Extron®

The ABCs of Digital Video Signals

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Abstract

Digital video signals are becoming widely prevalent throughout the A/V industry. They are considerably different in comparison to traditional analog video signals, with specific performance and timing requirements that must be maintained throughout the entire signal path. This paper offers an introduction to digital video signals and the digital video formats currently in use. It also explains how eye diagrams can be used to quantify and visualize digital video signal integrity, and the importance of digital video signal conditioning when designing digital A/V systems.

white paper

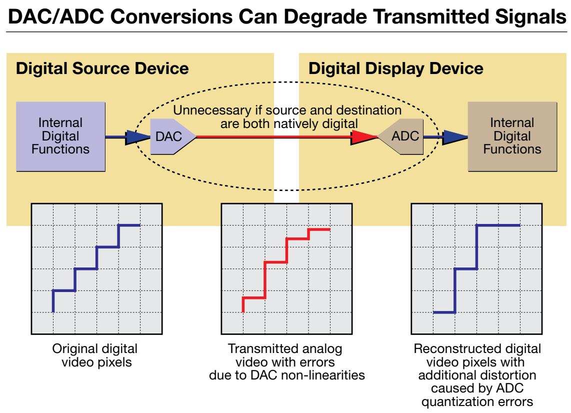


Figure 1: Extraneous ADC and DAC

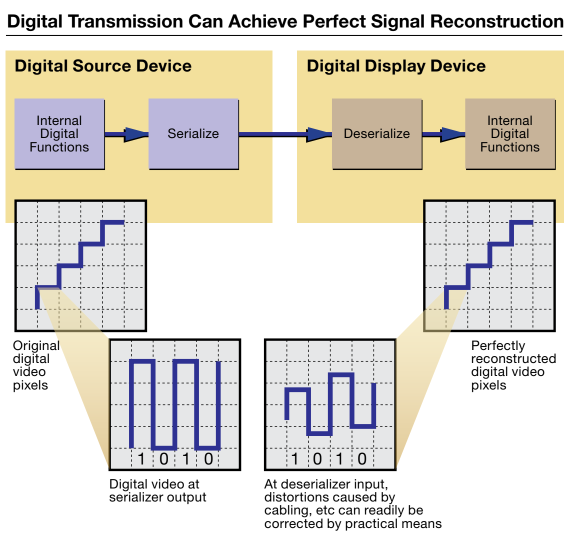


Figure 2: Perfect digital transmission

Introduction

The video marketplace is currently dominated by high resolution plasma and LCD flat panel displays, and LCD and DLP projectors. These displays are natively digital in their design, construction, and operation. Similarly, the vast majority of sources that drive these displays, including computers, DVD and Blu-ray Disc players, high definition digital video recorders or DVRs, and A/V receivers, are inherently digital devices. These products stand in contrast to the traditional, analog video sources and displays such as VHS recorders and CRT-based televisions or data monitors that utilized signal interfaces such as composite video or RGBHV.

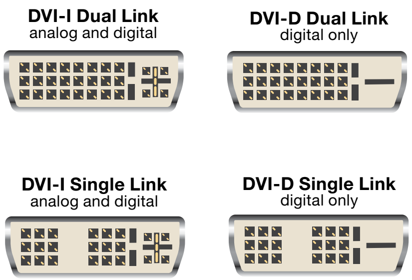
For a digital video source to initiate analog signal transmission, its digital output signals must be converted to analog video, a process known as digital-to-analog conversion or DAC. At the receiving end, a digital display must convert these analog signals back to digital, a process known as analog-to-digital conversion or ADC. Each DAC and ADC conversion introduces errors and distortion into the video signal. By employing all-digital transmission, these unnecessary errors, as well as the extra expense of ADC and DAC circuitry, can be eliminated. See Figure 1.

For digital signal transmission, a digital receiver circuit needs only to determine whether each incoming bit is “high” or “low” to completely reconstruct the transmitted signal. This is in contrast to analog transmission, where each amplification stage adds noise and therefore degrades the signal, such that exact reconstruction of the video signal is not possible. In analog transmission, the original signal can be recovered with sufficient fidelity by careful design, but the result is never exactly the same as the original. In digital transmission, it is practical to recover the original signal completely. See Figure 2. Therefore, digital transmission promises greater noise immunity and potentially perfect transmission and reproduction of the video signal.

There are several standard signal formats in use for digital video transmission between sources and displays. These include:

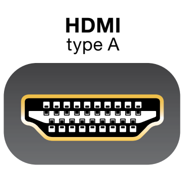
- **DVI** - Digital Visual Interface
- **HDMI** - High Definition Multimedia Interface
- **DisplayPort**
- **SDI** - Serial Digital Interface

Some, such as SDI, have been in use for many years while others, such as HDMI and DisplayPort, are relatively new and are being updated continuously through the standards revision process. At this point, it is premature to predict whether any one of these formats will ultimately dominate professional A/V. Each format has its own technical advantages as well as unique capabilities to meet specific integration requirements within the A/V industry. Let’s take a look at each one in some detail.



PIN #	SIGNAL NAME	PIN #	SIGNAL NAME
1	TMDS Data2-	16	Hot Plug Detect
2	TMDS Data2+	17	TMDS Data0-
3	TMDS Data2/4 Shield	18	TMDSData0+
4	TMDS Data4-	19	TMDS Data0/5 Shield
5	TMDS Data4+	20	TMDS Data5-
6	DDC Clock [SCL]	21	TMDS Data5+
7	DDC Data [SDA]	22	TMDS Clock Shield
8	Analog vertical sync	23	TMDS Clock +
9	TMDS Data1-	24	TMDS Clock -
10	TMDS Data1+	C1	Analog Red
11	TMDS Data1/3 Shield	C2	Analog Green
12	TMDS Data3-	C3	Analog Blue
13	TMDS Data3+	C4	Analog Horizontal Sync
14	+5 V Power	C5	Analog GND Return: (analog R, G, B)
15	Ground (for +5 V)		

Table 1: DVI pin configuration



PIN	FUNCTION	PIN	FUNCTION
1	TMDS Data2+	11	TMDS Clock Shield
2	TMDS Data2 Shield	12	TMDS Clock-
3	TMDS Data2-	13	CEC
4	TMDS Data1+	14	N/C
5	TMDS Data1 Shield	15	SCL
6	TMDS Data1-	16	SDA
7	TMDS Data0	17	DDC/CEC Ground
8	TMDS Data0 Shield	18	+5V Power
9	TMDS Data0-	19	Hot Plug Detect
10	TMDS Clock+		

Table 2: HDMI pin configuration

DVI - Digital Visual Interface

DVI and HDMI are based on a common signaling scheme for video known as TMDS - Transition-Minimized Differential Signaling. A DVI TMDS link consists of three serial data channels, one for each color – red, blue, and green – plus a fourth channel carrying a pixel rate clock which provides the timing reference that keeps the three color channels synchronized. Each DVI link is essentially a digitized RGB raster, with support for 8 bits per color, and video blanking intervals comparable to analog RGB. Horizontal and vertical sync information is carried on the TMDS blue data line. All TMDS data and clock lines are differential, or balanced, and are carried on twisted pairs within DVI cable assemblies.

To support different resolution requirements, the DVI specification provides for one or two video links per connector, commonly known as single link or dual link, respectively. The maximum pixel rate for single link DVI is 165 MHz, corresponding to 4.95 Gbps, which is more than sufficient for WUXGA 1920x1200 and HDTV 1080p/60, with a color depth of 8 bits per color. Higher resolutions and greater color depths can be supported by use of dual link DVI, which handles pixel rates up to 330 MHz and resolutions as high as 3840x2400.

The DVI specification also provides for two additional lines of communication, both of which are essential in achieving successful DVI transmission between devices - see Table 1. The DDC - Display Data Channel is a serial connection for EDID and HDCP communication.

The HPD - Hot Plug Detect pin allows for implementation of hot plug detection, which allows a PC, for example, to detect the presence of a display without user intervention. The DVI specification provides for two types of connectors: DVI-D, the standard connector, and DVI-I, which can carry analog RGBHV as well as digital signals.

DVI is a royalty-free standard originated by the DDWG - Digital Display Working Group. Version 1.0 of the DVI specification was released in April 1999, and there have been no subsequent revisions since then.

HDMI - High Definition Multimedia Interface

The HDMI format incorporates the TMDS video functionality of DVI and extends TMDS to carry digital audio and control information. By consolidating high definition video, audio, and control into a single, compact connector, HDMI has been very successful in the consumer audio/video market. See Table 2.

The most common HDMI connector is the 19-pin Type A, which contains a single TMDS link plus DDC and HPD lines. A 5 volt power supply line is also provided. In addition, HDMI connectors incorporate the CEC - Consumer Electronics Control line,

HDMI 1.3 Basic Performance Parameters

- ✔ Performance:
  - DVI compatible
  - 25-340 MHz
  - Upward of 10.2 Gbps data speed
  - Color depth: 24-bit, plus 30, 36, and 48-bit Deep Color
  - Color space: ITU-R BT709-5, xvYCC
- ✔ Simple, plug and play connection
- ✔ Only one cable required
- ✔ Integrated video, audio, and content protection
- ✔ High level consumer control
- ✔ Auto lip sync

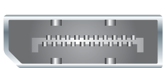
Table 3

HDMI 1.4 Enhanced Functionality

- ✔ HDMI Ethernet Channel:
  - Bi-directional data channel supporting 100 Mbps Ethernet connectivity
  - Allows multiple devices to share one network connection
- ✔ Audio Return Channel:
  - Returns upstream audio from a display's internal tuner to a receiver
- ✔ Supports higher maximum resolutions:
  - 3840x2160 at 24 Hz, 25 Hz, and 30 Hz
  - 4096x2160 at 24 Hz
- ✔ 3D Support up to 1080p
- ✔ Additional color space support:
  - Provides enhanced color accuracy with digital still cameras
- ✔ New HDMI Micro Connector:
  - Approximately 50% smaller than current HDMI mini connector

Table 4

DisplayPort
source-side



PIN	FUNCTION	PIN	FUNCTION
1	ML_Lane 0 (p)	11	GND
2	GND	12	ML_Lane 3 (n)
3	ML_Lane 0 (n)	13	GND
4	ML_Lane 1 (p)	14	GND
5	GND	15	AUX CH (p)
6	ML_Lane 1 (n)	16	GND
7	ML_Lane 2 (p)	17	AUX CH (n)
8	GND	18	Hot Plug Detect
9	ML_Lane (n)	19	Return
10	ML_Lane 3 (p)	20	DP_Power

Table 5: DisplayPort pin configuration (source-side)

which is used for integrated control of multiple devices within an A/V system. At this time, CEC control protocols are proprietary to each equipment manufacturer, and there is no CEC compatibility between manufacturers. However, there are implementation guidelines for CEC and manufacturers are beginning to work together to develop standardized control.

Other HDMI connector variations include Type B, a connector intended to support dual link HDMI applications but one that has not yet been implemented; and Type C, a miniaturized connector designed for portable equipment such as consumer camcorders.

The HDMI specification and licensing is administered by HDMI Licensing, LLC. In contrast to DVI, the HDMI specification has evolved through several standards revisions. Version 1.0 of the HDMI specification was released in June 2002. The current version is HDMI 1.3, released in August 2006. Compared to previous versions, HDMI 1.3 specifies a twofold increase in the maximum TMDS single link clock rate to 340 MHz, corresponding to 10.2 Gbps - see Table 3. The increased bandwidth of HDMI 1.3 enables up to 16 bits per color – also known as Deep Color, an extended color space, the latest high resolution surround sound audio formats for Blu-ray Disc, and video resolutions up to WQXGA 2560x1600. Version 1.3 also mandates the inclusion of High-bandwidth Digital Content Protection or HDCP, a digital rights management scheme that prevents the copying of digital video and audio content. The next version, HDMI 1.4 was recently announced and the specification is now available to adopters. See Table 4.

DisplayPort

DisplayPort is a royalty-free digital interface between sources and displays that is being positioned as a low-cost alternative to HDMI for PC equipment manufacturers. DisplayPort uses a digital video transmission scheme that differs from TMDS and is therefore not directly compatible with HDMI and DVI. However, the 20-pin DisplayPort connector, with characteristics similar to the HDMI Type A and Type C connectors, can be used to pass HDMI signals, provided that the device supports HDMI - see Table 5. For example, if a video source only has a DisplayPort connector, but also has HDMI signaling capability, then it is possible to use a DisplayPort-to-HDMI adapter to connect the source to an HDMI-equipped display. Such DisplayPort connections, referred to as "dual-mode" or "multi-mode," are symbolized by a special logo to indicate this capability:

DisplayPort video and audio signals are carried on four lanes of differential wires, with each lane running at either 1.62 Gbps or 2.7 Gbps for a maximum data rate of 10.8 Gbps. As with HDMI 1.3, DisplayPort is capable of supporting Deep Color, multi-channel high resolution audio, and video resolutions well beyond WUXGA 1920x1200 and HDTV 1080p/60. Analogous to the DDC channel for HDMI, DisplayPort connectors provide for a differential AUX channel for EDID communication. In addition, DisplayPort incorporates digital rights management similar to HDCP - DisplayPort Content Protection or DPCP.

In addition to zero licensing fees, DisplayPort is intended to provide further cost savings by unifying the interface signals for both internal and external connections within a device, such as the connection between the motherboard and display on a laptop PC. The VESA - Video Electronics Standards Association released the initial version of the DisplayPort standard in 2006. The most recent revision, 1.1a, was released in January 2008.

SDI - Serial Digital Interface

SDI is a set of video standards, defined by the Society of Motion Picture and Television Engineers or SMPTE, for serial transmission of video and audio over standard RG59 or RG6 coaxial cable - see Table 6. SDI standards encompass a variety of data rates from 270 Mbps to 2.97 Gbps per link and are primarily utilized on professional broadcast and video production equipment, with secondary use in live events, rental and staging, medical imaging, digital cinema, and telepresence cameras and recording devices. An SDI-based video infrastructure is becoming increasingly popular for A/V signal distribution, due to the benefits of inexpensive or existing cabling, ease of termination, and transmission distance capabilities up to 330 feet (100 meters) for HD-SDI and 3G-SDI signals. SDI is strictly a serial, one-way protocol for video, audio, and metadata such as time and date stamps or GPS coordinates, with no provisions for other auxiliary communications.

STANDARD	NAME	DATA RATE	VIDEO FORMAT	COLOR ENCODING	COAX DISTANCES
SMPTE 259M-C	SDI	270 Mb/s	480i, 576i	4:2:2 YCbCr	300 meters
SMPTE 292M	HD-SDI	1.485 Gb/s	720p, 1080i, 1080p/30	4:2:2 YCbCr	100 meters
SMPTE 372M	Dual Link HD-SDI	2.97 Gb/s	1080p/60, 2K	various	100 meters
SMPTE 424M	3G-SDI	2.97 Gb/s	1080p/60, 2K	various	100 meters

Table 6: SMPTE - Society of Motion Picture and Television Engineers SDI Standards

Anatomy of a Digital Video Signal

Digital video signals are considerably different in comparison to traditional analog video signals, with specific performance and timing requirements that must be maintained throughout the entire signal path. Terms such as equalization, jitter, and reclocking in the digital domain replace the familiar level and peaking terminology for analog signals. Signal conditioning requirements for digital signals are also different, and must be understood accordingly before designing a digital-based A/V system.

All standard digital video signal formats, including SDI, DVI, HDMI, and DisplayPort are synchronous, that is, the value of a synchronous digital signal may change only at

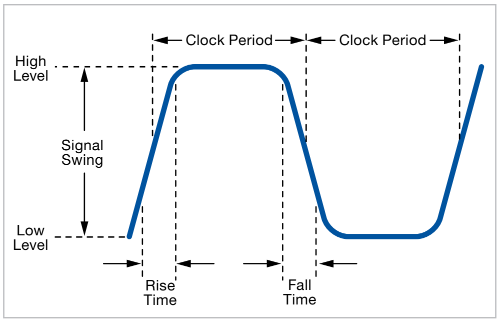


Figure 3: Digital data parameters

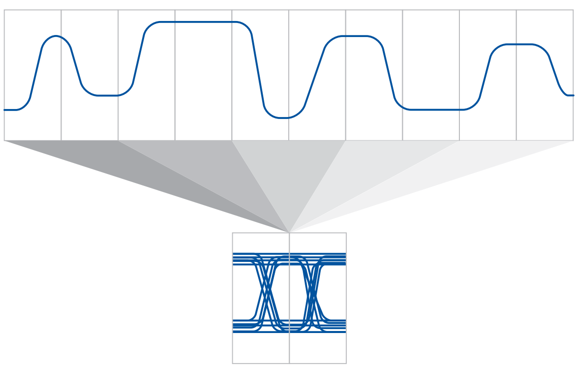


Figure 4: An eye diagram is formed by repeated sampling of a digital signal.

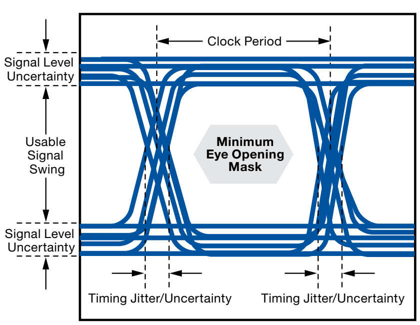


Figure 5: Eye diagram parameters

specific intervals determined by a reference signal known as the clock. Digital video signals are binary in nature - the signal can be either a high or a low level, with rapid transitions in between - see Figure 3. The amount of time it takes for a digital signal to transition from low to high is known as the rise time, and the time it takes for the signal to transition from high to low is known as the fall time. The difference between the high and the low values of the signal level is called the signal swing. The minimum allowable time interval between transitions is known as the clock period.

Because it is binary, a digital signal is fundamentally robust, since a receiver only needs to distinguish between "high" and "low" levels for each clock period in order to completely reconstruct the original transmission. However, this becomes increasingly difficult as the signal swing is decreased and as timing becomes less accurate. Rise and fall times, signal swing, and timing accuracy are all subject to degradation in digital signal transmission caused by cable attenuation, cable capacitance, impedance mismatch, noise coupling, crosstalk, and so forth. It is important to quantify the amount of signal degradation so that standards for signal integrity can be defined. If the signal is degraded beyond the receiver's ability to distinguish high and low signal values with correct timing, the receiver's output abruptly becomes meaningless, and the signal disappears, otherwise known as cliff effect. This is in contrast to analog transmission, whereby the receiver's output gradually degrades as the signal worsens, but still remains viewable long into its degraded state.

One of the key contributors to timing errors is jitter. Jitter is defined as the variation of the clock period in relation to the reference clock signal. Jitter can occur over long lengths of low quality cable, or through the cumulative effect caused by cascading several digital devices between the source and the destination.

Eye diagrams are useful in quantifying digital signal integrity. They can be produced on an oscilloscope by sampling a series of digital pulses in succession, and overlaying the samples on the oscilloscope display - see Figure 4.

The resulting diagram displays the aggregated levels and timing characteristics of the signal being transmitted - see Figure 5. The open, eye-shaped regions between the waveforms give the "eye" diagram its name. To determine whether the value of the signal is "high" or "low," the signal should be captured at intervals corresponding to the midpoints within these regions. These intervals are also the midpoints in time between signal transitions. The smaller the opening of the eye, the more difficult it is to accurately determine the signal value. Digital video format specifications include required values for eye openings as minimum standards for signal integrity. These values can be overlaid onto eye diagrams as a reference or limit "mask" when making signal quality measurements.

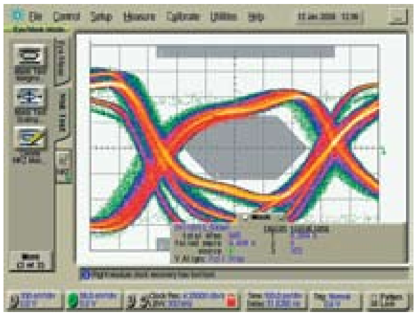


Figure 6: Fail

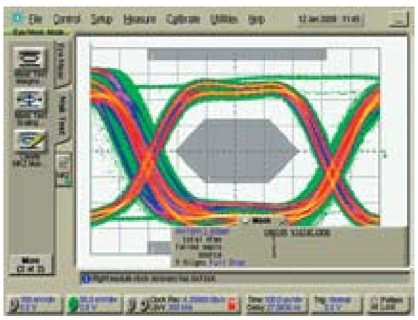


Figure 7: Pass

Maintaining Digital Signal Integrity

A clean digital signal path is crucial for signal integrity. Cable lengths should not exceed the driving capability of digital signal sources, as cable capacitance and attenuation will degrade signal rise time and amplitude as cable length increases. Since DVI, HDMI, and DisplayPort signals are transmitted over twisted pair-type cables, skew is introduced at long cable lengths due to the variations in twist rates of individual wire pairs in the cabling, which in turn impacts the relative timing between the video data lines. The compromised “eye” pattern in Figure 6 shows the resulting distortion caused by attenuation losses and skew-related timing errors from long cable lengths. The resulting waveform encroaches on the limit mask, which potentially leads to erratic images, or no image displayed at all.

Signal conditioning can be applied within digital video equipment via features such as **input signal equalization** and **output signal reclocking**. These advanced features provide compensation for losses experienced throughout the signal chain. It is important to note that such losses are not limited to the signal path, but may also be related to the source device itself. The direct signal output from the source device is often assumed to be good, but this is not always the case. Awareness of this is key to managing the integrity of the overall system. In situations where long cable lengths are unavoidable, active cable equalizers can be deployed to restore signal integrity and extend drive distances. Active equalizers are designed to compensate for the effects of long cable runs. Special amplifiers and filters matched to cable losses restore signal swing as well as rise and fall times. Clock and data recovery circuitry can remove jitter and restore clock timing, resulting in a measurable opening of the signal eye pattern. Figure 7 shows the result of signal conditioning applied by the Extron DVI 201xi Twisted Pair Extender to the distorted “eye” pattern in Figure 6. Signal conditioning features including input equalization and output reclocking are common to many Extron digital product solutions.

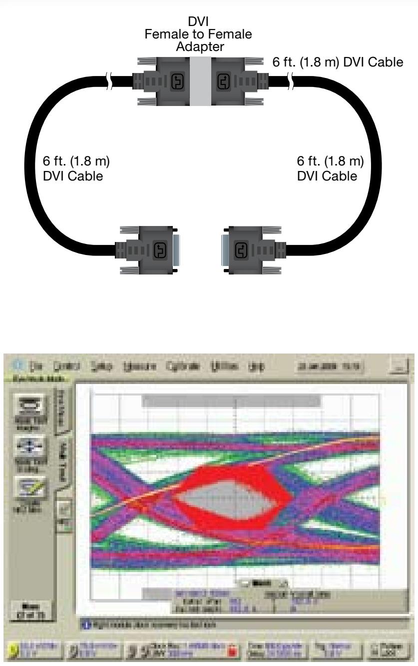


Figure 8

As video resolutions and associated signal frequencies increase, the signal becomes more and more susceptible to discontinuities along the cable. Such discontinuities cause reflections which will degrade the signal. Therefore, the bend radii of cables should be kept as large as possible, and cable splices, joiners, or gender changers should be avoided. Figure 8 depicts the substantial degradation that can be caused by simply inserting a gender changer between two cables. In this example, the eye diagram shows the result of a 1920x1200 source signal passing through a 6 foot (1.8 m) DVI cable, then through a DVI female-to-female coupler, and finally an additional 6 foot DVI cable. This emphasizes the importance of proper design considerations for management of all high resolution digital signals. System interconnects should be kept to a minimum, and signal distribution equipment should always feature signal conditioning capabilities to best accommodate specific design challenges that may compromise digital video signal integrity.

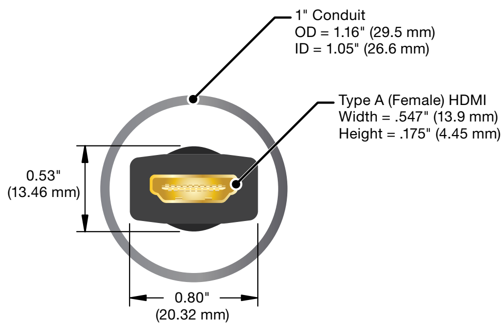


Figure 9: Running a preterminated HDMI cable through conduit can be inconvenient

Solutions for Extending Digital Video Signals

The customized nature of professional A/V systems usually presents many digital video distribution challenges to the integrator, including the need to send signals over significant distances. Extron offers a variety of products for specific digital video formats to help meet infrastructure-related requirements. For example, most installations call for cable runs of 35 feet (11 m) or beyond, and also require that cables be managed within walls and up into ceiling spaces. This can be a problem with standard digital cable assemblies, since the connectors are often too large to conveniently run through conduits and raceways, and terminating HDMI and DVI cables in the field is difficult with very few tools available - see Figure 9. Even when this is possible, most standard cable assemblies offer insufficient performance to send signals over significant distances. Fortunately, products and solutions are available that offer the flexibility to address specific system needs. A popular alternative to standard cable assemblies is to use an active transmitter and receiver pair to send digital signals over standard, shielded Category 5-type or fiber optic cable. This approach provides a means to conveniently route cabling through walls and within furniture, the convenience of field terminating connectors, and the ability to send signals extended distances.

Category 5-type twisted pair cable offers a cost-effective, easily installed and terminated option for digital signal transmission distances up to 200 feet (60 meters). For longer distance transmission requirements, up to several miles, and for applications where security or outside electrical interference are of concern, fiber optic products may be selected for a variety of reasons:

- **High image quality** – Pixel-for-pixel performance up to 1920x1200 resolution
- **Long distance transmission** – Image quality can be maintained at distances up to 30 km
- **Immunity to outside interference** – Can be utilized in environments that can't be served by copper-based cabling. such as elevator shafts or near HVAC and other electric machinery
- **Ideal for secure environments** – Well-suited for government, military, and judicial environments

Digital Content Protection

The migration of A/V to the digital domain is part of the greater trend of burgeoning computing, networking, and digital processing technologies. Images, audio, and video in digital formats can be transmitted, stored, and manipulated by widely available, affordable computing and network equipment. The ongoing exponential increase in digital storage capacity and computing power enables remarkable new capabilities.

At the time of this writing, one hour of compressed high definition video can be transmitted over a typical local area network within 12 minutes[1]. A typical mass storage drive can store over 110 hours of high definition video[2]. Over the Internet, large scale interconnection of computer networks and mass storage devices can enable high speed access to very large volumes of A/V content from anywhere in the world, transmitted perfectly without error.

The ease, affordability, and speed of storing and transmitting high quality digital A/V content can be disruptive to the businesses of producers and sellers of video material, including commercial motion picture distributors and television studios. For many years, profitable sales of tapes and discs to consumers helped establish an industry that sustained businesses engaged in content production, distribution, and retail sales. A system of copyrights and licensing controlled how each business in the value chain was compensated. The proliferation of digital technologies threatens this system by making copyrights difficult to enforce. If digital A/V content is leaked onto the Internet, it can be distributed and accessed by consumers with perfect quality, quickly and for very little cost, without authorization from and with no benefit to rights holders.

Over the years, rights holders have devised many methods to prevent and deter unauthorized copying and distribution of content, and they continue to introduce more. These methods may be technical, such as embedding signals in VHS tapes to disrupt recording, or encrypting DVDs to prevent digital copies. Legal means are also employed, such as lawsuits against those who infringe copyrights, and the proposal and passage of new laws against digital piracy. The rise of high definition video makes content protection more important than ever. If high quality HD video can be perfectly copied by unauthorized means, it would present a greater loss to copyright holders than if material in lower resolution formats such as VHS or DVD were compromised. To address this, another layer of content protection has been introduced: High-bandwidth Digital Content Protection - HDCP.

HDCP is an encryption protocol applied at the digital interface between video sources and displays to prevent unauthorized access to protected content. HDCP version 1.0 applied initially to the DVI interface. HDMI was incorporated in HDCP version 1.1, and HDCP version 1.3 added support for DisplayPort. With the release of version 2.0 in October 2008, HDCP became interface-independent, and can be applied to any two-way digital transmission between sources and displays, wired or wireless, compressed or uncompressed.

Digital Content Protection, LLC, a subsidiary of Intel, administers HDCP licenses to equipment manufacturers, and manages the distribution of encryption keys to licensees. Every HDCP device must have a unique set of encryption keys, including one public key, also known as the KSV, and 40 private keys. Manufacturers under HDCP license pay for blocks of these encryption key sets to implement into their products.

HDCP is meant to restrict what the end user can do with protected content. Such restrictions include limiting the number of simultaneous displays for content-protected video playback, disallowing recording or copying, and disabling analog outputs. For example, an A/V system may have the capability to distribute HDMI video to 16 displays and provide analog video recording. These functions will always be available when a PC with HDMI output is connected for PowerPoint presentations and other non-protected material. But once a protected Blu-ray Disc is inserted into the PC for playback, HDCP restrictions may disable output to several displays and to the recorder.

Since many large-scale A/V systems can display unencrypted video on a large number of displays, freely distribute analog signals, and provide video recording capabilities, end users of such systems must be made aware that some system functions may not be available when playing DRM-protected content.

Notes

1 One hour of 720p video compressed via the ATSC standard at 19.39 Mbps takes up 19.39 x 60 x 60 = 69.8 Gbits. This can be transmitted at 100 Mbps over a typical Ethernet network in 698 seconds or 11.6 minutes.

2 From [1], an hour of compressed 720p video can take 69.8 Gbits to store. A 1 "terabyte" hard drive has a storage capacity of 8,000 Gbits. Therefore, such a drive can store 8,000/69.8 = 116 hours of compressed 720p video.