ZÁPADOČESKÁ UNIVERZITA V PLZNI
Faculty of Electrical Engineering
Department of Applied Electronics and Telecommunications

Master thesis

HDMI Connection System

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Plzeň 2013

ZÁPADOČESKÁ UNIVERZITA V PLZNI
Fakulta elektrotechnická
Akademický rok: **2012/2013**

ZADÁNÍ DIPLOMOVÉ PRÁCE

(PROJEKTU, UMĚLECKÉHO DÍLA, UMĚLECKÉHO VÝKONU)

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Osobní číslo:	**E11N0075P**
Studijní program:	**N2612 Elektrotechnika a informatika**
Studijní obor:	**Telekomunikační a multimediální systémy**
Název tématu:	**HDMI propojovací systém**
Zadávající katedra:	**Katedra aplikované elektroniky a telekomunikací**

Zásady pro vypracování:

1. Seznamte se s HDMI systémem.
2. Popište možnosti propojení, použité signály a protokoly u jednotlivých specifikací.
3. Zaměřte se na možnosti využití HDMI pro 3D systémy.
4. Navrhněte laboratorní úlohy pro prezentaci HDMI využitelné pro předměty AVT, TRM a TVR.

Rozsah grafických prací:	**podle doporučení vedoucího**
Rozsah pracovní zprávy:	**30 - 40 stran**
Forma zpracování diplomové práce:	**tištěná/elektronická**
Seznam odborné literatury:	

Student si vhodnou literaturu vyhledá v dostupných pramenech podle doporučení vedoucího práce.

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Datum zadání diplomové práce:	**15. října 2012**
Termín odevzdání diplomové práce:	**9. května 2013**

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Abstrakt

Cílem této práce je popsat specifikaci High Definition Multimedia Interface a analyzovat druhy video formátů, se kterými umí pracovat. Nejprve bude představen vývoj verze HDMI kabelů a jejich přehled. Poté bude analyzována struktura dat, přenášených prostřednictvím kabelu, a princip práce celého systému. Systém bude také posuzován z hlediska přenosu 3D videa. Jako praktické části budou srovnány video signály různých formátů a přenosových rychlostí. Použitá videa jsou založená na kodeku H.264, který se často používá v HDTV vysílání, a ta budou hodnocena pomocí objektivních měření kvality.

Klíčová slova

HDMI, 3D, PSNR, SSIM, VQM, HDTV

Abstract

Povozniucov, Alexandr. *HDMI Connection System* [*HDMI Connection System*]. Pilsen, 2013. Master thesis (in English). University of West Bohemia. Faculty of Electrical Engineering. Department of Applied Electronics and Telecommunications. Supervisor: Jiří Masopust

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The main objectives of this thesis is to describe the specification of High Definition Multimedia Interface and to analyze the aspects of video format that it can carry. First the evolution of HDMI version cable will be presented and then it will be overviewed. After we will analyze the structure of a data transmitted by cable and principle of working of the entire system . The transmission of 3D video over HDMI will be considered.. As a practical part the video content with different formats and the bitrates will be compared. The mentioned video is based on H.264 codec which is often used in HDTV broadcasts and it will be evaluated by using objective quality measurements.

Keywords

HDMI, 3D, PSNR, SSIM, VQM, HDTV

Prohlášení

Předkládám tímto k posouzení a obhajobě diplomovou práci, zpracovanou na závěr studia na Fakultě elektrotechnické Západočeské univerzity v Plzni.

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Také prohlašuji, že veškerý software, použitý při řešení této diplomové práce, je legální.

V Plzni dne 2. května 2013

Bc. Alexandr Povozniucov

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Podpis

Poděkování

Rád bych poděkoval svému vedoucímu práce, panu Doc. Ing. Jiřímu Masopustu, CSc., za důkladné vedení a pomoc během celé mé práce.

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List of symbols and abbreviations

2K and 4K…...	Resolution of 2048 pixels × 1080 pixels and 3840 pixels × 2160 pixels
3D………….....	Three Dimensional
ACR-HR…….	Absolute category rating with hidden reference
ATSC………..	Advanced Television Systems Committee
AV…………....	Audio-Video
CEC………….	Consumer Electronic Control
CLI…………..	Command Line Interface
DCC…………	Display Data Channel
DTS-HD……..	Lossless audio codec created by Digital Theater System
DVB…………	Digital Video Broadcasting
DVD…………	Digital Versatile Disc
DVI………….	Digital Visual Interface
EDID………....	Extended display identification data
GNU…………	Unix-like computer operating system
GPL………….	General Public License
GUI………….	Graphical User Interface
HEAC………..	HDMI Ethernet & Audio return channel
HVS…………	Human Visual System
IEC…………..	International Electrotechnical Commission
ISDB………....	Integrated Service Digital Broadcasting
ITS…………..	Institute for Telecommunication Sciences
LPCM………..	Linear Pulse-Code Modulation
PCM…………	Pulse-Code Modulation
PLL………….	Phase-Locked Loop
TMDS……….	Transition Minimized Differential Signaling
UXGA……….	Ultra eXtended Graphics Array
VESA………..	Video Electronics Standards Association
VQEG……….	Video Quality Experts Group

1. Introduction

Digital interfaces such as HDMI have been around since early 2002 and have changed the technology of transmitting a multimedia data. It was co-developed by Hitachi, Panasonic Corporation, Royal Philips Electronics, Silicon Image, Sony Corporation, Thomson and Toshiba Corporation. HDMI is a digital replacement for existing analog video standards. DVI was a precursor to HDMI and it was used in many computer displays. The HDMI 1.0 specification was designed to improve upon DVI by using a smaller connector, adding support for audio, boasting richer colors and utilizing CEC functions. Both HDMI and DVI were pioneered by Silicon Image and are based on TMDS, Silicon Image's powerful, high-speed, serial link technology. With the development of HDMI some new features such as 3D support , 4K & 2K support, internet over HDMI, Audio Return Channel, more color space etc. were added.

HDMI implements the EIA/CEA-861 standards, which define video formats and waveforms, transport of compressed, uncompressed, and PCM audio, auxiliary data, and implementations of the VESA EDID. HDMI supports, on a single cable, any uncompressed TV or PC video format, including standard, enhanced and high-definition video, up to 8 channels of compressed or uncompressed digital audio, a CEC connection, and an Ethernet data connection.

HDMI supports many video formats which have different resolutions and very often the viewers of HDTV face with the question: What is the best format, and what is the best resolution that provides the best quality and the clearest image. To give a correct answer for these questions it is necessary to accomplish a video quality measurements for different formats. In this thesis will be compared several HDTV formats that are used for broadcasting TV and determine the influence on scanning emission, resolution and bitrate on video quality by using an objective measures.

To perform this measurements as original files (reference) some test sequenced files from Video Quality Experts Group (VQEG) resources will be used for different format that are offered free for education purposes. Afterward they will be converted in raw video with different bitrate and compared to reference (uncompressed) and between them. The received results will be presented in graphical form.

2. HDMI Overview

2.1 Referencing HDMI Version Numbers

HDMI devices are manufactured to adhere to various versions of the specification, in which each version is given a number, such as 1.0, 1.2,1.3 etc. Each subsequent version of the specification uses the same kind of cable but increases the bandwidth and/or capabilities of what can be transmitted over the cable. A product listed as having an HDMI version does not necessarily mean that it will have all of the features that are listed for that version, since some HDMI features are optional, such as Deep Color and xvYCC (which is branded by Sony as “x.v.Color“).

- Version 1.0 to 1.2

HDMI 1.0 was released December 9, 2002 and is a single-cable digital audio/video connector interface with a maximum TMDS bandwidth of 4.9 Gbit/s. It supports up to 3.96 Gbit/s of video bandwidth (1080p/60 Hz or UXGA) and 8 channel LPCM/192 kHz/24-bit audio. HDMI 1.1 was released on May 20, 2004 and added support for DVD Audio. HDMI 1.2 was released August 8, 2005 and added support for One Bit Audio, used on Super Audio CDs, at up to 8 channels. It also added the availability of HDMI Type A connectors for PC sources, the ability for PC sources to only support the sRGB color space while retaining the option to support the YCbCr color space, and required HDMI 1.2 and later displays to support low-voltage sources. HDMI 1.2a was released on December 14, 2005 and fully specifies CEC features, command sets, and CEC compliance tests. [1]

- Version 1.3

HDMI 1.3 was released June 22, 2006 and increased the single-link bandwidth to 340 MHz (10.2 Gbit/s). It optionally supports Deep Color, with 30-bit, 36-bit, and 48-bit xvYCC, sRGB, or YCbCr, compared to 24-bit sRGB or YCbCr in previous HDMI versions. It also optionally supports output of Dolby TrueHD and DTS-HD Master Audio streams for external decoding by AV receivers. It incorporates automatic audio syncing (audio video sync) capability. It defined cable Categories 1 and 2, with Category 1 cable being tested up to 74.25 MHz and Category 2 being tested up to 340 MHz. It also added the new Type C mini connector for portable devices. HDMI 1.3a was released on November 10, 2006 and had Cable and Sink modifications for Type C, source termination recommendations, and removed undershoot and maximum rise/fall time limits. It also changed CEC capacitance limits, clarified sRGB video quantization range, and CEC commands for timer control were brought back in an altered form, with audio control commands added. HDMI 1.3b was released on March 26, 2007 and added HDMI compliance testing revisions. HDMI 1.3b has no effect on HDMI features, functions, or performance, since the testing is for products based on the HDMI 1.3a specification. HDMI 1.3b1 was released on November 9, 2007 and added HDMI compliance testing revisions, which added testing requirements for the HDMI Type C mini connector. HDMI 1.3b1 has no effect on HDMI features, functions, or performance, since the testing is for products based on the HDMI 1.3a specification. HDMI 1.3c was released on August 25, 2008 and added HDMI compliance testing revisions, which changed testing requirements for active HDMI cables. HDMI 1.3c has no effect on HDMI features, functions, or performance, since the testing is for products based on the HDMI 1.3a specification. [1]

- Version 1.4

HDMI 1.4 was released on May 28, 2009, and Silicon Image expects their first HDMI 1.4 products to sample in the second half of 2009. HDMI 1.4 increases the maximum resolution to 4K × 2K (3840×2160p at 24Hz/25Hz/30Hz and 4096×2160p at 24Hz, which is a resolution used with digital theaters).In the first was implemented an HDMI Ethernet Channel, which allows for a 100 Mb/s Ethernet connection between the two HDMI connected devices, and introduces an Audio Return Channel, 3D Over HDMI, a new Micro HDMI Connector, expanded support for color spaces, and an Automotive Connection System. All these new features will be examined in more detail throughout this thesis. [1]

- Version 2.0

The HDMI Forum is working on the HDMI 2.0 specification. In a 2012 CES press release HDMI Licensing, LLC stated that the expected release date for the next version of HDMI was the second half of 2012 and that important improvements needed for HDMI include increased bandwidth to allow for higher resolutions and broader video timing support. Longer term goals for HDMI include better support for mobile devices and improved control functions.

On January 8, 2013, HDMI Licensing, LLC announced that the next HDMI version is being worked on by the 83 members of the HDMI Forum and that it is expected to be released in the first half of 2013.

Based on HDMI Forum meetings it is expected that HDMI 2.0 will increase the maximum TMDS per channel throughput from 3.4 Gbit/s to 6 Gbit/s which would allow a maximum total TMDS throughput of 18 Gbit/s. This will allow HDMI 2.0 to support 4K resolution at 60 frames per second (fps). Other features that are expected for HDMI 2.0 include support for 4:2:0 chroma subsampling, support for 25 fps 3D formats, improved 3D capability, support for more than 8 channels of audio, support for the HE-AAC and DRA audio standards, dynamic auto lip-sync, and additional CEC functions. [1]

According HDMI Licensing, LLC since January 1 2012 HDMI version numbers can be used only under limited circumstances, especially it's forbidden to use HDMI version numbers in the labeling, packaging, or promotion of any cable product [2]. All cables are labeled, both on the cable itself and on the front of the cable packaging, with the appropriate cable name:

Standard HDMI® Cable (Category 1)

Standard HDMI® Cable with Ethernet (Category 1 with HEAC)

Standard Automotive HDMI® Cable (Category 1)

High Speed HDMI® Cable (Category 2)

High Speed HDMI® Cable with Ethernet (Category 2 with HEAC)

Standard HDMI cable have maximum TMDS throughput per channel including 8b/10b overhead 74.25 Mbit/s , but High Speed HDMI Cable support up 340 Mbit/s.

2.2 HDMI Connectors

To organize a connection between a source device and a sink device to carry a data there is need to exist a physical interconnect between them. In the HDMI this role play connectors, obviously on side of the source and sink devices incorporate a HDMI type A receptacle (female) connector and on cable HDMI type A plug (male) connector. By increasing the expansion of using HDMI in various areas for today were developed five HDMI connector types, identified by a large latin letters. Type A and B are defined in the HDMI 1.0 specification, type C is defined in the HDMI 1.3 specification, and type D and E are defined in the HDMI 1.4 specification. All five connectors carry all required HDMI signals, including a TMDS link.

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- Type A

Nineteen pins, with bandwidth to support all SDTV, EDTV and HDTV modes. The plug (male) connector outside dimensions are 13.9 mm × 4.45 mm and the receptacle (female) connector inside dimensions are 14 mm × 4.55 mm. Type A is electrically compatible with single-link DVI-D. [1]

- Type B

This connector (21.2 mm × 4.45 mm) has 29 pins and can carry six differential pairs instead of three, for use with very high-resolution future displays such as WQUXGA(3,840×2,400). Type B is electrically compatible with dual-link DVI-D, but has not yet been used in any products. However, the use of the extra three differential pairs is reserved as of 1.3 specification. [1]

- Type C (mini-HDMI)

A Mini connector defined in the HDMI 1.3 specification, it is intended for portable devices. It is smaller than the type A plug connector (10.42 mm × 2.42 mm) but has the same 19-pin configuration. The differences are that all positive signals of the differential pairs are swapped with their corresponding shield, the DDC/CEC Ground is assigned to pin 13 instead of pin 17, the CEC is assigned to pin 14 instead of pin 13, and the reserved pin is 17 instead of pin 14. The type C Mini connector can be connected to a type A connector using a type A-to-type C cable. [1]

- Type D (micro-HDMI)

A Micro connector defined in the HDMI 1.4 specification keeps the standard 19 pins of types A and C but shrinks the connector size to something resembling a micro-USB connector. The type D connector is 2.8 mm × 6.4 mm, whereas the type C connector is 2.42 mm × 10.42 mm. For comparison, a micro-USB connector is 1.8 mm × 6.85 mm and a USB Type A connector is 4.5 mm × 11.5 mm. The pin assignment is different from Type A or C. [1]

- Type E

Automotive Connection System defined in HDMI 1.4 specification. The connector has a locking tab to keep the cable from vibrating loose, and a shell to help prevent moisture and dirt. A relay connector is available for connecting standard consumer cables to the automotive type with 19 pins. [1]

By specification Type E connector can support only up to 2 Gbps signal (720p or 1080i).

In the Table 2.2 are lists the pin assignment for all mentioned type of connectors.

PIN	Type A	Type B	Type C	Type D	Type E
1	TMDS Data2+	TMDS Data2+	TMDS Data2 Shield	Hot Plug Detect /HEAC-	TMDS Data2+
2	TMDS Data2 Shield	TMDS Data2 Shield	TMDS Data2+	Utility/HEAC+	TMDS Data2 Shield
3	TMDS Data2–	TMDS Data2–	TMDS Data2-	TMDS Data2+	TMDS Data2–
4	TMDS Data1+	TMDS Data1+	TMDS Data1 Shield	TMDS Data2 Shield	TMDS Data1+
5	TMDS Data1 Shield	TMDS Data1 Shield	TMDS Data1+	TMDS Data2–	TMDS Data1 Shield
6	TMDS Data1–	TMDS Data1–	TMDS Data1-	TMDS Data1+	TMDS Data1–
7	TMDS Data0+	TMDS Data0+	TMDS Data0 Shield	TMDS Data1	TMDS Data0+
8	TMDS Data0 Shield	TMDS Data0 Shield	TMDS Data0+	TMDS Data1–	TMDS Data0 Shield
9	TMDS Data0–	TMDS Data0–	TMDS Data0-	TMDS Data0+	TMDS Data0–
10	TMDS Clock+	TMDS Clock+	TMDS Clock Shield	TMDS Data0 Shield	TMDS Clock+
11	TMDS Clock Shield	TMDS Clock Shield	TMDS Clock+	TMDS Data0–	TMDS Clock Shield
12	TMDS Clock–	TMDS Clock–	TMDS Clock-	TMDS Clock+	TMDS Clock–
13	CEC	TMDS Data5+	DDC/CEC Ground/HEAC Shield	TMDS Clock S	CEC
14	Utility/HEAC+	TMDS Data5 Shield	CEC	TMDS Clock–	Reserved (N.C. on device)
15	SCL	TMDS Data5-	SCL	CEC	SCL
16	SDA	TMDS Data4+	SDA	DDC/CEC Ground/HEAC Shield	SDA
17	DDC/CEC Ground/HEAC Shield	TMDS Data4 Shield	Utility/HEAC+	SCL	DDC/CEC Ground
18	+5V Power	TMDS Data4-	+5V Power	SDA	+5V Power
19	Hot Plug Detect /HEAC-	TMDS Data3+	Hot Plug Detect /HEAC-	+5V Power	Hot Plug Detect
20	-	TMDS Data3 Shield	-	-	-
21	-	TMDS Data3-	-	-	-
22	-	CEC	-	-	-
23	-	Reserved (N.C. on device)	-	-	-
24	-	Reserved (N.C. on device)	-	-	-
25	-	SCL	-	-	-
26	-	SDA	-	-	-
27	-	DDC/CEC Ground	-	-	-
28	-	+5V Power	-	-	-
29	-	Hot Plug Detect	-	-	-

Table 2.1: Pin Assignment

2.3 Architecture HDMI

HDMI system architecture is defined to consist of Sources and Sinks. A given device may have one or more HDMI inputs and one or more HDMI outputs. Each HDMI input on these devices shall follow all of the rules for an HDMI Sink and each HDMI output shall follow all of the rules for an HDMI Source.

As shown in Figure 2.1, the HDMI cable and connectors carry four differential pairs that make up the TMDS data and clock channels. These channels are used to carry video, audio and auxiliary data. In addition, HDMI carries a VESA DDC channel. The DDC is used for configuration and status exchange between a single Source and a single Sink. The optional CEC protocol provides high-level control functions between all of the various audiovisual products in a user's environment. The optional HDMI HEAC provides Ethernet compatible data networking between connected devices and an Audio Return Channel in the opposite direction from TMDS. [3]

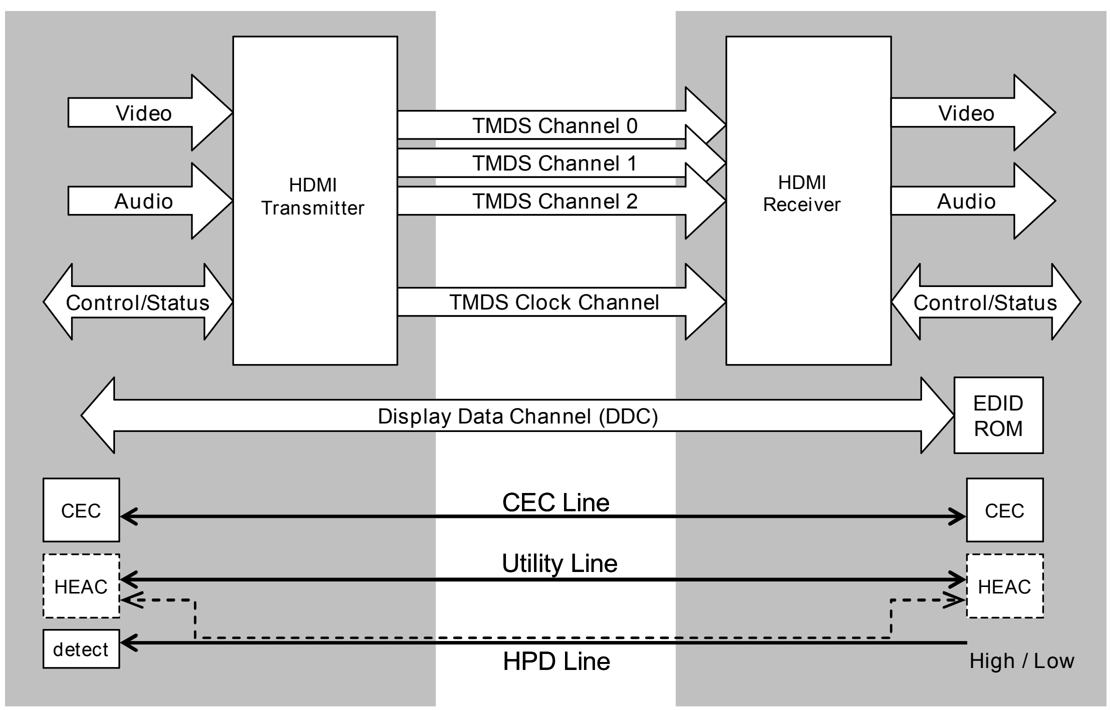

Fig. 2.1: HDMI Block Diagram, | Adapted from [3]|

Audio, video and auxiliary data is transmitted across the three TMDS data channels. A TMDS clock, typically running at the video pixel rate, is transmitted on the TMDS clock channel and is used by the receiver as a frequency reference for data recovery on the three TMDS data channels. At the source, TMDS encoding converts the 8 bits per TMDS data channel into the 10 bit DC-balanced, transition minimized sequence which is then transmitted serially across the pair at a rate of 10 bits per TMDS clock period. Video data can have a pixel size of 24, 30, 36 or 48 bits. Video at the default 24-bit color depth is carried at a TMDS clock rate equal to the pixel clock rate. Higher color depths are carried using a correspondingly higher TMDS clock rate. Video formats with TMDS rates below 25MHz (e.g. 13.5MHz for 480i/NTSC) can be transmitted using a pixel-repetition scheme. The video pixels can be encoded in either RGB, YCbCr 4:4:4 or YCbCr 4:2:2 formats. [3]

In order to transmit audio and auxiliary data across the TMDS channels, HDMI uses a packet structure. In order to attain the higher reliability required of audio and control data, this data is protected with a BCH error correction code and is encoded using a special error reduction coding to produce the 10-bit word that is transmitted. [3]

Basic audio functionality consists of a single IEC 60958 L-PCM audio stream at sample rates of 32 kHz, 44.1 kHz or 48 kHz. This can accommodate any normal stereo stream. Optionally, HDMI can carry such audio at sample rates up to 192 KHz and with 3 to 8 audio channels. HDMI can also carry an IEC 61937 compressed (e.g. surround-sound) audio stream at bit rates up to 24.576Mbps. HDMI can also carry from 2 to 8 channels of One Bit Audio and a compressed form of One Bit Audio called DST. [3]

The DDC is used by the Source to read the Sink's Enhanced Extended Display Identification Data (E-EDID) in order to discover the Sink's configuration and/or capabilities.

2.3.1 TDMS Protocol Specification

TMDS, developed by Silicon Image, is a technology for transmitting high-speed uncompressed serial digital data over twisted-pair copper wire.

The scope of introducing this technology in HDMI was to achieve of transmitting an extremely large quantities of uncompressed data at very high speeds and secondly to minimize errors and interference.

TMDS technology is based on using a differential signaling method and on implementing an advanced encoding algorithm that converts 8 bits of data into a 10-bit transition minimized, DC balanced character. All of these techniques, when put together, create a very reliable and resilient signal which has a very good chance of recovery, so long as the system is operating within its designated parameters.

In Figure 2.2 is represented HDMI Encoder/Decoder overview. The input stream to the Source's encoding logic will contain video pixel, packet and control data. The packet data consists of audio and auxiliary data and associated error correction codes. This auxiliary data includes InfoFrames and other data describing the active audio or video stream or describing the transmitter. [3]

The TMDS Clock channel constantly runs at a rate proportional to the pixel rate of the transmitted video. During every cycle of the TMDS Clock channel, each of the three TMDS data channels transmits a 10-bit character.

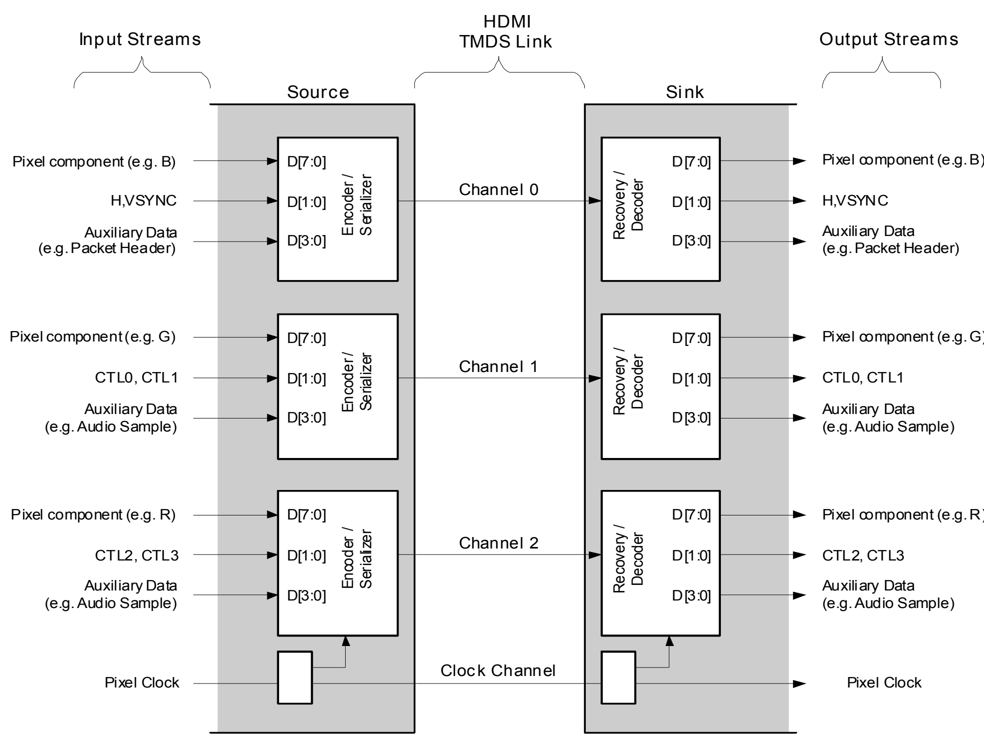

Fig. 2.2: HDMI Encoder/Decoder Overview, | Adapted from [3]|

The HDMI link operates in one of the three periods: Video Data Period, Data Island Period and Control Period. During the Video Data Period, the active video pixels are transmitted. During the Data Island Period, the audio and auxiliary data packets are transmitted. The Control Period is used when no video, audio or auxiliary data needs to be transmitted. A Control Period is required between any two periods that are not Control Periods. Every operating period transmits his characteristic data and uses an appropriate encoding type, these are specified in Table 1.

The encode process for the video data period can be viewed in two stages. The first stage produces a transition-minimized nine-bit code word from the input eight bits. The second stage produces a 10-bit code word, the finished T.M.D.S. character, which will manage the overall DC balance of the transmitted stream of characters. Data Island Periods are encoded using a similar transition minimized coding, TMDS Error Reduction Coding (TERC4), which transmits 4 bits per channel, or 12 bits total per TMDS clock period. During Control Periods, 2 bits per channel, or 6 bits total are encoded per TMDS clock using a transition maximized encoding. These 6 bits are HSYNC, VSYNC, CTL0, CTL1, CTL2 and CTL3. In Table 1 are summarized the encoding type for each period.

Period	Data Transmitted	Encoding Type
Video Data	Video Pixels	8B/10B
	(Guard Band)	(Fixed 10 bit pattern)
Data Island	Packet Data - Audio Samples - InfoFrames HSYNC, VSYNC	TERC4 Coding
	(Guard Band)	(Fixed 10 bit pattern)
Control	Control - Preamble - HSYNC, VSYNC	2B/10B

Table 2.2: Encoding Type Data Transmitted

2.3.2 Display Data Channel

The DDC channel is used by an HDMI Source to determine the capabilities and characteristics of the Sink by reading the E-EDID data structure. There an Enhanced DDC (E-DDC) protocols is used.

HDMI Sources are expected to read the Sink's E-EDID and to deliver only the audio and video formats that are supported by the Sink. In addition, HDMI Sinks are expected to detect InfoFrames and to process the received audio and video data appropriately.

DCC consist of data wire, clock and GND (common with CEC and HEAC channel). It works on I2C bus protocol. Data is synchronized with the SCL (clock) signal and timing shall comply with the standard mode of the I2C specification (100 kHz maximum clock rate). [3]

The EDID includes manufacturer name and serial number, product type, timings supported by the display, display size, luminance data and pixel mapping data. The EDID is stored in the EEPROM or EPROM on Sink side.

The DDC channel is actively used for High-bandwidth Digital Content Protection, that present a form of digital copy protection developed by Intel Corporation to prevent copying of digital audio and video content as it travels across connections. Before sending data, a transmitting device checks that the receiver is authorized to receive it. If so, the transmitter encrypts the data to prevent eavesdropping as it flows to the receiver.

2.3.3 Consumer Electronics Control

Consumer Electronics Control is an protocol in HDMI, is optional features. CEC is designed to allow the user to command and control up-to 15 CEC-enabled devices, that are connected through HDMI, by using only one of their remote controls (for example by controlling a television set, set-top box, and DVD player using only the remote control of the TV). CEC also allows for individual CEC-enabled devices to command and control each other without user intervention. The CEC line is used for high-level user control.

2.3.4 Ethernet and Audio Return Channel

This feature became available starting with version 1.4. HDMI Ethernet and Audio Return Channel (HEAC) enhances the HDMI standard through the addition of a high-speed bidirectional data communication link which is derived from the 100Base-TX IEEE 802.3 standard and audio data streaming which leverages the IEC60958-1 standard. [3]

For HDMI Ethernet and Audio Return Channel (HEAC), the signal pair composed of the HEAC- and the HEAC+ lines or only the HEAC+ line is used for transmission. The HEAC transmission is composed of HEC transmission and ARC transmission. HEC transmission employs MLT-3 signaling in differential mode. ARC transmission employs a single IEC 60958-1 signal in common mode or single mode. Each combination (HEC transmission only, ARC transmission only or HEC transmission with ARC transmission in common mode) is allowed. [3]

HEAC provides a full duplex connection between HDMI devices which conforms to the 100Base-TX IEEE 802.3 standard. HEAC defines a Category 1 and 2 HDMI cable which is able to carry the high-speed data signals. This transmission is defined as the HDMI Ethernet Channel (HEC).In Figure 2.3 is showed the relationship between the Open System Interconnection (OSI) 7-layer reference model, IEEE 802.3 standard (Ethernet) and HEC Physical layer.

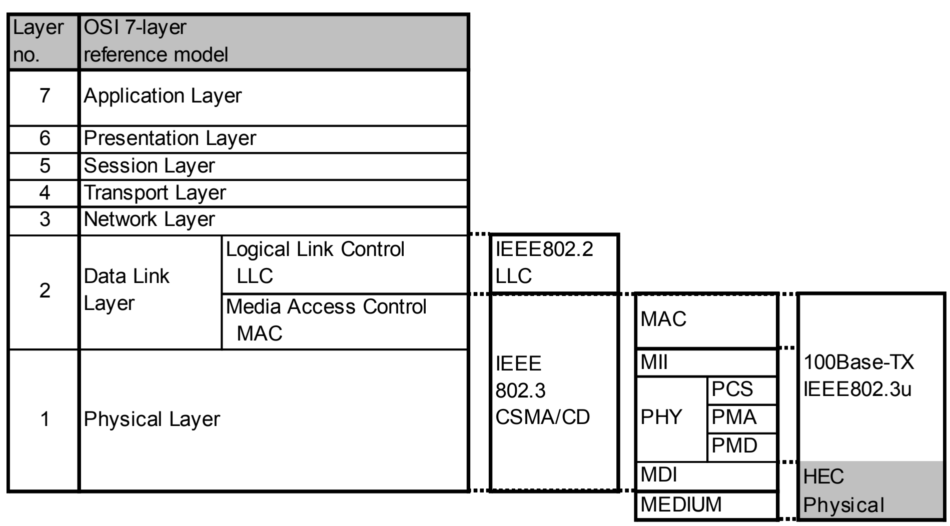

Fig. 2.3: Layer Architecture, |Adapted from [3]|

Figure 2.4 shows an example of a HEC network which is connected to the Internet via the Home Network. The connection to the Home Network may be implemented on any HEC device.

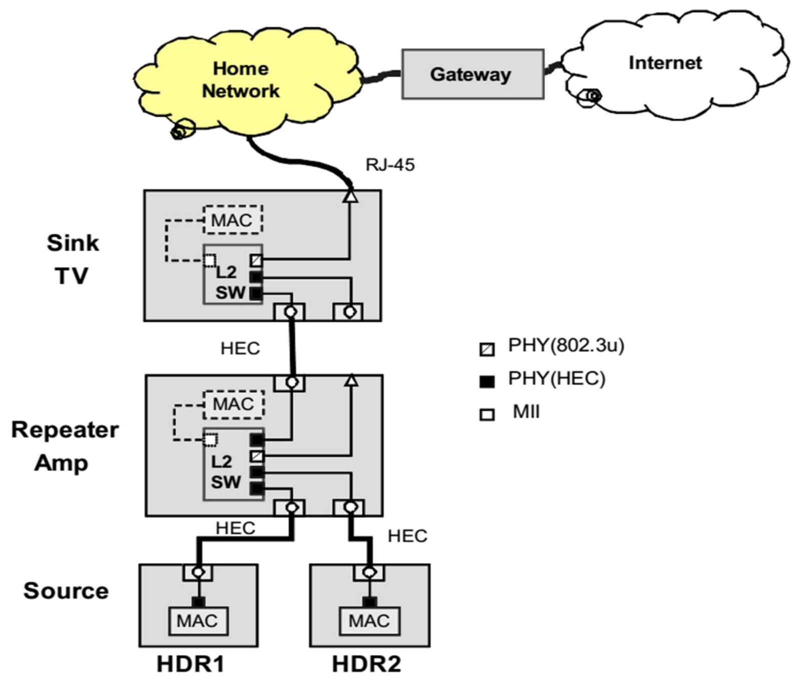

Fig. 2.4: Example of a Connection to the Internet, |Adapted from [3]|

Furthermore, HEAC provides audio data streaming which conforms to the IEC 60958-1 standard from an HDMI Sink to an HDMI Source or Repeater. This transmission is defined as the Audio Return Channel (ARC). Typically, the Audio Return Channel function is used as a connection between a TV (HDMI Sink) and an audio Amplifier (HDMI Source/Repeater) to deliver an audio signal from the TV to the audio Amplifier, in conjunction with using the CEC System Audio Control Feature. This means that no longer need to provide a separate audio cable between the TV and your receiver. Figure 2.5 shows an example of connection using ARC channel.

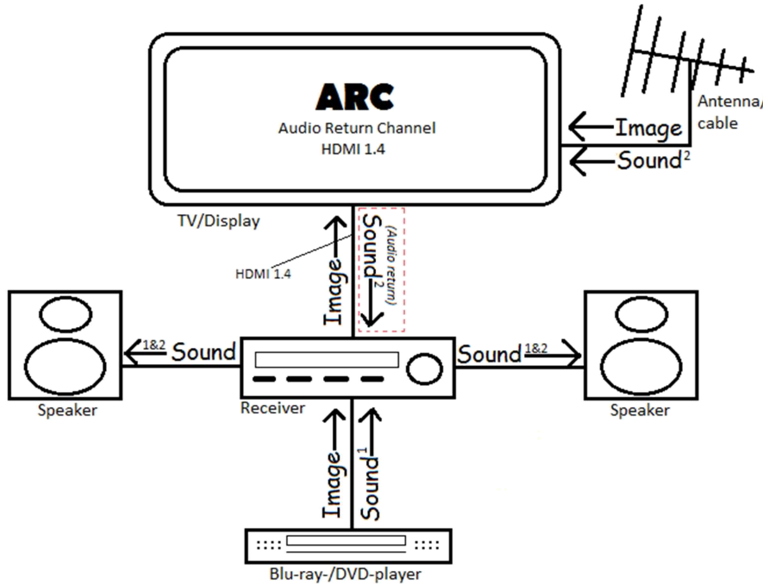

Fig. 2.5: Example of Connection Using ARC, |Adapted from [4]|

2.4 Electrical characteristics

2.4.1 TDMS

The HDMI uses transition minimized differential signaling for the base electrical interconnection.

The transition minimization is achieved by implementing an advanced encoding algorithm that converts 8 bits of data into a 10-bit transition minimized, DC balanced character.

The conceptual schematic of one TMDS differential pair is shown in Figure 2.6. TMDS technology uses current drive to develop the low voltage differential signal at the Sink side of the DC-coupled transmission line. The link reference voltage AV_{CC} sets the high voltage level of the differential signal, while the low voltage level is determined by the current source of the HDMI Source and the termination resistance at the Sink. [3] The termination resistance (R_T) and the characteristic impedance of the cable (Z_0) must be matched.

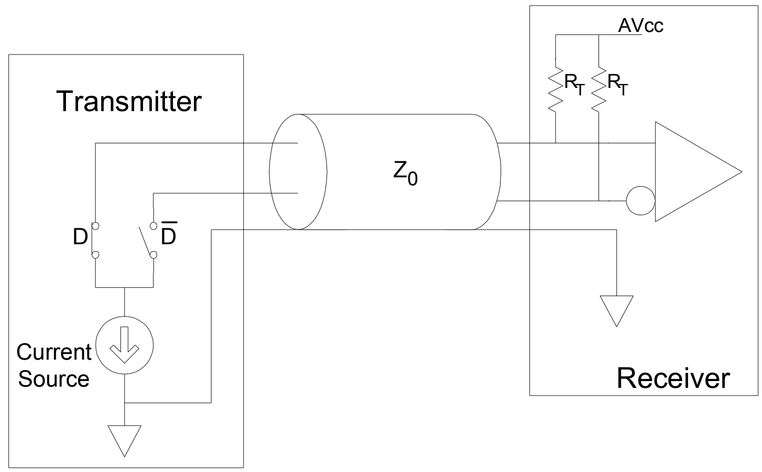

Fig. 2.6: Conceptual schematic for one differential pair |Adopted from [3]|

A single-ended differential signal, representing either the positive or negative terminal of a differential pair, is illustrated in Figure 2.7. The nominal high-level voltage of the signal is AV_{CC} and the nominal low-level voltage of the signal is (AV_{CC}- V_{SWING}). Since the swing is differential on the pair, the net signal on the pair has a swing twice that of the single-ended signal, or 2· V_{SWING}. The differential signal, as shown in Figure 2.8, swings between positive V_{SWING} and negative V_{SWING}. [3]

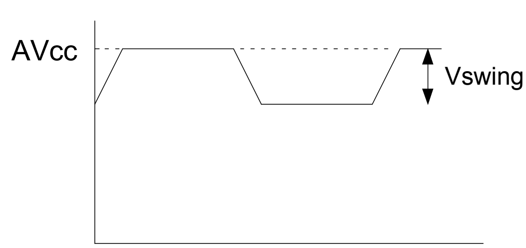

Fig. 2.7: Single-ended Differential Signal

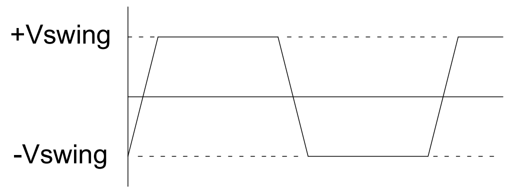

Fig. 2.8: Differential Signal

The required operating conditions of the TMDS pairs are:

Termination Supply Voltage AVcc=3.3V±5% and Termination Resistance, R_T=50Ω±10%. [3]

Due high frequency used for transmitting data in HDMI standards was establish jitter specification relative to an Ideal Recovery Clock (as a trigger source for measuring an eye diagram). The Ideal Recovery Clock shall be equivalent to the signal that would be derived by a perfect PLL (Ideal Clock Recovery Unit) with a jitter transfer function shown in Equation (1), when the TMDS clock signal were input into that PLL. This jitter transfer function has the behavior of a low pass filter with 20dB/decade roll-off and with a –3dB point of 4MHz. [3]

$$H(j\omega) = 1/(1 + \frac{j\omega}{\omega_0}) \tag{1}$$

$$Where\ \omega_0 = 2\pi F_0, F_0 = 4.0\ MHz$$

HDMI uses wide spectrum of frequencies for transmitting a signal, this may cause an uneven attenuation for signal that can lead to degradation for specified frequencies. To combat this effect and to respect eye requirements in sink devices is used cable equalization function which allows them to recover data from entire range of frequency. A cable equalization function is approximated to the performance implied by the Reference Cable Equalizer, Figures 2.9, which is a specified mathematical model of cable equalization. [3]

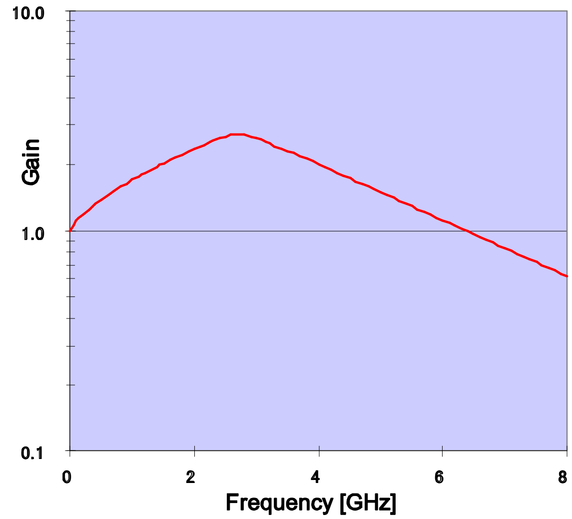

Fig. 2.9: Gain of Reference Cable Equalizer, |Adopted from [3]|

- HDMI Source TMDS Characteristics

Source shall have output levels of signals that meet the normalized eye diagram requirements of Figure 2.10. This requirement, normalized in both time and amplitude, specifies the minimum eye opening relative to the average differential swing voltage as well as the absolute maximum and minimum voltages. The time axis is normalized to the bit time at the operating frequency, while the minimum eye amplitude is normalized to the average differential swing voltage. [3]

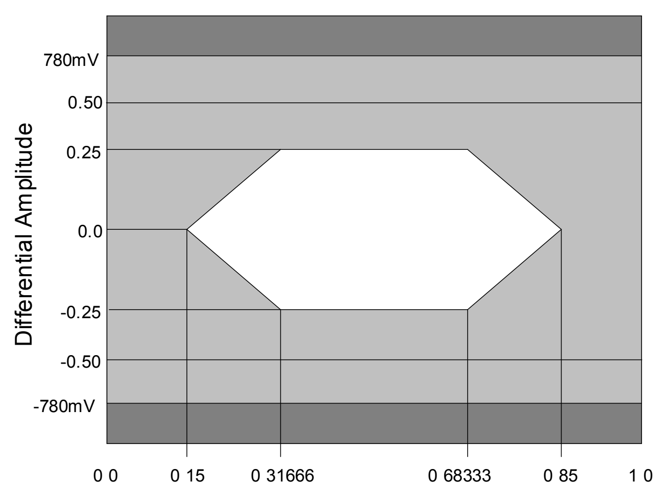

Fig. 2.10: Eye Diagram Mask for Source Requirements, |Adopted from [3]|

- HDMI Sink TMDS Characteristics

All input acceptable voltage level and maximal jitter time for HDMI sink devices can be illustrating by Eye diagram in Figure 2.11.

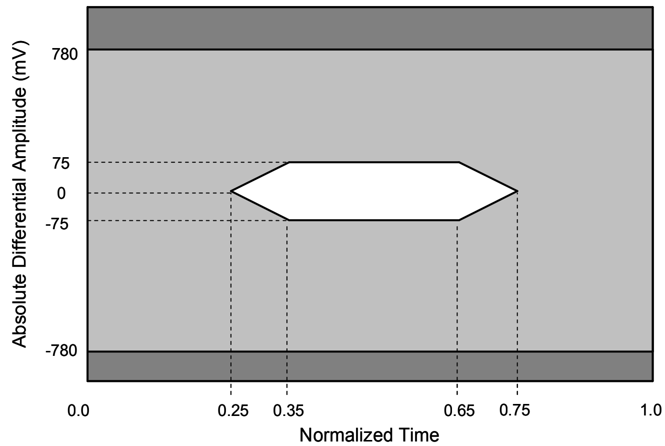

Fig. 2.11: Eye Diagram Mask for Sink Requirements, |Adopted from [3]|

2.4.2 +5V Power Signal

The HDMI connector provides a pin allowing the Source to supply +5.0 Volts to the cable and Sink. HDMI Sources shall assert the +5V Power signal whenever the Source is using the DDC or TMDS signals. The voltage shall be within range +4.8V and +5.3V and HDMI Source shall have over-current protection of no more than 0.5A. Minimal supply current is 55mA. The return for the +5V Power signal is DDC/CEC Ground signal.

2.4.3 DCC

The Display Data Channel (DDC) I/Os and wires (SDA, SCL, DDC/CEC Ground), shall meet the requirements specified in the I2C-bus Specification, version 2.1, Section 15 for “Standard-Mode” devices. [3]

2.4.4 Hot Plug Detect Signal (HPD)

The ground reference for the Hot Plug Detect signal is the DDC/CEC Ground pin. Output characteristics and detection level of hot- plug detect signal are indicated in the Table 2.3.

Item	Value	
	Minimum	Maximum
High voltage level (Sink)	2.4 V	5.3 V
Low voltage level (Sink)	0 V	0.4 V
Output resistance	800 Ohm	1200 Ohm
High voltage level (Source)	2.0 V	5.3 V
High voltage level (Source)	0 V	0.8 V

Table 2.3: Electrical characteristic of HPD

3. HDMI video formats

HDMI support any video format timing. To exist the interoperability between products, common DTV formats have been defined. There exists the primary and the secondary video formats, they are listed in the Table 3.1 and Table 3.2. Common video format define the resolution (pixel and line counts), timing, synchronization pulse position and duration, and the type of scan format. HDMI support three pixel encodings: RGB 4:4:4, YCbCr 4:4:4 or YCbCr 4:2:2.

The HDMI Source determines the pixel encoding and video format of the transmitted signal based on the characteristics of the source video, the format and pixel encoding conversions possible at the Source, and the format and pixel encoding capabilities and preferences of the Sink. For example if a Source processed a video which differs from a supporting format by the HDMI Sink, it must to change by adding or subtracting of lines, to appropriate format.

All specified video line pixel counts and video field line counts (both active and total) and HSYNC and VSYNC positions, polarities, and durations shall be adhered to when is transmitted a specified video format timing.

Primary Video Format Timings			
720(1440)x240p @ 59.94/60Hz	1920x1080p @ 50Hz	1920x1080i @ 119.88/120Hz	720x576p @ 200Hz
2880x480i @ 59.94/60Hz	1920x1080p @ 23.98/24Hz	1280x720p @ 119.88/120Hz	1280x720p @ 23.98/24Hz
2880x240p @ 59.94/60Hz	1920x1080p @ 25Hz	720(1440)x480i @ 239.76/240Hz	1280x720p @ 25Hz
1440x480p @ 59.94/60Hz	1920x1080p @ 29.97/30Hz	720x480p @ 239.76/240Hz	1280x720p @ 29.97/30Hz
1920x1080p @ 59.94/60Hz	2880x480p @ 59.94/60Hz	720(1440)x576i @ 100Hz	1920x1080p @ 119.88/120Hz
720(1440)x288p @ 50Hz	2880x576p @ 50Hz	720x576p @ 100Hz	1920x1080p @ 100Hz
2880x576i @ 50Hz	1920x1080i (1250 total) @ 50Hz	1920x1080i @ 100Hz	
2880x288p @ 50Hz	720(1440)x480i @ 119.88/120Hz	1280x720p @ 100Hz	
1440x576p @ 50Hz	720x480p @ 119.88/120Hz	720(1440)x576i @ 200Hz	

Table 3.1: Primary Video Format Timings

Secondary Video Format Timings
640x480p @ 59.94/60Hz
1280x720p @ 59.94/60Hz
1920x1080i @ 59.94/60Hz
720x480p @ 59.94/60Hz
720(1440)x480i @ 59.94/60Hz
1280x720p @ 50Hz
1920x1080i @ 50Hz
720x576p @ 50Hz
720(1440)x576i @ 50Hz

Table 3.2: Secondary Video Format Timings

Video Control Signals : HSYNC, VSYNC

During the Data Island period, HDMI carries HSYNC and VSYNC signals using encoded bits on Channel 0. During Video Data periods, HDMI does not carry HSYNC and VSYNC and the Sink should assume that these signals remain constant. During Control periods, HDMI carries HSYNC and VSYNC signals through the use of four different control characters on TMDS Channel 0. [3]

Pixel Encoding Requirements

HDMI supports only following pixel encoding: RGB 4:4:4, YCbCr 4:2:2 or YCbCr 4:4:4, but last listed is obligatory for both sink and sources devices. If an HDMI Sink supports either YCbCr 4:2:2 or YCbCr 4:4:4 then both shall be supported. Information about supporting type of pixel encoding is stored in sink's E-EDID and subsequently it's reading by source to transmit an appropriate encoding to sink devices. [3]

The following figures indicate the transmission of pixel encoding components over TDMS channels.

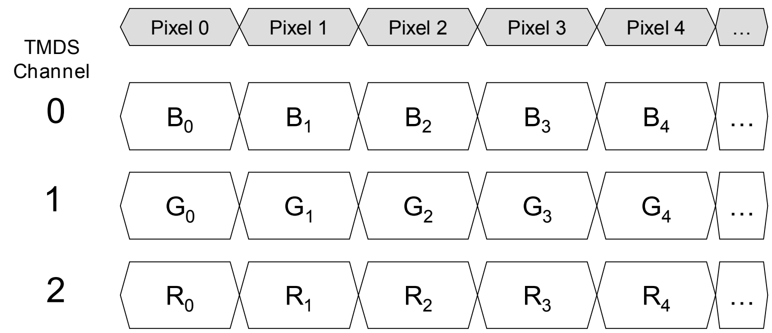

Fig. 3.1: Default pixel encoding: RGB 4:4:4, 8 bits/component, |Adopted from [3]|

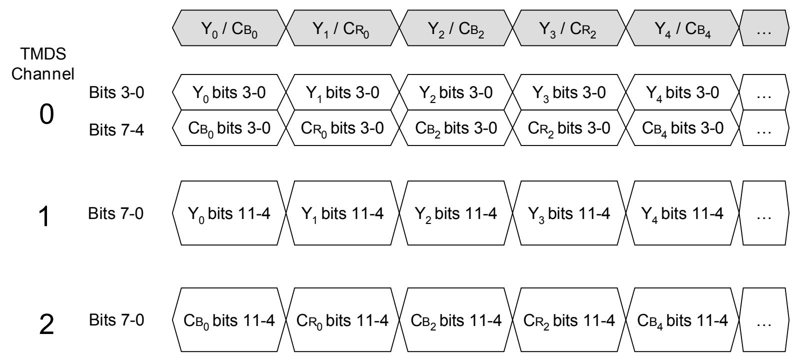

Fig. 3.2: YCbCr 4:2:2 component, |Adopted from [3]|

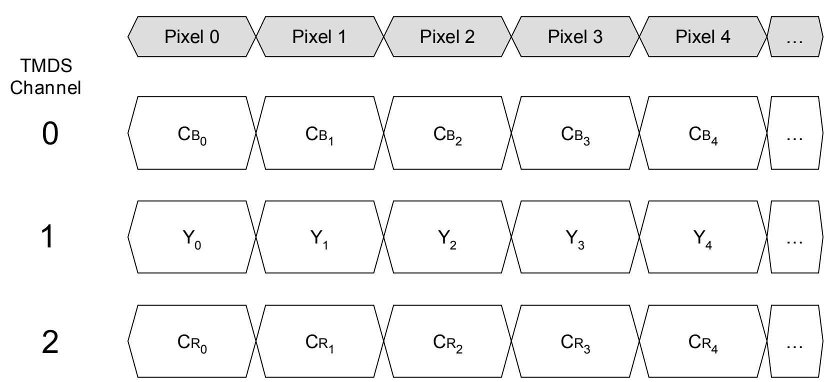

Fig. 3.3: 8-bit YCbCr 4:4:4 component, |Adopted from [3]|

Color Depth Requirements

HDMI may support 24,30,36,48 bits per pixel color depth. Obligatory for all versions HDMI is required 24 bit per pixel. Color depth greater than 24 bit per pixel is named “Deep Color” and is available for HDMI version 1.3 and upper. For Sink devices the information about color depth is stored in E-EDID. In the case if Sink devices not support “Deep Color”, the Source will transmit only minimal value (24 bit per pixel).

All specified video line pixel counts and video field line counts (both active and total) and HSYNC and VSYNC positions, polarities, and durations shall be adhered to when transmitting a specified video format timing. [3]

For example if a Source processed a video which differs from a supporting format by the HDMI Sink, it must to change, by adding or subtracting of lines, to appropriate format.

At deeper color depths, the TMDS clock is run faster than the source pixel clock providing the extra bandwidth for the additional bits. The TMDS clock rate is increased by the ratio of the pixel size to 24 bits: by 1.25 for 30 bit mode, by 1.5 for 36 bit mode and by 2 for 48 bit mode. [3]

Pixel-Repetition

Pixel repetition technique consists in up step the pixel rate (by adding same pixel values) at the Source and at the Sink to down step the pixel rate back (by dropping same pixel values). HDMI uses this technique only for video format with pixel rate below 25 MHz (for example NTSC 480i that has transfer rate 13.5 MHz).

The HDMI Source indicates the use of pixel-repetition with the Pixel Repetition (PR0:PR3) field in the AVI InfoFrame. This field indicates to the HDMI Sink how many repetitions of each unique pixel are transmitted. In non-repeated formats, this value is zero. But for pixel-repeated formats this value indicates the number of pixels that may be discarded by the Sink without losing real image content. The Source shall always accurately indicate the pixel repetition count being used. The use of the Pixel Repetition field is optional for HDMI Sink. [3]

Video Quantization Ranges

Black and white levels for video components can be either “Full Range” or “Limited Range.” In the Table 3.3 are specified the level values for each color component.

Color component	Component Bit Depth	for Full range		for Limited range		
		Black level	Nominal Peak (White level)	Black level	Nominal Peak (White level)	Valid Range
R/ G / B	8	0	255	16	235	1 to 254
R/ G / B	10	0	1023	64	940	4 to 1019
R/ G / B	12	0	4095	256	3760	16 to 4079
R/ G / B	16	0	65535	4096	60160	256 to 65279
Y	8	0	255	16	235	1 to 254
Cb/Cr		128	0 and 255	128	16 and 240	
Y	10	0	1023	64	940	4 to 1019
Cb/Cr		512	0 and 1023	512	64 and 960	
Y	12	0	4095	256	3760	16 to 4079
Cb/Cr		2048	0 and 4095	2048	256 and 3840	
Y	16	0	65535	4096	60160	256 to 65279
Cb/Cr		32768	0 and 65535	32768	4096 and 61440	

Table 3.3: Video Quantization Ranges, |Adopted from [3]|

Colorimetry

The color spaces supporting by HDMI version 1.0 to 1.3b are sRGB, YCbCr and xyXCC that are specified in ITU-R BT.601, ITU-R BT.709-5 and IEC 61966-2-4. Version 1.4 of the HDMI specification adds support for three additional color spaces: sYCC601, AdobeRGB and AdobeYCC601. Sources will typically use the specific default colorimetry for the video format being transmitted. [3] The information about colorimetry is indicated in AVI InfoFrame, but if no colorimetry is indicated in then the colorimetry of the transmitted signal shall match the default colorimetry for the transmitted video format. The default colorimetry for all SD format is based on SMPTE 170M. The default colorimetry for all HD format is based on ITU-R BT.709-5. The default colorimetry of other video formats is sRGB.

4. 3D Supporting

The key concept behind 3D images has to essentially create the illusion of depth by combining two different images, each seen by the left or right eye. 3-dimensional effect is created by rapidly displaying separate images for each eye, and keeping the images intended for each eye as entirely separate as possible. The way this is done is what differentiates the various 3D TV formats.

With the appearance on the market a 3-dimensional television (3D TV) the question has arisen about the possibility of transmitting a stereoscopic image to the display devices over a HDMI cable. To answer this question it is necessary first to review a structure of this 3D video formats and to examine each of these.

The HDMI 1.4 specification details three mandatory 3D video format structures and five discretionary 3D video format structures. In these chapter will be described only mandatory ones, because is sufficient to be related with HDMI.

- Frame packing format:

Frame Packing refers to the combination of two frames, both have full resolution, one for the left eye and the other for the right eye, into a single “packed” frame that consists of these two individual sub-frames.

This Full High Definition 3D (FHD3D) signal structure specifies a 1920x2205 pixel total frame area that is larger vertically than 2D HDTV frames. Each large frame contains a left eye 1920x1080 image and a right eye 1920x1080 image over and under each other, with 45 pixels of active blanking space separating the left and right images, for progressive , detail structure is depicted in figure 4.2, or left and right odd and even fields making up full left and right 1920x1080 frames, for interlaced, detail structure is depicted in figure 4.3. Only new HDMI 1.4a compliant 3D TVs, projectors, Blu-ray players and game consoles support this Full High Definition 3D (FHD3D) signal structure, with full 1920x1080 resolution for each eye.

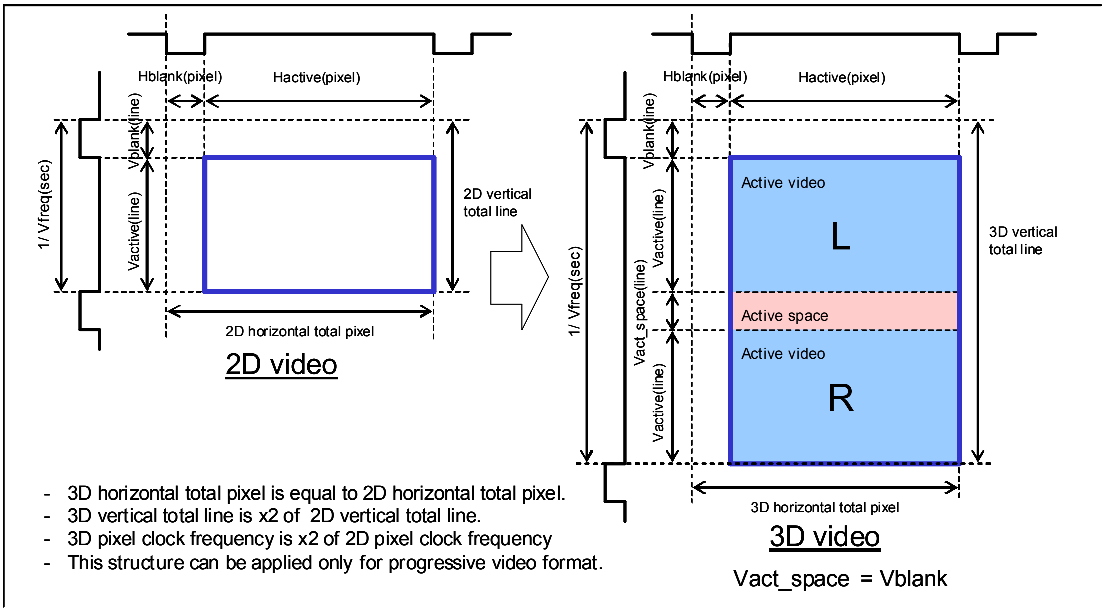

Fig. 4.1: 3D structure (Frame packing) progressive mode, |Adopted from [3]|

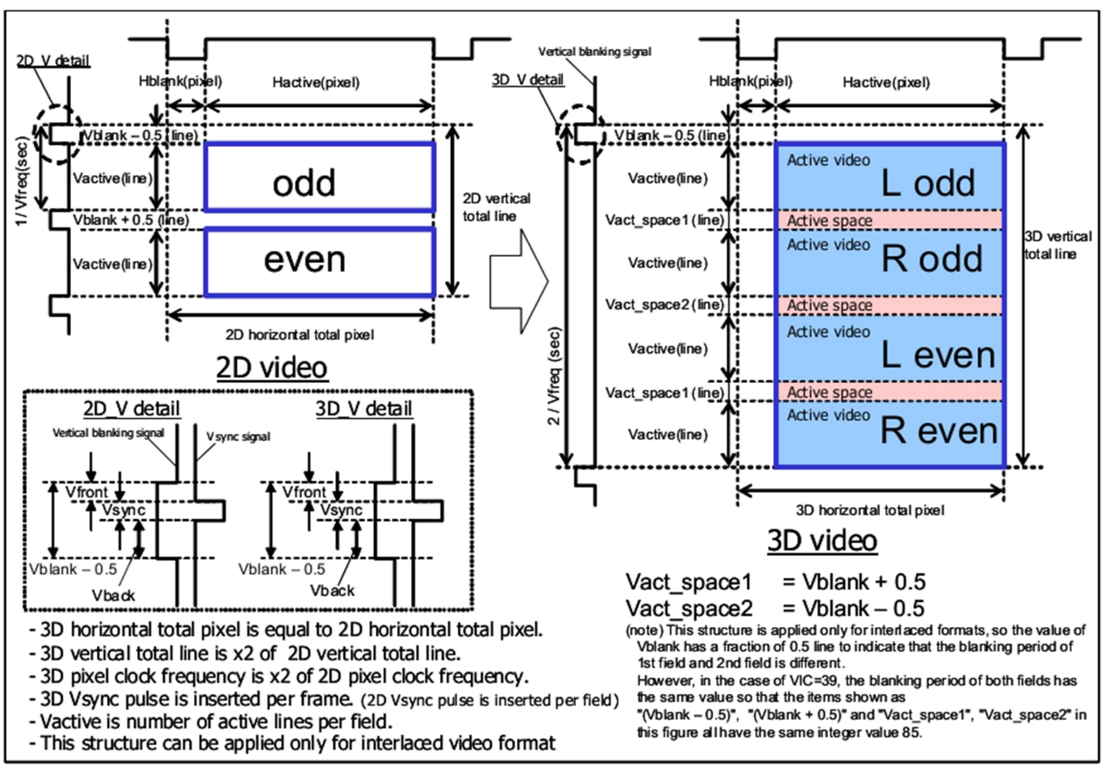

Fig. 4.2: 3D structure (Frame packing) interlaced mode, |Adopted from [3]|

For 1080p/24-25Hz, left and right progressive fields are alternately transmitted each at 24/25 Hz for a complete 3D frame and a total data rate of 1080p/48-50 Hz. This means that the 24/25 Hz information is doubled and alternated for each left and right image.

For 720p/50-60Hz left and right progressive fields are alternately transmitted each at 50-60Hz for a complete 3D frame and a total data rate of 720p/100-120Hz Hz for left and right information again doubling the 50-60Hz frame rate for alternating left and right material.

- Side by Side format:

There are 2 different versions of this method, Full or Half. The Side by Side method makes sure that the transmission frame rate remains the same as the original frame rate at 60 Hz or 50 Hz which is a more compatible scheme for TV broadcasters. [5]

Half Method: for Broadcast content at 1080i/50-60Hz, horizontal left and right material is sub-sampled to half horizontal resolution (960) and stored side by side with each odd and even field shown once, the signal structure of this method is depicted in figure 4.3. The Display will stretch each side to full width and display them sequentially. [5]

Full Method: For Broadcast content at 1080i/50-60Hz, horizontal left and right material is shown at full resolution (1920) and stored side by side with doubled frame rates. The Display will stretch each side to full width and display them sequentially. [5]

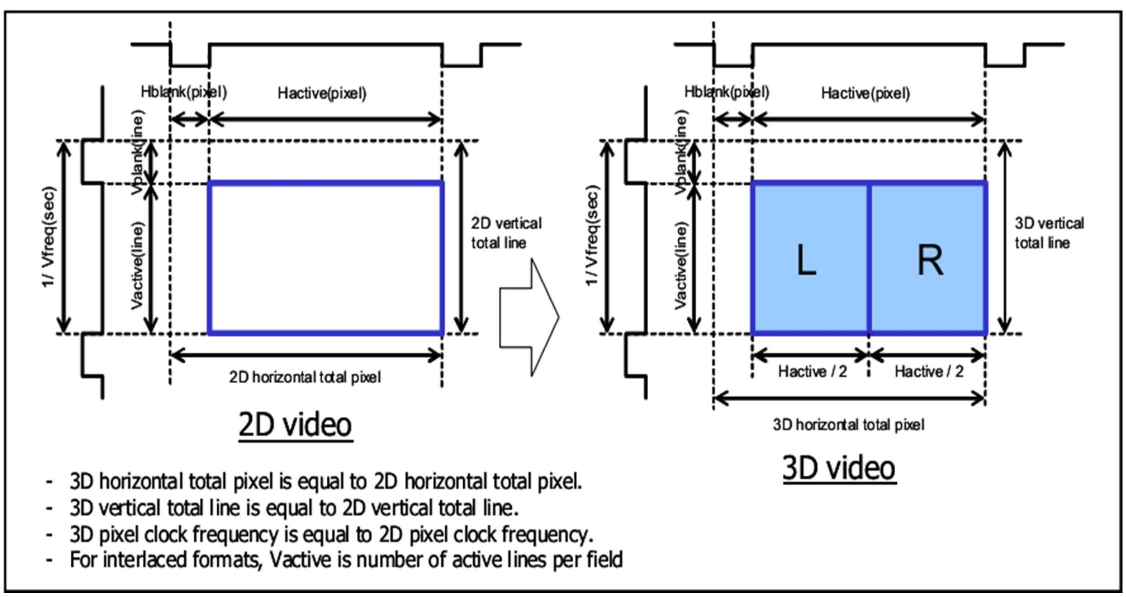

Fig. 4.3: 3D structure (Side by Side, Half Method) , |Adopted from [3]|

- Top by Bottom format:

There are 2 different versions of this method, Full or Half. The Top and Bottom method also makes sure that the transmission frame rate remains the same as the original frame rate of 60 Hz or 50 Hz. which is a more compatible scheme for TV broadcasters. [5]

Half Method – For Broadcast content at 1080p/24-25Hz and 720p/50-60Hz: left and right material is sub-sampled to half resolution in the vertical axis and stored top and bottom, the signal structure of this method is depicted in figure 4.3. The Display will stretch each frame to full height and display them sequentially [5]

Full Method – For Broadcast content at 1080p/24-25Hz and 720p/50-60Hz: left and right material is sampled at full resolution in the vertical axis and stored top and bottom. The Display will stretch each frame to full height and display them sequentially with doubled frame rates. [5]

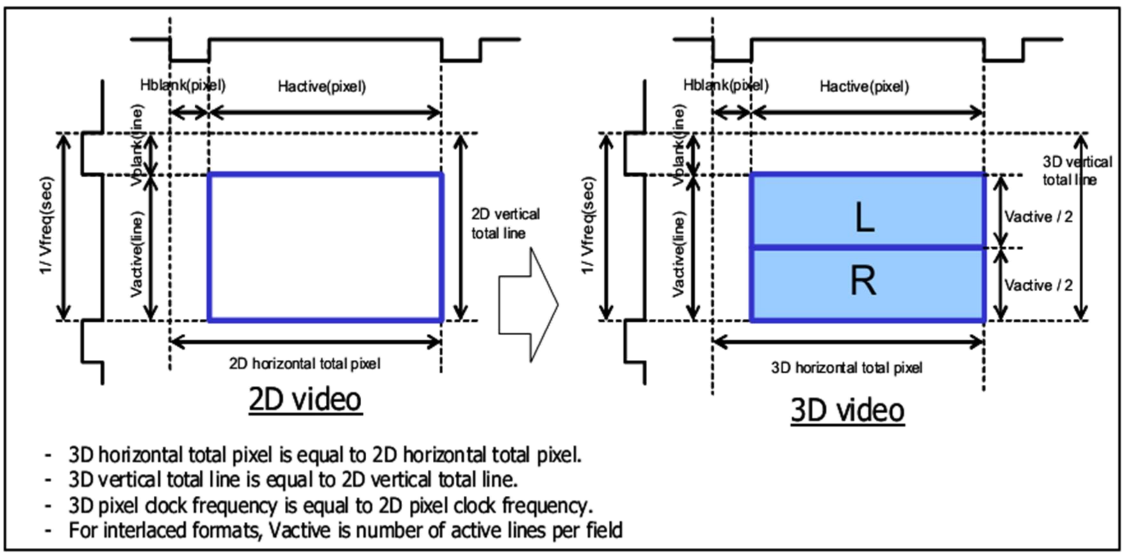

Fig. 4.4: 3D structure (Top by Bottom, Half Method) , |Adopted from [3]|

As concerned source, sink devices and repeaters for a correct display 3D content and interoperability between them is need that this devices have been equipped with HDMI version 1.4 or upper. Starting with version 1.4 was added new features for supporting 3D , one of which is the InfoFrame packets within the video stream that identify the 3D structure being used for a specific piece of content. The 3D video format is indicated using the VIC (Video Identification Code) in the Auxiliary Video Information (AVI) InfoFrame, in conjunction with the 3D structure field in the HDMI Vendor Specific InfoFrame. [3] The InfoFrame data tells the display information about the picture content that the source is sending. If you are watching 3D video content recorded with Side-by-Side 3D formatting and you then switch to content recorded with Top/Bottom structure, the sink (display) knows how to convert the video stream according to the InfoFrame data that rides with the video signal. The InfoFrame data is transmitted twice per video frame and may change when picture content changes, such as with commercials or from one show to another.

HDMI 1.4 specifies that all 3D sink devices (display) are able to support all mandatory formats: 1080p24 and 720p50/60 Frame Packing, 1080i50/60 Side-by-Side (Half), and 1080p24 and 720p50/60 Top-and-Bottom. Very often the question arises about compatibility 120Hz or 240Hz 2D display‘s with 3D content. While most 3D displays are capable of 120 or 240 Hz frame presentation, to be 3D compatible the display also needs to also be capable of recognizing 3D video content and converting it to a suitable form for output presentation (usually frame sequential display, controlling synchronized active shutter glasses). Unless the display is labeled as 3D-ready or 3D-capable, it probably cannot be used for 120Hz 3D. Although it may theoretically be possible for manufacturers to provide updated firmware for some of their 2D displays to make them compatible with the 3D frame compatible formats, it doesn't appear that any manufacturers are interested in doing that.

According to the HDMI 1.4 specification 3D video sources must support at least one mandatory 3D format. This insures that any 3D source is capable of generating a 3D video format structure that any 3D display device is capable of properly rendering. In the case that an HDMI 3D source device is capable of generating one or more of the discretionary 3D structures, it does need to check the EDID information it gets from the 3D display device, since 1.4a states, "An HDMI Source shall not send any 3D video format to a Sink (display) that does not indicate support for that format." [3]

3D HDMI Repeaters

HDMI repeaters (AV receivers, HDMI matrix switchers, HDMI splitters, etc.) are another type of component often found in an HDMI network. The HDMI 1.4a spec says that they must transparently pass all mandatory formats. This means that they must not only pass the 3D video stream, but they must also pass the 3D InfoFrame data. Many 1.3 compliant HDMI repeaters may be able to pass the video stream, but may not recognize or pass the 3D InfoFrame data, since it wasn't part of the standard when the device was designed. Or, when the 3D display sends EDID data indicating that it is FHD3D-compliant, the repeater may not recognize the code, and just shut off the HDMI signal. In some cases, a firmware update may be available from the manufacturer to make the device compatible with at least some of the 3D formats. [5]

Supporting cable for 3D formats

To see if the 3D signal can transmits over HDMI cable is need to calculate bitrate of each format and compare to maximal total TMDS throughput of cable. To calculate bitrate of 3D format is need take into account number of inactive line (Hblank, Vblank), number of "deep color" bits, resolution, 8b/10b encoding. In Table 4.1 are calculated bitrate for each format with different deep color. From calculated values it is evident that all mandatory 3D formats do not exceed the data rate of the regular 2D 1080p/60Hz format, hence every cable that can support 2D 1080p/60Hz work with 3D format.

Formats	**Deep Color Accuracy**				
	Data				
	8 bit	**10 bit**	**12 bit**	**14 bit**	**16 bit**
Frame Pack 1080p/24	3.568	4.46	5.352	6.244	7.136
Frame Pack 720p/60	3.96	4.95	5.94	6.93	7.92
Side by Side 1/2 H res 1080i/60	2.23	2.7875	3.345	3.9025	4.46
Side by Side Full H res 1080i/60	4.46	5.575	6.69	7.805	8.92
Top to bottom 1/2 V res 720p/60	1.98	2.475	2.97	3.465	3.96
Top to bottom Full V res 720p/60	3.96	4.95	5.94	6.93	7.92
Top to bottom 1/2 V res 1080p/24	1.784	2.23	2.676	3.122	3.568
Regular 1080p/60 - none 3D	**4.46**	**5.575**	**6.69**	**7.805**	**8.92**

Table 4.1: Comparison of maximal bitrate

5. Scope of this thesis

Scope of this thesis is to describe the aspects of HDMI system as using protocols, supporting formats and type of transmitted signals. Practical part of this thesis deals with video quality measurements for divers formats HDTV transmitted by broadcast.

To achieve the necessary goals it requires to perform the following tasks:

- To find appropriate video materials which matches European standards that plays a reference role.
- To create some video materials which proprieties are similar to transmitted video by broadcast TV.
- To create a chain of utilities and settings than converts video to appropriate format.
- To calculate a quality measures PSNR, SSIM and VQM by using a freeware tools.
- To compare the results of different formats and provide a conclusion.

6. HDTV Video Quality Objective Measurements

As we know HDMI interface can transmits High-Definitions Televisions which directly depends on two key factors : the availability of adequate HDTV broadcast to the consumer's home and the availability of HDTV display devices at mass market costs [6].

The availability of different transmitting formats through HDMI interface such as 720p/50, 1080i/25 and 1080p/50 places the question for many users which is best format should be used. 720p/50 format is a format with 1280 horizontal and 720 vertical pixel resolution and progressive scanning at 50 frames/sec as specified in SMPTE 296M-2001 [7]. 1080i/25 format is a format with 1920 horizontal and 1080 vertical pixel resolution and interlaced scanning at 25 frames/sec or 50 fields/sec as specified in SMPTE 274M-2005 [8] and ITU-R BT. 709-5 [9]. 1080p/50 format is a format with 1920 horizontal and 1080 vertical pixel resolution and progressive scanning at 50 frames/sec as specified in SMPTE 274M-2005 [8] and ITU-R BT. 709-5 [9].

In these thesis will be compared video formats which are used in broadcast application, obviously 720p/50, 1080i/25 and 1080p/50 compressed at 5 Mb/s to 20 Mb/s bitrate. Several subjective methods exist for comparing HDTV formats, but they has many disadvantages such as requiring a lot of observes, a special equipment, huge of time for viewing and processing results etc. Subjective assessment methods have been used reliably for many years to evaluate video quality, but these methods cannot easily be used to monitor video quality in real time.

Though several items are guided from subjective methods, especially from method called Triple Stimulus Continuous Evaluation Scale (TSCES), described in [10].

A debate in Europe about the best HDTV format for emission led to the Technical Recommendation R112 - 2004 [11] of the European Broadcasting Union (EBU) which recommends that emission standards for HDTV should be based on progressive scanning: 720p/50 is currently the optimum solution, but 1080p/50 is an attractive option for the longer term. Objections were raised by those who had decided in the past to adopt the 1080i/25 HDTV format.

Another type of information which can be transmitted over HDMI is the audio, which also can have different quality, compressed audio format and sample rates. But in this work will not be analyzed and compared audio component.

In this thesis for comparison different format is used objective perceptual video quality measurement with a full reference video (original video). This method is described in Recommendation ITU-R BT.1907 [12].

Also, this method can be implemented to real time monitoring, since the model does not require the source pictures, or a complete decoding process, and can get a good corresponding with the subjective assessments results.

6.1 Description of the full reference methodology

The double-ended measurement method with full reference, for objective measurement of perceptual video quality, evaluates the performance of systems by making a comparison between the undistorted input, or reference, video signal at the input of the system, and the degraded signal at the output of the system [12], this method can be represented by chain depicted in Figure 6.1.

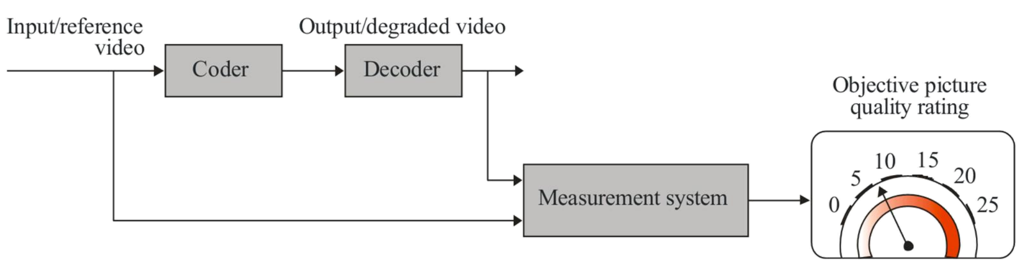

Fig. 6.1: Application of the full reference perceptual quality measurement method

It is generally accepted that the full reference method provides the best accuracy for perceptual picture quality measurements. The method has been proven to have the potential for high correlation with subjective assessments made in conformity with the ACR-HR methods specified in ITU-T P.910 [13].

6.2 Input data

In Rec. ITU-R BT.1907 [12] is mentioned that the studies of perceptual video quality measurements are conducted in an informal group, called the Video Quality Experts Group (VQEG), which reports to ITU-T Study Groups 9 and 12 and ITU-R Study Group 6. For this purpose as material for comparison is used test sequences ParkJoy and DucksTakeOff downloaded from FTP server of this informal group (VQEG). [14]

This sequences represents image file which data format 'sgi16' or is often named RGB interleaved, more information are available in Table 6.1. Each sequence has an appropriate resolution and the number of frames (files), more information are available in Table 6.2. [15] Interleaved RGB images have pixels stored contiguously (rgbrgbrgb...) in a single image plane. Planar RGB images have the red, green and blue image data stored in separate 8-bit sample planes.Each file in the raw video will represent one frame.

Transfer and chromaticity parameters	ITU-R BT.709, Gamma corrected values
Bit depth per color plane	Full interval 16 bit, no head room or foot room
Data format	'sgi16' (interleaved RGB), one file per frame

Table 6.1: Sequences formats

Width	Height	Scanning	Frames per second	Comments	Duration [s]	Number of frames
1920	1080	progressive	50		10	500
1280	720	progressive	50		10	500
1920	1080	interlaced	50	Top Field first	10	250

Table 6.2: Resolution of sequences

By reason of impossibility to direct convert image files to any video format, it’s necessary first to convert to raw video format. The video data in the file will have constant bitrate because each frame is exactly the same size in bytes. In our case planar raw video type YUV with colour space YUV 420 was chosen. This color space was chosen because this colour space is supported by programs used for coding the video. Although HDMI doesn’t support this format, it allows making the comparison without any affects on the final results of quality measures.

Y'UV420p (and Y'V12 or YV12) is a planar format, meaning that the Y', U, and V values are grouped together instead of interspersed. The reason for this is that by grouping the U and V values together, the image becomes much more compressible. When given an array of an image in the Y'UV420p format, all the Y' values come first, followed by all the U values, followed finally by all the V values. [16]

The Y'V12 format is essentially the same as Y'UV420p, but it has the U and V data switched: the Y' values are followed by the V values, with the U values last. As long as care is taken to extract U and V values from the proper locations, both Y'UV420p and Y'V12 can be processed using the same algorithm. [16]

As with most Y'UV formats, there are as many Y' values as there are pixels. Where X equals the height multiplied by the width, the first X indices in the array are Y' values that correspond to each individual pixel. However, there are only one fourth as many U and V values. The U and V values correspond to each 2 by 2 block of the image, meaning each U and V entry applies to four pixels. After the Y' values, the next X/4 indices are the U values for each 2 by 2 block, and the next X/4 indices after that are the V values that also apply to each 2 by 2 block. [16]

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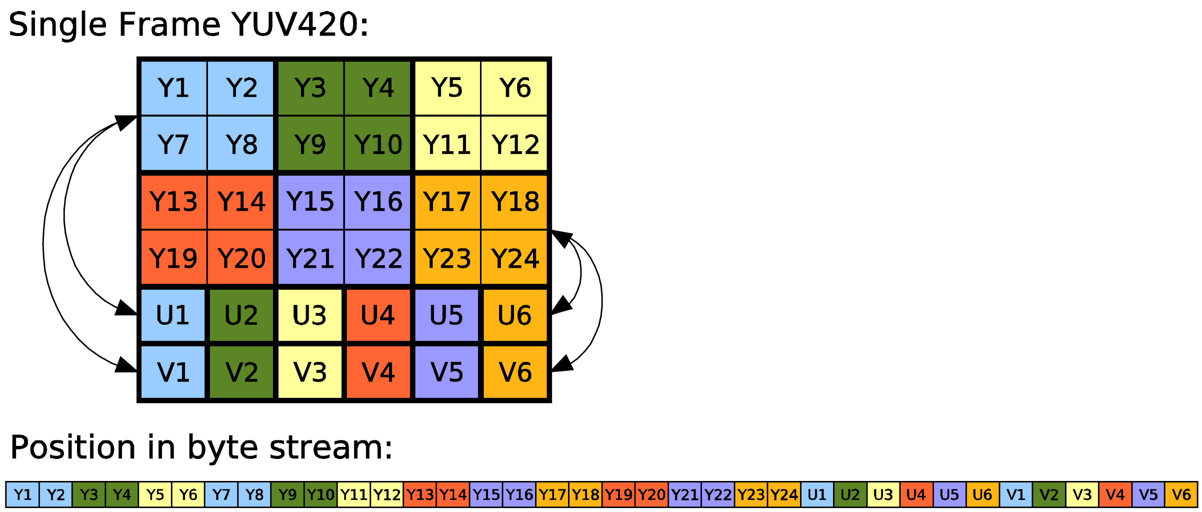

Fig. 6.2: Structure of planar format YUV420, |Adopted from **[16]**|

As shown in the above image, the Y', U and V components in Y'UV420 are encoded separately in sequential blocks. A Y' value is stored for every pixel, followed by a U value for each 2×2 square block of pixels, and finally a V value for each 2×2 block. Corresponding Y', U and V values are shown using the same color in the diagram above. Read line-by-line as a byte stream from a device, the Y' block would be found at position 0, the U block at position x×y (6×4 = 24 in this example) and the V block at position x×y + (x×y)/4 (here, 6×4 + (6×4)/4 = 30).

6.3 Conversion

The entirely chain of the process of conversion can be depicted in Figure 6.3.

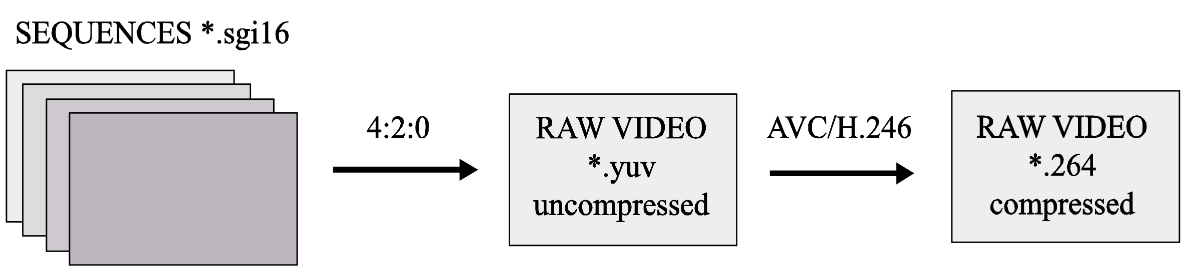

Fig. 6.3: Chain of conversion

The free command-line tool "sgi2yuv", available at [17], is used to convert the 'sgi16' data format into various useful raw video bit streams among which are:

- Planar YUV 4:4:4 video data, one file per sequence – extension *.yuv
- Planar YUV 4:2:2 video data, one file per sequence – extension *.yuv
- 'Abekas' YUV 4:2:2 video data, one file per frame – extension *.qnt
- Planar YUV 4:2:0 video data, one file per sequence – extension *.yuv

As was indicated in 5.2 paragraph, for comparison are used planar YUV 4:2:0 video data and 8 sample depths (bits). All configurations are located in file sgi2yuv.cfg. Example of settings for conversion for 720p to YUV420 is shown below:

```
    FramesToBeConverted   = 500       # Number of frames that should be converted
    SourceWidth           = 1280      # Width in pixel of the source
    SourceHeight          = 720       # Height in pixel of the source
    InputFilePrefix       = ""        # Prefix of the input files
    InputFileSuffix       = ".sgi"    # Suffix of the input file
    InputFileFirstFrame   = 15523     # Number of the first file that should be processed
    Count_digits          = 5         # Number of digits for the file count
    OutputFile            = "720p420" # Name of output file, without extension
    Color_subsampling     = 2         # 0: 4:4:4, 1: 4:2:2, 2: 4:2:0
    YUV_Format            = 0         # 0:planar yuv (one file per sequence)  1:abekas format
(one file per frame)
    BitDepth_out          = 8         # currently only 8 and 10 bit supported
    Stuffing16bit         = 0         # if this is set to 1, 10 bit data is stuffed with 6 '0' bits
to fill up two bytes.
```

Average time for processing one frame is about 1.5 seconds.

After converting the test sequences into one raw video file which extension .yuv is necessary to convert this raw video into H.264/MPEG-4 Part 10 format video by using an encoder, in our case x264 encoder one was chosen, available at [18], because it is a freeware with free library and application for encoding video streams into the H.264/MPEG-4 AVCformat. It released under the terms of the GNU GPL and provides a CLI. The H.264/MPEG-4 Part 10 or AVC (Advanced Video Coding) was chosen because is currently one of the most commonly used formats for the recording, compression, and distribution of high definition video. H.264 is perhaps the best known as being one of the codec standards for Blu-ray Discs, all Blu-ray Disc players must be able to decode H.264. It is also widely used by streaming internet sources, such as videos from Vimeo, YouTube, and the iTunes Store, web software such as the Adobe Flash Player and Microsoft Silverlight, and also various HDTV broadcasts over terrestrial (ATSC, ISDB-T, DVB-T or DVB-T2), cable (DVB-C) and satellite (DVB-S and DVB-S2). There exists a GUI version of x264 Encoder, program MeGUI, available at [19], their advantage is by automatic creating a code, which subsequently can be used as help to create a final code.

The possibility of executing programs from command prompt in Windows operational system, it is necessary to add the appropriate path to respective tool.

In order to find the optimal settings for coding video we will guess to settings indicated in the measurements provided for Subjective Picture Quality Assessment described in [[10]].The described method uses a three TV-set which displays a different quality video, the central TV-set displays a reference video and the rest two displays compressed video.

To convert *.yuv raw video into H.264/MPEG-4 raw bytestream format with *.264 extension it is necessary to creating a source code for x264 encoder on which defines the appropriate settings for each resolution. All setting have been based on settings used in subjective measurements, indicated at [10].

For all resolutions are set the following coding parameters: 1 slice per frame, search shape 8x8, CABAC entropy coding, default quantization matrix, uneven multi-hexagonal search as pixel motion estimation method (for higher values of motion vector search range), hierarchical B-frame coding (option‘ b-pyramid’), variable bit rate, average bit rate values: 5, 8, 10, 13 and 16 Mbit/s.

For specified resolution settings are indicated in Table 6.3.

Resolution	AVC Profile	Motion vector prediction	Motion vector search range	GOP	Additional
720p	Level 4	Temporal	96	24	
1080i	Level 4	Spatial	128	6	MbAFF
1080p	Level 5	Temporal	96	24	

Table 6.3: Encoder settings for specified resolutions

Note: MBAFF, or Macroblock-Adaptive Frame/Field Coding, is a video encoding feature of MPEG-4 AVC that allows a single frame to be encoded partly progressive and partly interlaced. Maintaining the quality of interlaced video can be a challenge in video encoding because of the larger spaces between horizontal lines in the same field. MBAFF allows an AVC encoder to examine each block in a frame to look for similarities between interlaced fields. When there is no motion the fields will tend to be very similar, resulting in better quality if you encode the block as progressive video. For blocks where there is motion from one field to another the quality is more likely to suffer if encoded progressive, so these blocks can remain interlaced. [17]

For creating source code to convert video, had been used program MeGUI witch provides a clearly GUI and generate a ready code , it can also be used direct for conversion, but in this case the average time for processing is longer than by using CLI mode. For this reason in this thesis all conversions are implemented strictly in CLI mode.

The example of code for encoding using a x264 encoder is write bellow:

```
x264 --level 4.0 --keyint 24 --tune psnr --tune ssim --slices 1 --me umh --bitrate 13312 --direct temporal --merange 96 --sar 1:1 --fps 50 --output "D:\test\720p13\720p13.264" --input-res 1280x720 "D:\test\720p420.yuv"
```

After creating a readies raw bytestream video with extension *.264 it's necessary to create an additional index file with extension *.dga which assists to open the raw video by Avisynth. DGAVCIndex.exe is a component part of decoder plugin for decode *.264 raw video and its purpose is to produce an index file named *.dga, note that the included decoder DLL (libavcodec.dll) must be in the same directory as the DGAVCIndex executable.

5.2 Objective quality measures

To be able to compare original and compressed sequences, there are used the following three objective quality measures:

- PSNR (Peak Signal to Noise Ratio)
- SSIM (Structural Similarity Index)

- VQM (Video Quality Measure)

  - PSNR (Peak Signal to Noise Ratio) [18]

PSNR is the ratio between the maximum possible signal power and the noise power:

$$PSNR = 10log_{10}\frac{255^2}{MSE} \quad (2)$$

$$MSE = \frac{\sum_i \sum_j (a_{i,j} - b_{i,j})^2}{x \cdot y}$$

In (2) $a_{i,j}$ and $b_{i,j}$ are pixels from original and compressed image, *x* and *y* describe height and width of an image and *MSE* stands for Mean Square Error. Despite its popularity, PSNR only has an approximate relationship with the video quality perceived by human observers, simply because it is based on a byte-by-byte comparison of the data without considering what they actually represent. PSNR is completely ignorant to things as basic as pixels and their spatial relationship, or things as complex as the interpretation of images and image differences by the human visual system. [19] There exist two type of PSNR: average = {SUM log(SNR)} / {numbers of frames} and global = log ({SUM SNR} / {numbers of frames}) In this thesis is used average PSNR (for luminance component) because there is no perfect frame and moreover, tested encoder has already implemented average PSNR for luminance component.

  - SSIM (Structural Similarity Index)

The structural similarity (SSIM) index is a method for measuring the similarity between two images. The SSIM index is a full reference metric, in other words, the measuring of image quality based on an initial uncompressed or distortion-free image as reference. SSIM is designed to improve on traditional methods like peak signal-to-noise ratio (PSNR) and mean squared error (MSE), which have proven to be inconsistent with human eye perception. [20]

The difference with respect to other techniques mentioned previously such as MSE or PSNR, is that these approaches estimate perceived errors on the other hand SSIM considers image degradation as perceived change in structural information. Structural information is the idea that the pixels have strong inter-dependencies especially when they are spatially close. These dependencies carry important information about the structure of the objects in the visual scene. [20] SSIM gives results between 0 and 1, where 1 means excellent quality and 0 means poor quality.

Main idea of the structure similarity index (SSIM) is to compare distortion of three image components:

- Luminance comparison
- Contrast comparison
- Structure comparison

In this paper we will use average SSIM across all frames (or fields), only for luminance component.

- VQM (Video Quality Measure) [21]

VQM is developed by ITS to provide an objective measurement for perceived video quality. It measures the perceptual effects of video impairments including blurring, jerky/unnatural motion, global noise, block distortion and color distortion, and combines them into a single metric. The testing results show VQM has a high correlation with subjective video quality assessment and has been adopted by ANSI as an objective video quality standard.

VQM takes the original video and the processed video as input and is computed as follows:

• Calibration

This step calibrates the sampled video in preparation for feature extraction. It estimates and corrects the spatial and temporal shift as well as the contrast and brightness offset of the processed video sequence with respect to the original video sequence.

• Quality Features Extraction

This step extracts a set of quality features that characterizes perceptual changes in the spatial, temporal, and chrominance properties from spatial temporal sub-regions of video streams using a mathematical function.

• Quality Parameters Calculation

This step computes a set of quality parameters that describe perceptual changes in video quality by comparing features extracted from the processed video with those extracted from the original video.

• VQM Calculation

VQM is computed using a linear combination of parameters calculated from previous steps.

5.4 Calculation of quality measures

There exists a specialized programs purposed for calculating a video quality measurements, as MSU Quality Measurement Tool , but unfortunately these are very expensive. In this thesis for calculating objective quality measures was used a freeware program Avisynth, available at [25], with external filters and plugins which can be downloaded also from official site.

For processing these files also will be used Avisynth that is a powerful tool for video post-production. It provides ways of editing and processing videos. AviSynth works as a frameserver, providing instant editing without the need for temporary files. Frameserver AviSynth is a kind of mediator between the physical media files on the hard drive and the installation program. This simplifies the final assembly with pre-installation through AviSynth. Avisynth can work with an external editing a encoding programs. For our purposes a freeware program VirtualDub was chosen, available at [26], that will be used for preview and processing a video files as *.yuv and *.264. The conceptual schematic of intercommunication between these tools is depicted in figure 6.4.

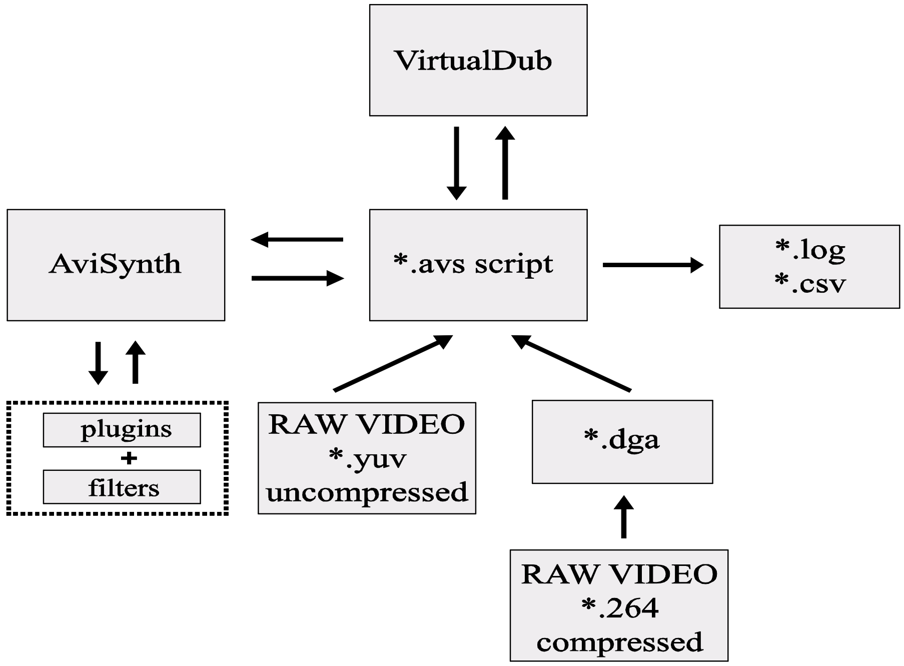

Fig. 6.4: Interconnection between VirtualDub and Avisynth

For opening a raw video by Avisynth, there was installed an addition plugins “RawSource”. As utility for displaying and processing a raw video, VirtualDub was used.

In Table 6.4 are listed an external plugins and filter used by Avisynth:

Plugin or Filter Name	Function
RawSource.dll	Loads raw video data directly from files
DGAVCDecode.dll	AVC/H.264 decoder
SSIM.dll	For calculation SSIM
VqmCalc.dll	For calculation VQM
libavccodec.dll	AVC/H.264 decoder
CompareYV12.dll	Compare file with color space YV12

Table 6.5: Avisynth addons

There a scripts have been written for processing and calculation of quality measures, which examples are available in the following tables.

Calculation PSNR

```
LoadPlugin("C:\Program Files\AviSynth 2.5\plugins\rawsource.dll")
LoadPlugin("C:\Program Files\AviSynth 2.5\plugins\DGDecode.dll")
clip1=rawsource("D:\test2\1080i420.yuv",1920,1080,"I420").assumefps(25)
clip1=ConvertToYV12(clip1)
clip2=AVCSource("D:\test2\1080i16\1080i16.dga")
clip2=ConvertToYV12(clip2)
Compare(clip1, clip2, "YUV","psnr1080i16.log",show_graph=true)
```

Calculation SSIM

```
LoadPlugin("C:\Program Files\AviSynth 2.5\plugins\rawsource.dll")
LoadPlugin("C:\Program Files\AviSynth 2.5\plugins\SSIM.dll")
LoadPlugin("C:\Program Files\AviSynth 2.5\plugins\DGDecode.dll")
clip1=rawsource("D:\test2\1080i420.yuv",1920,1080,"I420").assumefps(25)
clip1=ConvertToYV12(clip1)
clip2=AVCSource("D:\test2\1080i16\1080i16.dga")
clip2=ConvertToYV12(clip2)
return SSIM(clip1,clip2,"results-Test.csv","SSIM-Test.txt",lumimask=true)
```

Calculation VQM

```
LoadPlugin("C:\Program Files\AviSynth 2.5\plugins\rawsource.dll")
LoadPlugin("C:\Program Files\AviSynth 2.5\plugins\DGDecode.dll")
LoadPlugin("C:\Program Files\AviSynth 2.5\plugins\VqmCalc.dll")
clip1=rawsource("D:\test2\720p420.yuv",1280,720,"I420").assumefps(50)
clip2=AVCSource("D:\test2\720p13\720p13.dga")
return VqmCalc(clip1,clip2,"VQMTest720p13.txt")
```

5.3 Results

From all processed video obtained results were published in the excel spreadsheet and afterward constructed a graphs. Figures 6.5 to 6.10 show results for different video quality measures relative to bit rate. It's necessary to note that bitrate for each video may slightly varies because the video is not compressed at constant bitrate. In the graphs are specified average bitrates in Mbit per second.

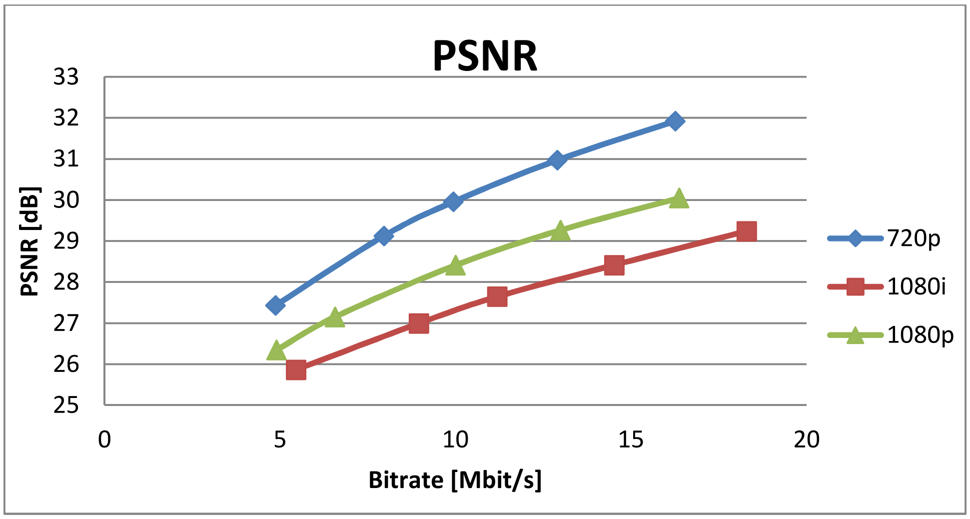

Fig. 6.5: PSNR relative to bitrate for ParkJoy

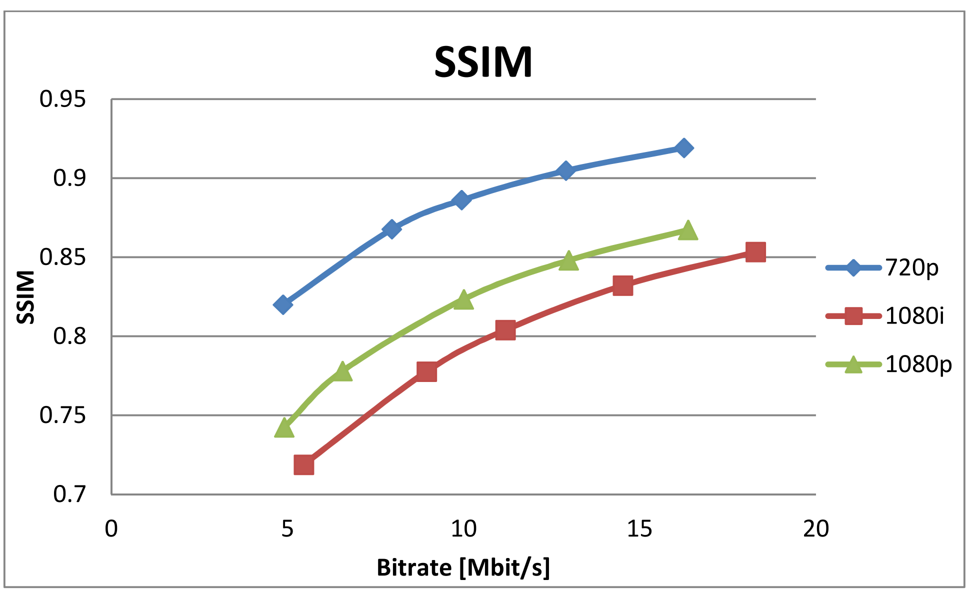

Fig. 6.6: SSIM relative to bitrate for ParkJoy

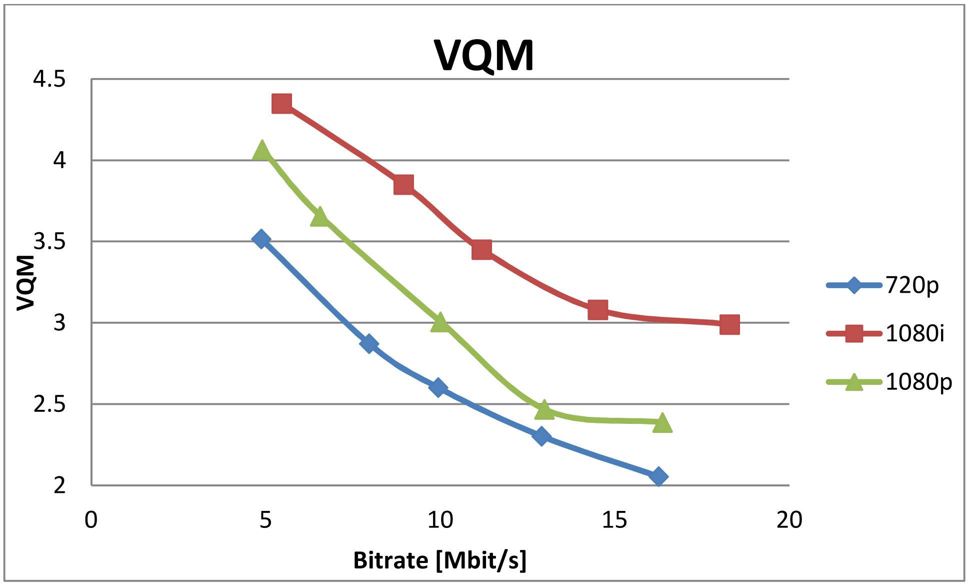

Fig. 6.7: VQM relative to bitrate for ParkJoy

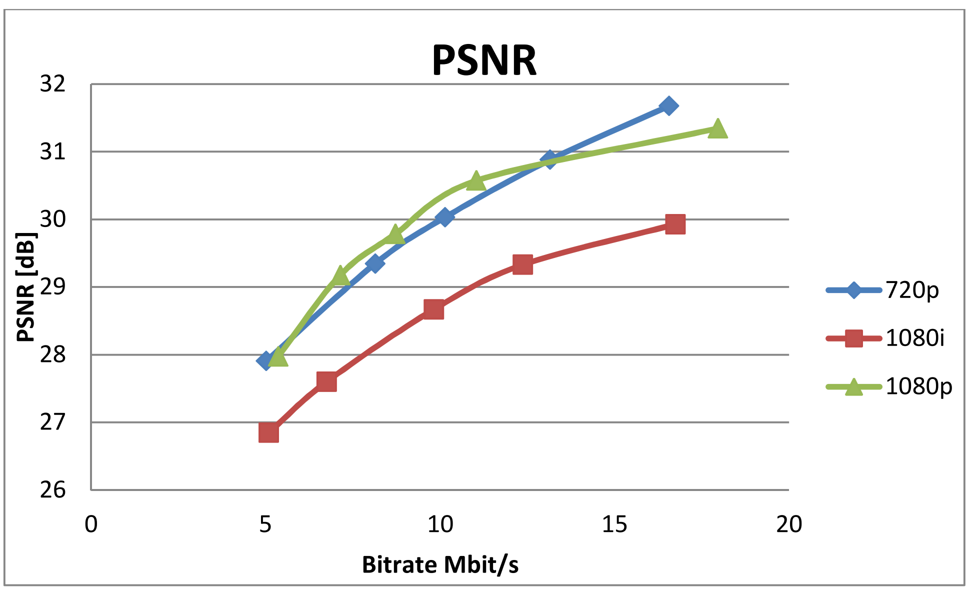

Fig. 6.8: PSNR relative to bitrate for DucksTakeOff

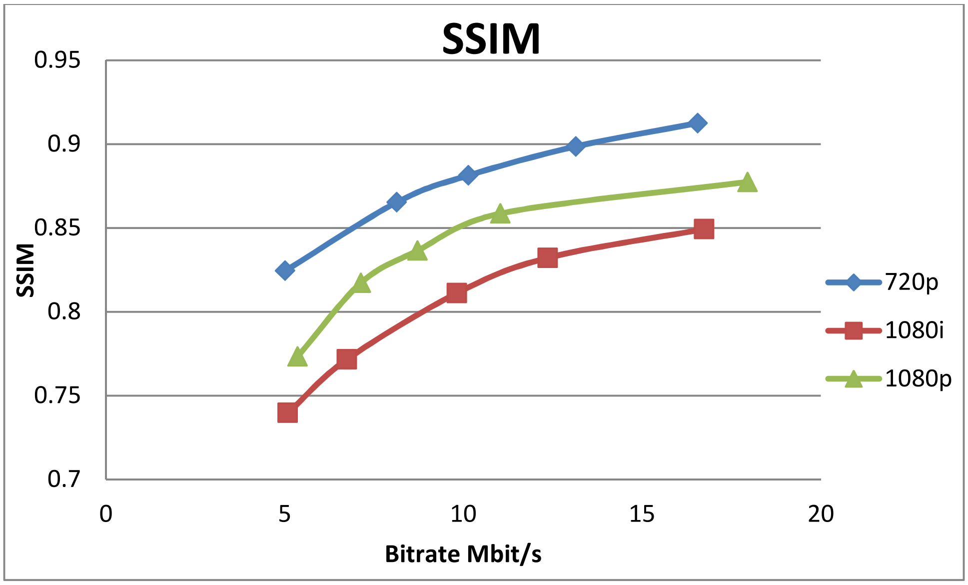

Fig. 6.9: SSIM relative to bitrate for DucksTakeOff

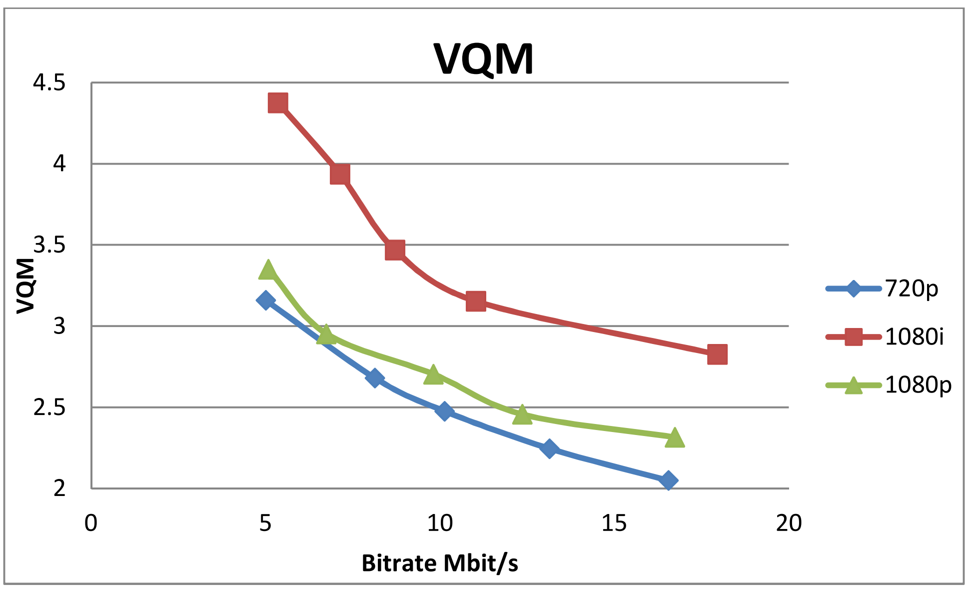

Fig. 6.10: VQM relative to bitrate for DucksTakeOff

The graph shows that all the results are proportional, and have a slight exponential dependence. It's noticeably that for all quality measures, 720p format shows the best index, the interlaced format is the worst.

From presented results in it can be concluded that 720p format is less distorting to reference video in range of bitrate from 5 to 18 Mbit/s, that were demonstrated by all three objective quality measures. Values slightly differ between for one video to the second, because the static background and presence of motion effects in the video also influences on the results. In this case, in ParkJoy video are presented more motion artefacts and contrast of many colors, but in DucksTakeOff video on the contrary the background is almost static and are not presented abrupt contrast of color. Due the fact that the HVS is less sensitive to temporal details and more sensitive to spatial details, if a video is stationary. However, for video with high motion, the opposite is true.

If we compare this results with the subjective results from [10] it can be seen that value correlates for range from 5 Mb/s to 16 Mb/s for "Parkjoy" video. Based on the results of subjective methods for bitrate greater than 20 Mb/s a video with resolution 1080p become better than 720p50. In [10] also comparison for many other sequences was performed, total seven, there the following facts were concluded that for any video 1080p format is the best, but for other 720p50. This indicates that the content of video plays an important role in selecting format. Another interesting comparison was performed and was concluded that an uncompressed SDTV has about the same quality level like 6 Mbit/s of the 1080i/25.

There are many factors exist which can influence on the perceived image quality. One of cardinal factor is the viewing distance to the display, recommended by ITU-R BT.500-11 the distance for measurements is 3 times picture height (3 h). [10] Other factor is format and screen size and aspect ratio. Today broadcasters are required to identify the target display size for the majority of viewers (i.e.37–42 inch display size) and aspect ratio 16:9. For this type of display the best matched for broadcast application is 720p format. For greater display size makes sense to use 1080p format. Another impact on image quality may be the process of up-sampling or down-sampling of video to desired format, provided by Source and Sink devices.

7. Conclusion

In this conclusion we can say that in this paper the specified goals have been achieved. At the beginning all types of versions HDMI were considered, the physical and electrical characteristics were specified and in details the using protocols were described, especially the TMDS. Also supporting video format and its components were listed and analyzed as resolution, timing and colorimetry. Much attention was paid to 3D systems, namely supporting 3D formats by HDMI, its structures and a very common question about 3D transmission signal was considered through the cable earlier versions.

In the practical part of this thesis a task for comparing a different HDTV formats using in broadcast TV was developed. The method for determining the similarity between the formats we used a full reference method, described in Rec. ITU-R BT.1907 [12]. For quality measures we used three objective quality measures: PSNR, SSIM and VQM. For validation our test, the results were compared with other subjective measures performed in [10].

The main advantage of this work is that all software used across the task is fully free and there is no necessity in special equipment, it can be used by any person who can also his safe financial budged.

This method can be implemented in very interesting application such as automatic control the video resolution on dependency of bandwidth availability, the similar method is described in [22]. Today this technology is used in such services as YouTube and Skype. Another useful application of this method can be implemented in display devices to automatic switch format on dependency of screen size and distance to viewer (by using special sensor for measuring the distance). With increasing number of different formats, in future this method might have a big popularity in display production.

While I was writing this thesis I encountered a number of interesting and challenging assignments that gave me the benefit and invaluable experience. I hope that this thesis will be useful for those who deal with the digital television and the described method will be implemented in laboratory task for education and commercial purposes.

8. Literature

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