TV and HRS Technologies

INTRODUCTION

As an entertainment medium, HDTV is not revolutionary. It is simply another step in the ongoing evolution of television that began with black and white (B&W) TV in the 1940s and will continue into the future with as yet undreamed of technologies. Each successive generation of TV technology attempts to provide a more realistic picture and sound within the constraints of low-cost, easy-to-use consumer technology.

Here we describe conventional NTSC[1] television, Advanced Television (ATV) systems, and some of their underlying technologies (box 4-l). The convergence of ATVS, computer and telecommunications equipment toward High Resolution Systems (HRS) is discussed later.

CONVENTIONAL TELEVISION: PRODUCTION, TRANSMISSION, AND RECEPTION

Television systems involve three distinct activities: 1) production, 2) transmission, and 3) display of the TV program.

TV cameras begin the process by creating, for each of the three primary colors (red, green, blue), an electronic signal proportional to the brightness of light at each point of a scene. This signal is transmitted immediately or recorded on magnetic tape for later use.[2] The quality of the transmitted picture is determined by the range of frequencies—''bandwidth' —that can be used, and by the efficiency with which the video signal is encoded and then modulated onto this bandwidth.[3] At the receiver, the transmitted signal is reconverted to a picture on the TV screen by scanning electron beams (one for each primary color) across the picture tube and varying their intensity in exact synchronism with the original picture signal.

The 1950s technologies used today to bring color TV pictures to the home have a variety of shortcomings and imperfections that modern systems can correct. TV production formats, established in the 1930s and 40s, were originally based on 35-mm motion picture film. This gave today's TV picture its nearly square shape (or aspect ratio) of 4 units wide by 3 high (4:3). Research has found, however, a strong viewer preference for screens 5 to 6 units wide by 3 units high—as seen in today's theatres—that correspond to the human field of vision.[4]

The original motion picture standard was 16 pictures per second—manually cranked cameras could go no faster.[5] At that rate the viewer saw a significant 'flicker' in the picture displayed (hence the term, the 'flicks' ').[6] In developing TV transmission standards, engineers sought a system that sent pictures often enough that viewers did not see them flickering, yet did not send so many that the needed bandwidth (information carrying capacity) was excessive. The effective picture resolution (or ability to show detail), its color fidelity, and its range of brightness were all limited in order to meet these bandwidth constraints.

Other shortcomings of today's NTSC system include: the blurring of bright colors around the edges; the generation of rainbow colors where brightness varies rapidly, such as striped shirts; and susceptibility to "ghosts," snow, interference from other stations, and image distortions.

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[1]National Television Systems Committee—the group that formulated the B&W and color TV standards in use in the United States today.

[2]Program production includes, of course, editing, the insertion of special effects, audio, etc.

[3]For terrestrial broadcasters, the available bandwidth is set by the Federal Communications Commission (FCC), which brokers competing claims for the limited radio-frequency spectrum.

[4]''Lee McKnight, W. Russell Neuman, Mark Reynolds, Shawn O'Donnell, and Steve Schneider, ''The Shape of Things to come: A Study of Subjective Responses to Aspect Ratio and Screen Size,' ATRP-T-87, MIT Media Lab, May 17, 1988.

[5]Richard J. Solomon, "Broadband Communications as a Development Problem,'' International Seminar on Science, Technology and Economic Growth, OECD, June 6, 1989, Paris. This was later increased to 24 frames per second to give better sound quality.

[6]Cary Lu, "High Definition TV Comes At A High Cost," *High Technology*, July 1983, p. 45.

Box 4-l—Inside Today's NTSC Analog Television

The production of a TV show begins with a TV camera. TV cameras separate the primary colors-red, green, and blue—of the scene with optics and filters and then focus the scene for each color on separate sheets of light-sensitive material. This material generates an electric charge that varies in size by the amount of light that falls on it. The charge on this sheet is then used to control an electron beam that scans across the sheet from left to right and top to bottom-just as we read text. By this means, three "electronic" pictures are formed, one for each color, every 1/30th of a second.

The three pictures thus formed consist of 483 active lines vertically. Each line has the equivalent of about 427 horizontal picture elements.[1] An additional 42 vertical lines and the equivalent of 82 horizontal picture elements could, in principle, be displayed. Instead, the time is allotted to generating vertical and horizontal synchronization, or sync, signals. These sync signals note the beginning of each new picture and of each horizontal line within the picture.

This electronic picture is encoded into a composite signal, including brightness, color, and sound. The composite then modulates the amplitude of a carrier (corresponding to a particular TV channel) which is transmitted over-the-air, through cable, or by other means. To be compatible with B&W TV, the brightness (luminance) signal transmitted is a complicated mix of the Red, Green, and Blue signals and corresponds to the relative sensitivity of the eye to these different hues. The "color" signal (chrominance) contains the rest of the information needed for the receiver to decode these combined signals back into the primary colors.

At the home, the transmitted signal induces a tiny voltage in the TV antenna or provides it directly via cable. The electronic picture, or video signal, is separated from the carrier and amplified. The same sync signals used by the camera now tell the receiver when to start scanning the electron beam across the inside surface of the picture tube for each new picture, as well as for each horizontal line composing the picture. As the electron-beam smoothly scans across the picture tube, its intensity is varied according to the brightness of the image as originally measured by the TV camera, and is thus reproduced on the phosphors of the picture tube. Color TVs do this simultaneously with three different electron-beams, one for each color of phosphor. This type of electronics, where the information content is represented by a continuously varying voltage or current, is known as analog electronics.

This system is much like writing on a blackboard at a distance using a set of strings to pull the pen back and forth. What is written onto the camera is reproduced on the picture tube. If there are errors in the transmission process, they are likewise written onto the TV screen at the other end. With the picture information carried by a continuously varying voltage, it is very difficult to tell if an error has crept in, let alone correct it.

Such a system was all that 1950s electronics technology was capable of. This approach carries with it a variety of impairments, including the use of interlaced scan, errors in displaying colors, an excessive susceptibility to transmission degradations, and inefficient use of the broadcast spectrum.

In developing TV transmission standards, engineers had to send pictures often enough that viewers did not see them flickering, yet did not send so many that the needed bandwidth, or information carrying capacity, was excessive. Both of these were accomplished by showing each picture twice using an "interlaced scan' technique. First, the odd horizontal lines (numbered consecutively from top to bottom) of the picture are sent; next, the even lines are sent. In this way, the 525 lines of today's TV (NTSC) set are displayed half (or a field) at a time, l/60th of a second apart. An entire picture, or frame, is then seen every l/30th of a second-minimizing bandwidth and flicker simultaneously.

Although the vertical resolution of such a picture could be 483 lines, it is normally much lower than this. As one example, when an interlaced scan system displays an odd horizontal line as black and the even line next to it as white, there can be an annoying flicker to the picture every l/30th of a second-easily perceivable by viewers. Consequently, the vertical resolution of the studio camera was reduced to, at most, 330 lines (by

[1] Analog TV does not really have discrete horizontal picture elements, but rather a continuous horizontal scan. The equivalence here is based on the scanning times and picture resolution.

changing the spot size of the scanning e-beam within the camera) and the horizontal resolution was reduced by roughly the same amount. Progressive scan systems, in which every line is sent, odd or even, in a single pass down the picture do not suffer this problem of flicker and can thus give much higher effective resolutions for a given line count.

The transition in the 1950s from B&W to color was achieved by reducing the resolution of the brightness signal and inserting a color signal as described above. This led to a slightly lower resolution for B&W TVs, among other problems. For color TVs, the manner in which the color and brightness signals were intermixed could cause bright colors, especially red, to blur at the edges; and places where the brightness varied rapidly, such as striped shirts and checked jackets, to degenerate into rainbow colors.

In the past, the interference between the brightness and color signals was minimized by further reducing the resolution of the receiver's circuits-to about 250 lines horizontal resolution. In 1978-79, special circuits (comb filters) were introduced which allowed more of the entire range of brightness to be displayed; in 1984, other special circuits were introduced that allowed the entire range of colors to be displayed with somewhat less susceptibility to the above degradations.

Other errors, or artifacts, in today's TV picture are also widely noted. Viewed up close, today's NTSC TV looks like an ant's nest with the dots and lines "crawling" around the picture. These are again due to the manner in which the color and brightness signals are intermixed and subsequently decoded by the receiver. Under certain conditions, NTSC sets have a tendency to switch between different colors. For this reason, the NTSC system has sometimes been disparaged as Never-Twice-the-Same-Color.

The NTSC system is also highly sensitive to transmission degradation. When the broadcast signal reflects off obstacles, viewers may see 'ghosts' and if reception is weak, viewers may see 'snow' or noise.

Finally, the NTSC system uses the broadcast spectrum inefficiently. These old electronics technologies and the use of low-quality home antennas required very strong sync signals to ensure proper operation. Further, the signals transmitted by broadcasters are all in the same format.[2] Because of this, TV stations cannot be operated on adjacent channels within the same geographic region without visibly interfering with each other. Thus, in the VHF band (channels 2-13) stations are separated by one blank-' 'taboo' '-channel; in the UHF band, stations are separated by as many as five taboo channels. These channels have not been usable for other purposes. Improved antennas, and perhaps other changes, might enable significant reductions in the channel and geographic separation requirements at a very small cost. This would enable closer packing of TV channels and might save spectrum for other purposes, but has not been required by the FCC.

Even within the normal 6-MHz bandwidth of a single channel the NTSC signal makes inefficient use of the available spectrum. Much of the available spectrum corresponding to extreme brightness or the most vivid colors, for example, is rarely used. It was such a "hole" in the spectrum that allowed the original B&W NTSC standard to be turned into a compatible color system. By slightly reducing the maximum B&W resolution, all of the color information could be squeezed in. Similarly, the EDTV proposals today offer alternative means of further exploiting NTSC's poor bandwidth use[3] to provide higher resolution and a wider screen without requiring a wider channel bandwidth.

Although the NTSC system has many shortcomings, it was a remarkable achievement in its day. The engineers that developed NTSC were working at the very limits of analog technologies in the 40s and 50s, with an overriding constraint to make the receivers as low cost as possible. Their remarkable achievements resulted in a system that has served us well for 40 years. With today' s technologies, however, we can do better.

References: "TelevisionEngineering Handbook,'' K. Blair Benson (cd.); Trudy E. Bell, "The New Television: Looking Behind the Tube,'' *IEEE Spectrum,* August 1984; Ronald K. Jurgen, ''High-Definition Television Update." *IEEE Spectrum*, April 1988; personal communications: Andrew Lippman, MIT, Aug. 16, 1989; William Schreiber, MIT, Oct. 12, 1989; John Henderson, Sarnoff Labs, Oct. 12, 1989.

[2]The signals are transmitted in the same raster scanned format as generated by the camera. Consequently, they are coherent.

[3]Other inefficiencies in spectrum use by NTSC include: the vertical and horizontal retrace intervals, during which additional picture information could be sent; the manner in which the carrier is modulated, including the use of a separate sound carrier; and the transmission of the entire picture in every frame, including redundant information within and between frames.

ADVANCED TELEVISION SYSTEMS: IDTV, EDTV, HDTV

Modern computer-like digital electronics can reduce many of the defects found in today's NTSC system. Three levels of improvement in television technology are either now under advanced development or are entering commercial markets.

The fiist level is Improved Definition TV (IDTV). IDTVreceivers take the standard broadcast and convert the continuously varying, analog voltage of the NTSC transmission into a digital signal. This digital signal represents the information content of the picture as a series of numbers specifying the color and brightness of each point in the image. A simple example of analog-to-digital conversion is shown in box 4-2.

The advantage of converting the analog broadcast to a digital signal within the receiver is that the picture information can then be manipulated (modified, adjusted, corrected, etc.) by digital signal processing techniques and/or stored in memory. This is similar to the way computers manipulate and store data. Special techniques can be used to reduce flicker, ghosts[7], snow, and other picture imperfections, and to improve apparent resolution and color. NA Philips (Netherlands) began marketing IDTVs in the United States in the spring of 1989.

Extended Definition TV (EDTV) is the next step in the evolution of TV technology. It requires modest improvements in today's TV transmissions and small changes in the broadcast standards. The improved TV signal will still be compatible with today's TVs, and it will not carry so much additional information as to require greater bandwidth than is available in today's 6-MHz TV channel.

EDTVs will use digital memory and signal processing techniques. In most proposals EDTV provides a widescreen picture and somewhat higher resolution than is now possible. Japan was scheduled to begin EDTV broadcasts in 1989, and Europe plans to do so in 1990. Some believe that the improvements in TV picture possible from IDTV and EDTV will significantly reduce the future market for HDTV (ch. 6).

High Definition TV (HDTV) is the third major step up from today's NTSC system. HDTV is typically portrayed as having roughly twice the vertical and horizontal resolution as is theoretically possible for current TVs; a widescreen picture (aspect ratio of at least 5:3) displayed on a large screen; better color; and compact disk (CD)-quality digital sound. The much higher quality pictures of HDTV, however, will require the transmission of substantially more information than current TV systems. The original Japanese NHK production system, forexample, required 30 MHz of bandwidth—the equivalent of five TV channels. To reduce this to manageable proportions, a number of tricks are used, beginning with an analysis of what the human eye can actually perceive.

VISUAL RESPONSE AND HIGH DEFINITION TV

Human vision responds rapidly to the gross details of bright or moving objects, particularly in peripheral vision, but does not perceive their fine detail or color well. Conversely, to perceive fine details or color requires the object to be stationary for longer periods—or for the eye to track a slowly moving object and ''freeze" it on the retina. Thus, efforts to avoid flicker by transmitting all of the color and detail of both moving and stationary images at the same maximum rate, i.e., 60 pictures per second (as an analog TV would), are unnecessary; the eye cannot perceive all of it.

The groups developing HDTV systems have used knowledge gathered in experimental work on visual perception to reduce the picture information that must be transmitted. Digital processing techniques are used to send the picture in low resolution at a rapid rate so that rapidly moving portions of the picture are seen quickly; and to also send the picture in high resolution and full color at slower rates so that the still portions can be seen in detail.[9] The TV receiver then uses digital signal processing techniques to reconstruct the picture in memory, from which it is flashed onto the screen 60 times a second.

These techniques reduce the bandwidth required to transmit the TV picture to a fraction of that of the

[7]Ghost cancellation usually requires adding a special test signal to the transmitted signal.

[8]To transmit this information may require a combination of greater bandwidth, much more efficient encoding and modulation techniques, various digital compression techniques, and good signal to noise ratios, among others.

[9]William F. Schreiber and Andrew B. Lippman, "Bandwidth-Efficient Advanced Television Systems," MIT Media Lab, no date.

Box 4-2—Inside Analog/Digital Television

The various proposals for advanced TV systems use combinations of analog and digital techniques to improve the picture seen on the receiver. The process of generating a picture is described in box 4-1. This process results in an analog signal coming from the camera-that is, with a continuously varying voltage or current proportional to the brightness of each point of the scene.

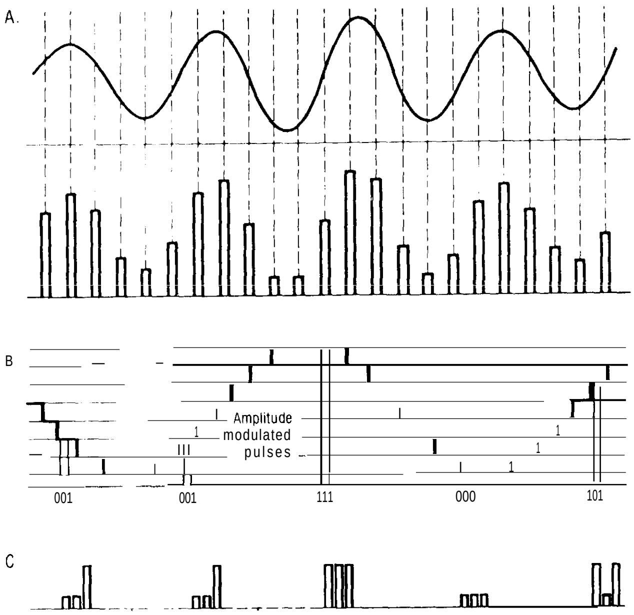
Selected portions or all, as desired, of the analog signal from the camera are then converted into a digital format for storage and/or transmission. In some cases, such as IDTV, the analog to digital conversion is only done in the receiver. A particularly simple example of analog to digital (A/D) conversion is Pulse Code Modulation (PCM).

The PCM process begins by sampling the continuously varying analog signal, as shown in figure 4-1. The sampling rate is usually at least twice the highest frequency of the analog signal. The result is a series of pulses whose amplitudes correspond to the analog signal at regular, discrete times.

These pulse amplitudes are next converted into numerical values by comparing them to a set of discrete amplitude steps. This does introduce errors, depending on how many discrete steps are used and how well the pulse amplitude matches the closest step. This error can be reduced by increasing the number of steps, but at the same time increases the circuit complexity and the amount of numerical information that must be transmitted.

The precision of this quantization is normally given by the number of steps used and is commonly cited in terms of the "bits" of binary information that result, each bit representing an additional power of 2 in the number of steps. Thus, 2 bits equals 4 steps; 3 bits equals 8 steps; 4 bits equals 16 steps; and so on. Some 256 steps, or 8 bits, are usually sufficient to encode the brightness information for each primary color—red, green, and blue-of a studio TV signal. This is a total of 24 bits.

Figure 4-1—Analog to Digital Conversion Using Pulse Code Modulation



A. The analog signal is sampled at regular intervals.
B. The amplitude of these samples is then compared to a set of discrete amplitude steps and converted into numerical values. These values are shown written in binary.
C. The numerical values can then be transmitted in a digital format. Information from other signals can be sent between these samples in a time division multiplexed format.

SOURCE: Kamilo Feher, *Advanced Digital Communications: Systems and signal Processing Techniques* (Englewood Cliffs, NJ: Prentice-Hall, Inc., 1987). Used with permission.

The binary information representing the picture can now be stored in a computer-like memory, manipulated, or transmitted with little degradation. Each "bit" of information, for example, can be transmitted as either "on" or "off." At the receiver, even if the amplitude of "on" was greatly reduced or distorted due to transmission problems, the receiver can usually still detect that it was ''on' and correct its value to the nominal level. In contrast, an analog receiver normally has no way of knowing whether or not a signal is distorted. It can only reproduce what it receives, errors and all.

In two-way transmissions of data, such as by a modem, a digital signal can also include information that tells the receiver how to check for errors in the transmission. For example, eight bits of information could be sent with a' 'parity" bit. The "parity" bit is "on" if the number of 1s" sent is even; "off" if the number of "1s " sent is odd. The receiver can check to see if the number of 1s' received and the parity bit correspond. In this way, at least some of the transmission errors so serious as to cause "on" to appear "off" and vice versa can be detected. More complex techniques will be used to reduce the number of errors in transmitting HDTV pictures and to ensure the correct transmission of critical components of the signal.

(continued on next page)

Box 4-2—Inside Analog/Digital Television-Continued

The basic digital signal for an HDTV picture carries an enormous amount of information-as much as 1.2 billion bits per second (1.2 Gbps). In comparison, a phone conversation uses less than 64 thousand bits per second (64 kbps). A personal computer uses just 16,000 bits of information internally to represent a screenful of text and, on a standard monochrome monitor, just 250,000 bits are needed to display this text—which often remains unchanged for long periods while one ponders what to write next. [1] To transmit the total 1.2 Gbps of the HDTV signal requires far more bandwidth than is available in all but the most advanced fiber or short-haul cable systems. Thus, digital signal compression techniques are used to make transmission to households practical.

Digital signal compression eliminates the redundant information in a signal. For example, a large expanse of blue sky in a picture carries little or no new information from one point to the next. Special ''intraframe'' compression techniques effectively tell the receiver that these picture elements are the same, and allow the repetitious "blue sky," "blue sky," . . . information to be eliminated.

Similarly, the stationary portions of a picture do not change from one frame to the next. There is no need to transmit such redundant information 60 times per second in full detail. In fact, if nothing moves no new information need be transmitted at all. In this case, one frame is compared to the next to do ''interframe compression' and only the differences are transmitted. Interframeprocessing, however, may result in other types of errors such as inaccurate depiction of moving objects.

As already noted, the eye is least sensitive to the color and detail of those parts of the picture which are moving. This information can be reduced simply by sending the rapidly moving portions at lower resolution.

Together, these techniques greatly reduce the information content of the transmitted signal and, in fact, make the transmission of HDTV pictures practicable. The Japanese MUSE HDTV system, for example, reduces the signal bandwidth from 60 to 8 MHz using such techniques.[2] Digital systems might reduce the information content from some 1.2 Gbps to 70-80 Mbps. Subsequently, the transmitted signal is decoded and turned back into a viewable picture in the receiver.

In some cases, it may also be desirable to fit additional information into the HDTV signal. This is illustrated in figure 4-1. This technique is known as "time division multiplexing" and is especially valuable in cases where the transmission media is filled close to capacity or is being used inefficiently.

TVs that use analog electronics alone cannot do this type of image manipulation. Because analog signals vary continuously, it is impossible to do such signal compression before transmission, to catch and correct transmission errors, to recreate the picture in memory at the receiver, to multiplex the signal, or to do a host of other advanced signal manipulations, Instead, purely analog systems are constrained to simply write the picture as transmitted directly on the screen, like chalk guided by a string.

References: Kamilo Feher, "AdvancedDigital Communications"; " Television Engineering Handbook,'' K. Blair Benson (cd.); William Schreiber, various papers, op. cit.; Submissions to the FCC, various. Dale N. Hatfield, "Report on the Potential for Extreme Bandwidth Compression of Digitized HDTV Signals," Mar. 20, 1989; "Television Technology Today, " Theodore S. Rzeszewski (cd.). Other references as in box 4-1.

[1] A screenful of text has 25 rows by 80 characters per row and 8 bits per character when handled as ASCII text internally. A standard graphics based monochrome monitor has 720 by 348 pixels, each either "on' or 'off.' Assuming that the text on the screen remains unchanged, this requires 250,560 bits to represent. If the text was being changed at 60 times per second, the data rate would be 15 Mbits per second.

[2] This total is for the component signals-30 MHz for lumina rice, 15 MHz for Red, and 15 MHz for blue. Larry Thorpe, Sony Corp., personal communication, Oct. 12, 1989.

basic unprocessed analog signal. Only the use of these and other (box 4-2) digital signal processing techniques makes HDTV practical. Such digital signal processing, however, comes at a price. In general, the greater signal compression required to reduce the bandwidth, the greater the complexity and cost of the receiver's electronics needed to decode the signal. In large-scale production, today's semiconductor technologies can minimize these added costs.

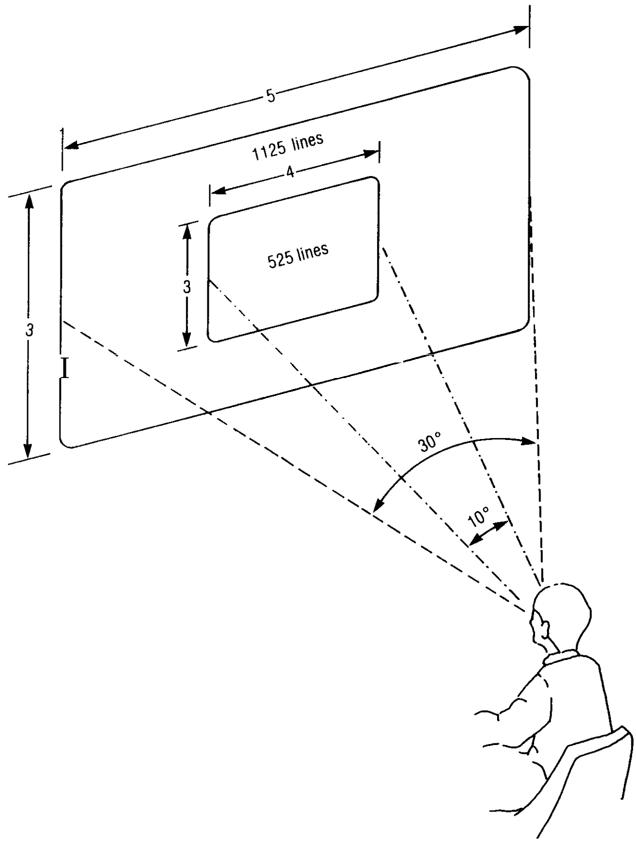
It is uncertain whether or not such visual tricks will work as well on the large screen that will likely be used for HDTV. Some note that, especially on large screens, the eye is able to track relatively slow-moving objects and freeze them on the retina. In such cases, the digital signal processing might remove visual informati'on that the eye does perceive—reducing the visual quality of the picture.

The most important attribute of an HDTV may be the much larger field of view it provides. The region of greatest visual acuity of the human eye is within the central one degree of the visual field. Viewers tend to move away from the screen to view moving objects in order to maximize the ii-action of the image within this central one degree field, and stop when the details of the image begin to be lost. The ideal viewing position for an NTSC set (525 lines) is experimentally found to be roughly 7 screen heights from the receiver, providing the viewer an 8 by 11 degree field of view. For the typical HDTV system (1125 line Japanese system), the preferred viewing distance is found to be about 3.3 screen heights away, providing the viewer a 17 by 28 degree field of view. These are compared in figure 4-2.

Thus, viewers position themselves for roughly the same resolution on the eye, but they have a much larger viewing angle with HDTV, contributing to a sense of "telepresence."[10] Although the higher resolution and picture quality of HDTV would be visible on a smaller screen TV, there would be less incentive to purchase such an HDTV. It would not provide the same sense of telepresence, and many people would find it difficult to focus on or experience discomfort if close enough to benefit from the higher resolution.

"Telepresence' or the sense of "being there" is a potentially powerful market inducement for large screen, high resolution displays. An example of this sense might be the feeling, when viewing a very high-quality motion picture screen up close, of moving with the airplane or roller coaster when it makes a fast turn, or of unconsciously putting your foot on the brake to prevent an accident. In watching sports, it allows one to have a greater sense of being in the stadium itself-being able to watch clearly and in detail the entire scene of a quarterback completing a pass to a receiver, rather than relying on instant replays of the separate tight closeups of the quarterback and receiver that are used today.

Figure 4-2-Comparison of the Field of View for an HDTV and Today's NTSC TV To Have the Same Resolution for the Viewer



SOURCE: William E. Glenn and Karen G. Glenn, "High Definition Transmission, Signal Processing, and Display," paper presented at the SMPTE Conference, San Francisco, CA, January 1989. Used wfth permission.

HDTV SYSTEMS: PRODUCTION, TRANSMISSION, RECEPTION

The key attributes of HDTV-twice the resolution of today's television, a wider screen, truer color, and digital sound-will require significantly more information to be transmitted than is currently the case. This cannot be done while simultaneously remaining compatible with today's TV receivers and charnel bandwidths. Significant changes are necessary in production, transmission, and reception standards and equipment to achieve such high definition pictures.

[10] William E. Glenn, "High Definition Television," Society for Information Display, 1988.

Production Standards

Today's production standards are based on 24 frame per second motion picture film or on video tape for television. Although the different world standards for color TV—NTSC (USA, Japan), SECAM (France, Eastern Europe), and PAL (Western Europe)-vary in their frame rate and number of lines scanned[11], equipment to convert from one standard to another (transcoding) with little loss in quality has been technically quite successful. The most difficult aspect of transcoding is to convert between formats with different frame rates. This requires interpolation between pictures in order to show motion smoothly. The conversion from interlaced scanning to progressive scanning has also been difficult.

Lower-cost and more flexible electronic video production systems will become increasingly important in coming years. Such systems will compete with film for many applications and complement cinema photography in cases such as special effects.

Each medium—NTSC, HDTV, and film—has its own artistic "look and feel" according to its technical characteristics and format. NTSC video tape, for example, can generate the afternoon soap opera' look under various conditions. This is due to the sensitivity and response characteristics of the electronic camera used. The low resolution of NTSC systems also forces the program producer to emphasize closeups or tight shots of the actors.

In contrast, the greater sensitivity, color, and brightness range of film and the better match of film's response to that of the human eye gives film a much more natural look for scenery; its higher resolution allows the producer to step back and use more wide-angle views. These characteristics give different artistic feels to the media, which are likely to persist well into the HDTV era.

In the longer term, however, electronic capabilities are likely to bring video media closer to the capabilities of film. In addition, electronic media offer advantages over film by eliminating processing and allowing, in the filly digital case, an endless number of overlays of special effects or addition of other material. These potential new applications and cross-technology interactions highlight the importance of production standards.

Although it is now unlikely that a single world standard for HDTV production will be adopted (ch. 2), international program exchange standards may yet be developed that allow easy transcoding from one system to another.[12]

Transmission Systems

HDTV transmission systems must take into account a variety of media as well as different degrees of compatibility with existing receivers and channel requirements. Although the U.S. communications infrastructure includes cable, satellite, VCRs, and will someday encompass fiber to the home, terrestrial broadcasting has been the major focus for U.S. HDTV development. This is due to its market importance and the constraints it faces in spectrum allocation. The technical requirements for terrestrial broadcasting are also significantly different than for the Direct Broadcast Satellite systems approach followed by Japan and Europe.

The FCC has received nearly 20 proposals for terrestrial transmission standards, although only a handful of these appear likely to be developed. These proposals encompass such issues as: the degree of compatibility with existing NTSC receivers and the current channel bandwidth; the means of adding additional information needed to improve picture resolution, including the video encoding technique; methods of widening the picture; and the manner in which the picture is scanned-interlaced or progressive.[13] In general, the proposals can be grouped in the following four categories: NTSC Receiver-Compatible HDTV; Channel-Compatible or Simulcast HDTV; Alternative Media HDTV; and Non-Compatible Recorded Media HDTV.

In September 1988, the FCC tentatively ruled that broadcasters must continue to transmit signals that can be received on today's TVs; and that no additional radio spectrum would be allocated for HDTV broadcasting outside the existing spectrum

[11] NTSC shows 59.94 fields per second in a 525 line interlaced scan, or equivalently, about 30 frames per second. SECAM (Sequential Color with Memory) and PAL (Phase Alternation by Line) show 50 fields or 2S frames per second at 625 lines per frame.

[12] W.F. Schreiber, "A Friendly Family of Transmission Standards for All Media and All Frame Rates" (Cambridge, MA: Massachusetts Institute of Technology, Feb. 12, 1989), draft.

[13] See, for example: "FCC Advisory Committee on Advanced Television Service: Systems Subcommittee, Interim Report," Apr. 10, 1989.

allocations for TV.[14] Together, these effectively rule out noncompatible HDTVS such as the original Japanese MUSE system, but would allow either the receiver-compatible or simulcasting approaches for terrestrial broadcasting (box 4-3).[15]

Today's TV audience views a picture far worse than what is theoretically possible, and might easily mistake a studio quality NTSC picture for HDTV. NTSC is susceptible to a variety of transmission problems-ghosts, snow (noise), interference from other stations, etc. (box 4-l). Further, NTSC does not use the available spectrum efficiently: more information could be packed into the existing bandwidth; and large amounts of spectrum are unusable—every other channel in VHF and typically five out of six channels in UHF are not used because of interference problems. To the extent that EDTV and HDTV require compatibility with the existing NTSC system, they could lock in these technical flaws for many years in the future. Better antennas and modem electronics can reduce some of these problems. Development of a new system, however, might achieve far more.

Box 4-3—Levels of Receiver Compatibility

0. The current receiver is unable to display, in any form, HDTV transmissions; the HDTV receiver is unable to display NTSC transmissions.
1. An adapter box can be purchased separately so that existing NTSC receivers can display HDTV transmissions at the NTSC level of quality; HDTV receivers can display either HDTV tmnsrnissionsat high definition or NTSC transmissions at NTSC quality.
2. An NTSC system can display HDTV transmissions at somewhat reduced quality compared to conventional transmissions. This is what happened in the conversion from B&W to color broadcasts. HDTV receivers, as above.
3. An NTSC can display HDTV transmissions at the same quality as a normal NTSC transmission; HDTV receivers, as above.

NTSC Receiver-Compatible HDTV

The transition from B&W TV to Color TV was done by altering the NTSC signal to include color while degrading the performance of B&W sets receiving color broadcasts only slightly-thus maintaining compatibility. This is also the most frequent proposal for making the transition to HDTV. The inefficiency of the current NTSC signal, however, means that only modest improvements can be achieved in the picture while staying within the current 6-MHz channel bandwidth. (The 6-MHz, NTSC-compatible HDTV proposals are here termed EDTV.)

HDTV quality and full receiver-compatibility require additional spectrum. The full 6-MHz channel (with some modifications) plus an additional one-half or full channel (3- or 6-MHz) someplace else in the spectrum must be used to augment the signal and to provide the additional detail needed for a high-quality picture. Standards proposals of this type include those from: Faroudja Labs (U. S.), Japan Broadcasting Corporation (NHK), MIT (U.S.), North American Philips (Netherlands), Sarnoff Labs for Thomson (France) and NBC.[16]

Channel-Compatible or Simulcast HDTV

An HDTV-quality picture could be broadcast within the current 6-MHz channel bandwidth, but only if the constraint of NTSC-compatibility is removed so that the bandwidth can be used more efficiently. In this case, a standard NTSC signal would be transmitted with no changes on one channel; an HDTV signal would be simulcast independently on another channel. With proper design of the signal, now unused "taboo channels" could likely provide the needed broadcast spectrum for such simulcasts. Over a long period of time, the conventional NTSC channels could be gradually phased out and replaced with the simulcast signal alone. The portion of the spectrum vacated could then be used for the next generation of television technologies or for other uses such as mobile communications.

Zenith and MIT are the principal proponents of such systems, with NHK (Japan) also recently offering a simulcast system and North American Philips announcing that they are developing one.

[14] Individual broadcasters could receive additional spectrum to augment their signal from within the current bands for TV broadcasting, however.

[15] Federal Communications Commission Record, FCC 88-288, 3 FCC Rcd No. 23, Sept. 1, 1988.

[16] Other initial proposals of this type but since withdrawn include the Broadcasting Technology Association of Japan, the Del Rey Group, and the New York Institute of Technology.

These latter proposals indicate the increasing attention and interest in the simulcast approach.

Alternative Media HDTV

These systems are designed for use with media other than terrestrial broadcasting. They are primarily oriented toward satellite broadcasts. NHK (Japan), North American Philips (Netherlands), and Scientific Atlanta are among the proponents of such systems.

Noncompatible Recorded Media

HD-VCRS or HD-Video disks in the noncompatible Japanese MUSE format might be introduced in the United States as early as 1991. These systems do not require FCC approval, but are a concern to broadcasters because they might accelerate the ongoing erosion of broadcasters market share. As a result, these media have been an important driving force behind the current FCC study of advanced television.

Receivers for HDTV

The various proposals for HDTV receivers respond to the current debate over transmission standards-speci.flea.lly, whether the transmission system will be receiver-or channel-compatible, and whether there will be one standard or many for the different media. Receivers now envisioned can be classified as “closed,” “**multiport,**'' ‘‘open,’ or ‘‘smart.

Closed Receivers

Closed receivers are similar to those used today. They are possible only if a single standard is set industry-wide for all media. Such a system has no flexibility to allow future changes in broadcast standards or to allow later options to be added to the HDTV without substantial modifications to the receiver.[17]

Over the near-term, these systems might cost somewhat less than more flexible designs discussed below. The current rapid pace of technological change might, however, make closed systems quickly obsolete-increasing the costs to consumers over the longer term.

Multiport Receivers

Multiport receivers will have multiple jacks or inputs that could accept several incompatible signals: one for terrestrial broadcasts, a second for cable, a third for DBS, and so on. Such HDTVS would have less flexibility to adapt to future changes or to allow the addition of various options than those described below. The costs of multiport (and other) receivers may be increased if they must accommodate several radically different standards.

Open Architecture Receivers

These receivers would be designed to accept a variety of standard plug-in circuit boards. The sets could be modified over time (at a price) to accept a wide variety of signals and standards, yet properly display the picture. These systems might also be adapted to provide other services-such as home computing and telecommunications-just as today’s personal computers can have circuit boards added to increase their versatility and power. Open Architecture Receivers might also create new business opportunities for third-party vendors of equipment and services.

Opponents of the Open Architecture Receiver argue that this approach would increase costs and complexity for users. Proponents point out that the rapid changes in technology demand flexible open systems and that such systems may ultimately lower overall costs to users. Nor are such systems necessarily complex. A simple channel selector and volume control like today’s can be provided for those who want only to watch TV.

‘‘Smart’’ Receivers

Smart receivers are the most technologically advanced receivers currently conceived. They would adjust to a wide variety of transmission standards by automatically decoding the transmission format. Such sets could even adjust to a format that varied according to the type of material displayed—scenery with little motion could be shown in very high resolution, whereas rapid action sports would emphasize the display of motion.[18] Smart receivers would probably be more expensive for the near term

[17]The original NTSC standard has been upgraded overtime-with color, stereo, closed captioning, etc. However, the rapid changes in communications technologies and electronics capabilities suggest that much more dramatic changes may be possible in the near future.

[18]William F. Schreiber and Andrew B. Lippman, ‘‘Single-Channel HDTV Systems, Compatible and NonCompatible,’' Massachusetts Institute Of Technology, Mar. 11, 1988.

due to the high cost of the electronics required for such advanced data manipulation.

HIGH-RESOLUTION SYSTEMS AND TECHNOLOGIES

The evolution of television technology towards digital electronics is converging with the evolution of computing towards multi-media presentations (including text, data, graphics, and full-motion video) .19 The underlying storage, processing, transmission, and display technologies of high-resolution entertainment video and multi-media computing are becoming largely indistinguishable.[20]

All of these technologies which emphasize high-quality imaging or displays can generically be termed High Resolution Systems (HRSs). HRSs encompass an enormous range of markets-ATVs generally and HDTV in particular; multi-media PCs; engineering workstations; scanning and imaging equipment for electronic document storage; digital photocopiers and facsimile machines; and many others.

The applications of HRSs are equally diverse. These could include: video entertainment (HDTV), interactive video systems, electronic imaging for document storage[21], desktop publishing, graphics for engineering workstations, and many others. Many foresee these markets merging. For example, an HDTV/PC might be able to receive or record an HDTV program, search a video database, or include a video clip in a report along with text and graphics. Such systems are potentially interactive, allowing the HDTV/PC viewer to request additional information of a news clip, or even to mod@ the picture being watched.

HDTV plays a particularly important role in the development of High Resolution Systems. HDTVS must handle enormous information flows and so require immense processing power. These demands make HDTV a significant driver of certain technologies (ch. 5). The high demand for video entertainment may aid the penetration of these powerful systems into the residential market. This might allow the HDTV/PC of the future to become the home terminal-an 'information appliance' '-on a national fiber network. It is this vision of the information society of the future that is being promoted by MITI and MPT (ch. 2). Whether or not HDTV can fulfill such a role in the United States is a matter of public debate (ch. 6).

[19] "Moving Beyond VGA," *Electronics,* July 1989.

[20] There are, of course, differences in terms of the signal transmission formats, receiver processing, and the brightness and size of the display, ete.

[21] "Imaging," *Electronics,* July 1989.