High Definition Television and Desktop Computing

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Multimedia seeks to engage people through interfaces that provide visual and aural richness. Providing a rich visual environment demands a lot of pixels and a high refresh rate. HDTV represents the state of the art of image quality in motion image capture, recording, processing and electronic distribution, and so will be important to high-end multimedia applications.

Advanced Television (ATV) systems for the distribution of entertainment to consumers are being standardized and will be deployed in about 1995. ATV technology will be used to distribute entertainment that will be produced primarily using film or HDTV studio technology. Consumer ATV receivers — and eventually VCRs and camcorders — will incorporate high performance digital compression and decompression technology, and ATV equipment will benefit from the economy of scale of manufacture in consumer volumes. Cheap consumer hardware and components, and the wide availability of program material in compressed digital form, will cause ATV to be a significant influence on multimedia. Several ATV proposals have elements in common with the ISO MPEG standards developed taking place in the computing and communications communities, and so there is a possibility that these standards could converge to the extent that common components could be used, much to the benefit of the computer and communications industries.

This article outlines the background of HDTV, describes the basic parameters of the 1125/60 production standard, discusses the features of proposed ATV systems, outlines potential application areas, and briefly describes standardization issues currently under discussion.

Overview

High definition television (HDTV) is defined as having twice the vertical and twice the horizontal resolution of conventional television, a picture aspect ratio of 16:9, a frame rate at least 24 Hz, and at least two channels of CD-quality sound. HDTV studio equipment commercially available at the moment has about two megapixels per frame (in a 1920×1035 format), six times the number of pixels as conventional television. The data rate of current studio-quality HDTV is about 120megabytes per second.

The parameters of HDTV are optimized for a viewing distance of about three times picture height. This enables a horizontal picture viewing angle of about thirty degrees, three times that of conventional television. This gives the viewer a much greater sense of involvement in the picture.

Advanced Television (ATV) refers to transmission systems designed for the delivery of entertainment to consumers, at quality levels substantially improved over conventional television. ATV transmission systems have been deployed in Japan, and a number of systems have been proposed for adoption in the United States. The parameters of these systems vary widely, although the data rate of each proposed systems is about 20megabits per second

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Standards for film, video and entertainment have historically developed in a three-level hierarchy: production, exchange and distribution. *Production* refers to the shooting and editing of material. *Exchange* refers to the buying and selling of programs (often on 35mm film). *Distribution* refers to the delivery of programs to consumers, which can take place using *transmission* as in conventional broadcasting, or using physical media such as videotapes and videodiscs. Transmission can be through conventional terrestrial broadcasting (VHF/UHF), cable television (CATV), direct broadcast by satellite (DBS), or potentially through telecommunications (*e.g.* “fiber to the home”, FTTH).

The development of HDTV and ATV standards is currently in disarray. The standards process is confused among production, exchange and distribution. Certain organizations have much to lose if the adoption of standards accelerates the introduction of HDTV; these organizations have deterred standards development. The U.S. Federal Communications Commission has jurisdiction only over standards for terrestrial VHF/UHF broadcast, but has no jurisdiction and no official position on other delivery standards, and no mandate to discuss production or exchange standards. Political, technonationalist and industrial policy concerns are frequently evident in standards discussions. The lack of formal standards for HDTV and ATV could encourage introduction of consumer ATV using physical media, since this would bypass the need for formal standards.

The television industry has reacted with alarm at the possibility of the introduction of ATV broadcasting. Networks and television stations face the prospect of making huge capital outlays to upgrade their plants for ATV, with no corresponding increase of revenue. Traditional consumer equipment manufacturers and traditional broadcasting interests have proposed ATV systems with parameters closely tied to existing practice, in the hope of minimizing new investment. For example, many U.S. interests hope to retain the same troublesome 59.94Hz field rate as NTSC just to be “compatible”. Unfortunately their European counterparts have also chosen to maintain their field rate of 50Hz, and the discrepancy between these two rates makes it unlikely that a common distribution standard will emerge.

Despite the chaos in distribution standards, the Society of Motion Picture and Television Engineers (SMPTE) has adopted SMPTE Standard240M for 1125/60 studio equipment. The emergence of this standard has encouraged equipment manufactures to invest in tooling to bring studio production equipment to the market. Much commercial studio production equipment that conforms to this standard is available for acquisition, recording, processing, transmission and display.

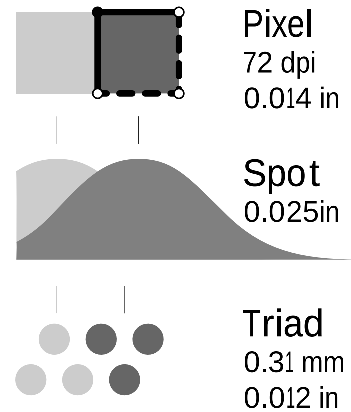
HDTV is different from video. It has greater resolution (2Mpx *vs.* 300Kpx) and improved color accuracy. Its color is coded with the component system (instead of the composite system, which suffers color quality impairments). In its digital form, HDTV is poised to exploit the emerging digital infrastructure in a way that NTSC and PAL cannot.

HDTV is different from film: has no judder, no weave, and no scratches! Being electronic instead of photochemical, HDTV offers consistent, reliable color reproduction compared to film, and has all the advantages of electronic, digital post-production. The image quality of HDTV is good enough for Hollywood: many feature productions are exploiting HDTV technology in effects sequences and synthetic computer graphics sequences.

HDTV is different from computer graphics. Commercial equipment is available today for real-time acquisition, recording, processing and transmission. HDTV technology is poised to bring motion and real-life images to computer graphics.

HDTV interchange standards have been designed to deliver convincing, emotive, artifact-free pictures. The coding of pictures into HDTV signals takes into account the perceptual characteristics of human vision to make the most effective use of the available bandwidth, and a standardized set of interchange parameters has been adopted, so that HDTV images maintain their quality (including color accuracy) when exchanged.

Low cost HDTV and ATV equipment is inevitable as HDTV moves towards the high unit volumes that will come from consumer acceptance. Large consumer electronic companies recognize the difficulty of the consumer’s encountering the “home theater experience” on a direct-view CRT display at most 32inches in diameter, the largest practical size of tube for the home. So despite the immense technological difficulties, flat panel displays are likely to emerge for HDTV. The computer industry will be the first beneficiaries of these products — at a high price — but the goal of the manufactures is to reap profits from consumer unit volumes, not from the comparatively small volumes of the computer industry.



At the moment there are several challenges to the integration of HDTV and computer graphics. Since HDTV was derived from television technology, it utilizes the 60 frame per second refresh rate and the interlace technique of conventional television. Computer applications generally require a refresh rate of 70Hz or greater because of the high ambient light levels typical of computer use in the office.

The computer community has been working toward standards for the compression of digital moving pictures and audio in the Moving Pictures Experts Group (MPEG) of ISO. Several ATV proponents have ATV transmission systems that have a close resemblance to MPEG, but it is not yet clear whether the resemblance is sufficiently close to allow huge investments in silicon to be exploited in both arenas.

Although political interests have apparently again split the world's television distribution into three domains — Japan, North America and Europe, in a 1990's version of the NTSC, PAL and SECAM trichotomy — many HDTV enthusiasts hope that a common production standard will emerge. Some of us also hope that ATV standards will have a deep-rooted commonality with MPEG and other compression standards emerging from computing and communications, in order to facilitate the exchange of images among the people of the world.

The Definition of "Resolution"

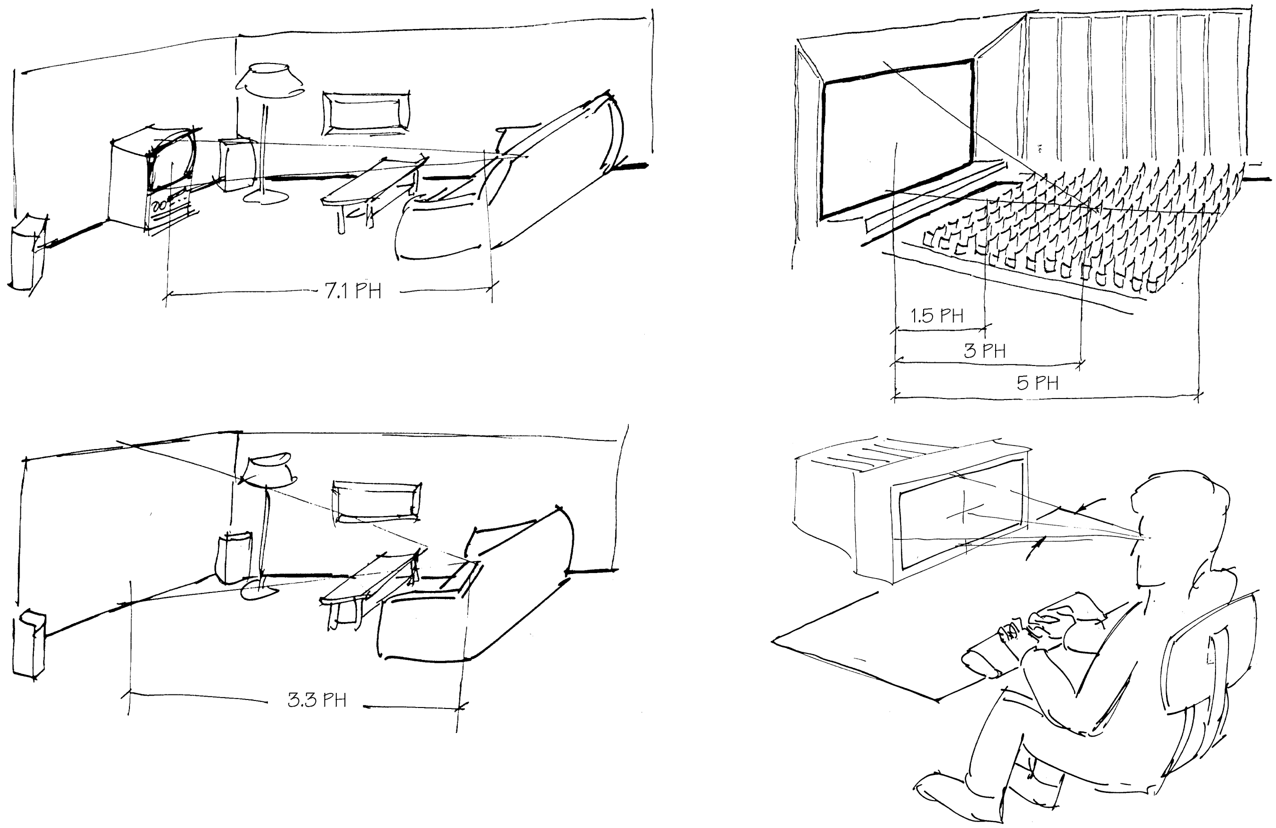
Resolution refers to the capability of an imaging system to reproduce fine detail. As picture detail increases in frequency, the response of an imaging system generally deteriorates.

In film, *resolution* is measured as the finest pattern of straight, parallel lines that can be reproduced, expressed in *line pairs per millimeter* (lp / mm). A line pair contains a black region and a white region.

In video, *resolution* refers to the number of line pairs (cycles) resolved on the face of the display screen, expressed in cycles per picture height (C / PH) or cycles per picture width (C / PW). A *cycle* is equivalent to a *line pair* of film. In a digital system, it takes at least two samples — or pixels or scanning lines — to represent a line pair. However, resolution may be substantially less than the number of pixel pairs due to optical, electro-optical and electrical filtering effects. *Limiting* resolution is reached at the frequency where detail is recorded with just 10% of the system's low-frequency response. In consumer television, horizontal resolution is expressed in terms of the *TV lines* that make up the picture height. Resolution in TVL is *twice* the resolution in C / PW, divided by the aspect ratio of the picture.

In computer graphics, *resolution* refers simply to the number of discrete horizontal and vertical *picture elements* — or *pixels* — that are employed to represent an image in digital form. For example, a 1152×900 system has a total of about one million pixels (one megapixel, or 1Mpx). Computer graphics has not traditionally been concerned with whether individual pixels can be discerned on the face of the display. In most color computer systems, an image comprising a one-pixel black-and-white checkerboard displays as a uniform gray.

Computer graphics often treats each pixel as representing an idealized rectangular area independent of all other pixels. This notion discounts the correlation among pixels that is an inherent and necessary aspect of image acquisition, processing, compression, display and perception. In fact the rather large spot produced by the electron beam of a CRT and the arrangement of phosphor triads on the screen produce an image of a pixel on the screen that bears little resemblance to a rectangle. If pixels are viewed at a sufficient distance, these artifacts are of little importance. However, we tend to view CRTs at close viewing distances, where these distortions need to be compensated in order to achieve good image quality. HDTV systems are optimized taking these distortions into account.



In the living room, *television viewing is best when the viewer is located at a distance of about seven picture heights from the screen. Cinema offers a wide range of viewing distances, but about three times picture height is optimum. In the long term, consumer HDTV will bring the cinema viewing experience to the living room. A workstation user typically sits very close to his screen, but for a large display surface his viewing angle approximates that of HDTV.*

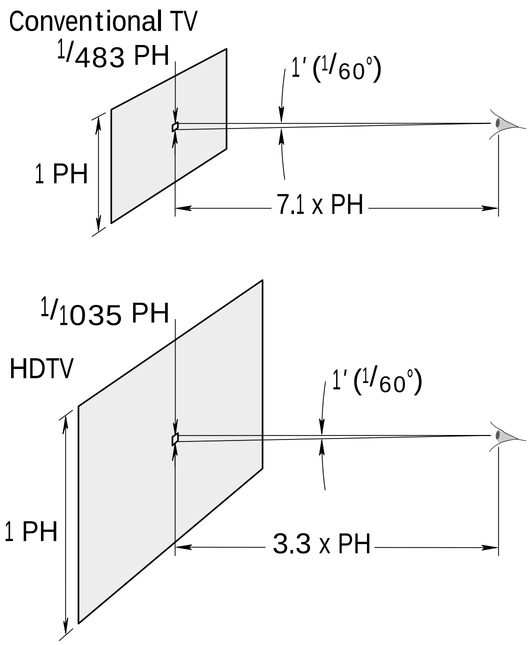
Resolution refers to the capability of a system to reproduce spatial detail. Another important aspect of digital picture representation is the capability to reproduce intensity values. HDTV uses eight bits for each of three components — red, green and blue — but the transfer function and color interpretation are established with careful attention to the needs of human visual perception.

Nomenclature, Video vs. Computing

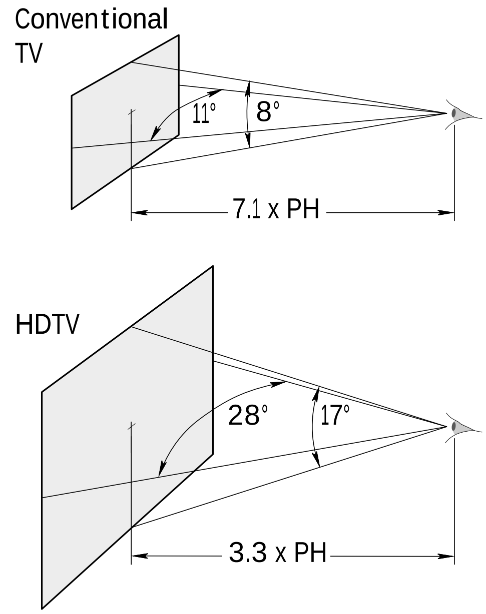
A video system is denoted by the total number of lines in its raster (frame), and its field rate — in hertz, or fields per second — separated by a slash. Broadcast television in the North America and Japan is denoted 525 / 59.94; the system used in Europe is denoted 625 / 50. These systems are colloquially called *NTSC* and *PAL* but those terms properly denote color coding and not raster structure. Conventional television has a 4:3 picture aspect ratio, and employs interlaced scanning (to be discussed later), which is implicit in the 525 / 59.94 notion.

The total number of lines in a raster is of less concern to the viewer than the number of lines that contain useful picture information. The number of *lines per picture height* (L / PH) is about four percent of the total number of lines in a field — in an interlaced system, eight percent of the frame — in order to accommodate vertical blanking interval overhead. For example, a 525 / 59.94 system has about 483 picture lines.

Computer users denote scanning structures by their horizontal and vertical pixel counts only, and generally do not indicate field or frame rate. For example, a 1152×900 system may have 937 total lines and a frame rate of 65.95Hz. Sometimes, scanning parameters are implicit in acronyms, for example, *VGA* implicitly has a “resolution” of 640×480.



Viewing distance *is established by the observer, who positions himself such that the smallest detail of interest in the scene — shown here as a pixel — subtends an angle of about one minute (1⁄60 degree) of arc, the limit of angular discrimination for normal vision. For the 483 visible lines of conventional television the corresponding viewing distance is about seven picture heights (PH). Closer than this distance, the scan lines are objectionable; further away the picture is unreasonably small. For HDTV with 1035 visible lines, the corresponding viewing distance is about 3.3 times screen height.*



Viewing angle *can be computed from viewing distance by simple trigonometry. Conventional television has a horizontal viewing angle of about 11 degrees. In HDTV, the increased pixel count and the increased aspect ratio result in the horizontal viewing angle being increased to about 28 degrees. The viewer of HDTV does not normally perceive increased "definition" (resolution) for the same size picture, but rather moves closer to the screen so as to experience a picture of similar spatial resolution to conventional video but which subtends a much wider field of view. Some argue that it would be more appropriate — and better for market differentiation — to call it "wide screen television" instead of "HDTV".*

HDTV, ATV, EDTV, IDTV

HDTV has about twice the horizontal and twice the vertical (linear) resolution of conventional television, a 16:9 picture aspect ratio, and at least 24Hz frame rate. Under this definition, HDTV has approximately double the number of lines of current broadcast television, at approximately the same field rate. The doubled line count, combined with the doubled horizontal resolution and the increase in aspect ratio, causes an HDTV signal to have about six times the luma (Y) bandwidth of conventional television.

Advanced Television (ATV) refers to delivery of entertainment television to consumers at a quality level substantially improved over conventional television. Terrestrial (VHF / UHF) ATV requires a change in FCC broadcasting regulations. HDTV studio equipment will be used to produce programming for ATV distribution, but the standards used for these two areas need not be identical. My definition of ATV reflects the wide latitude of choices available in setting ATV standards. For example, the ATV proposals of Zenith and ATVA / MIT offer only 900Kpx, substantially short of the two megapixels required for twice the vertical and twice the horizontal resolution of NTSC.

Enhanced Definition Television (EDTV) describes a 525 / 59.94 or 625 / 50 broadcast television signal that is originated with altered or augmented signal content, requiring broadcast regulation changes, that makes possible higher quality at consumer receivers.

Improved Definition Television (IDTV) describes receiver techniques that improve the quality of standard NTSC or PAL broadcast signals but require no emission regulation changes. A receiver is considered IDTV if it

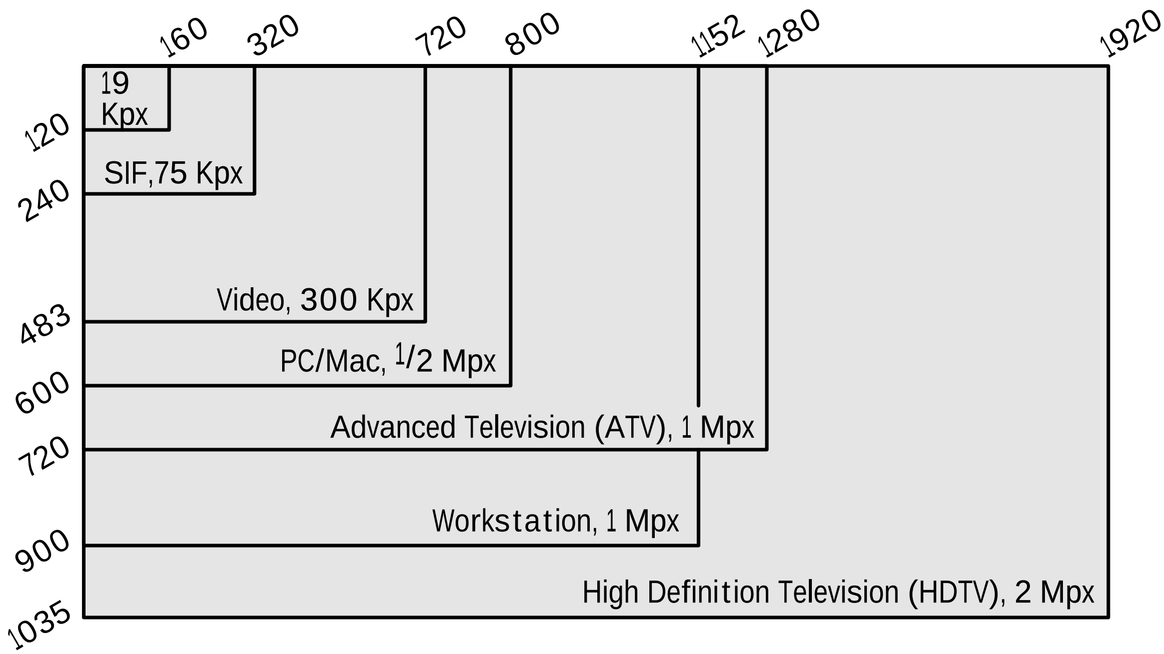


Image sizes *of various display systems are compared, showing the horizontal and vertical pixel counts of each. The smallest format shown here, 19kilopixels, is representative of the image size typical of motion playback through current software decompressors. SIF resolution is used in today's MPEG-1 implementations. Direct-view CRT displays are available for all of the larger formats. HDTV has about six times the number of pixels as conventional video, and about five hundred times the spatial and temporal resolution of today's software image decompressors.*

employs frame-rate doubling to eliminate inter-line twitter, although additional techniques such as noise reduction may also be employed. IDTV does not require changes in signal transmission standards, and consequently can be implemented entirely at the receiver.

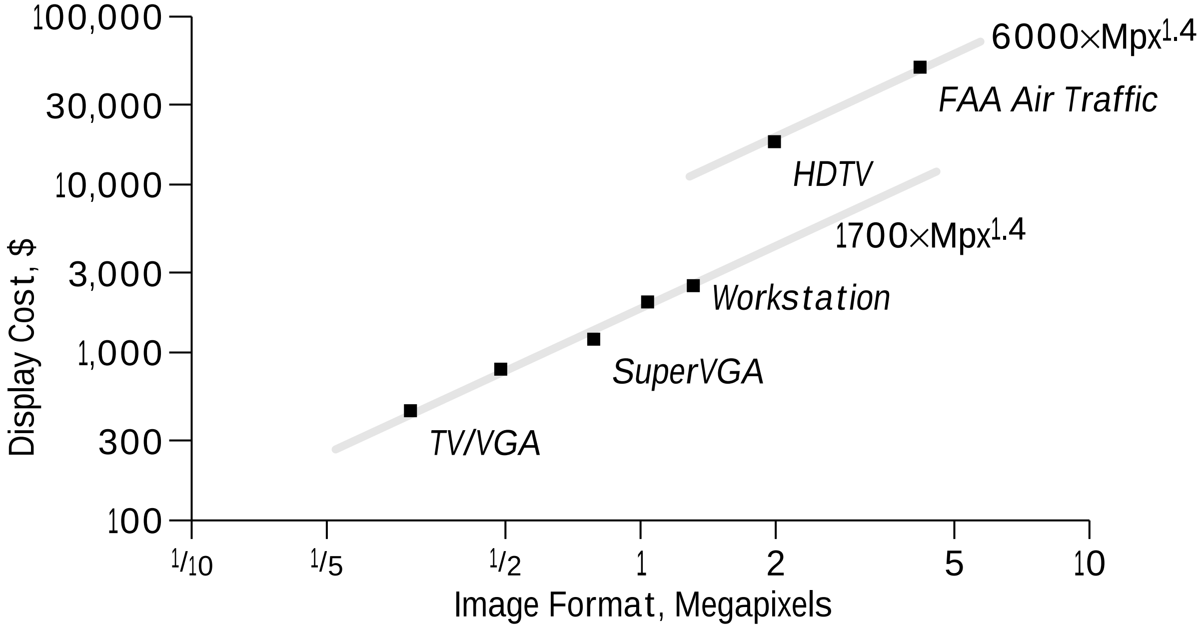
Psychophysics

The fundamental development work for HDTV was done at the Japan Broadcasting Corporation (NHK), after extensive psychophysical and perceptual research led by Dr. Takashi Fujio. Human viewers tend to position themselves relative to a scene such that the smallest detail of interest in the scene subtends an angle of about one minute of arc (1⁄60°), which is approximately the limit of angular discrimination for normal vision. For the 483 picture lines of 525-line television, the corresponding viewing distance is about seven times picture height, and the horizontal viewing angle is about 11°. For the 1035 visible lines of 1125-line HDTV, the corresponding viewing distance is 3.3 times screen height and the horizontal viewing angle is almost tripled to 28°.

Using an acuity of 1⁄60°, viewing distance in terms of picture height should be about 3400 divided by the number of picture lines. A computer user tends to position herself closer than this — about 60% to 75% of this distance — but at this closer distance individual pixels are discernible.

The viewer of HDTV consequently does not perceive increased "definition" (resolution) for the same size picture compared to conventional television, but rather moves closer to the screen. Psychophysical research has shown that a viewer's emotional involvement in a motion picture is increased when the picture subtends a large viewing angle. Consumer HDTV should be called *wide screen television*, and this designation would probably be more appropriate to consumer marketing and product differentiation than "HDTV".

It is unnecessary to increase the vertical angle of view as much as the horizontal, and the aspect ratio of 16:9 has been standardized for HDTV, compared to 4:3 for conventional television. The HDTV aspect ratio, about 1.78:1, is almost the same as the most common cinema aspect ratio of 1.85:1.



***Display cost** is related to the image format and to unit volumes. The points on the lower line represent displays currently being manufactured in high volume; the shaded line is the function 1700×Mpx$^{1.4}$. The points on the upper line represent displays currently being manufactured in low volume; the shaded line is the function 6000×Mpx$^{1.4}$. As HDTV displays approach consumer volumes, we can expect their prices to fall to the lower line.*

NHK research has revealed that in combination with large viewing angles, high-quality stereo sound impacts the psychophysical response of the viewer to the picture. In particular, the viewer's eye-tracking response is dramatically different from conventional television. Most HDTV proposals include CD-quality stereo audio.

Quality

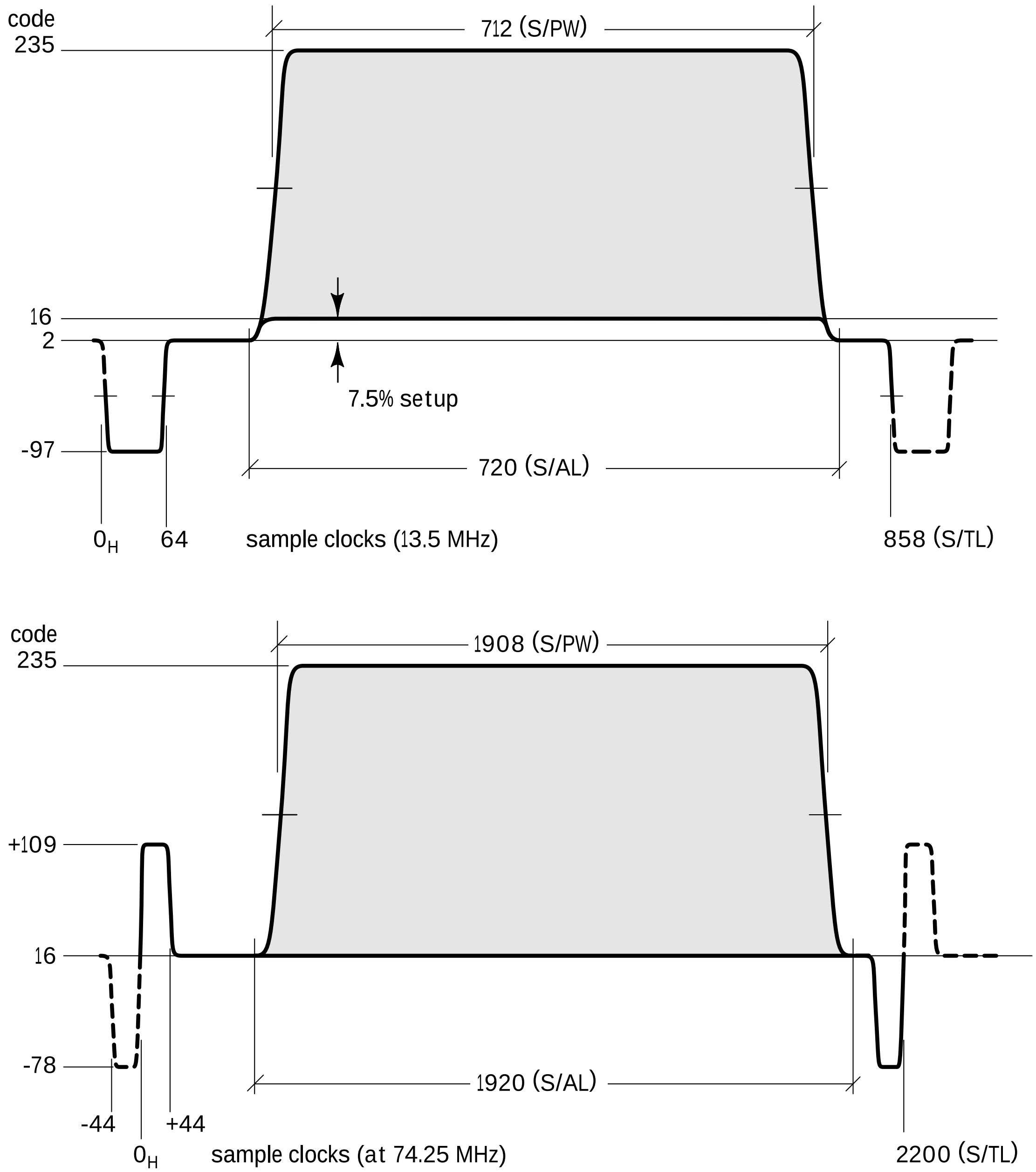
The picture quality of HDTV is superior to that of 35mm motion picture film, but less than the quality of 35mm still film. Motion picture film is conveyed vertically through the camera and projector, so the width — not the height — of the film is 35mm. Cinema usually has an aspect ratio of 1.85:1, so the projected film area is about 21mm × 11mm, only three tenths of the 36mm × 24mm projected area of 35mm still film. In any case the limit to the resolution of motion picture film is not the static response of the film, but judder and weave in the camera and the projector.

The colorimetry obtainable with the color separation filters and CRT phosphors of a video system is greatly superior to that possible with the photochemical processes of a color film system. There are other issues related to the subjective impressions that a viewer obtains from viewing motion picture film — the *film look* — that are still being explored in HDTV. For example, specular highlights captured on film have an appearance that is subjectively more pleasing than when captured in video.

HDTV Standards

Standards for motion pictures and video exist in three tiers: production, exchange, and distribution. *Production* is the shooting and assembling of program material. *Exchange* of programs takes place among program producers and distributors. *Distribution* to the consumer may take place using *physical* media such as videotape or videodisc, or through one of four *transmission* media: terrestrial VHF / UHF broadcast, cable television (CATV), direct broadcast from satellite (DBS) or telecommunications.

The film production community will produce material in the electronic domain only if it can be assured the access to international markets afforded by 24Hz, which translates easily to both 29.97Hz and 25Hz with minimal artifacts. Electronic origination at either 25Hz or 30Hz would introduce serious artifacts upon conversion to the other. It is my contention that a single worldwide standard for HDTV production is feasible only if it accommodates distribution of material originated at 24Hz.



Video waveforms *of a single scan line of luma information for conventional CCIRRec.601-1, 525/59.94 video (top) and SMPTE 260M, 1125/60 HDTV (bottom) are shown. HDTV has a bandwidth — or in a digital system, data rate — about 5.5 times that of 525/59.94. Tri-level sync is used in HDTV to obtain the necessary high timing accuracy, and setup is eliminated to improve color reproduction.*

Broadcasters have recently made proposals to produce HDTV material in Widescreen-525 or Widescreen-625 production formats with a 16:9 aspect ratio. These proposals would use conventional video production equipment, modified for wide aspect ratio. This technique would allow broadcasters and perhaps even local stations to originate wide-aspect-ratio programming with minimum expenditure. However, programs would contain approximately the same amount of picture detail as conventional television, therefore the viewer could not take advantage of the wide viewing angle and the increased sense of involvement which in my opinion is the key to consumer differentiation of HDTV.

SMPTE 240M: 1125/60 Production Standard

The technical parameters of the 1125/60 production system were standardized in SMPTE Standard 240M, adopted in February, 1989. Disclaimers on this document indicate that it is applicable to HDTV production only, although the MUSE broadcasting system in use in Japan is based on 1125/60 parameters. SMPTE 240M applies to the 1125/60 analog signal. A digital representation of 1125/60 having a sampling structure of 1920×1035 and a sampling rate of 74.25 MHz has recently been adopted in SMPTE Standard 260M.

SMPTE 240M specifies RGB or YP_bP_r color components, with carefully-specified colorimetry and transfer functions. Luma (Y) bandwidth is specified as 30 MHz, about five or six times the bandwidth of current broadcast television. Not all currently-available HDTV equipment meets this bandwidth, and most of the proposed transmission systems do not come close to the performance of the studio production equipment.

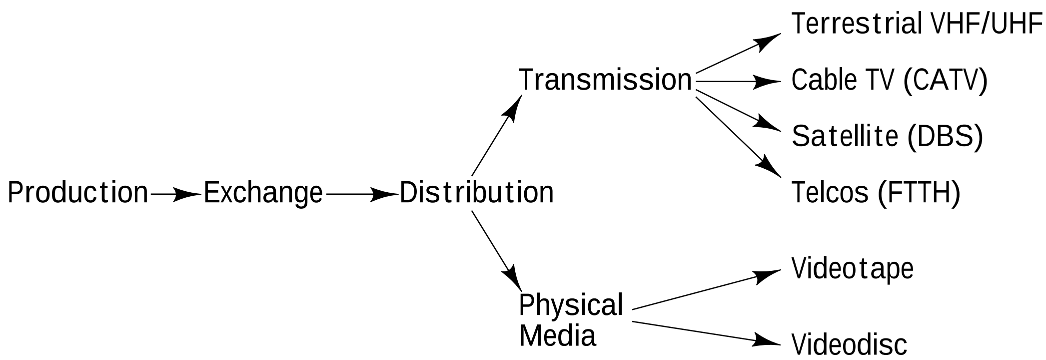
Although the field rate of SMPTE 240M system is exactly 60 Hz — emphasized by the *60.00* notation in the document — certain organizations propose operating at a field rate of 59.94 Hz to maximize compatibility with existing NTSC equipment and production processes. Some current HDTV studio equipment is configurable for operation at either rate. There are several system problems with 59.94 Hz field rate. In 59.94 Hz operation with standard digital audio sampling frequencies of either 44.1 kHz or 48 kHz, there is not an integer number of audio samples in each frame. This, and the requirement for dropframe timecode, imposes a penalty on operation at that rate. However the production procedures for 59.94 Hz are of course well established for conventional 525/59.94 video, troublesome though they may be.

1125/60 Studio Equipment

Commercial hardware operating with the 1125-line system is now widely available. Professional studio equipment that is commercially available for purchase at the time of writing (in January 1993), includes:

- Cameras
- Videotape recorder (analog, 1 inch open reel)
- Videotape recorder (digital, 1 inch open reel)
- Videotape recorder (analog “Uni-Hi”, 19 mm cassette)
- Videodisc
- Telecine (film-to-video)
- Film recorders
- Video monitors
- Video projectors
- Still and sequence stores
- Up-converters
- Line doublers
- Cross-converters
- Down-converters
- Production Switchers
- Graphics and Paint Systems
- Blue-screen matte (Ultimatte)
- Test equipment

Sony has demonstrated a fourth-generation 1125/60 CCD camera that has resolution, sensitivity and noise performance comparable to the best film cameras and motion picture film.



A digital studio HD-VTR records a raw data rate of about 1.2 gigabits per second (Gb/s); this is the state-of-the-art for digital magnetic recording.

Real-time digital video effects equipment has been demonstrated by several manufacturers, but no commercial DVE is deployed in an independent commercial facility at the time of writing.

HDTV is being used for the production of material to be released on theatrical (cinema) film. Its acceptance as a production medium for cinema awaits the wider availability of HDTV production facilities and more knowledge of HDTV production techniques on the part of the film production community.

HDTV Exchange Standards

The *de facto* international television program distribution standard has been for the last 40 years, and continues to be, 35mm motion picture film. In North America, film is transferred to video using *3-2pulldown* , which involves scanning successive film frames alternately to form first three then two video fields. The film is run 0.1% slower than 24 frames per second, to result in the required 59.94Hz field rate. In Europe, film is run four percent fast with *2-2 pulldown* to result in a 50Hz frame rate.

Discussions of exchange standards are in an early stage, but there is general agreement that film “friendliness” will be important for ATV: it is certain that the primary origination medium for consumer ATV in any form will initially be 35mm motion picture film, due to the vast amount of existing program material in that medium.

ATV Transmission Standards

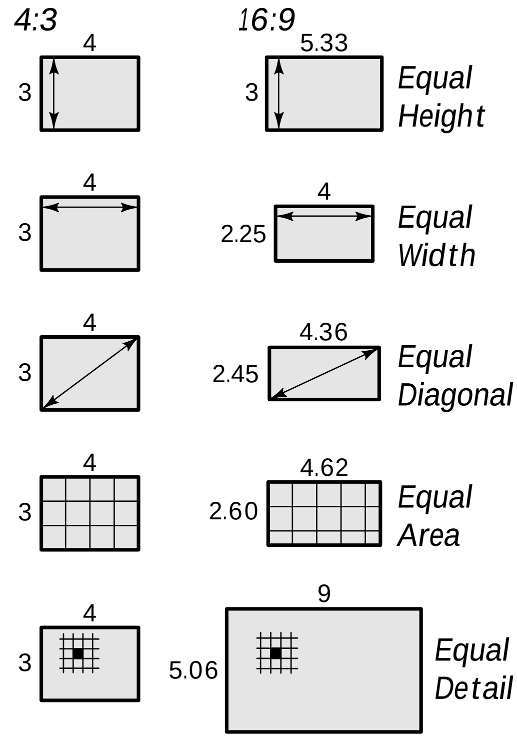
All proposed transmission standards involve the reduction of transmission bandwidth by exploiting the statistical properties of “typical” images and the perceptual properties of the human visual system.

Terrestrial and satellite broadcasting requires spectrum allocation, which is subject to domestic and international political concerns. Broadcasting standards are agreed by the International Radio Consultative Committee (CCIR), a treaty organization that is part of the United Nations. CCIR *Recommendations* — which you and I might call standards — are agreed unanimously and internationally. The CCIR started setting broadcasting standards well before the introduction of video recording, and the CCIR has inherited video production and exchange standards even though they do not strictly speaking involve the radio spectrum. The CCIR has adopted Recommendation709 for an HDTV production system. HDTV colorimetry has been agreed, but the recommendation is in a half-finished state reflecting the lack of international agreement on remaining parameters, particularly frame rate and raster structure.

Broadcasters in Europe and the U.S. have proposed transmission systems having on 50Hz and 59.94Hz field rates respectively, citing requirements for “compatibility” with local broadcast standards. No commercial equipment, and very little experimental equipment, exists for either of these standards.

It is now evident that there will be no single worldwide transmission standard for ATV, mainly for political and national industrial policy reasons. In the United States, adoption of SMPTE240M as an ANSI standard was blocked by a legal challenge by the ABC television network, which cited “lack of industry consensus”. This was the first time in history that a SMPTE standard was not endorsed by ANSI, and the ABC objection

Picture Size *of HDTV, with its 16:9 aspect ratio, has been compared to conventional video with 4:3 aspect ratio on the basis of equal height, equal width, equal diagonal and equal area. The first four rows of this diagram show graphical representations of these comparisons. These relationships have even been used in consumer preference testing for HDTV. But any comparison on aspect ratio alone disregards the most significant aspect of HDTV: its capability to reproduce picture detail. A comparison on the basis of equal detail is shown in the bottom row. The main goal of HDTV is to present — with roughly the same angular resolution as conventional television — a much larger picture .*



ATV Transmission in Europe

The standardization process in Europe is substantially different from the standardization process in North America. Most broadcasting organizations are state-owned. Standards are agreed upon by the European Broadcasting Union, whose only members are broadcasters. These meetings are closed; manufacturers (and other interested parties) attend only when invited.

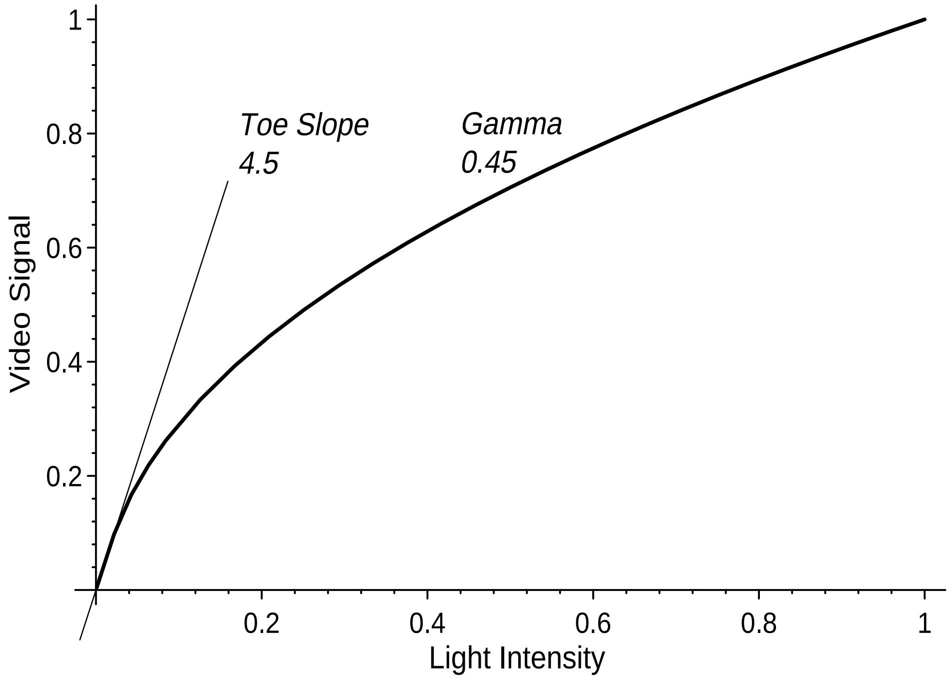
Systems based on 1250 / 50 scanning, with a raster structure of 1920×1152, have been proposed by the Eureka-95 project in Europe. These proposals are HDTV extensions to the MAC system (HD-MAC). British and Swedish researchers have introduced a revolutionary broadcasting technology called *orthogonal frequency division multiplexing* (OFDM) that may accelerate the consideration of digital broadcasting in Europe.

The Europeans (and the Australians) had a strong political interest in basing HDTV on MAC, due its recent deployment. Receiver manufacturers include MAC decoders in their new receivers, but consumers must install set-top converters in order for old receivers to receive MAC. The European broadcasting community would have found it embarrassing to require consumers to purchase new converters for another new standard— for digital ATV — just a few years after the heavily-publicized introduction of MAC. MAC is therefore currently being promoted in Europe as being capable of upgrade for HDTV (HD-MAC), but the recent business failures associated with D-MAC make extension of the service to HD-MAC problematic.

Commercial/Industrial/Scientific Applications

Current 525-line video systems have about 640 visible pixels per line and about 480 visible lines per frame for a total of about 0.3 megapixels. Current workstations have between 1 and 1.25 megapixels per frame (*e.g.* 1152×900 or 1280×1024). HDTV has approximately two megapixels per frame, or roughly twice the pixel count of current workstations. This pixel count, combined with a picture aspect ratio of 16:9, allows a display measuring 19 inches by 11 inches at 100 dots per inch. This is sufficient for two 8.5 by 11-inch (A4) pages side-by-side or an 11 by 17inch (B-size or A3) engineering drawing, with a few inches left over on the side for menus and icons. Many computer workstation users today obtain a two megapixel display by attaching two screens to one workstation; this “two-headed configuration” is also typical of computer animation and medical systems. This interim solution to increased pixel count will be remedied by HDTV displays.

Computer users have for many years been plagued by a wide variety of incompatible monitor interface standards. For example, at one megapixel, the user doesn’t particularly care whether the display is 1152×900 (Sun), 1120×832 (NeXT), 1152×870 (Mac) or 1024×864 (DEC), but each manufacturer carries the burden of specifying its own unique monitors and monitor interface standards, and users have difficulty interfacing to



CCIRRec.709 Transfer Function. *A true power function requires infinite gain near black, which in a practical camera or scanner would introduce a large amount of noise in dark regions of the image. CCIR Recommendation 709, for HDTV, introduces a linear segment near black. The power curve has its y-intercept shifted negative, and its gain increased, such that the linear segment meets the curve where their values and slopes match. The mapping of unity is undisturbed.*

peripheral equipment. HDTV offers a common scanning and interface standard for the next generation of workstations. This will simplify the interfacing of workstation to monitors, projectors, downconverters, film recorders and other peripheral equipment. 1125 / 60 is available as an output standard for computer graphics equipment such as workstations from Silicon Graphics and Symbolics. Third-party HDTV adapters are available for Sun, Macintosh and other computers.

Use of the HDTV production standard by the computer industry will open access to equipment for image capture, recording, transmission, distribution and display. Interface to 525-line video equipment has been difficult due to the disparity in interface standards between computer graphics equipment and video equipment. Further, poor detail and color resolution in NTSC have precluded its use in application areas such as medicine and graphics arts. HDTV remedies those deficiencies by adopting component color coding (instead of composite coding as in NTSC), zero setup for accurate reproduction of blacks (instead of 7.5percent setup as in NTSC and in EIA-343-A), a single well-characterized colorimetry standard (as opposed to the wide variety of phosphor chromaticity and white point values currently in use in computer graphics) and a well-defined transfer function that will allow accurate gamma correction.

In the past, many application areas have been forced to adopt proprietary display interface standards because the resolution or color accuracy available from standard workstation platforms has been inadequate. HDTV has a display quality that will meet the requirements of even the most exacting users and this will allow the use of platform technology in place of proprietary solutions in applications such as printing and publishing. Quantel’s HDTV Graphic Paintbox is optimized for printing and publishing applications, and includes interfaces to prepress equipment. The Rebo Research ReStore offers access to HDTV through a Macintosh computer, and thereby allows the use of HDTV imagery and equipment with commercially-available Macintosh programs for retouching, presentation, color separation, and many other applications.

Obtaining motion in computer graphics has in the past required either very expensive graphics accelerator hardware or painstaking frame-by-frame non-realtime animation. HDTV will allow easy access to video equipment designed to handle motion video and therefore will bring motion to the workstation world.

Square Pixels

Current digital 1125 / 60 HDTV production equipment conforms to SMPTE260M, which has 1920 samples per active line (S / AL), 1035 lines per picture height (L / PH) and conforms to the 16:9 aspect ratio of SMPTE240M. This combination of parameters yields samples spaced about 4% closer horizontally than vertically, that is, a sample aspect ratio of about 0.96. This situation came about due to lack of a cohesive input from the computer industry during the standards development process. Some U.S. interests were buoyant at this development, perceiving that non-square pixels would deter the deployment of non-American HDTV equipment. Others were dismayed that since no American equipment was available, the effect of the standard would be to deter the computer industry from exploiting HDTV.

Unequal vertical and horizontal sample spacing — or *non-square pixels* — is very inconvenient to computer users. Although many rendering systems can utilize any pixel aspect ratio and geometric calculations are only moderately inconvenienced by unequal spacing, interchange of raster data is severely compromised by non-square pixels. If raster data at a sample aspect ratio of unity is to be utilized in a system with a different sample aspect ratio, spatial re-sampling is necessary. Re-sampling requires substantial computation. This computation takes time in non-realtime applications or requires dedicated arithmetic hardware in realtime applications. Also, re-sampling introduces picture impairments that are unacceptable in certain applications, such as in graphics arts where 90 degree picture rotation is a common operation that must be accomplished with no impairments.

Square pixels have a number of important properties that make geometric calculation straightforward. There exists a huge volume of image data that is already scanned and stored in square-pixel form and adoption of a standard with square pixels assures easy access to this data. Many imaging devices (such as CCD sensors) and display devices (such as LCD and plasma screens) have inherently fixed geometry and having these devices use square pixels would allow the same devices to be used for television and industrial applications.

The term *Common Image Format* (CIF) refers to an attempt to standardize the spatial sampling structure of an HDTV image, independent of its frame rate. Square pixels can be accommodated in a Common Image Format of 1920 samples per line and 1080 picture lines. This would result in just slightly less than two megapixels per frame, an arrangement that results in optimum utilization of DRAM and VRAM devices. There have been proposals for a 2048×1152 common image format, but its total storage requirement of 2 ¼Mpx has poor utilization of power-of-two memory and multiplexer components. Unfortunately it is in the interest of some organizations in the United States to delay the adoption of any HDTV standard, and despite ATSC's endorsement of the 1920×1080 common image format, the United States is took no official position on the matter at the 1990 international CCIR standards discussions.

Display Refresh Rate and Interlace

A scanned display must be operated at a field rate sufficient to overcome *wide-area flicker,* which is a strong function of ambient brightness level. Although 48Hz is an adequate refresh rate in the dark environment of a movie theater, and 60Hz is adequate for the average North American living room, a refresh rate of at least 70Hz is necessary for the high-ambient-brightness environments typical of computer displays.

All 525 / 59.94, 625 / 50 and 1125 / 60.00 television systems currently utilize interlaced scanning. Interlace is a mechanism of reducing transmission bandwidth by half, for a given wide-area flicker rate, by transmitting a single frame as two fields whose scan lines intertwine. Interlaced systems reduce transmission bandwidth at the expense of introducing *inter-line twitter* in pictures with a large amount of vertical detail.

Interlace works reasonably well in television because the electro-optical filtering that is inherent in television image sensors (such as camera tubes) reduces vertical detail and consequently reduces inter-line twitter. Interlace causes objectionable twitter in pictures that have not been electro-optically or otherwise filtered, such as in synthetic computer graphic pictures that have large amounts of vertical detail or contain spatial aliasing components.

Aside from issues of inter-line twitter, interlace is undesirable for television production because of its inherent confusion of vertical detail and motion. Interlace is now generally seen by the HDTV production community as an expedient way to achieve a 2-to-1 bandwidth compression in order to permit economical camera and recording equipment in the short term. When technology permits, HDTV production equipment will utilize progressive scanning.

Although current-generation 1125/60 acquisition and recording equipment is universally 2:1 interlaced, there is general agreement that the industry will tend towards progressive (non-interlaced) systems for transmission and display. Zenith and ATVA/MIT have proposed transmission systems that rely on a 787.5/59.94/1:1 production standard with progressive scan. Essentially, these proposals take a factor of two penalty in spatial resolution — from 2Mpx to 900Kpx — in return for a factor of two increase in temporal resolution. The claim is made that these systems have better temporal resolution than interlaced systems, but the cameras that have been shown for 787.5/59.94 have relatively poor performance compared to the best available 1125/60 cameras, and to date no conclusive experiments on HDTV/ATV motion rendition have been conducted.

Handling 24Hz Sources

Although a Common Image Format would be appealing in the absence of a single world standard, it ignores the most difficult issue of frame rate conversion. Frame rate conversion — temporal re-sampling — causes highly objectionable picture impairments. Also, the Common Image Format proposal does not address the desire for a common sampling frequency that would allow equipment commonality.

About eighty percent of prime time television in the United States originates on film at 24frames per second. Film will undoubtably provide the vast majority of initial program material for consumer ATV. These facts suggest that the ATV transmission system adopted in the United States should easily accommodate 24Hz original material. Motion video compression relies heavily on accurate motion prediction to achieve good performance, and it has proven very difficult to perform motion-compensated DCT compression of a source image on film after it has been subjected to 3-2 pulldown. Certain ATV proponents advocate "source coding" at the native frame rate of the source for this reason. This technology may make it possible to encode in the channel a representation that can be decoded at different frame rates. For example, consumer receiver could be designed to have a relatively fixed field rate of 60Hz, and perform the equivalent of 3-2 pulldown at the display in the case of a film source. A more sophisticated receiver could potentially display a 24Hz source at three times that rate, 72Hz, to achieve a higher quality display.

The possibility of an electronic production standard at 24Hz has been discussed. Images originated at 24Hz would obviously be suitable for display at three times that rate, and 72Hz refresh rate is appealing to computer users, who require refresh rates considerably higher than 60Hz to avoid flicker in their work environments. 24Hz origination has certainly proven to be adequate for motion rendition for the entirety of cinema film production, admittedly with the cinematographer's assistance as a temporal prefilter.

Conclusions

It is evident that ATV broadcasting will use different standards in different parts of the world. However, there is no reason that the computer community should continue to suffer a diversity of display standards that are functionally equivalent. HDTV offers a technology base for the next-generation computer display standard. With cooperation among computer manufacturers, computer users and the entertainment production community, a single 1920×1080 standard is possible.

Producers of entertainment programming — and future producers of multimedia "titles" — wish to have access to a world market, not just a continental one. It is obviously advantageous to program producers to have a single production standard, preferably one that is "computer friendly". If the computer graphics community participates sufficiently in HDTV standards efforts, a single HDTV production standard could serve entertainment, communications and computing applications. If a standard is chosen for advanced television broadcasting that is incompatible with the needs of emerging communications technology, it is more likely to accelerate the demise of television than to deter the new applications.

It is difficult to imagine a world in which audio cassettes or compact discs could not be freely exchanged among the countries of the world. Why should we settle for less with pictures? Thirty years ago when the incompatible NTSC, PAL and SECAM standards were adopted, there were political motivations to deter communication among the peoples of the world. Now, the walls between East and West have been torn down and the worldwide political situation is in favor of open communication. In the context of this world situation, HDTV represents not just a once-in-a-generation opportunity but a once-in-a-*century* opportunity to adopt a single worldwide standard for the production and exchange of motion pictures in electronic media.

I have not yet given up hope that our generation can agree on a single world standard for HDTV. If ever there was a time to apply television technology to social ends, that time is now.