion

Laptop
  DSUB
  HDMI

HDMI Matrix

HDMI

Projector 1
  HDMI
  DSUB

Projector 2
  HDMI
  DSUB

BluRay
  HDMI

Questions