HDMI Demystified

HDMI 1.3 ● Eye Pattern ● Cliff Effect ● Cable ● Speed Rating

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The release of the new HDMI 1.3 specification in June 2006 created both excitement and confusion in the consumer electronics industry. The discussion below is provided to help clarify this new technology and provide you with a better understanding of what you need to know about HDMI products.

What is HDMI?

High-Definition Multimedia Interface, or HDMI, is a digital audio, video and control signal format defined by 7 of the largest consumer electronics manufacturers. Released on 12/9/2002, it is supported by more than 300 companies. The advantages of HDMI over other signal formats are:

- Uncompressed digital signals for the highest picture and sound quality

- One cable for video, audio and control

- Two-way communication for easy system control

- Automatic display and source matching for resolution, format and aspect ratio

- PC compatibility

What's new in HDMI 1.3?

- Higher speed: The maximum data rate doubles from 5 to 10 Gbps

- Deeper color: The color depth is increased from 24 bit to 30, 36 or 48 bit.

- Wider color space: The range of colors is widened to the entire visible spectrum of colors.

- Supports lossless audio formats: Dolby TrueHD, DTS-HD Master and more

- Lip sync: synchronizes audio and video compensating for signal processing delays

- New mini plug: Type C for portable devices such as camcorders in addition to the current Type A and Type B

All the signals travel inside one HDMI cable:

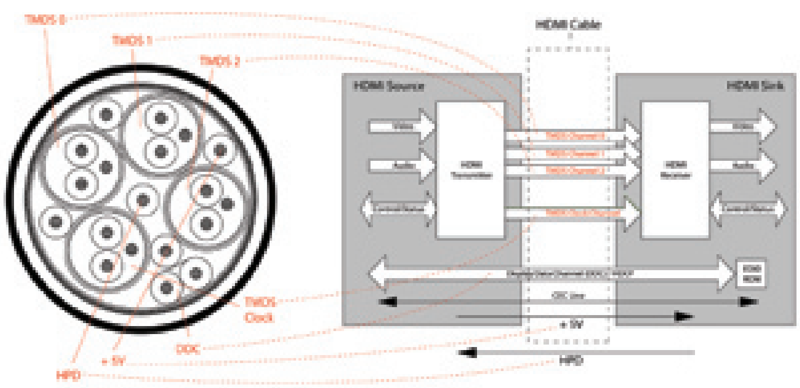

Fig.1 Inside an HDMI cable

- TMDS (Transition Minimized Differential Signaling) signals are transmitted over 4 twisted pairs of wires, including 3 digital video signals (RGB or YCrCb) and 1 clock signal; the digital audio signals are multiplexed into the digital video signals. The Dual-Link HDMI has 3 more twisted pairs of wires for digital video signals to achieve a higher data rate.

- DDC (Display Data Channel) data and clock lines carry the two-way communication signals; the HDCP (High-bandwidth Digital Content Protection) signal also floats here.

- CEC (Consumer Electronics Control) data line distributes remote control signals for one touch system controls.

- HPD (Hot Plug Detection) allows the source equipment to detect a connected display in real time.

- +5 V power line supports remote circuits for communication even when the power is not turned on.

Video signal resolution and data rate

Resolution: refers to how many pixels in horizontal and vertical direction per frame. 720p has a resolution of 1280x720, while both the 1080i and 1080p are 1920x1080.

Refresh rate: refers to how many frames or fields of pictures per second. The common rates are 30 and 60 Hz in the US, or 25 and 50 Hz in Europe.

Color depth: refers to how many bits of data needed to encode each pixel. Most common are 24, 30, 36 and 48 bits.

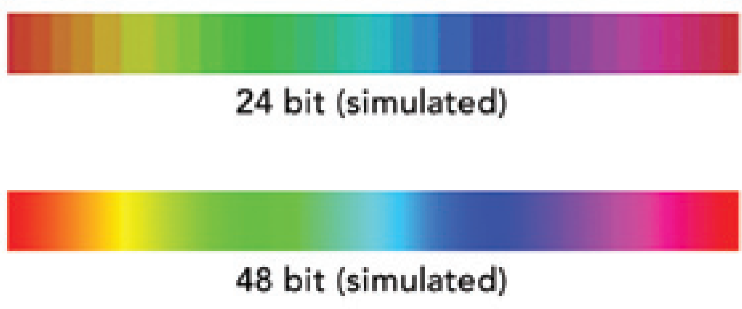

Fig.2 Deep Color

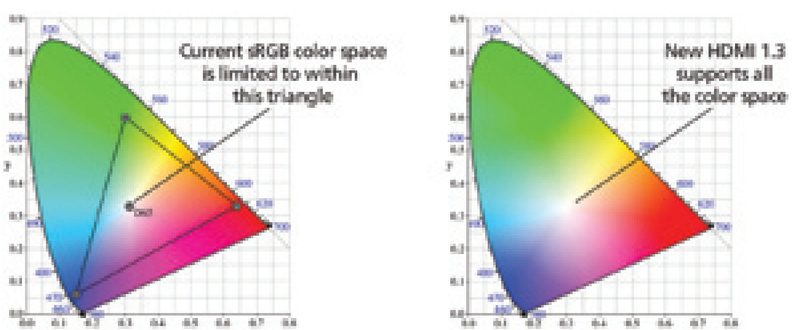

Fig.3 Wider Color Space

Data rate: refers to the total number of digital bits per second for a given signal. It's roughly the multiplication of all the three preceding numbers (above) together. Thus, the higher the resolution, refresh rate and color depth, the higher the data rate. The max data rate for HDMI 1.0 thru 1.2 is 5 Gbps, while the new HDMI 1.3 max is 10 Gbps.

Type of HDMI plugs and cables

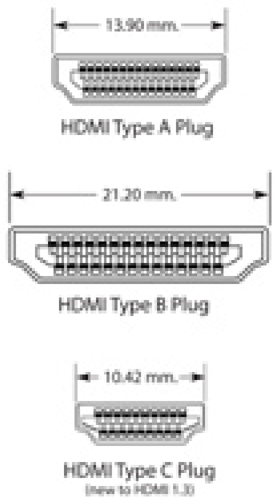

Fig.4 HDMI plug types

Type A plug: the most common HDMI plug, 13.9 mm wide, 19 pins, designed with one set digital video TMDS lines (Single-Link)

Type B plug: a seldom used HDMI plug, 21.2 mm wide, 29 pins, designed with two sets of digital video TMDS lines (Dual-Link) for higher data rates

Type C plug: the new mini HDMI plug, 10.42 mm wide, 19 pins, designed with one set of digital video lines (Single-Link) for small portable devices

SingleLink HDMI uses one set of digital video TMDS lines to carry lower data rate signals using cable with at least 15 conductors

DualLink HDMI uses two sets of digital video TMDS lines to carry higher data rate signals using cable with at least 22 conductors

Before HDMI 1.3, the Single-Link was good for 5 Gbps; the Dual-Link could handle 10 Gbps. HDMI 1.3 changed that, now the Single can carry 10 Gbps, the Dual even more.

Type of HDMI cables

For the first time, HDMI 1.3 specification divided the HDMI cables into two categories:

Category 1 or Cat 1 cable: can carry a signal with a maximum pixel clock of 74.25 MHz (roughly equivalent to data rate of 2.2 Gbps) Category 2 or Cat 2 cable: can carry a signal with pixel clock greater than 74.25 MHz (roughly equivalent to data rate greater than 2.2 Gbps)

All of the HDMI cables made before the publication of the HDMI 1.3 specifications are at least HDMI Cat 1 compliant.

DDC, HDCP and compatibility issues

The DDC (Display Data Channel) lines in the HDMI cable are very busy. Not only do they carry the handshake communications at the initialization (plugged in or powered up), they also constantly transmit the HDCP (copyright) encryption keys for copy-protected content. The source needs to verify if the display is HDCP compliant; the display needs the keys constantly to decode the encrypted digital signal.

This critical communication is running on a protocol called I^2C (read "I squared C", or Inter-Integrated-Circuit) developed by Philips originally for the communications between IC chips in the same device. It's not the most reliable protocol for long distance transmission like HDMI cables. The communication lines have an "open" stage in addition to the high and low stage; this "open" stage is not stable as it is highly dependent on the impedance and capacitance of the cable and the device. The HDMI standard is derived from DVI, which was originally designed for the tightly specified computer industry. Additionally, distance was not at issue as the monitor is generally in close proximity to the CPU. Longer cables and unknown devices introduce the potential for communication error. The symptoms of communication error can range from no picture, jumping picture, snowy picture, wrong resolution or no audio.

There are IC chips available to reduce or eliminate this problem, but the circuit may cause power overload as explained below:

+5 V power line overload

The HDMI signal source supplies a +5 V power line to power up the DDC communication circuit in the display ("sink") even when the display is not turned on. The purpose of this design is to enable the source component to "know" information about the targeted display at all times. This is a very convenient feature. However, some products on the market take advantage of this power source to eliminate the need for an extra power supply. According to the HDMI standard, the sink should not draw more current than 50 mA from the +5 V line when the sink is turned off and no more than 10 mA when the sink is turned on. Some HDMI cables use a built-in electronics driver that draws more than 150 mA constantly. This could result in poor picture performance, or even damage to the source electronics.

Lip Sync

Modern AV devices have many signal processing features. Most signal processing causes signal delay. Usually, video processing has a longer delay than audio processing causing the picture and sound to be out of sync. HDMI 1.3 added communications via the DDC line to allow the source to adjust the audio delay based on video-audio mismatches reported by the downstream devices. This solved the lip sync problem. All HDMI cables made before the HDMI 1.3 specification was published can support the Lip Sync feature because the inserted data is part of the DDC line.

1080p

TV manufacturers started promoting 1080p at about the same time as the HDMI 1.3 standard was released. This resulted in some confusion as to whether they are one and the same. They are not. 1080p has been part of the HDMI standard since the very first revision. HDMI 1.3 added signal rates higher than 1080p. You don't need HDMI 1.3 compliant products to enjoy 1080p (60 Hz, 24 bit encoding) but you do need an HDMI connection as most devices will not output 1080p through the component video outputs due to copyright concerns.

Backwards compatibility

In most cases you don't need to worry about the evolution from HDMI 1.2 to HDMI 1.3. Like most new technologies, HDMI 1.3 is backwards compatible. Also, most of the HDMI devices have DDC communication capability. If any device in the chain is not HDMI 1.3 compliant, the whole system will fall back to HDMI 1.2 or lower to ensure compatibility through the DDC communication. The only time you may have compatibility issues with HDMI 1.3 is when one of the devices is not HDMI 1.3 compliant, and it does not “speak up” (no DDC communication capability, e.g. many extenders and distribution amplifiers), or if the cable length is too long AND you are running a signal higher than 1080p 30 Hz.

Analog video signal related to cable length:

When an analog video cable length is increased, the signal quality gradually declines. See fig. 5 on the next page.

The main types of analog video signal loss are:

1) Amplitude loss: the result is a dimmer image.
2) High frequency signal loss: the result is a softer image.
3) Low frequency signal loss: the result is horizontal smearing on the image.

There are marked differences in image quality between poor quality and superior quality analog video cables.

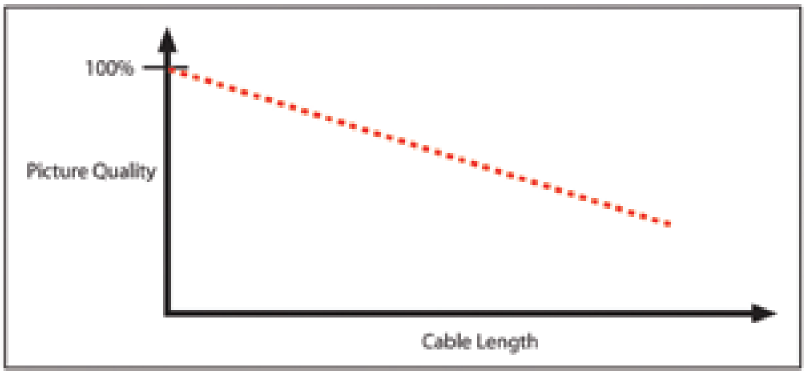

Fig.5 Picture quality of an analog single gradually declines over longer length of cable.

Regardless of how bad the signal loss is, the display will still generally show a picture. Many viewers would not know how much image quality was lost without comparing pictures to a perfectly functioning display. In addition, there is no two-way communication between the source and display in an analog video based system. These are the two key reasons for fewer percieved issues, and complaints, where analog video based systems are concerned.

Digital video signals over long cables: the “Cliff Effect”

Digital video signals behave quite differently from analog video. When the cable length increases, the image quality is perceived to be perfect by the human eye upt to a certain length. After that length, the image is either unrecognizable or disappears all together. Fig. 6 illustrates what is called the “Cliff Effect”.

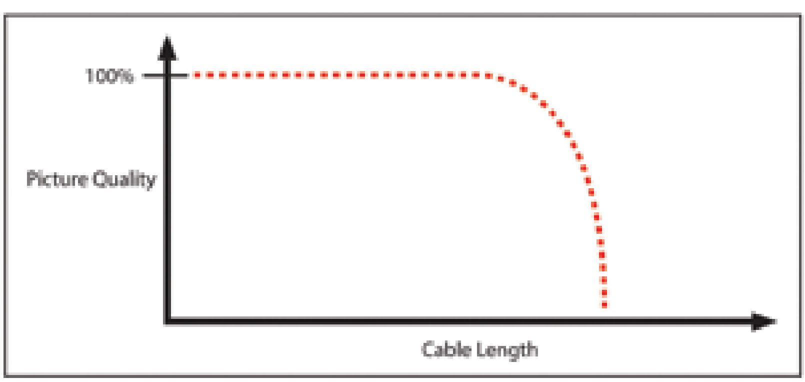

Fig.6 Picture quality of digital signal (e.g. HDMI) drops suddenly after certain length of cable.

Why should consumers pay for better cables if they are below the “Cliff Effect”?

This is a hot topic among consumers and manufactures. One side insists that you do not need to pay more for higher performance cables as long as the signal has not exceeded the “cliff”. Even cheap HDMI cables will provide a quality image. The other side argues that there are always differences between higher and lower quality products and it is worth paying for that difference.

Let’s use an analogy to further elaborate this point. Schools usually use 60 out of 100 points as the pass/fail threshold for students. Student A gets 95 points. Student B gets 65 points on their final exam. They both “pass” this final test. However, is their performance the same? Which one would you hire to work for you? The answer is quite obvious. Similarly, good and bad HDMI cables pass the test right up to the point where they fall off the “cliff”. But there are, indeed, measurable differences between the two.

Seeing is deceiving

Even when the cable length is below the “cliff effect” threshold, there are already data errors occurring in transmission. See fig. 7.

Why don’t we see these defects when we are near or on the edge of the “cliff”? The answer is the built-in error correction technology used in digital transmission. The display can tolerate a certain amount of error bits per second. The picture would still be perfect as long as the error rate is below that threshold. Once the error rate exceeds the capability of the display, signal recovery may fail altogether. HDMI cables are not created equal. But how would we know that there are meaningful differences? There are two industry standard tests for HDMI cable: the BER test and the “Eye Pattern” test.

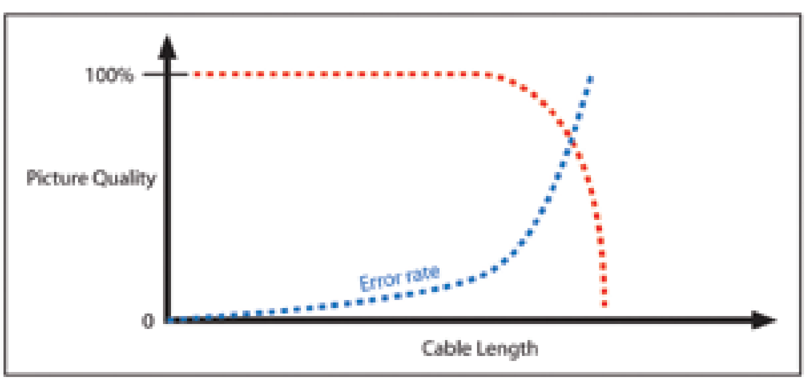

Fig.7 Long before reaching the “cliff”, the signal error rate starts to increase with length of cable.

BER test:

BER stands for Bit Error Rate. In a BER test, the signal generator would output billions of data bits (per the HDMI standard), send them to the cable (or the input of other devices) and receive them from the other end of the cable (or the output of other devices). A comparison is then made bit by bit with the sent data. The BER display then shows the results as the total numbers of error bits in a given period of time (usually less than a second).

The BER test accurately shows the real number of bad data bits a display could receive under a given condition. The higher the number, the worse the signal. The BER test is the most accurate real world test for HDMI cable performance and quality control.

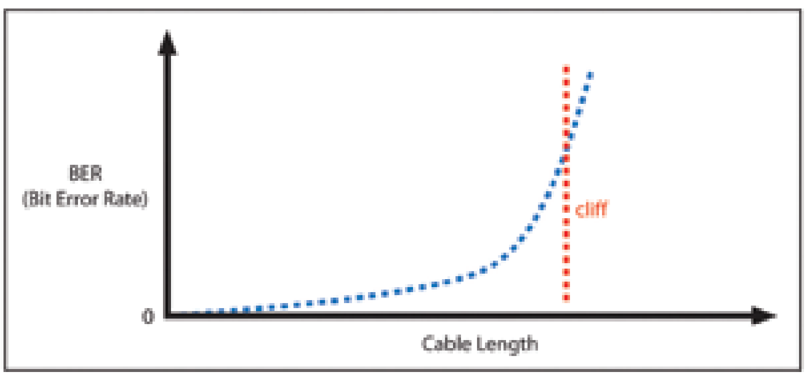

Fig. 8 BER (Bit Error Rate) test counts the number of error data at the far end of the cable. the "cliff" effect is visible.

Eye pattern test:

"Eye pattern" is what the digital signal looks like on an oscilloscope. The traces of many 1s and 0s overlap on the oscilloscope to form a pattern that resembles an eye shape. See fig. 9.

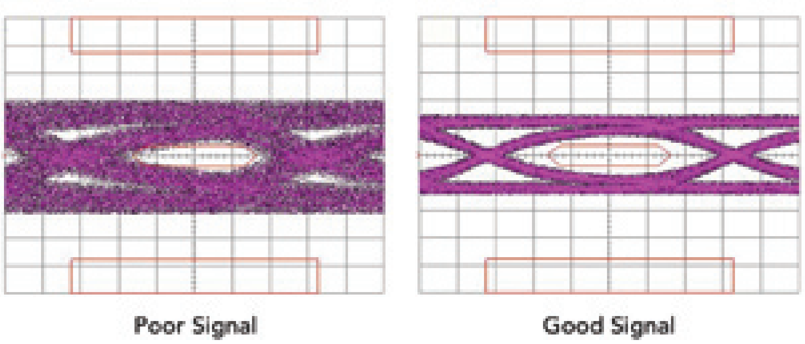

Fig.9 HDMI "Eye" patterns

The eye pattern test shows many aspects of the digital signal:

1) Signal amplitude: the height of the "eye" represents the signal amplitude. It must not fall into or become smaller than the marked diamond shaped area in the middle, otherwise the signal will be too small for the display to recover. The "eye" will appear to be closed in the vertical direction.

2) Timing jitter: the rising and falling edges of digital bits do not always arrive at the precise time they should. This is called "timing jitter". On an oscilloscope it appears that the eye gets fuzzy in the horizontal direction as a result of some bits shifting left, some shifting right and all overlapping each other. The internal width of the eye can't fall into or become narrower than the marked diamond area in the middle, otherwise the display won't recover the data. In short, if the "eye" collapses in either horizontal or vertical direction, the signal is lost.

BER vs. eye pattern test

Both tests are essential in the HDMI industry. They are similar in that they both show elements of digital signal integrity. Figs. 10 and 11 show these two different tests revealing the same "cliff effects".

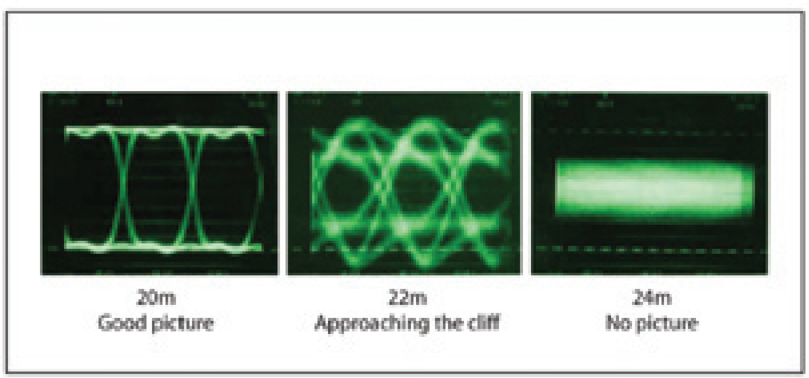

Fig.10 "Eye pattern" test shows the wave forms of the digital signal (bits) visually. it also shows the "cliff" effects.

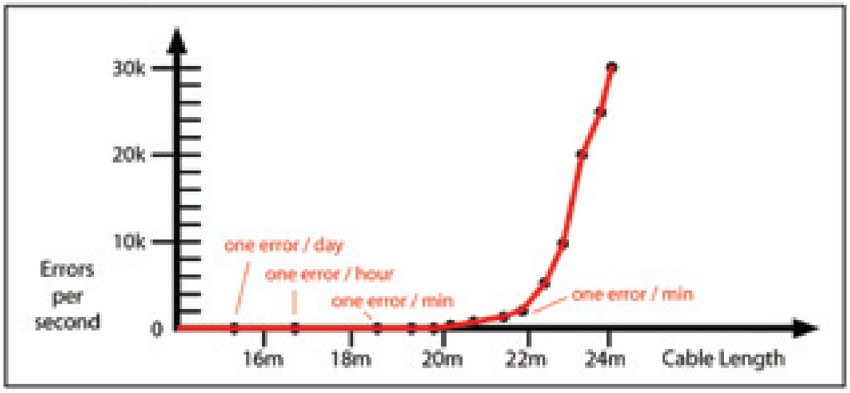

Fig.11 BER test also shows the "cliff" effects.

These two tests are considerably different.

The BER test shows the scale (how many) of data errors, but does not tell the cause of the problem. The BER equipment costs tens of thousands of dollars. The test time is about a second for all 4 TMDS pairs and all other lines within an HDMI cable. These make the BER test the best for QC (quality control) and real world field support applications.

The eye pattern test on the other hand shows the cause (what went wrong) of the problem, but not the scale (how many) of the data errors. This equipment costs hundreds of thousands of dollars. This test takes about 15 to 20 minutes because the technician needs to test one pair at a time, and needs to analyze the pattern subjectively one by one. This makes the eye pattern test the best for engineering design and fault analysis.

AudioQuest employs both types of testing. Their extensive use begins throughout the design phase and ends with a 100% QC process to ensure the highest quality for each cable.

Fig.12 BER and Eye Pattern test equipment.

HDMI cable length vs. max data rate

This is a complex issue. The max length for an HDMI cable to transmit a usable HDMI signal depends on the entire system: the source device performance, the display performance, the signal data rate and the cable performance and length.

In the analog world, we use bandwidth to describe the amount of information of the signal. The higher the picture resolution, the higher the signal bandwidth.

In the digital world, we use data rate to describe the amount of data bits per second of the signal. The higher the picture resolution, the higher the refresh rate. The deeper the color, the higher the data rate. 720p and 1080i have about the same data rate of 2 Gbps (regular 24 bit encoding). 1080p has about twice the data rate at 4 Gbps (regular 24 bit encoding). 48-bit deep color has about twice the data rate of the 24 bit encoding, or about 8 Gbps for 1080p deep color.

The higher the data rate, the shorter the maximum length for a given HDMI cable design. See the chart below:

HDMI cable max data rate vs. cable length

Model \ Length (m)	1.0	2.0	3.0	4.5	6.0	7.5	9.0	12.0	15.0	20.0
Premium HDMI cable	30	25	18	18	13	11	9	7	5	4

Future proof; beyond HDMI 1.3 — "**Deep Color**" 1080p, 48 bit, 60 Hz or 8 Gbps — "**1080p**" 24 bit, 60 Hz or 4 Gbps

Note: Note: all data rates are nominal, in Gbps

Higher data rate signals present a bigger challenge to long HDMI cables.

All HDMI cables made prior to the enactment of HDMI 1.3 will pass HDMI 1.3 signals. However, when data is sent at the maximum rate, the effective HDMI cable length is reduced by half. Keep in mind that HDMI 1.3 only EXTENDS the max allowable signal data rate; it does not INCREASE the data rate of a given signal. Your cable will still run the same distance on the same 1080p signal regardless of whether the devices are HDMI 1.2 or 1.3. The maximum distance will be reduced when you run the higher data rate signals now made possible by HDMI 1.3.

HDMI extender (repeater, amplifier) compatibility with HDMI 1.3

Unlike cables, most of the IC chips used in electronic HDMI extenders have a hard cut-off on their maximum data rate limit. Therefore, extenders made before the HDMI 1.3 standard was published often won't work with the HDMI 1.3 signals with a data rate higher than 5 Gbps.

Future proof your system

Taking a look at the cable length and data rate from the "cliff effect" chart, it is clear that the higher the data rate, the closer the edge of the "cliff".

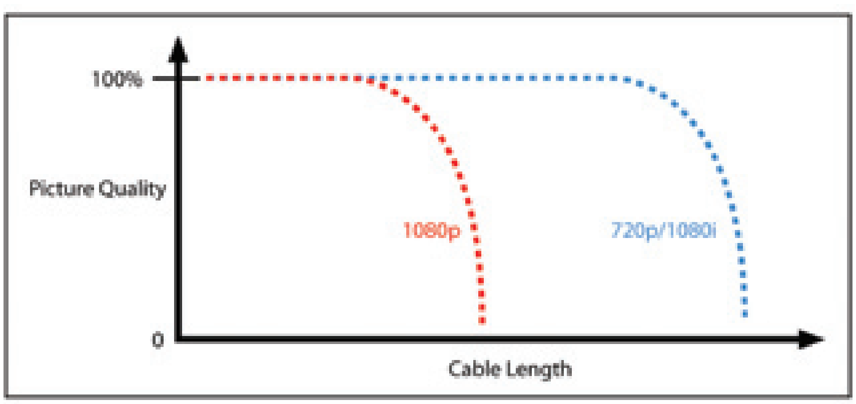

Fig.13 The edge of the "cliff" of a given cable varies by signal rate. The max distance of 1080p is only 1/2 of 1080i.

We can expect the “cliff” to “move in” with the advancement of technology that will enable higher data rates over time.

From the discussion above, we can see that there are absolute differences among cables. The worse the cable, the closer the “cliff”.

A low quality cable that may work fine for the 1080i signal you are using today may not work for the 1080p signal you may use tomorrow. A good quality HDMI cable does not cost much more than a mediocre one, especially compared to the cost of the HDTV in your system.

What makes a better HDMI Cable?

There’s a wide spread myth about digital video cables like HDMI. Due to the “cliff effect”, all the cables have the same perfect picture when they work, even those of the lowest cost. The discussion in previous sections already shows that there are test methods to clearly show the differences between cables. Now let’s examine the differences from a design and manufacturing point of view.

Better Design:

Don’t let the simple appearance of HDMI cables fool you. HDMI cables carry signals up to 10 Gbps. It’s one of the most challenging cables to manufacture due to this super high data rate (just compare to the data rate of any network or computer, which is only a small fraction of the data rate of HDMI). Here are some of the elements for a good HDMI cable:

1) Better conductors: this is the most critical element. OFC (Oxygen Free Copper) copper is a very pure copper (higher than 99.99% purity) and is used in better quality cables. Silver-plated OFC is an even better conductor. High purity silver is plated at the surface where high frequency signals concentrate due to skin effect.

2) Solid core construction: a single solid conductor eliminates interferences around the electro-magnetic fields of the signals traveling in different strands in a stranded cable.

3) Superior cable geometry: the core elements of the HDMI cable are the 4 twisted pairs with an ultra-precise twist ratio. Some high end cables use twisted quad for better performance

4) Insulation: better cables use skin-foam-skin (gas injection with hardened skins) insulation to achieve better electrical performance while maintaining mechanical stability.

As a result, a cable benefiting from a more advanced design has a much cleaner eye pattern. (See illustration below.)

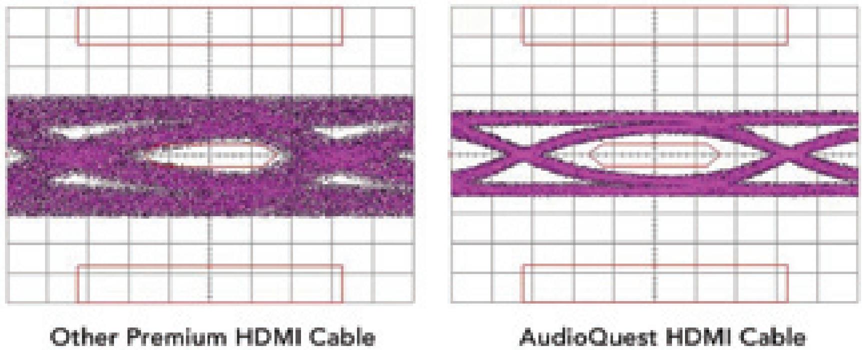

Fig.14 Eye pattern test results

Better manufacturing:

Manufacturing techniques, equipment, processes and quality controls are critical to make every cable you buy the highest quality possible. This is even more important for HDMI cables. HDMI cables are very complex and require high precision manufacturing controls.

1) Precision HDMI twisted pair machine: HDMI cables can handle up to 10 Gbps data rate which is higher than the fastest computer. To achieve such a high performance, the twist ratio control on the 4 twisted pair wires inside a HDMI cable is critical. The picture below is an ultra-precision twist machine for making high quality HDMI cables.

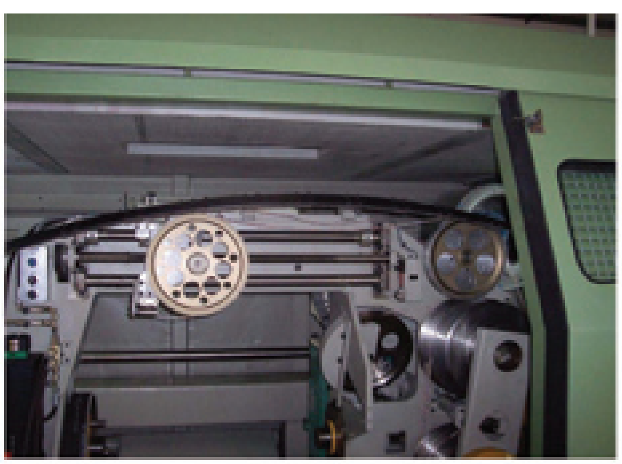

Fig.15 The precision twisted-pair machine

2) HDMI crimping technology: There are 19 connections in one HDMI plug and the distance between the pins is very small. Most factories rely on the production technicians to solder the many wires onto the tiny pins, one by one. By doing so, there is a high probability of overheating and loosening of the pins, a short circuit between pins or a cold solder joint. Each could render the cable defective. On the other hand, the new Cold-Weld technology can clamp all 19 wires in place and crimp them in one step, significantly increasing the reliability of the contact and eliminating the chance of worker related error.

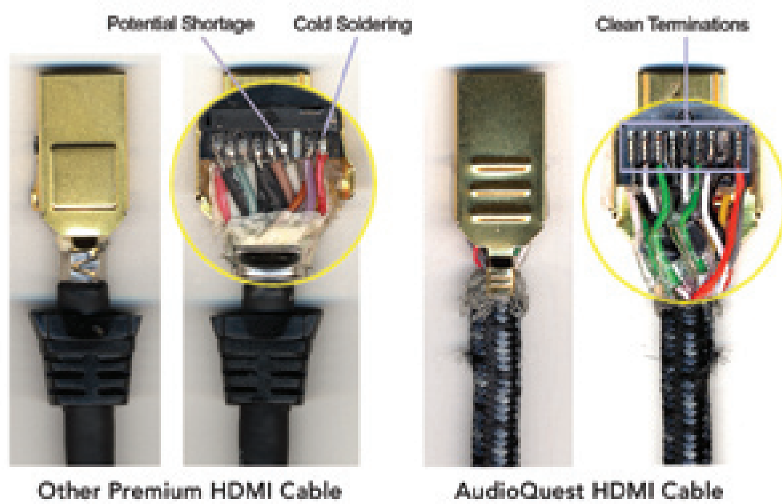

Fig.16 Soldering vs. crimped connection

The speed rating system:

It isn't useful or accurate to describe a signal by its resolution, refresh rate or bit depth. For example, 720p and 1080i have about the same amount of information; 1080i 60 Hz and 1080p 30 Hz have about the same amount of information.

Speed, or more accurately, data rate, which is measured in bits of data per second, is the combination of resolution, refresh rate and bit depth. It's a single, meaningful number. For example, 4 Gbps is (roughly) the data rate for 1080p, 60 Hz and 24-bit bit depth. The max data rate a given cable can carry depends on the cable quality and the cable length. See the table on page 14. Some manufacturers give a fixed speed rating to a cable series (family) regardless of cable length. This is neither useful, nor accurate. A more accurate speed rating system should be based on cable quality and cable length.

Summary:

In this article, we have discussed how HDMI works, what's new in HDMI 1.3, the compatibility issues related to devices and cables, the "cliff effect" for digital transmission, the two ways of measuring the digital transmission performance – the eye pattern test and the BER test – and the design and manufacturing requirements for building a good HDMI cable.

Hopefully this information will help you in selecting the right HDMI cables for your system and, more importantly to understand that there are marked differences in performance and quality between today's HDMI cable products.

The paper was authored by AudioQuest's Senior Vice President of Product Development, Xiaozheng Lu. An industry veteran with degrees in electrical engineering and physics, Mr. Lu also holds a number of U.S. patents for his design work.

AudioQuest, based in Irvine, CA is a manufacturer and distributor of premium performance audio and video cable products and accessories. Founded in 1980, the company sells to 500 specialty audio/video dealers in the United States and 60 independent distributors around the world. The company is privately owned.

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