HDTV – High Definition Television

Jim Krause, M.A.

Assistant Professor,

Indiana University Department of Telecommunications

1229 East 7th Street

Bloomington, IN, 47405

jarkraus@indiana.edu

(812) 856-2172

(Revised September 9, 2006)

HDTV – Bringing TV one step closer to film

OUTLINE

1. Introduction to HDTV
    a. Overview
    b. History of TV
        i. The search for standards: the FCC and the NTSC
        ii. Color TV
        iii. PAL and SECAM
        iv. HD advances
        v. ATSC
    c. DTV, SDTV and HDTV
        i. Comparison to SDTV
2. Technical Aspects
    a. Codecs
    b. Metadata
    c. Interlaced vs. progressive scanning
    d. Frame rates
    e. Color space
    f. Color sampling
    g. Quantization
    h. Format conversion
        i. Aspect ratio conversion
        ii. 3-2 pulldown
3. Implementation
    a. Cameras

    b. Recording and playback formats
    c. Editing
        i. Video Capture
    d. Video storage, servers and networks
    e. Display technology
    f. Cables and connectors
    g. Broadcast transmission and reception
    h. Reception
        i. Terrestrial
        ii. Cable
        iii. Satellite
        iv. IPTV
    i. Usage/saturation
4. Impact of HDTV
    a. Users
    b. TV Production
    c. DVD
    d. Feature film
5. Conclusion
    a. Additional resources
6. Glossary

KEY WORDS

aspect ratio, ATSC, broadcast, DTV, digital cinema, digital television, FCC, film, HDTV, high definition, interlace, NTSC, progressive scan, television, letterbox, video, widescreen

ABSTRACT

Ever since the first black and white television broadcasts, engineers have worked to improve the quality of the signal, increase the size of the image, to give it more resolution, to make it sound and look more realistic. In 1941, the National Television System Committee (NTSC) established a set of standards for analog broadcast television. While the system was slightly revised to allow for color, more than 50 years passed before broadcasters, engineers, and government regulators finally compromised on an upgraded standard that could be conveniently packaged within a 6 MHz slice of bandwidth and distributed to consumers. In 2003, a milestone was reached as total dollar sales of HDTV-capable monitors surpassed those of traditional, NTSC TV sets. This chapter examines the HDTV specifications, technical characteristics, and discusses its implementation in broadcast and production.

INTRODUCTION TO HDTV

Overview

Ever since the first black and white TV image was displayed, both developers and viewers sought ways to make it better: to add more resolution, to increase the contrast ratio, and to be able to faithfully replicate the color spectrum. An obvious yardstick to measure the progress and quality of television has been cinematic film, which for years has been capable of providing high-resolution moving images. Imagine a TV developer in 1939 who watched the cinematic premiere of *The Wizard of Oz* or *Gone with the Wind*. What would he think after retuning home to face the comparatively small and grainy image on a black and white television set?

But with HDTV the gap has narrowed. George Lucas shot the last additions to his popular *Star Wars* collection using high definition video cameras. More and more HDTV sets have made their way into a growing number of residential households. Despite the fact that we're closer than ever to having a high-definition cinema experience in all of our homes, there are still obstacles to overcome. Broadcasters need cost-effective production tools. Consumers want to be able to inexpensively purchase, record, and play back their favorite programs. The Federal Communications Commission planned to end all analog television broadcasts by 2006, but recent legislation has pushed this cutoff date back to February 17, 2009.

As we consider HDTV, it's useful to trace the path it has evolved from and to maintain some perspective. High-definition is a relative term. It's higher resolution, but higher than what? This chapter will examine the environment in which HDTV has been developed and identify some of its more important technical characteristics.

History of TV

The exact beginning of what most of us refer to as television is debatable. In 1842 Alexander Bain managed to transmit a still image over wire, inventing what can readily be called the first fax machine. In 1884 Paul Gottlieb Nipkow went a step further, and discovered (and patented) a way to scan a moving image and transmit it sequentially. Nipkow's process used two synchronized, spinning disks, each with a spiral shaped pattern of holes in it. On the transmitting side, a disk was placed between the subject and a light sensitive element. The receiving side had a similar disk placed between a light source and the viewer. The resolution of Nipkow's disk system depended upon the number of holes in the disk. His system was thought to have been able to achieve between 18 and 30 lines of resolution and marked the beginning of the era of electromechanical television.

However John Logie Baird, a Scottish inventor, publicly demonstrated what some consider the first recognizable video image of a human face on January 26, 1926. Baird's grayscale image, presented to members of the Royal Institution in London had only about 30 lines of resolution. Baird used a spinning disk (similar to Nipkow's), which was embedded with lenses, and provided an image just clear enough to display a human face. Baird's TV proved to be popular. His company, Baird Television Development Company, continued working to

improve and refine the image. The maximum resolution ever achieved by his electromechanical system was around 240 lines (BBC 2006).

But electromechanical television was cumbersome and interest diminished as developers realized that an electronic process was necessary in order to provide higher levels of resolution. In 1934 Philo Farnsworth gave a public demonstration of an all-electronic system. The system used a camera on one end and a cathode ray tube (CRT), to serve as a display on the receiving end. Both camera and CRT used an electron beam controlled by modulating a magnetic field. Compared to electromechanical TV, the all-electronic system was more convenient and interest in TV broadcasting soared. Other developers soon began developing improved versions of television and began successfully marketing them to the public.

The search for standards: the FCC and the NTSC

The Federal Communications Commission (FCC) oversees radio, wire, cable, satellite, and television broadcast in the United States (www.fcc.gov). Established by the Communications Act of 1934, the FCC initially set to the task of regulating the ever-increasing use of the broadcast spectrum. One of the FCC's early challenges was setting technical standards for television. In 1936, the Radio Manufacturers Association (RMA) recommended a standard for television using 441 horizontal scan lines and 30 frames per second with a 4:3 aspect ratio. The public was accepting of the 4:3 aspect ratio, as it was close to existing 16mm and 35mm film formats, which used the Academy Aperture (11:8 aspect ratio). RCA embraced this standard and had already begun broadcasting and manufacturing TV receivers capable of displaying 441 scan lines.

However a number of opponents argued that more picture detail was necessary. After a series of formal hearings, the FCC urged the RMA to form the National Television System Committee (NTSC) in 1940. Its goal was to set technical standards for the broadcast of black and white television. The next year the NTSC established its first set of standards, which kept the 4:3 aspect ratio but called for a higher resolution image with 525 scan lines refreshing at a rate of 30 interlaced frames, or 60 fields per second. Each interlaced frame consisted of two fields. First the odd lines were scanned for field one and then the even lines scanned for field two. Television stations were allotted 6 MHz of bandwidth per channel, which ultimately covered a frequency range spanning from 54 MHz to 890 MHz on the broadcast spectrum.

Color TV

In order to broadcast in color, the original NTSC standard for black and white television had to be revised. NTSC presented an update to it in 1953. Creating the new standard was no easy task as engineers had to make color broadcasts backward compatible with the large base of existing black and white televisions. (10 million sets had been sold by 1949.) To do so, engineers split the signal into two components, luminance, referred to as luma, which contained the brightness information, and chrominance, which contained the color. The color information was encoded onto a 3.58 MHz subcarrier added onto the video signal. Black and white sets could ignore the color subcarrier using only the luma portion, while color sets could take advantage of both. Unfortunately, the color subcarrier interacted with the sound carrier creating minor visible artifacts. In order to reduce interference, the field refresh rate of 60 Hz

was slowed down by a factor of 1000/1001 to 59.94 Hz. So instead of running at 30 frames per second, broadcast television downshifted to 29.97 frames per second.

PAL & SECAM

While the US, Canada, and Mexico adopted NTSC standards based on a 60 Hz frequency, most other countries developed color television systems based on 50 Hz. (The refresh frequencies varied as they were dependent on the operating frequency of the region's electrical systems.) Most versions of PAL (Phase Alternating Line) and SECAM (Séquential Colour avec Mémoire) while still employing a 4:3 aspect ratio, had 625 horizontal scan lines. The 100 extra scan lines provided more picture detail, but some felt the slower, 25 Hz scan rate created a noticeable flicker.

HD Advances

During the next 30 years many improvements were made in cameras, production and broadcast gear, and in television receivers. But despite these advances, the quality of analog broadcast was still limited to the NTSC standard of 60 fields and 525 horizontal scan lines. To take television to the next level, the entire analog broadcasting system had to be replaced. A number of manufacturers had developed and were already using high-definition digital television systems. While the exact format had yet to be determined, it was clear that the replacement for analog would use digital television technology. What was needed was a set of standards to ensure compatibility.

ATSC

A number of industry associations, corporations, and educational institutions formed the Advanced Television Systems Committee (ATSC) in 1982. The ATSC is a not-for-profit organization that develops voluntary standards for advanced television systems (www.atsc.org). Such advanced systems include enhanced analog TV, digital TV (DTV), standard definition TV, high-definition TV, and data services. The ATSC's published broadcast standards are voluntary unless adopted and mandated by the FCC.

In 1987, The FCC formed an Advisory Committee on Advanced Television Service. The goal was to explore the issues of advanced television technologies (ATV) and to advise the FCC in both technical and public policy matters accordingly. By 1989 there were as many as 21 proposed systems submitted by various proponents. After a peer review process the field was narrowed down to four systems. Proponents of these systems formed what was known as The Grand Alliance, which was composed of AT&T, General Instrument Corporation, Massachusetts Institute of Technology, Phillips Consumer Electronics, David Sarnoff Research Center, Thomson Consumer Electronics, and Zenith Electronics Corporation. The Grand Alliance built a working prototype of an HDTV terrestrial broadcasting system, which used MPEG-2 compression. After a series of testing, ATSC proposed DTV Standard (A/53) that specified the protocol for high-definition broadcasting through a standard 6MHz channel. DTV Standard (A/52) outlined the use of digital audio through Dolby Digital or AC-3 compression.

In December 1996, the FCC adopted most of the standards proposed by the ATSC, mandating that broadcasters begin broadcasting digitally. According to the ATSC, within one year of the November 1, 1998 rollout, more than 50 percent of the US population was in a position to receive digital broadcasts. During a transitional period, television would be broadcast both digitally under the FCC's digital terrestrial television (DTT) guidelines and through traditional analog means. At the present time, Congress has voted to terminate analog broadcasting by February 2009, though the deadline could be extended.

DTV, SDTV and HDTV

While the NTSC standards defined one analog format, ATSC created a framework supporting multiple digital formats. Their DTV broadcasting standards provide for standard-definition television (SDTV) and high-definition television (HDTV) programming using several possible frame rates. Because the technology is relatively new, there is a considerable amount of confusion among consumers regarding HDTV. DTV broadcasts can be either high-definition or standard definition. While standard definition television (SDTV) can use either the 4:3 or 16:9 aspect ratios, HDTV always uses the 16:9 aspect ratio. (See Table 1.1)

HDTV/SDTV	Horizontal lines	Vertical lines	Aspect Ratio	Frame Rate
SDTV	640	480	4:3	23.976p, 24p, 29.97p, 30p, 59.94p, 60p, 59.94i, 60i
SDTV	704	480	4:3 and 16:9	23.976p, 24p, 29.97p, 30p, 59.94p, 60p, 59.94i, 60i
HDTV	1280	720	16:9	23.976p, 24p, 29.97p, 30p, 59.94p, 60p
HDTV	1920	1080	16:9	23.976p, 24p, 29.97p, 30p, 59.94i, 60i

Table 1.1 ATSC Digital Standard A/53E Supported formats

(i = interlaced, p = progressive)

Comparison to SDTV

Assuming an NTSC standard definition display of approximately 640 x 480 pixels, a 1080 x 1920 HDTV image has nearly seven times more pixels. But in addition to the greater visual detail the increased pixels provide, there are many other notable improvements that contribute to a heightened viewing experience. The delivery method of ATSC programming is considered to be an improvement over NTSC. Analog television is susceptible to interference

such as ghosting and snow. DTV is digitally compressed, which while not making it immune to all interference, does eliminate a great deal of broadcast-related distortion. Because the signal is digital, the data either arrives perfectly intact, or is noticeably absent. Another improved element is audio. The ATSC standards call for AC3 or Dolby Digital sound, which can provide 5.1-surround sound, as well as provide support for multiple audio bit-streams. This allows broadcasters to deliver programming in multiple languages

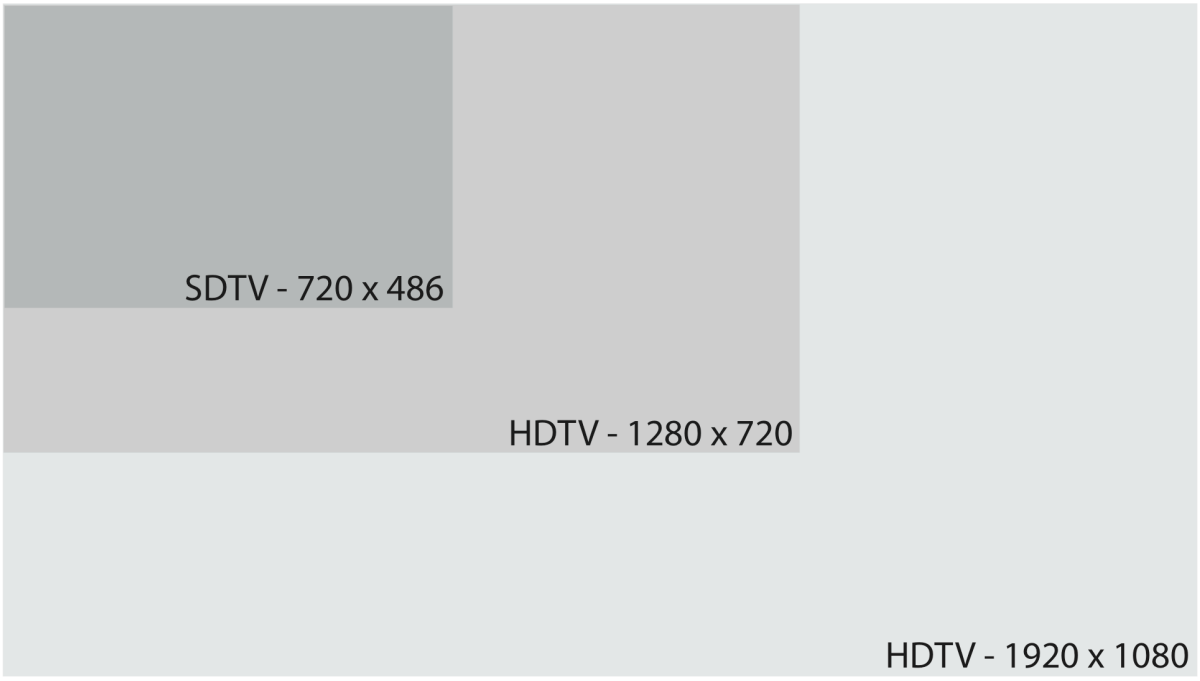

Image 1.1 Comparison of standard and high definition video formats.

TECHNICAL ASPECTS

Codecs

Codec is short for compressor-decompressor or coder-decoder, and refers to a manner in which data is compressed and uncompressed. Compression can be achieved with software, hardware or a combination of the two. In uncompressed form, a 1920 x 1080 HDTV signal requires nearly 1 Gbps of bandwidth. An HD-SDI interface (high-definition serial digital interface), specified by SMPTE 292M, can carry high-definition video, up to 16 channels of embedded audio, and ancillary data at a nominal data rate of 1.485 Gbps. In order to squeeze the data into a form that can be reliably broadcast within a 6 MHz section of bandwidth, the signal must be compressed at about a 50:1 ratio. The ATSC DTV standard conforms to the main profile syntax of MPEG-2 compression standard.

As utilized in the current distribution of digital television, MPEG-2 uses interframe compression, which compresses both spatially and temporally. Intraframe codecs such as DV treat each frame individually and thus only compress spatially. Because MPEG-2 can compress over time as well as space it is capable of delivering a high-quality image in a smaller amount of bandwidth than an intraframe codec can deliver. A great deal of MPEG-2's efficiency is due to the fact it compresses the video into groups of pictures (GOPs) and not simply individual frames. In MPEG-2 compression, images are divided into macroblocks, which are typically areas of 16 x 16 pixels. The GOPs are created with three types of pictures: I, P, and B frames. I frames are intracoded frames, which are sometimes referred to as index

frames. P are predicted frames and B are bidirectional frames. A GOP starts with an I frame. In MPEG-2 compression, P frames are compared to the previous I or P frame. If there is a difference, a proper vector is determined to move the macroblock. If there is no change (if there is no movement within the shot), the bit rate can be reduced significantly. B frames, or bidirectional frames work similarly, but reference previous and future frames.

Some compression methods use intraframe compression, which treats every frame individually, compressing one after the next. These types of compressors such as M-JPEG or DV, facilitate editing because each frame is independent of the others and can be accessed at any point in the stream. Since MPEG-2 breaks the video stream into chunks known as GOPs, ease of editing is reduced in favor of maximizing compression. So while MPEG-2 is perhaps ideal for transmission, its multi-frame GOP structure is not optimized for editing. It is possible to edit MPEG-2 without recompression as long as the edit points resides on a GOP boundary.

Metadata

DTV broadcasts with MPEG-2 also provide for metadata to be included along with the signal. Metadata is auxiliary information related to the program or its content. It can include information such as audio dialog level data, closed captioning content, format descriptor tags, and digital rights management (DRM) data. Metadata can be processed at many stages along the delivery path.

Interlaced vs. Progressive Scanning

An NTSC video signal is made up of 525 scan lines. On a cathode ray tube (CRT) display, the image is created by an electron beam, which excites phosphors on the face of the screen. The electron beam scans each row from left to right, and then jumps back to draw the next line. The excited phosphors on CRT displays decay quickly after the electron beam makes its sweep. Because of the decay, images displayed at about 30 frames per second, presented a noticeable flicker. In order to reduce the flicker, the display frequency had to be increased. To achieve this, the frame was broken down into two fields. The first field displayed only the odd lines while the second displayed only the even lines. So instead of drawing approximately 30 frames per frame, interlacing uses two fields, one after the next, at the rate of nearly 60 times a second.

Interlacing creates some unfortunate visible artifacts. Visual elements with fine horizontal lines will tend to flicker when displayed. In addition, capturing still frames or creating slow motion effects shows temporal artifacts because the two fields have not been captured simultaneously, but $1/60^{th}$ of a second apart. Other problems can occur when converting footage shot at 24 fps into 60 Hz interlaced fields.

By contrast, in progressively scanned video, the entire frame is captured all at once without two separate fields.

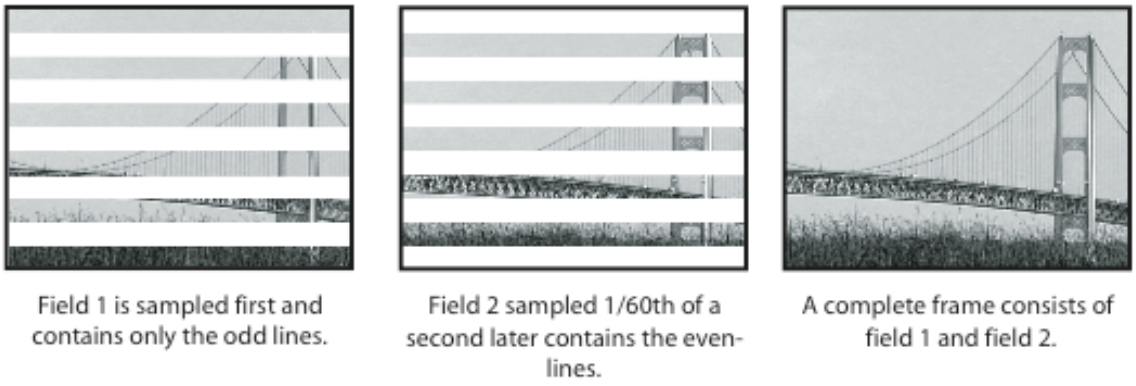

Image 2.1 Interlaced scanning. For illustrative purposes, the number of scanlines has been greatly reduced. Illustrations courtesy Tabletop Productions.

Frame rates

The ATSC standards bring new possible frame rates and also provide the ability to comply with existing, traditional standards. Broadcast video under the NTSC standards employs an interlaced frame composed of two separate fields. As stated earlier, for technical reasons the refresh rate was reduced from 60 to 59.94 Hz. In common terminology and documentation, sometimes the true 29.97 or 59.94 frame rates are used but often this figure is rounded up for the sake of convenience: 29.97 becomes 30 and 59.94 become 60. Because of this and the fact that the frame numbering protocol used in timecode is based on the rate of 30 frames per second, many mistakenly think that the NTSC frame rate is a whole number. ATSC standards support both the NTSC, .1% reduced frame rates as well as whole integer frame rates of 24, 30, and 60.

Frame rate has a direct impact on the bandwidth required to carry a signal. A 60p signal would require about twice the bandwidth needed by a 60i signal.

One frame rate appealing to digital video cinematographers is 24p, as this has been the standard film frame rate used by the motion picture industry for years. This lessens the steps and expense required to transfer a copy to film for theatrical release and also helps the video look more like film.

Color Space

Computer-based digital imaging systems typically operate in an RGB color space or a variant of it, while broadcast video transmission adopted a *color difference* model. This was not only because the signal had to be compatible with existing black and white televisions but it also had to take up as little bandwidth as possible. Most professional video cameras (both SDTV and HDTV) capture images into an RGB color space via three CCDs (charge coupled devices). However, a growing number are using CMOS (complementary metal oxide semiconductor) sensors. Initially captured in uncompressed form, the RGB values are processed and converted into a color difference mode.

In the color difference system, the color signal can be numerically represented with three values: Y, B-Y and R-Y. Mathematically, Y represents the value of the luma portion with B-Y and R-Y representing the two color difference values. The formulas used to derive the color difference values vary depending upon the application. YIQ was the color encoding system originally developed for NTSC while YUV was used for PAL. YPbPr uses a slightly different formula optimized for component analog video, while YCbCr uses a different scaling factor optimized for digital video.

Humans are more sensitive to spatial detail in brightness than in color information. Because of this, most of the important detail needed to comprehend an image is provided through the luma portion of the video signal. Engineers found they could throw out more than half of the color information and still get pleasing results. Compared to RGB, Y,B-Y,R-Y can store color data in a smaller amount of space and thus use less bandwidth when broadcast.

Color Sampling

Unless working in an uncompressed RGB mode, the color signal is converted into a color difference system. After converting the RGB, the signal is sampled, quantized, compressed (usually), and then recorded to tape, hard drive, optical disk, or in some cases a memory card.

Color sampling figures convey the manner in which the luma and color components are sampled for digitizing and are typically presented as a ratio with three figures (x:x:x). The first figure is usually four and refers to the number of luma samples. The second two figures correspond to the number of samples for the two color difference signals. For instance, DV's 4:1:1 states that for every four luma samples, only one sample is taken for each of the color difference samples. A 4:2:2 format (such as DVC Pro50 or digital Betacam) means that for every four luma samples taken, two samples will be taken of each of the color difference signals. A 4:1:1 format would record half the color information that a 4:2:2 format would. When a codec is represented by a 4:4:4, it is typically referring to an RGB signal.

The 4:2:0 color sampling format comes in a few different variants. As usually employed in MPEG-2, the color difference signals are sampled at half the rate of the luma samples, but also reduced in half, vertically.

While formats using lower color sampling ratios require less bandwidth, those with higher sampling ratios are preferred for professional editing, keying and compositing.

Quantization

After sampling, the signal must be quantized, or assigned a numeric value. The number of quanta corresponds to bit-depth. Video signals are usually captured into 8-bit or 10-bit per color channel formats. An 8-bit sample has 256 possible values, while a 10-bit sample has 1,024 possible values. Generally speaking, a 10-bit sample will take more storage space but offer more contrast information.

Format conversion

Because of the numerous types of media and formats in use, it's often necessary to convert from one type of format to another. Transcoders provide a means for doing so. Some can convert analog signals into digital (referred to as A to D) or digital into analog (D to A). Others provide a means to provide pulldown, de-interlacing, upconverting and downconverting. Upconverting occurs when content is transferred to a superior format. Downconverting is copying to a format of lesser quality. (For example one could downconvert HD footage into SD footage.) Sometimes it's necessary to manipulate the visual

or pixel aspect ratio, or change the image size (scaling). Other common transcoding tasks include changing the format temporally (vary the frame rate), and also interlacing or de-interlacing the image. Bi-directional interfaces allow transfers from one format to another, such as from HD-SDI to analog component or SDI to HDMI.

Aspect ratio conversion

One of the benefits of HDTV is that its aspect ratio more closely matches that of widescreen film formats. Its 16:9 or 1.78:1 aspect ratio is close, but not quite as wide as the popular 35mm anamorphic widescreen. Some may argue that the widescreen format is at a disadvantage for playing old movies like "The Wizard of Oz" or "Gone with the Wind," but in general, widescreen formats have become more favored for film since the 1950s.

Common Aspect Ratios	
Aspect Ratio	**Application**
4:3 or 1.33:1	Traditional television, 16mm, and 35mm
1.37:1	Academy aperture
16:9 or 1.78:1	Widescreen television
1.85:1	Standard theatrical widescreen
2.20:1	70 mm
2.40:1	CinemaScope

Table 2.2 Common Aspect Ratios

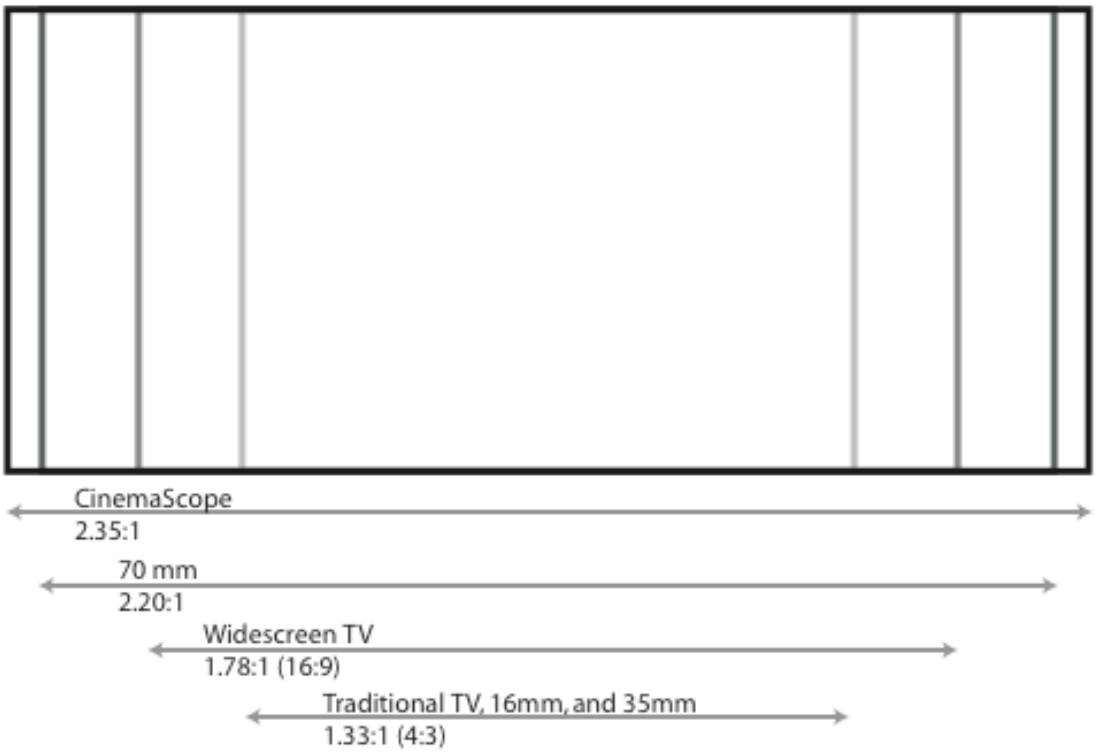

Figure 2.2 Common Aspect Ratios.

While HDTV content is designed to fill a 16:9 frame, the display of programming from other sources with varying aspect ratios is also possible. Programs shot in the 4:3 aspect ratio or in wider, cinematic formats can easily be displayed inside of a 16:9 frame without distortion by shrinking the image. Unfortunately it's quite common to see broadcasters delivering images with the improper aspect ratio (Example A of figure 2.3). Traditional, 4:3 content is ideally viewed on widescreen displays by presenting the image as large as possible, centered within the frame. (Example B) This is sometimes referred to as pillar boxing. This allows the original image to be seen as it was intended. Some broadcasters magnify the 4:3 image so that it fills the entire 16:9 frame. (Example C) This can often be identified by the lack of headroom. Content from cinematic formats with wider aspect ratios can be accurately displayed within

the 16:9 frame with letterboxing. (Example D) It's also frequently necessary to present widescreen programming inside of traditional 4:3 displays with letterboxing.

The ATSC standard supports an Active Format Descriptor (AFD) data tag that can be embedded into the encoded video. The AFD data tag describes the aspect ratio of the signal when it does not extend to the edges of the frame. If utilized, the receiver or set top box (STB) can decode the AFD data tag and display the signal with the proper aspect ratio.

Example A 4:3 content improperly displayed within a 16:9 frame. The image has been stretched to fill the entire frame.

Example B 4:3 content properly displayed in the center of the 16:9 frame.

Example C 4:3 content scaled up in order to fill the entire 16:9 frame.

Example D Content from a 70mm film with a 2.20:1 aspect ratio letterboxed within the 16:9 frame.

Figure 2.3 Content with varying aspect ratios displayed within a 16:9 frame.

Images & illustrations courtesy Tabletop Productions.

3-2 Pulldown

A common frame conversion task is required by the frequent need to change 24p content into 60i. Such is the case when converting film (which runs at 24 fps) into 60i. Sometimes called the telecine process, it's also required when changing 24p video into 60i. Some systems employ a 2-3 pulldown, which while reversing the order achieves the same end result.

The basic idea between the 3-2 pulldown is that 4 frames of 24p footage are converted into 5 interlaced video frames. It's called 3-2 (or 2-3) because each consecutive 24p frame is transferred into 2 fields followed by 3 fields, then 2 fields, etc. One of the steps is to slow the film down by .1% to the rate of 23.976 frames per second. In the example below we have 4 frames of 24p material, labeled A, B, C, & D. The first video frame contains two fields of frame A. The second video frame contains one field of A and the second field of B. The third video frame contains one field of B and one of C. The fourth video frame contains two frames of C. The fifth video frame contains 2 fields of D.

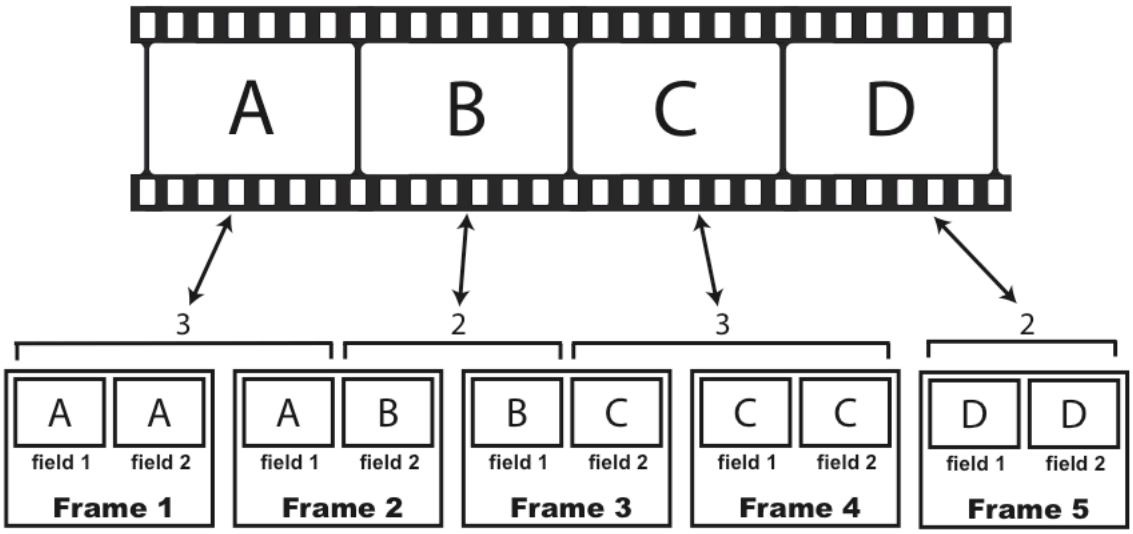

Illustration 2.4 The 3-2 Pulldown. Illustration courtesy Tabletop Productions.

IMPLEMENTATION

The HDTV production chain typically begins with a high-definition camera, or a project shot on film then converted to a digital format. However other means are possible. Much of Tim Burton's recent stop-motion feature, *The Corpse Bride* was shot with a Canon digital still camera, and then transferred to digital video for editing. Many commercials, cartoons, and full-length features have been created solely with 2D and/or 3D animation software.

Cameras

HDTV cameras have been used long before the ATSC standards were in place. Because of the move to DTV and the growing acceptance of HDTV by consumers, many broadcasters are choosing to replace retired or existing standard definition equipment with high-definition camera gear. While higher-end production cameras suitable for studio or digital cinematography can cost more than $200,000, many professional HD camcorders used for daily production tasks can be found between $20,000-$60,000. Recently a few companies have released HDTV camcorders priced less than $1,500 targeted to consumers. Generally speaking, camcorders with high quality lenses that are capable of writing higher data rates and recording images up to 1920 x 1080 pixels in varying frame rates will be at the higher end of the price range. Camcorders with lower quality optics that use lower data rates, GOP-based compression, and have fewer frame rate options will occupy the lower end of the price range.

Recording and playback formats

Recording, storage and playback of HDTV content can be done in a number of ways. As in standard definition digital video, the data can be written to tape, hard-drive, optical disc, or RAM. Following are some of the more popular formats currently used for high-definition video production. (Refer to table 3.1 for a side-by-side comparison.)

D-VHS – This consumer format from JVC records onto VHS tapes using an MPEG-2 stream at up to a 28.2 Mbps data rate. It's backwards compatible with VHS appealing to consumers with sizable VHS tape collections. It is not considered a viable commercial production format.

HDV – Canon, Sony and JVC offer lower cost HDV cameras that record at a maximum resolution of 1440 x 1080. HDV uses a form of MPEG-2 compression that can be recorded onto miniDV cassettes. In 1080i mode, HDV can record a 25 Mbps signal. In 720p mode it records at 19 Mbps. Because MPEG-2 employs Groups of Pictures (GOPs) instead of discreet frames, HDV data is often up-converted into a different format for editing. Because the data rate is relatively low, HDV content can easily be transferred over a FireWire (IEEE-1394) connection.

DVCPRO HD – Also known as D12, DVCPRO HD was developed by Panasonic and has versions that record on magnetic tape as well as memory cards. The 100Mbps data rate is still low enough to be transferred over a FireWire connection from a VTR into an editing system. DVCPRO HD is restricted to a maximum resolution of 1280 x 1080 pixels.

XDCAM HD - Sony's tapeless format records onto Blu-Ray optical discs using several possible frame rates and codecs. It can record HD content using MPEG-2 encoding at 35 Mbps or DVCAM at 25 Mbps. Its HD resolution is restricted to 1440 x 1080 pixels.

D-5 HD – Developed by Panasonic in 1991, the D-5 format has been updated to HD. It records at a 235 Mbps data rate and can handle 720 and 1080 content at most possible frame rates.

HDCAM - Sony's format records onto 1/2" videocassettes at a number of possible frame rates. It uses a 140 Mbps data rate and supports up to 4 channels of audio. It too is restricted to a maximum resolution of 1440 x 1080 pixels.

HDCAM SR – Sony's higher end version of HDCAM shares some of the same features but can write data rates up to 880 Mbps with up to 12 audio channels.

Name	Format	Pixel dimensions (recorded)	Color sampling	Bit Depth	Compression	Data rate	Audio Channels
HDV	1080 60i 1080 50i	1440 x 1080	4:2:0	8	MPEG-2	25 Mbps	2
	720 60p 720 50p 720 30p 720 24p	1280 x 720	4:2:0	8	MPEG-2	19.7 Mbps 19 Mbps	2
XDCAM HD	1080 60i 1080 50i 1080 30p 1080 25p 1080 24p	1440 x 1080	4:2:0	8	MPEG-2	Adjustable: 18 Mbps 25 Mbps 35 Mbps	4
D9-HD	1080 60i 720 24p	1280 x 1080 960 x 720	4:2:2	8	DCT	100 Mbps	8
DVCPRO HD (D12)	1080 60i 1080 50i 720 60p 720 50p	1280 x 1080 1440 x 1080 960 x 720	4:2:2	8	DCT	100 Mbps	8
D5 HD	1080 60i 1080 30p 1080 24p 720 60p	1920 x 1080 1280 x 720	4:2:2	8 10	DCT	235 Mbps	8
HDCAM (D11)	1080 60i 1080 50i 1080 25p 1080 24p	1440 x 1080	3:1:1	8	DCT	140 Mbps	4
HDCAM SR	1080i 60 1080i 50 1080PsF 30 1080PsF 29.97 1080PsF 25 1080PsF 24 1080PsF	1920 x 1080	4:2:2 @ 440 Mbps 4:4:4 @ 880 Mbos	10	MPEG-4	440 Mbps	12

	23.98 720p						

Table 3.1 Comparison of HD field and production formats

Editing

While linear, tape-to-tape based editing is still viable (and sometimes best suited for the job), most editors work with computer-based, non-linear editing systems. With dozens of vendors making HD-capable editing systems, there are many codecs available to choose from. Some codecs require proprietary hardware to use, while others are hardware independent. In addition to the standard bit depths of 8 and 10, there are also higher end, 16-bit codecs available from companies like Pinnacle and Digital Anarchy.

While HDTV is routinely compressed using MPEG-2 for transmission and delivery, uncompressed or mildly compressed data is preferred for editing. Since it's often necessary for editors to composite many layers of content together in order to create special effects, it's important to keep the signal as pristine as possible. This is why editors will often upconvert footage to a codec with better bit depth and higher resolution.

Video Capture

HDTV data may be brought into a computer through FireWire, HD-SDI, or digital or analog component capture. Footage can be transferred into an editing system bit for bit, or can be encoded into a codec more suitable for editing. While a detailed discussion of HD editing codecs is outside the scope of this chapter, color space, bit depth, and compression are three

factors that should be considered along with the overall format and frame rate. In addition, certain broadcast channels or clients have precise technical requirements that may impact the choice of codecs. As mentioned previously, 10-bit files contain more information than 8-bit files but also require more storage. Projects with demanding chromakeying or color compositing needs will be better served by codes with higher color sampling ratios (4:2:2 over 4:1:1, etc.). Similarly, compressed footage requires less bandwidth at the tradeoff of some quality loss. Lastly, choosing a lossless codec that operates in a 4:4:4 resolution will offer the highest quality but at the expense of requiring the greatest amount of storage.

Video Storage, Servers and Networks

In uncompressed form, HDTV content requires more disk space than standard definition video and a larger bandwidth in order to access or deliver the media. Consider this comparison. An hour of standard definition DV footage with a stereo pair of 16-bit audio tracks captured at 25 Mbps takes approximately 14 GB of disk space. An hour of 10-bit 1920 x 1080 HD footage with a pair of 24-bit audio channels requires nearly 600 GB of space. The same footage captured in RGB uncompressed would fill almost 900 GB.

Video editing, production, and broadcast delivery systems often require several streams of video to be accessed simultaneously. As well as providing access to multiple users, it's also important that the HDTV data is safeguarded in some way. A common approach to this utilizes network-based storage architecture. Typical systems incorporate a video server that allows for multiple connections and interfaces with a RAID (redundant array of independent disks) storage device. While it is possible to store and retrieve HD content over standard or

Fast Ethernet connections, the high bandwidth and constant throughput required to deliver HD in professional applications requires the use of Fiber Channel, or 10-gigabit Ethernet (10-GigE). Architecture for storage systems will likely be based on a SAN (storage area network) or NAS (network attached storage). Either way, they will likely rely on RAID storage. RAIDs use multiple hard drives in a single enclosure that are written to and read simultaneously. Common RAIDs used for HD storage are listed below.

RAID 0 – Stripes the data across two or more disks. No parity information for redundancy is recorded so there is no protection offered against data loss. If one drive goes out all of the data is lost.

RAID 3 – Uses at least three or more drives. Parity information is recorded on one of the disks while the data is striped evenly across the other drives. RAID 3 arrays can be backed up with relative ease if one of the drives were to go bad.

RAID 5 – Contain three or more drives per set. Parity information is stored on all of the drives equally. RAID 5 sets can generally handle data transfers quicker than RAID 3.

RAID 50 (5+0) – These use two or more RAID 5 sets striped together into a single RAID 0. Each of the RAID 5 elements typically is on an individual controller. RAID 50 provides an excellent mix of fast read/write speeds and redundancy.

Display technologies

HDTV content can be viewed using several different technologies including CRT (cathode ray tube), LCD (liquid crystal display), plasma, DLP (digital light processing), and LCoS (liquid crystal on silicon). Displays can be direct view where the image is generated on the screen's surface, or projected form the front or rear. Each technology has its strengths and weaknesses. While some argue that traditional CRT displays are the best means to accurately monitor color, their vacuum tube construction ultimately renders them unsuitable for large, widescreen displays. Because of their limitations, other micro-display technologies, such as LCD, plasma, DLP, and LCoS have gained favor in both consumer and professional markets. In addition to these, there are other viable HDTV display technologies including Organic Light-Emitting Diode (OLED), Grating Light Valve (GLV), NanoEmissive, and Surface-conductive Electron Emitter displays.

Besides pixel resolution, important factors to consider when comparing different displays include contrast, brightness and color. In addition, how well the displays scale and de-interlace images are significant. These factors ultimately determine why some displays look better than others or are more suitable for a particular installation or location.

CRT - CRT monitors draw the lines one after the next, from top to bottom to make an entire frame. Generally speaking they have pleasing color balance performance and wide viewing angles. Because of their use of vacuum tubes, the displays can't be constructed much larger than 40" or so. They weigh more than the other types of displays, use a significant amount of power, and generate heat. Rear projection monitors typically use three CRTs (red, green and

blue) that converge onto a projection screen. While rear projection CRT displays have good colors and black levels, they are heavy, take up a sizable amount of room and suffer from low output and limited viewing angles. Front projection systems offer excellent resolution and are still favored by many but are large, and require periodic maintenance to ensure proper convergence and focus.

LCD – LCD HDTV monitors work by casting light through an array of cells sandwiched between two polarized planes. LCD monitors come in both flat panel and rear projection varieties. Flat panel, direct-view monitors have become popular as computer and DTV monitors because of their brightness, high contrast, and relatively long life span. Traditionally, LCDs have had a slower response time and lessened viewing angles than their CRT counterparts, but their speed and angle of view have been improved in recent years. Unlike plasma monitors, LCDs do not suffer from "burn-in". Burn-in is damage that results when a static or constantly illuminated image area begins to dim over time.

Plasma – Like LCD monitors, plasma HDTV sets are thin and are made up of cells that correspond to pixels sandwiched between glass plates. Plasma cells contain three separate gas-fill sub-cells, one for each color. When a current is applied to a sub-cell, it ionizes the gas emitting ultraviolet light. The ultraviolet light in turn excites fluorescent substances in the sub-cells that emit red, blue or green light. Compared to LCD, plasma sets can cost more but have larger viewing angles. While they also can suffer from low-level noise in dark material in general they have deeper blacks. Some older plasma sets suffered from burn-in and limited life spans, but this has improved in recent years.

DLP – Digital light processing is a technology used in projection displays. In DLP monitors, light is reflected off an array of microscopic hinged mirrors. Each tiny mirror corresponds to a visible pixel. The light is channeled through a lens onto the surface of the screen. Single chip DLP projectors can display 16.7 million colors. While some manufacturers claim their 3-chip DLP projectors can display 35 trillion colors, critics have observed that humans are only capable of discerning around 10 million.

LCoS – LCoS projection systems use liquid crystals arranged in a grid in front of a highly reflective silicon layer. The liquid crystals open and close, either allowing light to reflect or to be blocked.

Cables and connectors

With the large and growing number of cameras, displays, recorders, and playback devices for both professional and consumer markets, there are numerous connection options available. HDTV production equipment typically features digital inputs and outputs, along with legacy analog formats for both monitoring and additional I/O flexibility. Because HDTV content is digital data that is routinely stored, delivered and processed over networked systems, standard computer connectivity such as Ethernet, Wi-Fi, and USB can be used. It should be noted that the limited bandwidth of these connections might not support real-time delivery. In addition to the before mentioned computer connections, the following connectors are commonly used in HDTV equipment.

HD-SDI - A SMPTE 292M bit serial digital interface connection (HD-SDI) provides for transfers up to 1.485 Gbps over a 75-ohm coaxial cable. This is a standard method of transferring a HDTV signal from one device to another, such as from a digital recorder to an editing system. Up to 16 channels of digital audio can be delivered along with the video.

IEEE-1394 (**FireWire or iLink)** – Created as a versatile multimedia serial bus, IEEE-1394, commonly referred to as FireWire, allows bi-directional connectivity between a growing number of computers and multimedia devices. Two variations of FireWire support either 400 Mbps or 800 Mbps.

Component – Both analog and digital color difference connectors can be found on HDTV equipment. In the case of digital connections, YCbCr is used. Analog uses YPbPr, with audio being handled through a separate connection.

HDMI (High definition multimedia interface) – An HDMI connection can carry both multi-channel audio and video through one cable. It's found on some satellite and cable boxes along with a growing number of consumer and semi-professional gear.

DVI – Digital video interface connection are commonly found to connect computers and flat panel displays. DVI can be connected to HDMI with an adaptor. There are three types of DVI interfaces:

- DVI-A contains only analog
- DVI-D is only digital
- DVI-I supports both analog and digital

DisplayPort – This new display interface is physically smaller than a DVI connector and supports resolutions up to 2048 x 1536 pixels at 30-bits per pixel. It is designed to replace DVI and LVDS connectors and can be used for both external and internal display connections.

UDI (Unified display interface) – This is another new interface for PCs and consumer electronic devices designed to replace the VGA standard. It is designed to be compatible with HDMI and DVI interfaces, delivering high-definition video and metadata through a single connector.

Broadcast transmission and reception

Overall, the traditional model of broadcast transmission over the RF spectrum is unchanged. However, DTV requires broadcasters to replace analog with digital transmission gear and consumers to upgrade to digital receivers. The new technologies and digital infrastructure are providing broadcasters with new options, such as multicasting. Within a single 6 MHz section of bandwidth, a broadcaster can deliver a 1080i HDTV broadcast, and/or offer multiple audio and video streams along with a variety of data.

Reception

HDTV programming can be received via traditional terrestrial broadcast, cable, satellite or even IPTV (Internet protocol television). In order to receive HDTV programming (via DTV broadcast), end-users need a receiver with an ATSC-compliant tuner. Cable and satellite

companies currently provide set-top tuner/demodulators. Some contain PVRs (personal video recorders), which are capable of recording and playing back both standard and high-definition content. Many new HDTV sets referred to as "plug and play" or "digital cable ready" can interface with the digital service providers by means of a security card (known as a cableCARD), which is a small card with integrated circuits that plugs into the back of the console. Interfacing with the broadcast service providers through some form of return channel is necessary in order to use services such as pay-per-view (PPV), video on demand (VOD), or in some cases, interactive programming.

Terrestrial - This traditional, over-the-air system of transmission uses radio frequencies allocated by the FCC. TV stations broadcast from a single point, or through ancillary translators or repeaters that rebroadcast the originating signal, to end-users who are physically located within the station's receiving area. Reception of terrestrially broadcast DTV requires an antenna and limits the reception to those located within the TV stations' service area. While new sets are being manufactured with DTV-compatible tuners, stand-alone set-top devices will be available so that existing analog televisions can still be used. It should be noted that existing antennas would work fine for DTV broadcasts.

Cable – Cable service providers re-transmit programming to end-users over coaxial or optical cable. One of the main benefits of digital cable is the ability to offer a wide variety of programming as well as provide a broadband Internet connection. Two-way digital cable is uniquely structured, providing a built-in return channel facilitating the use of PPV, VOD, and interactive programming.

Satellite – Direct broadcast satellite (DBS) service transmits digitally compressed programming to users via small, Ku band antennas. Like cable, satellite service providers re-transmit existing content and offer a variety of programming packages.

IPTV – Interest and development is growing rapidly in IPTV, which provides DTV service over a broadband connection. Wire-service broadband providers, such as telephone companies, who haven't traditionally been vested in television, seem to have the most interest in developing the technology. There is also growing interest in providing IPTV use over standard 802.11g wireless networks.

Usage/Saturation

A recent survey carried out by Panasonic in December of 2005 (Broadcast Newsroom 2005) reported that 26% of US households will own or will purchase a high-definition set by the end of 2006. Given the imminent demise of analog broadcasting and the growth of HDTV content, it's safe to assume the figure will continue to grow.

The NAB (National Association of Broadcasters) maintains a growing list of stations that have made the move to digital broadcast. In December 2005, 1,550 stations were broadcasting digitally. As of January 2006, the major commercial broadcasting networks (ABC, CBS, FOX, and NBC) have begun offering most of their prime time programming in HD form. The Discovery Channel is running 24-hour HDTV programming and PBS HD is expanding their schedule as well. Major satellite and cable service providers DirecTV, Dish Network,

Comcast, Insight all offer an increasing lineup of HDTV programming along with time-shifting, personal video recorders (PVRs).

Users

According to studies, HDTV results in a heightened sense of "presence" (Bracken 2005) in viewers. Presence is when the viewer has a sense of being in the televised environment. Another aspect of presence is the degree in which the technological medium is ignored as attention becomes focused on the content. Because HDTV delivers an increased viewing experience, it is also suggested that levels of media effects will rise as well. The primary factors leading to the increased feeling of presence included screen size and image quality. Bracken's research found that subjects viewing HDTV content felt an increased feeling of immersion or involvement in the material. Participants also reported feeling a greater spatial presence of objects as well as an increased sense of the televised characters' expressions and body language.

TV Production

HDTV's wider aspect ratio and more detailed image are two elements affecting production. Sets, graphics and other production elements that may have served well for the 4:3 aspect ratio needed to be re-designed to fill the wider space. The increased visual clarity has forced designers to spend considerably more money on sets, set dressings and props. With the old analog system, fake, painted-on books might have served well for a backdrop. But now that viewers can see more detail, real books, or at least a better paint job is needed. There has been some press about the need for TV actors to invest in cosmetic surgery, or at least spend more

time in makeup, because of the greater detail HDTV provides. This is mostly a myth. The likenesses of film talent have been displayed at a much greater size and with far more clarity on large movie screens for years. By using soft lights and decreasing the angle of key lights lighting designers can greatly reduce the appearance of wrinkles and imperfections. Contrast reduction filters also can help minimize blemishes and small shadows.

DVD

High-definition DVD manufacturers are currently engaged in a format war, with the major contenders being Blu-ray and HD DVD. Both formats have considerable industry backing. The formats are similar in that they use the familiar 120 mm diameter CD-sized discs, but use higher-frequency, 405 nm wavelength lasers capable of writing and reading the data more tightly together. Players of both formats are being made that are capable of reading existing analog DVDs.

Blu-ray

Single layer discs can hold about 25 GB and dual-layer discs can hold about 50 GB writing MPEG video at data rates up to 36 Mbps. While the Blu-ray lasers aren't directly compatible with existing DVDs and CDs, an additional optical pickup device achieves playback.

HD DVD

The DVD Forum, an industry group whose purpose is to establish technical standards for DVD technology has sided with the HD DVD format. While HD DVD players write with the same 36 Mbps rate as the Blu-ray format, a single sided disc can only hold about 15 GB and a dual layer disc about 30 GB.

Feature film

The era of digital cinema began when George Lucas released *The Phantom Menace* digitally to select theatres on June 18, 1999. Digital cinema replaces traditional film distribution and projection with digital delivery and projection. While digital cinema uses high-definition technology, it's not directly tied to ATSC's DTV standards. The formats currently used in digital cinema provide even higher resolution than HDTV, including 2K (2048 x 1080) and 4K (4096 x 2160). Much of the equipment and interconnections used for HDTV production also work with digital cinema formats.

Using digital cameras to shoot a motion picture project is referred to as digital cinematography. While some filmmakers have resources to shoot with larger, ultra-high definition cameras such as Panavision's Genesis, most are opting to shoot in HDTV, or with even smaller, standard-definition formats because of the mobility, ease of editing, and low cost. Digital cinematography provides filmmakers with a means to shoot, edit, and master a project in the digital realm. With digital cinema, they now have a direct path into theatrical distribution. While some film production companies view HDTV and digital cinema as a

threat, many studios are major proponents who see it as a way to reduce the costly expense of duplication and distribution. A single 35mm film print can cost over $1,500 to produce. Other benefits include the fact that there is no loss of quality after multiple viewings and that more advertising can be run and edited more quickly and efficiently.

While the 1999 Phantom Menace screenings used media and projectors that were only capable of producing 1280 x 1080 sized images, current installations are using more advanced technology. The latest digital projectors are capable of displaying images with pixel dimensions of 4096 x 2160. Christie, a leading manufacturer of high-definition projectors for the digital cinema market has agreements to install 2,300 projection systems by November 2007.

CONCLUSION

As analog broadcast retires, and broadcasters and their viewers transition to DTV, HDTV programming, products, and services will continue to grow exponentially. While both broadcasters and consumers may have experienced a few bumps as they transitioned to DTV, the move will come cheaper, quicker, and easier as products and services become more widespread and people grow accustomed to the new technology.

Savvy shoppers have already become familiar with HDTV along with the nuances of different displays and formats. According to the Consumer Electronics Association (CEA), in 2003, total dollar sales figures of HDTV sets surpassed those of analog sets. The purchasing process for uninformed consumers has been made easier by the FCC, which has required that manufacturers include ATSC-compatible digital tuners in their TVs. As well, the FCC has established a standard for digital cable ready (DCR) televisions, known as "plug and play." This allows cable subscribers to receive digital and high-definition programming without the need for a set-top box.

One interesting phenomenon is that despite advances and increased availability in HDTV gear and service, the demand for low definition video has also increased. While some might watch the latest episode of *Lost* or *Desperate Housewives* on large HDTV sets, a growing number are downloading 320 x 240 sized versions onto their iPods and portable digital media players.

HDTV has brought a more cinematic experience into viewer's homes and with digital cinema, delivered the film industry a few of the benefits of television. However, HDTV has much

lower resolution than 70mm film. It's only a matter of time before some will begin pressuring for another increase in quality.

# # # #

Additional resources:

Advanced Television Systems Committee

http://www.atsc.org/

DTV Digital Television (An informational site run by the FCC)

http://www.dtv.gov

Federal Communications Commission (FCC)

http://www.fcc.gov

HDV Organization

http://www.hdv-info.org/

HDTV Magazine

http://www.hdtvmagazine.com/

Museum of Television

Toronto Ontario

http://www.mztv.com

TV Technology

http://www.tvtechnology.com/

REFERENCES

Advanced Television Systems Committee http://www.atsc.org/

Bracken, Cheryl Campanella (2005). Presence and image quality: The case of high-definition television. *Media Psychology*. 7 (2), 191-205.

British Broadcasting Corporation (BBC)
http://www.bbc.co.uk/history/historic_figures/baird_logie.shtml (Date of access 9/5/2006)

Broadcast Newsroom http://www.broadcastnewsroom.com/articles/viewarticle.jsp?id=36377
(Date of access 5/5/2006)

Consumer Electronics Association (CEA) http://www.ce.org/ (Date of access 12/10/2005)

Montag, Bruce (2004) High Definition TV in the US
http://www.dell.com/downloads/global/vectors/2004_hdtv.pdf (Date of access 11/16/2005)

DTV http://www.dtv.gov (Date of access 5/7/2006)

Federal Communications Commission http://www.fcc.gov/ (Date of access 5/6/2006)

HDTV Magazine http://www.hdtvmagazine.com/ (Date of access 5/5/2006)

Montag, Bruce (2004) High Definition TV in the US
http://www.dell.com/downloads/global/vectors/2004_hdtv.pdf (Date of access 11/16/2005)

Museum of Television, Toronto Ontario http://www.mztv.com (Date of access 5/1/2006)

Poynton, Charles (2001) YUV and luminance considered harmful: A plea for precise terminology http://www.poynton.com/PDFs/YUV_and_luminance_harmful.pdf
(Date of access 10/23/2005)

Poynton, Charles (2002) Chroma subsampling notation
http://www.poynton.com/PDFs/Chroma_subsampling_notation.pdf
(Date of access 10/23/2005)

GLOSSARY

Aspect ratio A ratio of screen width compared to height.

Bandwidth The amount of data that can be sent through a signal path.

Digital TV (DTV) A standardized system of transmission and reception of digital television over radio frequencies.

Downconvert Converting a higher resolution format into a lesser resolution format.

High definition TV (HDTV) A high level of DTV capable of displaying 720p or 1080i television content using a 16 x 9 aspect ratio.

Interlace scan A technique in which a television image is created with two separate fields. Used in NTSC broadcasts.

Letterbox The effect of an image presented in a display with a narrower aspect ratio. When this occurs, horizontal black bars are visible at the top and bottom of the screen.

Metadata in the digital television context refers data about the programming, such as start and stop times, titles, and information on the following show.

MPEG-2 (Moving Picture Experts Group) is a version of the MPEG video file format used to deliver digital video.

Multicast When a broadcaster splits their bandwidth into separate channels or program streams.

Personal Video Recorder (PVR) allows the user to record, store and playback video such as television broadcasts from a hard drive.

Progressive scan Method of scanning all of the scan lines from top to bottom sequentially without two interlaced fields.

Standard definition TV (SDTV) The lowest quality level of DTV capable of displaying 480i television content.

Upconvert Converting a lower resolution format into a higher resolution format.

Widescreen Used to describe displays with an aspect ratio greater than 4:3.