HDTV

HDTV promises to change the way we experience television. This article looks at the advent and specifics of the technology, and the opportunities it presents to those in optics.

Re-inventing Television for the Digital Age

By Glenn A. Reitmeier

It's official: the future of television is digital. That's the significance of the December 1996 landmark Federal Communications Commission (FCC) decision, which adopted a new U.S. technical standard for the terrestrial broadcast of digital television. By the time this article appears, there should be 26 digital TV (DTV) stations preparing to broadcast, or on the air, in major markets. By November 1999, the top four stations in each of the 30 largest cities are required to provide DTV service, reaching over 50% of U.S. homes.[1]

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In mid-2002 all commercial stations will offer DTV, with all public stations following suit by mid-2003. Analog broadcasts will likely phase out late in that decade. DTV is already coming at us from space; mini-dish satellite receivers have been with us for several years now, and this fall, direct satellite subscribers nationwide will also have access to two channels of high-definition television (HDTV), DTV's highest resolution pictures. And finally, cable operators around the country will also offer DTV as soon as their systems are ready.

The new digital system is highly flexible, enabling not just better, but more, television. It gives broadcasters the ability to offer four separate programs at today's picture resolution over a single channel. Several broadcasters have announced plans to use this "multicasting" procedure to offer more choices to their daytime hour viewers.

DTV also has a sophisticated data broadcast capability, meaning broadcasters can include a stream of data with every broadcast. The data might include text, pictures, audio, stock quotes, or even different camera angles. Data will travel to a viewer's set at speeds of at least 500 Kbps, or 10 times as fast as standard modems. If the programs do not require the full 19.4-Mbps bandwidth of the channel they're on, data streams can be expanded to even higher speeds.

All of these capabilities are far beyond anything our 50-year-old, one-program-per-channel analog system can offer. This article concentrates on HDTV—the crown jewel of DTV's feature set—exploring its roots, the technologies behind it, and some of the implications it holds for the optics and photonics fields.

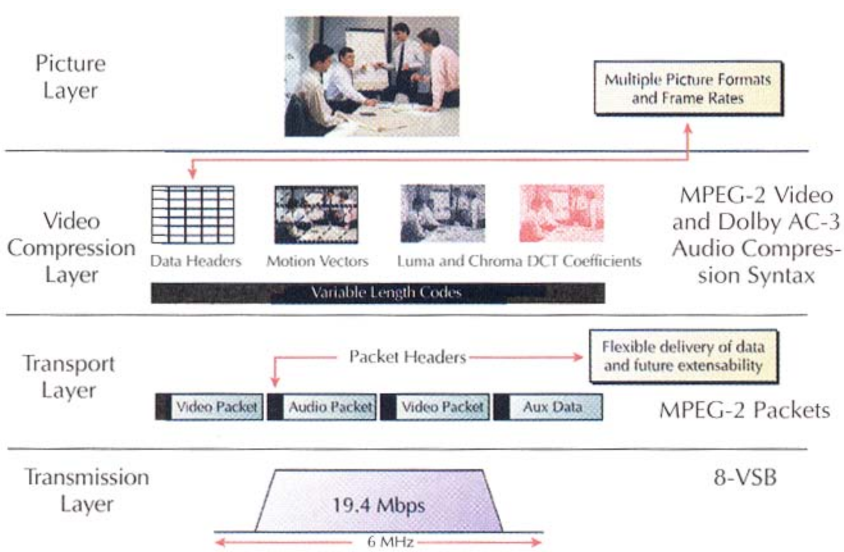

Figure 1. Layered architecture of the Grand Alliance HDTV system.

How the U.S. HDTV standard evolved

From the viewer's perspective, HDTV is as much an advance over our current NTSC analog system as the CD was over vinyl records. Few people can imagine the impact of HDTV until they see it, with its perfect, snow- and ghost-free pictures with five times the information of an NTSC screen. Presented on a wide 16:9 aspect ratio screen, it's more like a movie screen than today's virtually square television. And it's accompanied by an enveloping CD-quality surround sound field. The combination can be an overwhelming experience, especially on a large screen.

The concept of HDTV was pioneered in Japan in the late 1970s and early 1980s. During the mid-1980s, development of analog HDTV systems continued in Japan and Europe. But despite advances in cameras and production equipment, one fundamental problem remained—how to transmit the signal. In early 1987, U.S. broadcasters petitioned the FCC to reserve spectrum for terrestrial broadcasting of HDTV. As a result, the Advisory Committee on Advanced Television Service (ACATS) was formed in August 1987, with a charter to recommend a standard to the FCC for approval. This began a competitive process of selecting an appropriate transmission standard. Over the course of the next three years, ACATS explored over 23 proposals for analog systems. Some systems sent slightly improved television over a single broadcast channel. Others used two standard channels to transmit HDTV. Then, in 1990, the FCC made a startling announcement, asking for a system that achieved full HDTV in a single channel. They also required that the signal be available in the so-called "taboo" channels—the ones left vacant to avoid interference with signals in neighboring broadcasting regions.

None of the proposed systems could meet these requirements, which seemed impossible. But within a year, four radically new digital systems were announced by competitors that included both individual organizations and teams. Each offered clever technical solutions to squeezing an HDTV signal into the narrow 6-MHz space of a standard broadcast TV channel. All four digital systems were extensively tested in 1992, but there was no clear winner. So in 1993, seven former competitors created the Grand Alliance for Digital TV. Working together, they began a collaborative effort with ACATS to combine the best individual features of each system into the best overall HDTV system possible. The result of this cooperation is the HDTV system we have today, the highest performance, most flexible television system ever invented.

Grand Alliance System overview

The Grand Alliance HDTV (GA-HDTV) System is a layered digital system (see Fig. 1). One advantage of layering is that elements of the system can be combined with other technologies to create new applications. Another advantage is that modular receiver designs can be created that offer enhanced capabilities and features. Each layer supplies significant capabilities to the system. Below are some of the most important.

Picture layer

The picture layer consists of pixel-oriented data, organized as pixels, scan lines, and frames. These elements contain all the information needed to repetitively show frames and present a moving picture. At the picture layer, the HDTV transmission standard strives to be easily interoperable with a wide variety of existing pixel for-

Spatial Format (X × Y active pixels)	Aspect Ratio	Temporal rate
1920 × 1080 (square pixels)	16:9	23.976/24 Hz progressive scan 29.97/30 Hz progressive scan 59.94/60 Hz interlaced scan
1280 × 720 (square pixels)	16:9	23.976/24 Hz progressive scan 29.97/30 Hz progressive scan 59.94/60 Hz progressive scan
704 × 480 (CCIR 601)	16:9 or 4:3	23.976/24 Hz progressive scan 29.97/30 Hz progressive scan 59.94/60 Hz interlaced scan 59.94/60 Hz progressive scan
640 × 480 4:3 (VGA, square pixels)		23.976/24 Hz progressive scan 29.97/30 Hz progressive scan 59.94/60 Hz interlaced scan 59.94/60 Hz progressive scan

Table 1. ATV Formats.

mats, including those used in motion picture film, on currently available HDTV production equipment, in the current analog NTSC television standard, and on computers. The two high-definition pixel formats provided by the GA-HDTV system are 1920 × 1080 and 1280 × 720. Each format has a wide 16:9 aspect ratio, with square pixels important for computer interoperability.

There are also two standard definition (SDTV) formats. The 704 × 480 format is currently used in television production. The standard for DTV supports both wide-screen (16:9) and conventional (4:3) aspect ratios in this format; this preserves compatibility with existing television equipment. The 640 × 480 VGA computer format (4:3) provides simple interoperability with VGA format text and graphics. Table 1 shows the complete set of ATV formats standardized by the ATSC.

To be flexible and interoperable with television, film, and computers, the GA-HDTV system also provides three different frame rates; 60-, 30-, and 24-Hz. All combinations of pixel format and frame rate are progressively scanned except for the highest combination (1920 × 1080 at 60-Hz), which is interlaced. This interlaced format is preferred for some types of picture material, such as that used for much entertainment television, and provides interoperability with existing interlaced sources. Note that just as conversions can be performed among various pixel formats, an interlaced scan can be converted to a progressive scan by a de-interlacing filter that "fills in" the alternate lines. The GA-HDTV system thus provides for multiple formats and frame rates, all of which will be decoded by any GA-HDTV receiver and converted to its own native display format.

Compression layer

The compression layer of the system transforms the raw video and audio samples into a coded bit stream. This data is then compressed to only 2% of its original volume. The video compression syntax conforms to the International Standards Organization video data compression standard called MPEG-2 (for Motion Picture Experts Group, the industry committee that created it). It produces a nominal video data rate of approximately 18.5 Mbps.

A good analogy for video compression is frozen orange juice concentrate. Orange juice processors squeeze most of the water out of the juice, reducing it to one-fourth its original volume, so it can be shipped in smaller packages. The buyer reconstitutes the product by adding water. To achieve the bit rate reduction required for outstanding picture quality at the 18.5 Mbps available in a 6-MHz television channel, the GA-HDTV system exploits modern, sophisticated video compression to squeeze out repetitive data. Full HDTV requires a 50:1 compression before transmission. The receiver then uses sophisticated algorithms to restore the picture to full HDTV.

The compression layer also uses Dolby Digital audio compression (formerly known as Dolby AC-3). Developed by Dolby Labs, this so-called 5.1 system squeezes five channels of surround sound—including left, right, and center front channels, left and right rear or surround channels, plus a low-frequency effects (subwoofer) channel—into a nominal data rate of 384 Kbps. The Grand Alliance's use of MPEG-2 video compression also allows HDTV devices to interoperate directly with MPEG-2 and MPEG-1 computer multimedia applications at the compressed bit stream format. This means, for example, that consumer HDTV-VCRs can produce an output bit stream that can be input to a multimedia computer, and that HDTV receivers can be interfaced to CD-ROMs containing full-motion video. There is still work to do in establishing the appropriate interfaces, but using a common compression standard clearly makes interoperability much easier.

Transport layer

The transport layer is the key to the flexibility of the GA-HDTV system, since it defines the basic format of data packets. This packetization serves many purposes. It

- packages the data into fixed-size units suitable for forward error correction encoding,
- multiplexes the various media elements (video, audio, data, etc.) of a program into a single bitstream,
- provides time synchronization for those elements, and
- provides flexibility and extensibility with backward compatibility.

The transport layer of the Grand Alliance system uses a fixed length packet format. The packet is 188-bytes long, consisting of 184 bytes of payload and 4 bytes of header data. Each packet contains a single type of data (video, audio, program guide, etc.) identified by the packet's ID number (the PID). This approach separately packetizes video, audio, and auxiliary data. It also provides the basic multiplexing needed to provide data streams that

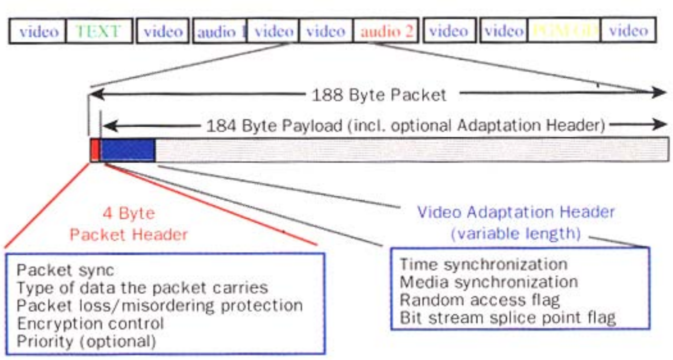

Figure 2. The Grand Alliance/MPEG-2 transport layer uses fixed length packets with 4 byte-headers to multiplex video, audio, and auxiliary data streams. Many services can be dynamically multiplexed and delivered to the viewer.

nominally include video, five-channel surround-sound audio, and an auxiliary data capacity (see Fig. 2, page 33).

However, there is no predetermined mix of data that is required, and the mix can change dynamically from moment to moment. In fact, the entire channel capacity can be reallocated in bursts for data delivery. This capability could be used to distribute decryption keys to a large audience of receivers during the seconds preceding a popular pay-per-view program, or download program-related, computer software to a "smart receiver."

This structure gives us the potential to extend the system to answer future demands for services that we cannot anticipate today. The key to this capability is the ability of the transport architecture to provide open-ended extensibility for new services. New elementary bit streams can be handled at the transport layer without hardware modifications: by assigning new PIDs at the transmitter and filtering on these new PIDs in the bit stream at the receiver. Backward compatibility is assured when new bit streams are introduced into the transport system since existing decoders will automatically ignore new PIDs. This capability could possibly be used to compatibly introduce 1,080-line progressive formats or 3D-HDTV by sending augmentation data along with the normal ATV data.

Transmission layer

The transmission layer modulates ones and zeros of the serial bit stream into a multi-level signal suitable for transmission over a 6-MHz analog channel. The GA-HDTV system uses a trellis-coded 8-level vestigial side-band (8-VSB) modulation technique. Each 8-VSB symbol occupies one of eight different levels, conveying three bits of information for every symbol transmitted. Trellis coding provides the ability to deliver approximately 19.4 Mbps in the 6-MHz terrestrial simulcast channel. Digital systems make it much easier to achieve interoperability at the transmission layer. Thus, it is anticipated that DTV receivers will not only be designed to receive terrestrial broadcasts, but that cable and satellite reception capabilities will be included as these industries embrace DTV.

Impact on optics

The commercial success of the U.S. DTV standard will likely have a substantial impact on at least two different aspects of optics and photonics. First, the higher resolution provided by HDTV formats and the freedom from artifacts (snow, ghosts, other interference) provided by digital transmission will tend to reinforce and accelerate the trend to larger screen sizes and the use of projection systems. As a result, as sales of DTV receivers overtake and eventually replace those of analog sets, a higher proportion of sets that feature high resolution projection optics systems can be expected. To give some idea of the potential magnitude of this shift, U.S. sales of all analog televisions currently exceed 15 million units per year.

However, there are still some technical challenges to be resolved. Projection systems need both high resolution for HDTV and high brightness for a brilliant picture. But an increase in resolution tends to produce a corresponding decrease in brightness. New display technologies to minimize these difficulties are now under development, and industry competition to come up with a practical, low-cost display with the desired attributes will no doubt be heightened by the potential for sales of new HDTV sets.

The second major area in which HDTV influences the optics and photonics professional is optical fiber. Since the new era of TV will be digital, the production and distribution of DTV programming will promote extensive use of computer-like networking. This will take place within the television studio, in post-production facilities, and on distribution links between various studios and networks.

The packetized data format of DTV facilitates its transmission over ATM/SONET and fiber channel optical fiber networks. The first successful demonstration of this capability occurred in late 1995, when the Grand Alliance sent its signal over the Bell South ATM network in North Carolina. With its demand for bandwidth, and with the certainty of its widespread use in the future, DTV promises to fully use the expertise of the optical networking community, and perhaps even provide opportunities for further developments in this field.

Bumps in the road

HDTV still has some hurdles to overcome. The biggest technical issues are probably in the studio and broadcast areas. The basic technology for assembling and broadcasting programming is either in place or coming on line. But the advanced "studio-without-walls" concept made possible by digital technology hinges on the ability to transport, store, and seamlessly integrate material from several different sources, including network feeds, live local material, stored material, and station logo overlays. This is complicated by the fact that all of these materials may be in different picture formats and at different bit rates. Barrier-breaking work is in progress today to create efficient and cost-effective ways of managing all of this seamlessly, without sacrificing picture quality.

Market issues also stand in the way of fast acceptance. The first HDTV sets will be very expensive—around $7,000 for a 60-inch diagonal rear-protection model. A great deal of work in optics, electronics, and other aspects of set design is needed before the new medium is truly affordable as a mass consumer electronics product. The second market problem is the issue of how to send DTV and HDTV over cable. Although the technology is available, some cable systems will require upgrading before they can carry additional digital channels. Economic and policy issues could also delay introduction via cable.

Future views

The advent of DTV, and especially of HDTV, opens exciting new vistas for everyone involved in television, communications, computers, optics, and photonics. The technology is so new that we have only begun to explore its potential applications. But one thing is certain: it holds the promise of a new world of information and entertainment, in which all media appliances—from computers and TVs to set-top boxes and peripherals—will share not just text or data, but voices, images, and motion.

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WebTOP

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Fresnel diffraction

This module has three separate submodules: Fresnel Single Slit, Fresnel Double Slit, and Fresnel Circular. In these submodules, light is incident upon an aperture or a set of apertures, and the corresponding intensity pattern is viewed on an observation screen. The user can vary the properties of the incident light, the locations and sizes of the apertures, and the location of the observation screen.

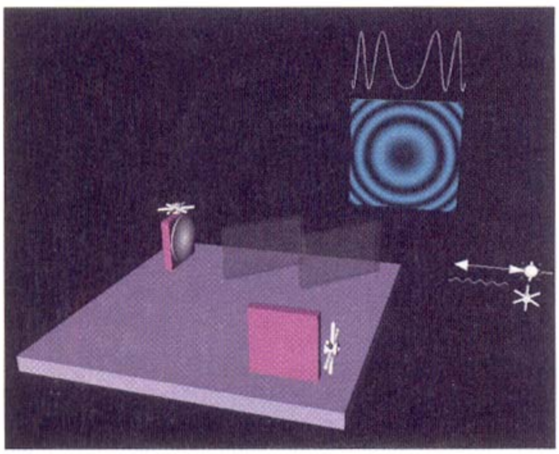

Figure 1. In TOP's Michelson Interferometer submodule, the wavelength of the light is 450 nm and the path length difference is 1200 wavelengths. The white curve is a plot of the intensity as a function of position across the center of the pattern.

3-D interactivity

Unlike most educational software programs, TOP's interactivity is accomplished by having the user interact with 3-D "widgets" in the scene. Consider the Michelson Interferometer submodule pictured in Figure 1. Here the white bulb represents a monochromatic point source located at this position. The wheel below it is a 3-D widget: by clicking on the wheel and rotating it, the user can increase or decrease the wavelength of the light emitted by the source. Similarly, for the interferometer's translation mirror (the mirror in the foreground) the wheel attached to its side allows the user to move the mirror back and forth. The wheel on top of the interferometer's tilt mirror allows the user to tilt that mirror. Finally, the user can drag and resize the observation screen with the cursor. This direct manipulation in the 3-D scene contrasts with conventional input through sliders and text-entry boxes positioned outside the scene window.

WebTOP

The WebTOP version of the Fresnel Diffraction Single Slit submodule running inside a Netscape browser is pictured in Figure 2. WebTOP uses VRML (virtual reality modeling language) files to represent the geometry and for interaction; it uses Java for recalculating the geometry based on the given parameters. In Figure 2 the "dashboard" on the bottom of the screen has controls for the rotation, translation, and zooming of the scene.

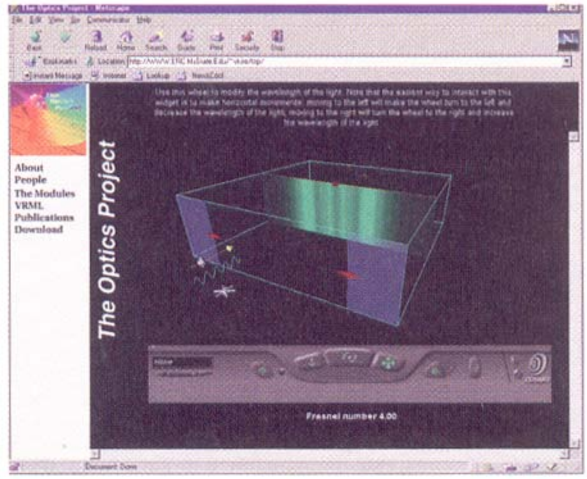

Figure 2. WebTOP's Fresnel Diffraction, Single Slit submodule running across the Web on a PC.

The change of the physical parameters is done, as with TOP, by interacting with 3-D widgets. This module runs within Netscape and Microsoft Internet Explorer, and on Windows and Unix platforms.

Creation and use in the classroom

TOP was created at Mississippi State Univ. and used there to help teach Intermediate Optics in 1997 and 1998. It was also used for teaching purposes at the Univ. of North Carolina at Chapel Hill in 1998. Student response to TOP was very positive and it will be used again at these two schools in 1999.

At Mississippi State, TOP is used in three different ways: to present material in class, for problem solving outside of class (homework assignments involve using TOP to simulate an optical phenomena; students ftp a screen shot of their results to the instructor), and as a way to generate 3-D movies of optical phenomenon (the class is divided into two-person teams, and each team uses TOP to make a QuickTime movie, which is presented to the class).

The TOP Web site (www.erc.msstate.edu/~foley/newtop) has approximately 70 still pictures and 40 QuickTime movies, plus a working version of the WebTOP Fresnel Single Slit module. Anyone who would like to beta test TOP or WebTOP should contact us at foley@erc.msstate.edu.

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References

1. The DTV standard is the result of technical contributions and professional collaborations by hundreds of individuals. However, special acknowledgement is due to individuals whose vision, dedication, and talents helped to shape the standard in very fundamental ways:
   The Grand Alliance Steering Group—B. Allan, P. Bingham, J. Carnes, J. Donahue, R. Friedland, D. Leonard, J. Lim, J. Perlman; the Grand Alliance Technical Oversight Group—C. Basile, B. Beyers, R. Cerbone, J. Lim, W. Luplow, W. Paik, R. Rast, G. Reitmeier; the Grand Alliance Communications Strategy Group—B. Allan, R. Graves, A. Grewe, J. Lim, T. Patten, R. Rast, G. Reitmeier, Q. Rodgers, A. Schlosser, J. Taylor; the Grand Alliance Technical Experts—W. Bretl, D. Bryan, R. Citta, K. Challapali, A. Cugnini, M. Deiss, N. Hurst, R. Keeler, E. Krause, R. Lee, S. Lery, P. Lyons, J. Mailhot, J. McDonald, M. Muterspaugh, E. Petajan, K. Pitts, R. St. Girons, G. Sgrignoli, T. Smith, P. Snopko, A. Tom, J. Zdepski; the Advanced Television Systems Committee (ATSC)—R. Graves, J. McKinney, R. Hopkins, M. Richer, S. Baron, L. Perlstein; the Advisory Committee on Advanced Television Service (ACATS)—R. Wiley, J. Flaherty, I. Dorros, J. Henderson, R. Hopkins, M. Richer, and other companies and organizations—P. Fannon, C. Rhodes, P. Hearty, B. Jones, C. Todd.

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