Within a few months television in North America will undergo a change as fundamental and sweeping as the advent of color. In November broadcasters in large metropolitan areas will begin digital broadcasts, which promise much sharper picture and sound than the current system provides. Called digital television, or DTV for short, the new system also has many features that are absent from conventional broadcasting, such as auxiliary channels for data and easy connection to computers and telecommunications networks.

The changeover from the current system, established in the 1940s and 1950s by the National Television System Committee (NTSC), to the new digital form has been a slow, often contentious process. There were many years of competition and cooperation among major organizations. Officials at the Federal Communications Commission (FCC), broadcasters, television manufacturers and academics tried to come up with a digital standard that would not render existing TVs immediately obsolete. Some of the details, especially those regarding the introduction of computer services to the television realm, still need to be worked out.

Meanwhile the international situation remains unclear. So far Canada and the Republic of Korea have committed themselves to the new U.S. standard. Most of Asia, Europe and Latin America, however, are now evaluating that standard, as well as other possibilities.
But most of the dust has settled, and advances in communications, signal processing and very large scale integration technologies have enabled a major overhaul of the television system rooted in half-century-old technology. The new system will operate in channels mainly in the ultrahigh-frequency (UHF) band, spanning 470 to 890 megahertz (channels 14 to 83). The old and new systems will coexist until 2006, when broadcasters are expected to cease using NTSC signals on both the very high frequency (VHF) band, between 54 and 216 megahertz (channels 2 to 13), and the UHF band. The FCC will then reallocate those channels to digital TV or to other services, such as wireless communications.

Historically, the FCC has exercised authority over technical standards for terrestrial broadcast media. The FCC’s influence, however, does extend to cable and satellite operators, because they may wish to adopt terrestrial broadcast standards in order to avoid confusion, added expense and technical complexities for themselves and for their customers. In this scenario, though, the complication is that some cable and satellite operators have already begun broadcasting digital signals—but not in high-definition format. At some point, this situation will have to be resolved if broadcast, cable and satellite operators are all to coexist in technical harmony.

Driving television to the new system was the desire for a better picture, which actually began before the digital era. In the late 1960s NHK, Japan’s government-sponsored TV broadcaster, made the first foray into high-definition television, or HDTV. Together with Japan’s electronics manufacturers, NHK developed an analog system called MUSE, for multiple sub-nyquist encoding. The encoding was a scheme that delivered five times more information to produce a sharper image. The problem was that it required five times as much broadcasting airspace as well. The NTSC system delivers audio and video signals within a six-megahertz-wide channel, but MUSE would need some 30 megahertz of channel space.

There was not enough room to accommodate such a scheme. In the early days of NTSC, plenty of bandwidth existed. The NTSC method, by today’s standards, is highly inefficient in the way it uses bandwidth. In video the intensities among neighboring picture elements (pixels) are quite often very similar or at least dependent on those immediately near them. Because NTSC transmits entire scenes without exploiting this dependence, much of the redundant information is transmitted again. This type of inefficient use of the spectrum generates interference among the different NTSC signals. As the number of TV stations increased, interference became a serious problem.

The solution was to leave some channels, known as taboo channels, unused. Typically, in a highly populated area in the U.S., only one of two VHF channels and only one of six UHF channels are assigned. Mobile radio and other telecommunications services also placed demands on the available bandwidth. The end result was that there was simply no room in the U.S. spectrum for bandwidth-hungry HDTV systems such as MUSE.

At the request of the broadcast organizations, the FCC created the Advisory Committee on Advanced Television Service (ACATS) in September 1987. The ACATS was chartered to advise the FCC on matters related to the standardization of advanced television service in the U.S., including the establishment of a technical standard. In 1988 the ACATS asked industries, universities and research laboratories to propose advanced television standards.

Dueling Approaches

While the ACATS screened the proposals and prepared testing laboratories for formal technical evaluation, the FCC made a key decision. In March 1990 it selected the simulcast approach for advanced television service, rather than the receiver-compatible approach.

In the latter approach, current TV sets would be able to obtain an HDTV signal and generate a viewable picture. The NTSC relied on such a method when it introduced color, so that existing black-and-white sets would not become obsolete. The receiver-compatible approach worked because color information did not require a large amount of bandwidth. A small portion of the six-megahertz-wide channel could contain the color information without seriously affecting the black-and-white picture.

An HDTV signal, however, requires much more information than a color signal. So the receiver-compatibility requirement would demand an augmentation channel to carry the additional information HDTV requires—basically, another six-megahertz-wide channel.
Avoiding a Hard Decision

Even though the new standard adopted by the Federal Communications Commission (FCC) exceeds the initial requirements of a digital television system and will serve very well for years to come, its ultimate degree of success depends in part on certain decisions the FCC left to the marketplace. The standard is flexible: it permits not only the six transmission formats originally proposed by the Grand Alliance but also a large number of additional formats, in part because of a last-minute compromise reached among industries with differing preferences. To understand the potential consequences of this decision, it is helpful to review the basic differences between interlaced scanning and its modern replacement, progressive scanning.

The interlaced scanning format is the basis for the National Television System Committee (NTSC) standard. The format delivers pictures that are snapshots of a scene recorded a specific number of times per second. In interlaced scanning, a single snapshot consists of only odd lines; it is followed by a snapshot consisting of only even lines, and the sequence then repeats. Each snapshot—odd and even—is called a field.

Although only snapshots of a scene are shown, the human visual system perceives continuous motion, as long as there are enough snapshots. In the NTSC system, the snapshots are flashed at a rate of 60 fields per second. This rate is sufficiently high for the viewer to perceive continuous motion and to avoid notice of display flickering. The total number of active lines is approximately 480, and each line contains approximately 420 pixels, or picture elements. (The number of lines represents the vertical spatial resolution in the picture, and the number of pixels per line represents the horizontal spatial resolution.)

An alternative to interlaced scanning is progressive scanning, in which all the lines for each snapshot are scanned. The snapshot in progressive scanning is called a frame. This type of scanning, however, proved impractical for the NTSC method; because of bandwidth limitations, it could be done only at 30 frames per second, which would cause images to flicker badly. In principle, a receiver could avoid flicker if each progressively scanned frame is displayed twice. But that would require a frame memory, a technology that did not exist when NTSC was standardized. Hence, interlace took hold of the television manufacturing and broadcasting industries. Subsequently, much HDTV video equipment, including cameras, has been developed for interlaced scanning.

Unfortunately, interlace introduces certain video artifacts, such as interline flicker. Though usually not very bothersome for entertainment material, they can be quite objectionable in the display of text, computer graphics or other material that has sharp lines. Consider a sharp horizontal line that is in the odd field but not in the even field. Even though the overall scan rate is 60 hertz, the scan rate for the sharp horizontal line is slower, at 30 hertz. As a result, the line flickers. Partly for this reason, almost all computer monitors use progressive scanning. It is possible to deinterlace a signal so that it can be viewed on a progressive-scan monitor, but the conversion requires complex signal processing to achieve high performance. And the image is still not as good as it would be if the transmission were originally in a progressive-scan format. Not surprisingly, the computer industry advocates progressive scanning, which would help it gain a greater foothold in the broadcast industry and the general home market. Other advocates include the movie industry, which desires a better display for film.

The disagreement over transmission formats generated considerable heat and delayed digital TV in the U.S. The Grand Alliance HDTV system proposed five progressive-scan formats and one interlaced-scan format. To accommodate standard definition, the recommendation by the Advisory Committee on Advanced Television Service (ACATS) specified 12 additional standard formats that consisted of both progressive and interlaced formats. But the FCC in December 1996 adopted a compromise that was reached between the broadcast and computer industries. This hastily reached agreement removed most of the restrictions on transmission formats; it not only allowed all the 18 formats that included interlaced scanning but also allowed many additional progressive and interlaced formats. In effect, this decision left the choice of transmission formats to free-market forces.

In fact, there is very good justification for permitting multiple transmission formats. A TV system must accommodate many video input sources: video cameras, film, magnetic and optical media, synthetic imagery and the like, all of which have different requirements. It requires an NTSC channel as a basis to transmit an HDTV signal, which means that the highly spectrum inefficient NTSC system cannot be converted to a modern, efficient technical system. In addition, the introduction of HDTV would permanently require a new channel for each existing NTSC channel.

For these reasons, the FCC adopted the simulcast approach. Unlike the receivers-compatible case, in which the HDTV signal is obtained from the NTSC signal and the additional information is in the augmentation channel, a simulcast HDTV signal is broadcast in its own six-megahertz-wide channel, independently of the NTSC signal. In this way, a modern transmission system could be crafted for the entire HDTV signal.

The drawback, of course, is that today’s television sets would not be able to receive an HDTV signal. To ensure that they do not become obsolete immediately, the FCC decided to give one new channel for HDTV service to each of the U.S.’s 1,500 stations that requested it. During the transition period, both services would coexist. Initially the FCC required the same program be broadcast simultaneously or within a short period from each other on both channels, hence the name simulcast. (This requirement was later eliminated.) Once enough of the country was using HDTV, NTSC...
their own kind of format. In the NTSC system, which uses only a single transmission format, the various input sources are converted to one format and then transmitted. For instance, the format of film is 24 frames per second; it is converted to 60 fields per second with interlaced scanning (that is, the NTSC format) and then transmitted. One transmission format, however, is an inefficient way of using the available spectrum.

To understand why, consider a movie broadcast. Each new channel can handle 60 frames per second (at 720 lines of progressive scanning). Film is shot at 24 frames per second, so only about half the bandwidth needs to be used (the empty part could contain an additional HDTV movie, computer data or other programming). Forcing a single format means that the movie would have to be transmitted at 60 frames per second—in other words, each frame would be sent two or three times, and there would be less room for other data. The spectrum therefore becomes occupied with repetitive data.

Permitting multiple transmission formats also allows the use of different formats for different applications. For example, broadcasters of sports events can use a format that features high resolution. On the other hand, a news program can choose a format with somewhat less resolution and use the resulting savings in channel capacity to transmit an additional program.

In permitting the new digital television standard to have many different transmission formats, the FCC allows for a video transmission format that is identical or very similar to the format of the original source. From the viewpoint of spectrum efficiency, allowing all possible video formats may be ideal.

**INTERLINE FLICKER** occurs in interlaced scanning when fine lines (such as the red ones boxing “WATCH.”) fall on individual scan lines. When the odd lines are scanned (top left), image portions that fall on the even lines are not displayed; the reverse happens in the subsequent (even-line) scan (bottom left). As a result, the eye detects a flickering. In progressive scanning (right), all lines are scanned in each instance, so there is no interline flicker.

But from the viewpoint of the receiver—that is, the consumer’s TV set—too many formats can be costly. A monitor typically can display images in only one format, so the different formats received must be converted to one display format. Allowing for too many formats can complicate the conversion. In any case, most of the benefits derived from multiple formats can be obtained by carefully selecting a small subset of formats.

All new displays in the not too distant future are likely to be progressive because of the format’s overall superior performance. But the decision by the FCC to allow both progressive and interlaced formats in the transmission path gives broadcasters a choice. If broadcasters use progressive scanning in the transmission, both interlaced- and progressive-scan displays can be accommodated with little additional cost to the receivers. That is because the progressive-to-interlace conversion can be performed well with relatively simple digital processing. All digital receivers are expected to have such capabilities. But if broadcasters use interlaced scanning, a progressive-scan receiver has to convert the interlaced-scan format. Such a deinterlacing operation demands complex signal processing to achieve good performance, raising the cost of progressive-scan displays, which are currently more expensive than interlaced ones.

Broadcasters have some incentive to send interlaced signals: cameras and other production equipment that utilize interlaced scanning are more readily available now. In addition, substantial amounts of video material exist that have been captured in the interlaced format.

By allowing interlaced formats in the transmission path, the FCC in essence requires deinterlacers in all progressive-scan receivers (unless every single major broadcaster shuns interlaced formats). That is far more burdensome to the general public than requiring deinterlacers at the transmitters, of which there are far fewer. In addition, deinterlacers perform much better at the transmitter than at the receiver, because the transmitter has access to the uncoded original video.

One important function of a standard is to make restrictions that serve the public interest. Limited to a specific video-compression approach, for example, digital TV receivers need to implement only the decoding method for the video-compression approach adopted by the FCC. In the case of the transmission formats, however, the FCC avoided making a difficult decision. The decision now will be made by short-term market forces. That may leave the broadcast industry and the general public tied to interlaced formats and their associated equipment much longer than if the FCC had made a hard decision that narrowed the options to the long-term, preferred progressive-scan formats. —J.S.L.

service would be discontinued. The spectrum it previously occupied would be used for additional HDTV channels or for other services.

There are a number of advantages to the simulcast approach. It permits the design of a new, spectrum-efficient HDTV signal that requires significantly less power and that interferes much less with other signals, including the NTSC signal. This design enables the use of the taboo channels. (Without the taboo channels, the FCC cannot give an additional channel to each existing NTSC broadcaster for HDTV service.) In addition, simulcast ultimately eliminates the spectrum-inefficient NTSC channels following the transition period. Furthermore, removing the NTSC signals that have strong interference characteristics allows the more efficient use of other channels. The 1990 FCC ruling was a key decision in the process to standardize HDTV in the U.S.

Soon thereafter many groups began proposing HDTV systems based on the simulcast approach. Ultimately, the FCC’s ACATS approved five proposals for formal evaluation. One advocated an analog system; the other four were completely digital. Laboratory tests at the Advanced Television Testing Center in Alexandria, Va., evaluated the five systems. The Advanced Television Evaluation Laboratory in Ottawa, Canada, subjectively judged picture quality.
Toward a Single Standard

The four digital proponents indeed decided to work on a single scheme. In May 1993 they formed a consortium called the Grand Alliance, which comprised seven organizations: AT&T, Zenith, the David Sarnoff Research Center in Princeton, N.J., Chicago-based General Instrument Corporation, the Massachusetts Institute of Technology (for which I was the representative), Philips Electronics North America and France-based Thomson Consumer Electronics. Between 1993 and 1994 the Grand Alliance chose the best technical elements from the four systems and made further improvements on them. A technical standard based on the Grand Alliance HDTV prototype was documented by the Advanced Television Systems Committee to the FCC, which accepted it except for one detail. The standard restricted broadcasters to 18 video resolution formats—that is, ways to transmit images. The FCC eased this restriction in December 1996 [see box on page 80].

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In early 1997 the FCC made additional rulings to support the new technical standard, such as the allocation of channels. Starting this fall, major broadcasters are scheduled to transmit digital TV signals in large metropolitan areas, including Boston, Los Angeles and Washington, D.C.

A digital television system based on the standard will be quite flexible. It can deliver spectacular high-definition video and multichannel surround sound within a six-megahertz bandwidth. Or it can send several programs of standard-definition TV, resolution of which is comparable to that of today's programs. Because of the flexibility, the acronym describing the system changed from HDTV, or high-definition television, to the broader term DTV, for digital television. Moreover, the new standard can reach a larger area with much lower transmitter power than the NTSC system can.

The standard can also incorporate future improvements in technology. For example, MPEG-2 specifies only the syntax of the coded bit streams and the decoding process. This leeway allows some flexibility in the encoding process, which can be upgraded without changing the standard.

Getting the Digital Picture

As we have seen, today's televisions cannot receive the new signal and display a viewable picture. There are two solutions. One, of course, is to obtain a new set: digital TV receivers were demonstrated at the Consumer Electronics Show held in Las Vegas this past January. They will be commercially available starting this fall.
available in the fall. Initially a large-screen digital television receiver with HDTV display capability will be expensive—more than $5,000. As more receivers are sold, however, the price will decrease rapidly.

An alternative approach is to attach a “set-top” box to an NTSC receiver. The box, which will cost a few hundred dollars, decodes the digital television signal and converts it to an analog NTSC signal. Although a viewer will not experience HDTV resolution, the video quality will be better than that of the same program broadcast through the analog NTSC channel.

One improvement that will be apparent even without a digital set will be the reception quality. Unlike the analog NTSC signal, which suffers from channel degradations such as multipath effects (“ghosts”) and random noise (“snow”), the digital video will be perfect within a certain coverage area, or else there will be no picture at all. This all-or-nothing case mirrors that for digital music, in which a player cannot read dirty or damaged compact discs.

The high spatial resolution of a digital TV system will also allow for increased realism, by way of a bigger screen. In the NTSC system, the recommended viewing distance is approximately seven times the picture height, to avoid the visibility of a line structure on the screen. Hence, for a display screen two thirds of a meter high (a 40-inch-diagonal set), the recommended viewing distance is 4.25 meters. This distance makes it difficult to place a large-screen television receiver in many homes. And because of the distance, the viewing angle is approximately 10 degrees.

For a digital TV with high definition, the recommended viewing distance is typically three times the picture height. So for the set described above, this distance would be 1.8 meters, which is practical for many homes. And with a wider screen, this distance affords a larger, more realistic field of view of about 30 degrees.

Another plus of the new standard is the increased aspect ratio, or the relation between width to height of the image. An NTSC television receiver displays images that have an aspect ratio of 4:3, which mirrored movies that were made when the NTSC system was first developed. Since then, movies have become much wider. To reflect this change, a digital TV system has a larger aspect ratio, such as 16:9.

A digital television system can also deliver CD-quality, multichannel sound, which enhances the visual experience. Multiple audio channels can produce the effect of surround sound employed in movie theaters. They can also be used for transmitting different languages in the same video program.

The new digital system will transform television in another, perhaps more profound way. Traditionally, the TV has been a stand-alone device whose primary purpose was entertainment. But in addition to a better picture and multiple programs, the digital system will be able to accommodate data from telecommunications services, delivering such information as stock quotes or e-mail. In this way, the display can be used as a videophone, a newspaper service or a computer monitor.

The promise of this integration has been the impetus for the computer industry’s entrance into the domain previously dominated by broadcasters. Much still needs to be worked out between the two camps, but the convergence seems inevitable. Almost assuredly, in the near future, the television will be regarded as the home center for entertainment, telecommunications and information. In the end, it may be this integration that will have a far greater effect on us than the better picture and sound that the digital system will deliver.

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**The Author**

JAE S. LIM is professor in the department of electrical engineering and computer science at the Massachusetts Institute of Technology, which he joined in 1978 as an assistant professor. He is also director of M.I.T.’s Advanced Telecommunications Research Program. His research interests include digital signal processing and its applications to image, video, audio and speech processing. During the past 10 years, he has participated in the Federal Communications Commission’s work on standardizing advanced television. He represented M.I.T. in the design of the M.I.T./G.L. system (one of the four finalist systems) and in the design of the Grand Alliance system that led to the FCC’s adoption of the U.S. Digital Television Standard in December 1996. The opinions expressed here are those of the author only. Lim thanks David Staelin of M.I.T. for his valuable comments and suggestions.

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**Further Reading**

**DIGITAL TELEVISION: HERE AT LAST**

Digital Television: Here at Last. Scientific American, May 1998

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