

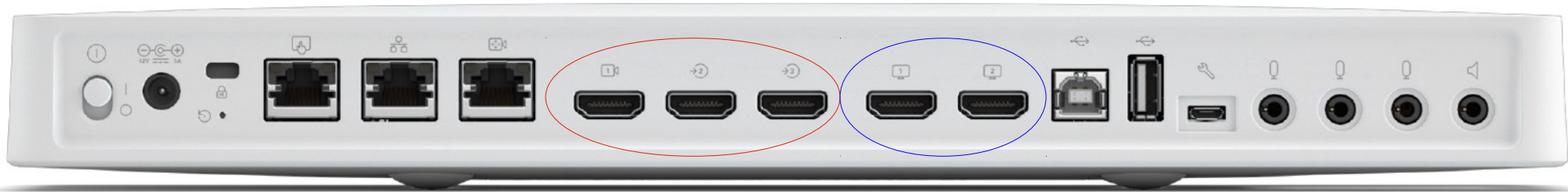
HDMI 4k Video: Lessons Learned

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Three inputs (red): 1x 1080p60, 2x 4kp30: used to connect laptops, cameras.

Two outputs (blue): 2x 4kp60: used to connect TVs or PC monitors (less common).

HDMI & 4k



Main HDMI Lines

- Three differential pairs for data and one pair for the clock signal. Commonly known as the TMDS (Transition-Minimized Differential Signaling) lines.
- DDC (Display Data Channel): two lines, basically an i2c bus. Used to read the EDID (the display information), negotiate HDCP (video encryption) and for SCDC (Status and Control Data Channel, HDMI 2.0 only).
- 5V line. Supplied by the source. If the sink detects a voltage between 4.7 and 5.3V then that indicates that a source is connected to the sink.
- Hot Plug Detect: pulled high by the sink if it has a valid EDID. The source assumes HPD is high if it detects a voltage between 2 and 5.3V.
- A sink can use the 5V from the source to power an eeprom containing the EDID and pull the HPD high. This allows the source to read the EDID even if the sink is powered off.
- Note: there are other lines as well for e.g. CEC and ARC. Those are unrelated to 4k video so they will not be discussed here.

What Does HDMI 4k Video Mean?

- '4k' stands for a resolution of 3840x2160 pixels.
- Typical frame rates: 23.276, 24, 25, 29.97, 30, 50, 59.94, 60 Hz. Only 30 and 60 Hz really matter for this presentation.
- Encoding: RGB, YUV 4:4:4, YUV 4:2:2 (utilizes the same bandwidth as RGB/YUV 4:4:4) and YUV 4:2:0 (half the bandwidth of RGB, not always supported!).
- HDMI Pixel Clock: 148.5 MHz (standard HDMI cable), 297 MHz (High Speed cable), 594 MHz (Premium High Speed cable).
- YUV 4:2:0 4k @ 30 Hz can be transmitted at a clock rate of 148.5 MHz.
- Both YUV 4:2:0 4k @ 60 Hz and RGB 4k @ 30 Hz need 297 MHz.
- RGB 4k @ 60 Hz needs 594 MHz (Requires HDMI 2.0).
- So '4k' only refers to the resolution, it says *nothing* about the frame rate and pixel encoding. It can be very difficult to determine what *exactly* is supported by a device advertised as '4k'.

HDMI HW & Protocol Lessons



Hardware Design Lessons

- Video at 4kp60 is at the edge of what is possible over an HDMI cable.
 - Make sure all signals are clean. Remember that cables, adapters, etc. will degrade the signal, so if it is borderline at the source, it will likely be out-of-spec at the sink.
 - Check eye diagrams, voltages, clock signals.
- Note: the actual TMDS clock frequency is higher for 297 MHz than 594 MHz (10 bits per clock cycle vs 40 bits per clock cycle). So make sure to test at both frequencies.

HDMI Protocol Lessons

- Don't send Null Packets even though this is allowed by the standard: causes flickering in some displays.
- Apple does random-access reads on the EDID instead of reading the EDID in 128-byte chunks: make sure you support this.
- SCDC (Status and Control Data Channel): new for HDMI 2.0.
 - Scrambling to reduce electro-magnetic interference on the data lines. Must be enabled for clock frequencies above 340 Mhz, optional for lower frequencies (only if both source and sink support scrambling). Set by the source.
 - TMDS Bit Clock Ratio: either 10 (< 340 MHz) or 40 (>= 340 MHz) bits per clock cycle. Set by the source.
 - Sink status flags (clock detection, channel sync lock status).
 - Error detection counters.
- Recommended to be able to log the SCDC status. Useful when debugging.

HDMI RGB Quantization Range Lessons



HDMI RGB Quantization Range (1)

- Two RGB quantization ranges: 0-255 (full range) or 16-235 (limited range).
- Wrong interpretation can lead to light-gray becoming white if full range is interpreted as limited range or to white becoming light-gray if limited range is interpreted as full range.
- By default the RGB quantization range depends on the video timings: IT (VESA) based timings use full range, consumer electronics timings (720p, 1080p, 4k) use limited range.
- Sinks can support 'selectable quantization range' allowing sources to be explicit about what they are sending. Sinks signal this in the EDID and sources signal this in the AVI InfoFrame.
- General rule: always support selectable quantization range, either as a sink (set the bit in the EDID) or as a source (if the bit is set in the EDID, then explicitly signal the quantization range you transmit).
- Helpful for interpreting the EDID: edid-decode utility.
- Support to log the HDMI InfoFrames is very useful when debugging quantization range problems.

HDMI RGB Quantization Range (2)

- Apple Intel driver: always uses full range for RGB.
- Windows Intel driver: uses the default quantization rules for RGB, does not appear to support selectable quantization range.
- Linux Intel driver: uses the default quantization rules for RGB, but also supports selectable quantization range.
- So an Apple laptop sends full range, a Windows laptop sends limited range and a Linux laptop is explicit.
- Solution: enable YUV support in the EDID: Apple (and only Apple) will switch to sending YUV which is always limited range.
- Few displays support selectable quantization range. Monitors typically interpret video as full range and TVs use limited range. Impossible to know what to do without presenting test images and asking how it looks.
- OSDs give it non-standard names like 'Black Level', typically undocumented what each value means.

HDMI RGB Quantization Range (3)

- CE Video timings are identified by a VIC number (Video Identification Code). This number is part of the AVI InfoFrame transmitted by the source.
- If $VIC == 0$, then it is an IT format and uses full range, otherwise it is a CE format and uses limited range.
- VIC codes are standardized in the CTA-861 standard, not in the HDMI specification.
- Exception: HDMI 1.4 introduced four 'HDMI VIC' codes for the 4k format at 24, 25 and 30 Hz and for the 4096x2160p24 timing. In a later revision of the CTA-861 standard 'CTA' VIC codes were added for these same timings.
- The HDMI Specification says that you have to use the HDMI VIC codes (signaled via the HDMI Vendor Specific InfoFrame) for these four formats and set the VIC code (signaled via the AVI InfoFrame) to 0. The HDMI VIC codes are only used for 2D, not for 3D. For 3D formats the 'CTA' VIC codes are used.
- Question: what is the default quantization range for 4kp30? Since $VIC == 0$ the CTA spec says full range. But the timings are equivalent to a valid VIC code, so it would be reasonable to interpret it as limited range. Both standards are silent about how this should be interpreted.
- In practice it seems full range is used by sources.
- Warning: some sources set both HDMI VIC and VIC to non-0 values! Still sending full range, though.

HDMI RGB Quantization Range (4)

**Conclusion:
Total Chaos!**

HDMI Driver Lessons



Driver Lessons

- Interrupts vs polling: even though many if not all i2c-controlled HDMI receivers and transmitters have interrupts to signal format/HPD/etc. changes, this is often flaky. It is not unusual that some or all interrupts stop working. Replacing interrupts by polling X times per second is usually the best alternative.
- Continuously plugging/unplugging the HDMI cable is a good way to find these issues.
- HDMI-to-CSI receiver: sometimes it would detect the signal, sometimes not, sometimes intermittent. Depended on the source, cabling, adapters.

Turns out that it has an 'Equalizer Bypass' bit that enables or disables an equalizer for the TMDS lines. Was originally undocumented.

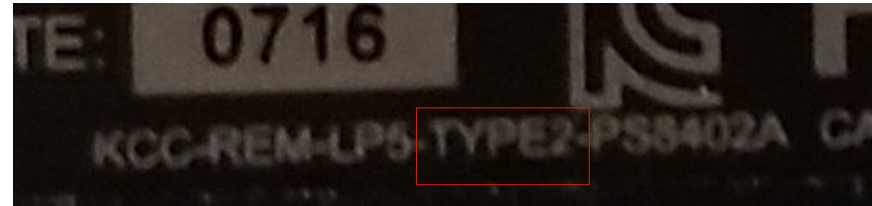
The only way of determining whether to set it or not is by trial-and-error. A nightmare to implement and impossible to get 100% right.

HDMI Cables/Adapter Lessons



DisplayPort to HDMI Adapters

- Dual-mode (aka passive) DisplayPort to HDMI adapters: can be Type 1 (rated up to 165 MHz) or Type 2 (rated up to 300 MHz).
- Type 2 adapters provide Adapter Registers which contain the adapter revision (2). Type 1 adapters do not have these registers.
- The Intel Linux GPU driver will check for this and prevent using frequencies higher than 165 MHz if a Type 1 is detected. The Intel Apple and Windows GPU drivers do *not* check for this, so it may or may not work.



USB-C to HDMI Adapters

- A very common problem with these adapters is a substantial voltage drop on the 5V line. Can cause problems reading out EDID (if the eeprom with the EDID is powered by the 5V line and/or if the sink loops the 5V to the HPD pin).
- Some adapters enable HDCP even when the sink doesn't support HDCP: major problem for video conferencing since encrypted presentations from a laptop are not allowed to be transmitted to the remote party in the call. Sometimes a firmware update of the USB-C to HDMI adapter will fix this.

HDMI Cables

- Only use HDMI 2.0 (594 MHz) cables that went through the Premium HDMI Cable Certification Program: see <http://www.hdmi.org/>
- Long cables: 5V voltage drop can be a major problem.

HDMI Accessories in General

- Very, very poor specifications. If they are given at all!
- No standardized labeling of adapters/cables (except for certified HDMI 2.0 cables, but even there it is not compulsory to actually label the cable).
- Poor quality control.

Resources



Resources

- Git repository for edid-decode:
`git://anongit.freedesktop.org/xorg/app/edid-decode`
- My email: `hverkuil@xs4all.nl`

Questions?

