CHAPTER

27

Video Transmission

About This Chapter

Cable television networks have long used fiber optics to distribute signals partway to homes, reaching neighborhood nodes that distribute signals through coaxial cables to individual homes. As you learned in Chapter 25, cable systems are converging with local phone systems, with both expanding to offer voice, video, and data services. Cable networks also are shifting to digital television.

This chapter explains the basics of video systems and transmission, covering both today's analog video technology and the new digital television standard. It explains how cable systems operate, how they use fiber technology, and how they are adapting the new digital technology. A final section describes other video applications of fiber.

Video Basics

Video signals encode changing images, usually in color, and usually include sound. Because the images are changing, new pictures must be transmitted continuously, so the human eye can see the changes. This requires more bandwidth than audio signals, and makes video signals considerably more complex. The details depend on the technology used to display the image and on the signal format.

Analog television is raster scanned.

Traditional analog television breaks the image into a series of parallel horizontal lines, a process called *raster scanning*. You can see the lines best if you look at an old analog black-and-white television with a cathode-ray-tube (CRT) screen. The color and brightness vary continuously along the length of each line, and your eye blends the lines into a composite image. Figure 27.1 shows how raster scanning represents a simple black-and-white picture, with the thin raster lines left in the background to show how they build the image.

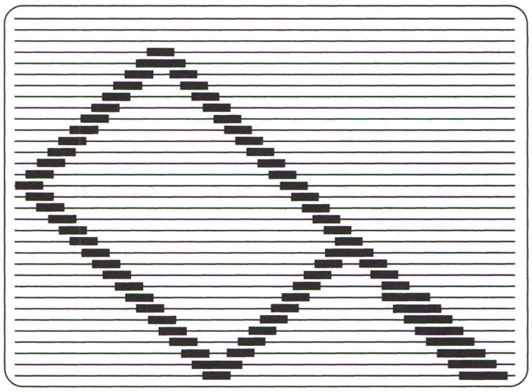


FIGURE 27.1
Raster scanned image is made from many parallel lines.

Digital television displays patterns of dots.

Digital television breaks the image into a pattern of dots arranged in straight lines across the screen. You can see this pattern if you look at your screen through a magnifier. Each line of dots is equivalent to a raster-scan line on a CRT analog television. If fact, in a newer color set, the lines break down into an array of dots when magnified.

On a color screen, each "point" of white light actually is an array of three colored spots—red, blue, and green—which together look white to the eye. This color information is included in both analog and digital signals. Changing the relative brightness of the three colored picture elements or *pixels* generates many intermediate colors.

Frame rate is the number of images shown per second.

The *frame rate* is the number of new images shown each second. Flashing these images sequentially gives the illusion of motion, although each frame is actually a still picture. The standard frame rate for motion picture film is 24 frames per second; for analog television it's 30 frames per second. These rates are fast enough that the eye does not see the flicker of changing pictures.

Resolution measures the number of lines or pixels on the screen. The more lines, the better the picture quality and the more detail visible to the eye.

Video Transmission Requirements

Video requires much more transmission capacity than sound or text.

Video transmission requires much more transmission capacity than sound or text files. It's often said that one picture is worth a thousand words, but Table 27.1 shows that a picture requires considerably more transmission capacity than a 1000-word text file. It also shows that bandwidth requirements increase with the resolution, although it is hard to compare digital and analog bandwidths.

The bandwidth required to transmit raw digital *high-definition television* (HDTV) is 1.5 Gbit/s, a staggering amount considering the number of video channels that have to be transmitted. Fortunately digital technology can reduce the bandwidth requirements by comparing sequential frames. If you step through individual frames on a DVD player or videotape, you can see that the picture displayed usually doesn't change too much from frame to frame. Digital processors can compare successive frames and throw away the parts that are unchanged, transmitting only the changes. Some losses are inevitable, but

Table 27.1 Comparison of approximate video, voice, and text transmission requirements

Transmission	Analog Equivalent	Digital Equivalent (No Compression)	Digital Equivalent (Compressed)
Standard U.S. analog television (NTSC)	6 MHz	270 Mbit/s	2–10 Mbit/s
HDTV (U.S. format)	~100 MHz	1.5 Gbit/s	19.3 Mbit/s
Voice telephone	3 kHz	64 kbit/s	~10 kbit/s
One standard TV video frame		9 Mbits	
One HDTV video frame (1/60 s)		25 Mbits	
1000 spoken words (5 min on phone)		20 Mbits	
1000-word text file		60 kbits	

usually they aren't significant; and *compression* reduces the data rate down to 19.3 Mbit/s, which is far more manageable.

The artifacts from digital compression are visible when data rates are squeezed even further for Web casting to broadband Internet links at 150 kbit/s or 300 kbit/s. The picture occupies only a small part of your screen, and objects in the picture get lost if they move too fast on the screen.

Transmission Standards

Video is transmitted in standardized formats.

Video signals are transmitted in standardized formats so transmitters can talk to receivers. These formats have evolved for historical reasons and are often not ideal. One difference in analog video formats is the number of frames per second, originally chosen to be half the frequency for alternating current (60 Hz in North America and 50 Hz in Europe). The North American standard for analog broadcast color television was chosen in the 1950s to be compatible with older black-and-white receivers because broadcasters did not want to lose that audience.

New standards have been developed for digital television. The original goal was higher screen resolution, or *HDTV*, for large screens, but the standards were broadened to cover *advanced television* (ATV), for sets with smaller screens. The technology comes in part from high-resolution computer monitors. Importantly, the digital standard signals are *not* compatible with existing analog television sets, which will require adapters when television broadcasts shift completely to digital television.

Other video standards are in use, such as those for computer monitors, but I will concentrate on television standards.

Standard Broadcast Analog Video

NTSC video displays 30 analog 525-line frames a second.

The present analog standard for broadcast television programs in North America is the *NTSC* format, from the National Television System Committee. The analog signals carry information representing the lines that compose the screen images. Pictures are displayed as 525-line frames (although a few lines do not actually show up on the screen). Nominally, NTSC shows 30 frames a second, but to keep the image from flickering to the eye, NTSC uses an interlaced scanning technique. First it scans odd lines on the display, then the even lines, then the odd lines again, as shown in Figure 27.2. Technically, this interlaced scan displays 60 half-images (called fields) a second, with only 267 lines of resolution each, but this fools the eye, giving the appearance of high resolution while avoiding the flicker of slower scanning speeds.

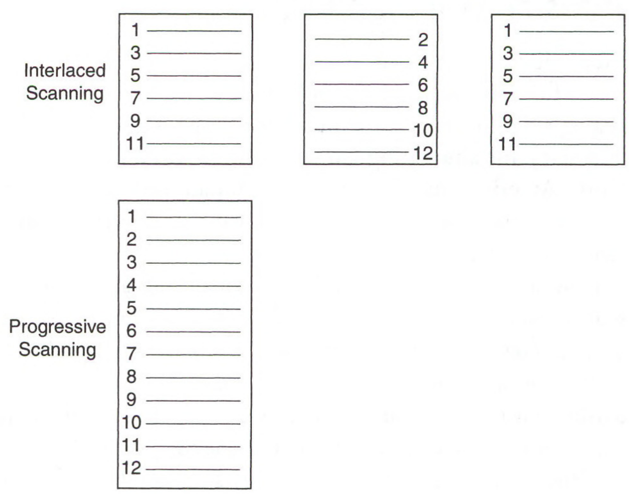
Nominally, the NTSC video bandwidth is 4.2 MHz, with the sound carrier at a higher frequency. However, for broadcast the video signal is used to modulate a radio-frequency signal, a process that increases overall bandwidth to 6 MHz, which is the amount of radio-frequency spectrum allocated to each broadcast television channel in the United States. Figure 27.3 shows the structure of this signal, which extends from 1.25 MHz below the carrier frequency to 4.75 MHz above the carrier. The NTSC format is used in North America, Japan, Korea, the Philippines, and much of South America.

PAL and SECAM are interlaced scanning systems showing 25 frames of 625 lines each per second.

Two other broadcast television standards are in wide use: PAL and SECAM. Both are interlaced scanning systems that show 25 frames (50 fields) per second, each frame with 625 lines. These have nominal video bandwidth of 5 to 6 MHz and broadcast channel bandwidth of about 8 MHz. PAL and SECAM systems are used in Europe, mainland Asia, Africa, and parts of South America.

These standards were set for television broadcasting from ground-based transmitters. National and international standards set aside specific frequencies for television broadcasting, with each channel allocated the required bandwidth (6 MHz for NTSC channels).

FIGURE 27.2
Interlaced and progressive scanning.



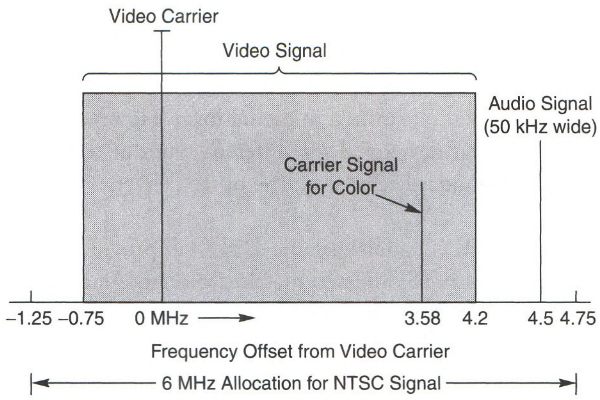


FIGURE 27.3
Structure of NTSC broadcast video signal.

These standards have come into wide use for other types of video because NTSC, PAL, and SECAM equipment is readily available.

Broadcast video standards were established decades ago, when color television came on the market. (The NTSC standard was a modified version of the original North American standard for black-and-white television, which goes back to 1948.) This means that these standards were developed for the vacuum-tube technology available in the electronic stone age.

Standard video formats are decades old.

Computer Displays and Video Formats

It might seem logical to use standard television displays for computers, but the two technologies are not readily compatible. Television sets are adequate displays for many computer-based video games, and sufficed for some early personal computers. However, text displayed on a screen with interlaced scanning does not show up well because the interlacing effectively mixes information from successive frames. The best displays for computers use progressive scanning in which all lines are scanned one at a time, then the entire screen is rescanned, as shown in Figure 27.2.

Computer displays require progressive scanning to show text clearly, not NTSC format.

Progressive scanning demands more bandwidth and faster electronics than interlaced scanning—because it transmits 60 (or sometimes more) complete frames a second to avoid flicker. NTSC video transmits 60 interlaced half-frames or fields, so its resolution is lower.

Multimedia or interactive video displays are hybrids, based on a combination of computer and television technologies. They don't have their own special display standards; those that play on computers use computer formats, those played on television sets use television formats. The American HDTV standard allows both progressive and interlaced scanning.

Several different technologies are used for displays. Until several years ago, virtually all desktop computers and television sets used cathode-ray tubes (CRTs). Liquid crystal displays (LCDs) have now become common for desktop as well as laptop computers. LCDs also are used in some television sets, and in projection televisions, which project an image onto a large screen. Plasma panels are less common, but used for some large-screen televisions. All these displays show standard video and computer formats.

Digital Television

Digital cable and DVDs are compatible with old televisions; HDTV is not.

Video signals can be digitized like any other analog signal. With the advance of digital technology, video signals increasingly are being transmitted in digital form. However, there are two different types of digital transmission developed for different types of television sets. One is essentially a digital version of standard television; the other delivers a higher-resolution image.

Satellite systems, cable systems, and DVDs (Digital Versatile Disks) all provide digital signals that are compatible with conventional NTSC television. Electronic interfaces built into a DVD player or provided in satellite or cable tuners convert the digital signal into NTSC analog format. You can plug a satellite dish or a DVD player into any standard NTSC set that has a suitable video or antenna input. The pictures are sharper and clearer than normal broadcast television or video cassettes, but the difference isn't dramatic. You still get a nominal 525 lines per screen.

The new digital standard for HDTV is different. This standard is intended for new large-screen televisions that can display up to twice as many lines per screen as NTSC television, but also can be used for smaller sets. These new digital televisions can't display NTSC television, and NTSC sets can't display signals in the new digital format without a special adapter. HDTV will require many changes in cable television and broadcasting, so we'll consider it in more detail.

High-Definition Television (HDTV)

North America, Europe, and Japan have separate HDTV standards.

The consumer electronics industry began campaigning for a new generation of high-definition television technology in the 1980s. Their goal was to offer larger, wider images of better quality and—not coincidentally—to make money by selling a new and more expensive generation of large-screen television sets. Japanese electronics firms developed analog HDTV, but after lagging on analog systems, American industry switched to digital transmission and developed a digital HDTV standard that was accepted by the Federal Communications Commission. Europe and Japan are implementing their own digital HDTV standards.

Officially, the U.S. standard is known as the *Digital Television (DTV)* standard of the Advanced Television Systems Committee. It includes 18 distinct digital video formats with different numbers of scan lines and screens per second. Six are classed as high definition and the other 12 are standard definition television (SDTV), which offers somewhat better image quality than NTSC analog television. The HDTV formats are intended for large-screen sets; the SDTV formats are for smaller screens. Table 27.2 lists these formats.

Digital television supports several levels of screen resolution.

A single digital signal will support all these formats. Digital electronics in new sets will decode the signal to produce a display that matches the screen. This compromise allows both the interlaced scanning preferred by the television industry and the progressive scanning preferred for computer displays. The different picture sizes accommodate the variety of television set sizes.

Broadcast HDTV is compressed to 19.3 Mbit/s

Broadcast HDTV digitally compresses signals by a factor of 75, reducing the data rate to 19.3 Mbit/s. Digital compression does degrade signal quality, so video production and archival storage use the lower degrees of compression listed in Table 27.3. Video producers avoid compression techniques that depend on the sequence of frames, which could

Table 27.2 Advanced television digital formats

Picture Size (Lines High by Pixels Long)	Frames per Second	Aspect Ratio
1080 × 1920	60 interlaced	16:9 (wide-screen)
(HDTV)	30 progressive	
	24 progressive	
720 × 1280	60 progressive	16:9 (wide-screen)
(HDTV)	30 progressive	
	24 progressive	
480 × 704	60 interlaced	16:9 (wide-screen)
(SDTV)	60 progressive	
	30 progressive	
	24 progressive	
480 × 640	60 interlaced	4:3 (conventional)
(SDTV)	60 progressive	
	30 progressive	
	24 progressive	

change during editing. (The digital signals on DVDs and digital cable channels also are compressed, but not by as large a factor; digital cable delivers 5–5.5 Mbit/s.)

The high compression of HDTV used in the U.S. system allows the signal to be transmitted in a radio band only 6 MHz wide, the same width as NTSC channels. This retains the channel structure used for analog broadcasting and for transmitting video signals in cable-television networks, although channel assignments change.

All the interested industries lobbied Congress and the FCC heavily to assure that they got some benefits from the change from analog to digital. Broadcasters persuaded Congress to give every television station a free digital channel, as long as they meet deadlines for turning on digital transmitters and agree to return their analog channel to the FCC. The cellular telephone industry will claim the high-frequency end of the old broadcast television

Table 27.3 Compression levels for HDTV

Task	Compression Ratio
Video production	4:1
Archival storage	25:1
Transmission	75:1

THINGS TO THINK ABOUT

The HDTV Mess

Many problems have slowed the switch from NTSC analog television to HDTV digital television, and more are likely to emerge.

- Broadcasters, electronics manufacturers, and the entertainment industry delayed in making needed changes until Congress and the FCC agreed to provisions they wanted, so digital video products came to market very slowly.
- The public was reluctant to start buying HDTV-compatible televisions because the real benefits of HDTV come with large screens, and large-screen sets are very expensive.
- HDTV broadcasts also slipped behind schedule, giving those who bought HDTV receivers little to watch.
- Cable television systems were slow to offer programs in HDTV format because they had only a limited number of channels available.
- Flaws in the U.S. HDTV broadcast standard may make digital signals harder to receive than analog signals.

Clearly 85% of television viewers won't have HDTV-compatible televisions by the end of 2006. Should some group give digital-to-analog converters to the people who still have analog sets? If so, should that group be the industries that benefit from the switch to digital television or the government? Or will the people with analog sets have to foot the bill if they want to continue receiving television signals?

The communications industry affects us all, and we should think about how this change will be implemented, who will pay for it, who will benefit from it, and what the side effects will be. If nothing else, someone will have to deal with all the obsolete television sets, which some states regulate as toxic waste because the picture tubes contain lead.

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spectrum once analog transmission stops. Entertainment producers were reluctant to adopt HDTV unless restrictions were imposed on copying of programs in digital form.

Analog TV broadcasts are supposed to stop in 2006.

Stations are scheduled to stop analog broadcasts in 2006—provided that at least 85% of viewers in their area have sets that can receive digital broadcasts. That isn't going to happen, but the cell phone industry is still lobbying intensely to shut down analog television broadcasts in the bands they want. The timetable for the transition from analog to digital is unclear, but the political pressures and lobbying are sure to get intense.

Transmission Media

So far I haven't said much about how video signals are distributed. Because this is a book on fiber optics, our main interest is in the use of fiber in cable television systems. However, you also should know a bit about other important transmission technology: ground-level broadcast at radio or microwave frequencies, satellite broadcast at microwave frequencies, and coaxial cables.

Terrestrial Broadcast

Television began as a broadcast medium, with local stations transmitting radio-frequency signals from tall antennas. NTSC, PAL, and SECAM standards were all based on the assumption that signals would be broadcast from terrestrial towers to antennas connected to home receivers. The radio waves induce small electrical currents in the antennas and receivers amplify and process the signal to extract the video. Government agencies assign specific frequencies for stations to use at their locations. Other stations may use the same frequencies if they are far enough away that the signals will not interfere.

Local stations broadcast at radio frequencies on assigned channels.

The U.S. HDTV signal was also designed for broadcast, in the same 6-MHz frequency bandwidth assigned to an analog broadcast. The Federal Communications Commission assigned each station a second channel for digital broadcasts, at a different frequency than any analog channel used in the area, but in the same band of channels assigned to television broadcast. Digital signals are not supposed to interfere with analog broadcasts.

Microwave Rebroadcast Services

Your television antenna can only receive broadcast signals from stations near you. Some services use microwave frequencies to distribute signals from distant stations and premium services, such as Home Box Office, to paying subscribers. These services include direct broadcast satellites and local multipoint distribution services.

A *direct broadcast satellite* transmits many video signals simultaneously in the microwave band to subscribers with small dish antennas and decoders. The transmitting satellite is placed in an orbit above the equator so it circles the planet exactly once every 24 hours. This makes it appear to stay in place above the same point. Its transmitting antenna beams microwaves to the area it serves. This design allows a single transmitter to cover most of the United States, including rural areas where cable service is usually unavailable.

Satellites broadcast microwave signals that carry many channels.

A *local multipoint distribution service* (LMDS) is a fixed wireless system that transmits microwave signals from many small terrestrial antennas distributed in its service area. Each antenna broadcasts signals over a small area, like a cell phone, but it distributes signals to fixed receivers. This distribution of antennas allows the system to offer two-way services such as high-speed data, teleconferencing, interactive video, and voice telephone service. The service also can distribute video signals to subscribers in the same way as direct broadcast satellites.

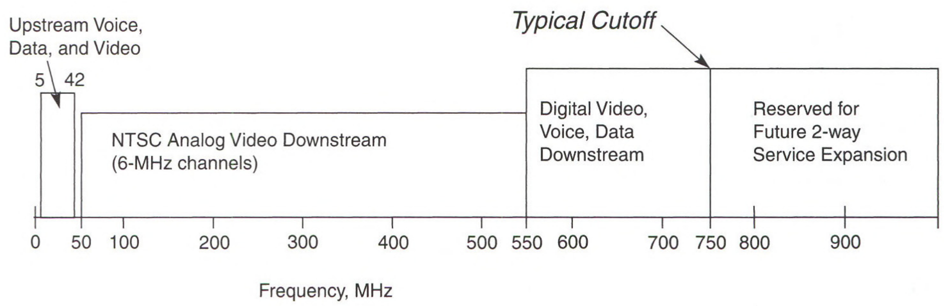
So far, direct broadcast satellites are much better developed and are posing a serious challenge to cable television. Few fixed terrestrial systems have been installed. Direct broadcast satellites usually transmit digital video, encoded for microwave transmission.

Cable Television

Cable television began as community antenna television (*CATV*, an acronym still used by the industry), which delivered broadcast television signals to people who otherwise could not receive them. The system operator built one big antenna to pick up broadcasts from distant stations, then distributed the signals through cables to local subscribers. Eventually the concept spread to urban and suburban residents who could receive broadcast signals, but wanted better reception or more channels. More features have been added since.

Cable television's core business is video.

FIGURE 27.4
Spectrum of hybrid fiber/coax.



The core business of a cable system is distributing video channels to subscribers. Basic service usually includes local channels and selected national channels, and is transmitted to all subscribers in unencrypted form. Premium video channels are encrypted, so they can be viewed only by subscribers who pay for special decoder boxes. Modern cable systems offer both analog and digital channels, with basic services in analog form and some premium channels in digital format. In general, the digital signals today are *not* HDTV format; the digital format offers higher quality than analog transmission, but like DVDs it does not offer dramatically higher resolution than standard analog television. Many cable systems with digital service also offer video on demand, which allows customers to select particular programs to be transmitted directly to their homes through the cable system.

Video, voice, and data are bundled as "triple-play" services.

Modern cable networks also provide voice and data services over special channels set aside for those purposes. They were the first to offer customers bundles of "triple-play" services that standard telephone lines do not have the bandwidth to offer. To add video service, phone companies must either install fiber to homes, build terrestrial microwave networks for video distribution, or form partnerships with satellite television companies.

Cable systems can transmit frequencies as high as 650 MHz to 1 GHz through their network of fiber-optic and coaxial cables. The upper limit of a particular system depends on its design and the equipment it uses, but coax attenuation becomes a problem above 1 GHz. That spectrum is divided into three basic blocks, as shown in Figure 27.4. Frequencies of 5 to 42 MHz typically are reserved for upstream voice, data, and video. Frequencies from about 50 to 550 MHz are reserved for upstream video signals transmitted in standard NTSC analog format, each with its own 6-MHz band. Higher frequencies generally are reserved for digital television channels and downstream voice and Internet connections, with the number of channels available depending on the system. However, these digital signals are converted into analog format for cable transmission.

Cable companies will phase in HDTV by replacing old NTSC video channels, since HDTV signals fit in the same channel bandwidth.

Cable Television Architecture

Hybrid fiber/coax combines fiber and coax.

The dominant technology for cable television today is called *hybrid fiber/coax (HFC)*. Fiber-optic cables distribute signals from a control center called a *head-end* to neighborhood distribution nodes. Coaxial cables distribute signals from neighborhood nodes to individual

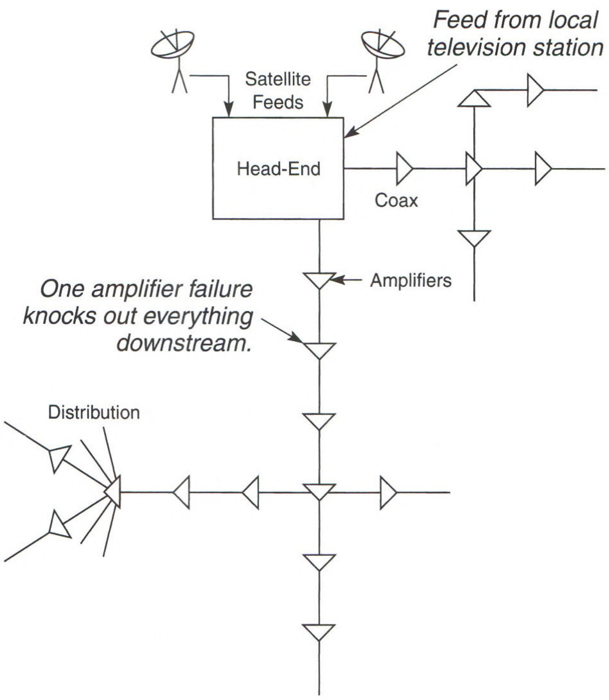


FIGURE 27.5
All-coax cable network required many in-line amplifiers.

homes. This structure has evolved over the years to take advantage of fiber to meet the growing demand for video service.

Basic Cable System Structure

Early cable networks were one-way tree systems with cables radiating from the head-end, as shown in Figure 27.5. The head-end received video signals from satellite dishes and local television stations, and multiplexed them into 6-MHz slots in an analog radio-frequency signal that it distributed through coaxial cable. The high attenuation of the coax required that amplifiers be installed about every 600 meters (2000 feet) along the cable. This delivered the signal, but long chains of analog amplifiers introduce noise and distortion into the signal. Even worse, an amplifier could fail, which would knock out service to everyone downstream.

Coax requires amplifiers about every 600 m.

Fiber has much lower attenuation than coax, so it replaced coax in the *trunk lines* going from the head-end to the local distribution nodes. This eliminated the need for amplifiers in trunk lines, improving the quality of the signal reaching subscribers and greatly reducing the chance of failure in the distribution network.

Cable networks transmit analog signals, so they must convert digital signals to an analog form at the head-end, just as modems convert digital data into analog form for transmission over phone lines. This requires the use of highly linear laser transmitters located at the head end to send signals through single-mode fiber trunk cables. Meeting the cable industry's performance requirement was a challenge, and required the development of highly linear distributed-feedback laser transmitters, which now are standard in cable systems.

Cable systems use linear analog laser transmitters.

Hybrid Fiber/Coax Network Structure

Fiber trunks link head-ends to distribution nodes.

Fiber trunk cables deliver the analog signals to local distribution nodes, which convert the optical signals into electronic form and distribute them through coaxial cable to homes in the neighborhood. Traditionally, typical nodes in hybrid fiber/coax systems serve 500 to 2000 homes, but the trend is toward nodes serving fewer homes. Thick coaxial cables connect the head end to the nodes, but the drop cables are a thinner and lighter grade of coax. These distribution cables require few amplifiers.

Figure 27.6 shows a representative hybrid fiber/coax distribution network. The head-end collects video signals from local television stations and satellite feeds. It also links to the telephone network and the Internet for voice and data service. Fiber trunks run from the head-end to distribution nodes; they also may run to secondary hubs, which connect to their own sets of distribution nodes. The distribution nodes convert the optical signals into electronic form and transmit them to subscriber homes through coax. Likewise, they convert electronic signals from subscribers into optical format and send them through the fiber to the head-end. The illustration shows that cable amplifiers may be needed to span the full distance from the distribution node to subscribers.

Hybrid fiber/coax is a tree-and-branch network.

Like the original cable television network, hybrid fiber/coax is fundamentally a tree-and-branch structure, which physically distributes the same signals to groups of subscribers. The electronic decoder (set-top box), which the cable company supplies, determines which video channels the subscriber can receive depending on what services they pay for.

Voice and data services are distributed like data through a local-area network; each signal physically goes to all the terminals, but only the one addressed by the signal pays any attention. How voice and data signals are distributed from the cable node depend on the customer base. If the node serves 500 homes and most of them have cable modems, the node may have separate branches going out to 25 groups of 20 homes each. All the homes on each branch effectively share a local-area network for cable modem service.

Hybrid Fiber/Coax Transmission

Cable bandwidth can reach 1 GHz, but most cable systems transmit only to 750 MHz.

The combination of fiber-optic trunks and coaxial distribution is widely accepted as hybrid fiber/coax. It allocates frequencies in the analog cable spectrum as shown in Figure 27.4. The 5- to 40-MHz band is allocated for upstream data, voice, and video signals from subscribers. Standard NTSC video is transmitted at 50 to 550 MHz. These bands overlap standard television broadcast bands, but only a few broadcast channels transmit at the same frequency on cable systems. Frequencies higher than 550 MHz are allocated for premium channels transmitted in digital form, and for the downstream portion of telephone and data traffic. Typical cable systems reserve 550 to 750 MHz for digital video as well as additional capacity for future expansion of video and two-way services. One consequence of this design is that cable modems have more bandwidth to transmit downstream to subscribers than subscribers have to transmit upstream. Total bandwidth of the cable network potentially can reach 1 GHz.

Upstream and downstream signals travel simultaneously in opposite directions in the coax part of a hybrid/fiber coax network. The fiber part of the network separates signals by transmitting them either through different fibers or at different wavelengths through the

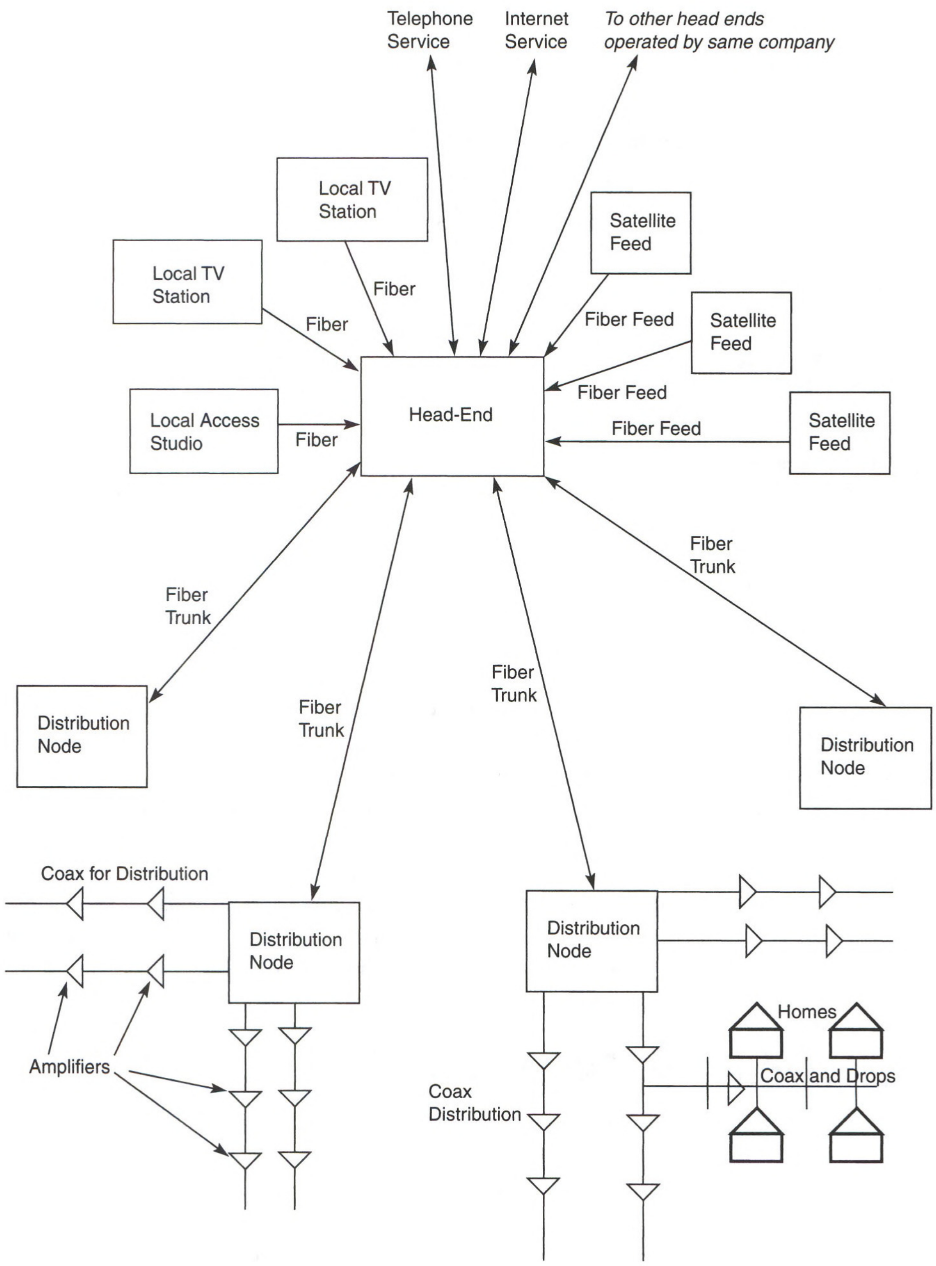


FIGURE 27.6
Hybrid fiber/coax.

same fiber. Typically signals would be transmitted downstream at 1550 nm and upstream at 1310 nm.

So far we've assumed that the same programs are broadcast to all subscribers. One trend in the cable industry is to direct some programs to specific subscribers, a practice called *narrowcasting*. Narrowcasting can be combined with broadcasting by transmitting the two sets of signals at different wavelengths, as shown in Figure 27.7.

Narrowcasting directs programs to specific subscribers.

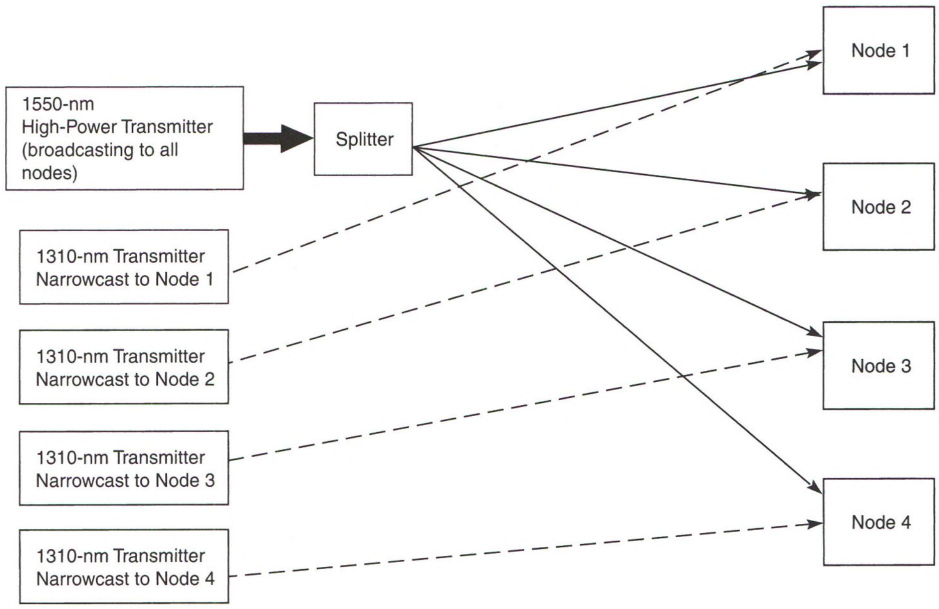


FIGURE 27.7
Broadcasting and narrowcasting with hybrid fiber/coax.

Identical signals can be broadcast to all nodes by splitting signals from one powerful transmitter at the head-end, shown emitting at 1550 nm in Figure 27.7. This can save money because one 100-mW transmitter generally costs less than 10 10-mW transmitters.

Other signals can be narrowcast by directing the output of one lower-power and lower-cost transmitter to a specific node. Figure 27.7 illustrates this process with four 1310-nm transmitters, each directing signals to a separate node. Narrowcasting is natural for services directed at individual customers, such as video-on-demand programs, telephone, or data transmission. It also allows cable companies to target specific advertising to certain groups of customers. For example, a cable company might direct an advertisement for a local Mercedes dealer to the affluent side of town, and an advertisement for a used-car dealer to a poor neighborhood.

Cable Modems and Telephone Service

A cable modem is a node on Ethernet distributed from a cable node.

Data channels delivered from the head-end provide downstream data for cable modems. Standard cable modems are really nodes on an Ethernet local-area network. You share that network capacity with your neighbors. The number of households connected depends on the system design and the number of people who subscribe to the service.

The distribution nodes receive downstream data and distribute those among one or more Ethernet networks on the cable. If the node serves 500 homes but only 2% have cable modems, it may deliver data to all 10 of you through one local-area network. If 60% of subscribers sign up for cable modems, the cable company typically would arrange its cables to split its 300 customers among 20 or 30 LANs.

Like other LANs, cable modems can carry data all the time without tying up a phone line. Although the network is shared, downloads can reach peak speeds in the megabit range as long as too many other users don't try to download at the same time. Access speeds also can be limited by traffic jams at other points on the Internet, not just by the cable modem's capacity.

Cable networks also can transmit telephone signals in digital form, with special hardware converting the digital signals to analog form so you can use standard telephones over the cable network. The signals are transmitted in the same way as cable modem signals.

Evolving Cable Networks and Bandwidth

Interactive services such as telephone, cable modems, and two-way video increase the demand on distribution nodes. Present nodes are very efficient at distributing identical signals to several hundred subscribers. They are less efficient in distributing different services to each of those subscribers. The more bandwidth each subscriber needs, the more serious the problem.

One way to enhance the bandwidth per subscriber is to split nodes so each one serves fewer households. Splitting nodes also can extend fiber farther into the community and closer to the home. Such extensions will be needed if cable networks are to compete with fiber-to-the-curb and fiber-to-the-home telephone networks for home users who want broadband net access.

Both cable and telephone networks are installing fiber closer to homes as they strive to offer voice, broadband data, and video services. Convergence won't make the two networks identical, but it will make them look more alike.

HDTV and Cable

The introduction of HDTV poses problems for cable systems, but it may also offer some opportunities.

Cable can transmit HDTV in standard 6-MHz channels.

The HDTV broadcast standard at least nominally solved the technical problem of fitting the broader-bandwidth high-definition signal into the same channel slot as NTSC analog signals. Broadcast HDTV squeezes 19.2 Mbit/s into a 6-MHz slot, so cable companies can simply transmit the signal in broadcast format. Cable carriers can provide the needed interfaces between digital signals and analog sets—and digital sets and analog signals—by installing new set-top boxes.

However, most cable companies don't have extra slots available for HDTV channels to use. They would have to turn off other channels to make room for them, and they don't have much incentive to do that as long as only a few people have HDTV. Another factor slowing the spread of HDTV has been a lack of available programs. The people who care most about video quality usually subscribe to cable or satellite services, so they face a choice of quality of images in HDTV versus quantity of programs on cable.

The cable industry won't have to replace its existing network because most of the changes are in the transmitter and receiver equipment. But it will have to pay for the new transmitters needed for HDTV signals, and for the new set-top boxes to convert the signals into the proper format for subscribers. The changeover will take time, and cable companies will lag behind broadcasters, who are much further along in the switch to HDTV.

The issues of restrictions on the copying of digital programs remain unsolved. The entertainment industry wants to ban copying, but the cable companies don't want to annoy customers who pay for premium services partly so they can record movies at odd hours and time-shift them to more convenient times.

Stay tuned for interesting times.

Other Video Applications

Small, light, and durable fiber cables are valuable for portable systems.

Cable television is the largest-volume video application for fiber optics, but there are many other cases where fiber is used for video transmission. Table 27.4 lists a sampling of important applications, with brief descriptions. Most involve point-to-point transmission.

Transmission requirements vary widely for these systems. Although many require high transmission quality, security video systems must be low in cost. Although metal cables can do some of these jobs, fibers offer benefits of lighter weight, smaller size, higher signal quality, longer transmission distances, immunity to electromagnetic interference, better durability, and avoidance of ground loops and potential differences.

Small, light, and flexible fiber cables offer important benefits where portability is important, such as in remote news gathering and when covering special events. Many systems use rugged cables and connectors developed to meet rigid military specifications for durability. Whenever cables are strung anywhere, they are vulnerable to damage. Wireless systems often cannot meet quality requirements, especially for broadcasting.

Fiber transmission also offers more subtle advantages, notably avoiding the need to adjust transmission equipment to account for differences in cable length. Television studio amplifiers are designed to drive coaxial cables with nominal impedance of 75 Ω. However, actual impedance of coaxial cables is a function of length. As cable length increases, so does its capacitance, degrading high-frequency response if the cable is longer than 15 to 30 m (50 to 100 ft). Boosting the high-frequency signal, a process called *equalization*, can compensate for this degradation, but proper equalization requires knowing the cable's length and attenuation characteristics. Compensation also becomes harder with cable lengths over 300 m (1000 ft) and is impractical for cables longer than about 900 m (3000 ft). There is no analogous effect in optical fibers, so operators need not worry about cable length.

Table 27.4 Other video-transmission applications for fiber optics

Application	Requirements	Special Notes
Electronic news gathering, special-event coverage	Light, durable cable to link mobile camera to fixed equipment	Wireless an alternative, but quality is lower
Security video	Vary; low cost important	Often low resolution
Studio and production transmission	High-quality link inside studio	1.5 Gbit/s for HDTV
Feeds to and from remote equipment (e.g., antennas)	High transmission quality	

What Have You Learned?

1. Video signals encode continuous changing pictures and sound. They are transmitted in standard formats and require considerably more capacity than voice or digital data.
2. Analog NTSC video displays 30 analog 525-line frames a second with interlaced scanning. Each NTSC channel requires 6 MHz of broadcast spectrum. PAL and SECAM are interlaced scanning systems that each second show 25 analog frames of 625 lines each. These formats are decades old.
3. Computer displays need progressive scanning to show text clearly, not the interlaced scanning of NTSC, PAL, or SECAM. Progressive scanning demands more bandwidth and faster electronics.
4. Digitized video signals can be compressed by a factor of 75 without seriously degrading quality.
5. Digital television standards cover both high-definition (HDTV) and standard-definition (SDTV) video. The HDTV formats have 720 or 1080 lines and a wide-screen format.
6. Digital television broadcasting is being phased in to replace analog broadcasts in the United States, but the change probably will take much longer than had been planned.
7. Video signals can be broadcast from a ground station to serve a local area. Microwave transmission from direct broadcast satellites can serve a much larger area; customers need satellite dishes and converters.
8. Modern cable television systems now carry dozens of analog NTSC video channels over fiber-optic and coaxial cables; the fiber runs from the head-end to distribution points or optical nodes. Coaxial cables run from those points to homes. Customers need set-top converters to access premium channels.
9. Hybrid fiber/coax systems transmit NTSC video to subscribers at 50 to 550 MHz. Digital services are transmitted to optical nodes at 550 to 750 MHz, and signals from subscribers return at 5 to 40 MHz. Each optical node serves about 500 homes.
10. Hybrid fiber/coax can deliver services including Internet connections, telephony, and subscription video services. Internet connections via cable modem work like local-area networks.
11. Hybrid fiber/coax can be upgraded by splitting optical nodes to serve fewer subscribers.
12. Video transmission generally is over single-mode fiber at 1300 or 1550 nm.
13. Small, lightweight fiber cables are valuable for portable news gathering and sports event coverage.
14. HDTV signals are compressed to a digital rate of 19.3 Mbit/s, which can be broadcast or transmitted through cable in a signal that fits into the same 6-MHz band used for analog channels.

15. Digital cable and DVDs are compatible with analog television sets; HDTV is not. Analog televisions will have to be discarded or equipped with adapters when television transmission is all-digital. The adapters can be installed in cable decoders.

What's Next?

In Chapter 28 you will learn about the role of fiber optics in vehicles and other mobile communications for civilian and military applications.

Further Reading

Analog television: *http://www.ntsc-tv.com/*

Walter Ciciora, James Farmer, and David Large, *Modern Cable Television Technology: Video, Voice and Data Communications* (Morgan Kaufmann, San Francisco, 1999)

Digitaltelevision.com: *http://www.digitaltelevision.com/*

Gary M. Miller, *Modern Electronic Communication*, 6th ed. (Prentice Hall, 1999). See Chapter 7 on television.

Ken Nist, *An HDTV Primer: http://www.hdtvprimer.com*

Questions to Think About

1. Analog-to-digital conversion generates lots of extra bits, so it isn't fair to say that a 25-megabit HDTV frame contains only 2.8 times more information than an NTSC frame digitized to give 9 megabits. It's fairer to compare the number of lines of resolution and the width of the screen. Using those guidelines, how much more information does a 1080-line HDTV image contain than a 525-line NTSC image? Remember that the HDTV image has a 16:9 aspect ratio, while the NTSC image is only 4:3. (*Hint:* calculate the number of picture elements or pixels.)
2. The highest resolution possible for digital television is 1080 lines by 1920 pixels, in 60 interlaced frames per second. The lowest is 480 lines by 640 pixels in 24 progressive scans per second (corresponding to a digitized movie). How do the numbers of pixels per second compare? (Note that multiple bits encode each pixel, so this is not the data rate.)
3. Digitizing voice and video both produce data streams with much higher numbers of bits per seconds than the bandwidth in hertz. Compare the ratios of bits per second per hertz for voice and video. What might cause the difference?
4. A broadcast transmitter in a hybrid fiber-coax system generates output power of 10 dBm (10 mW). Analog receivers require an input power of 5 μW (−23 dBm) for adequate signal-to-noise ratio. If the transmission loss between head-end and distribution node is 10 dB (not counting the splitter), and system margin is

10 dB, how many nodes can this transmitter support? How many could you serve by reducing the system margin by 3 dB?

5. You need narrowcast transmitters for the same system. What power level do they require if system margin, receiver sensitivity, and cable loss are the same?
6. You need to lease capacity on a metro network to transmit one channel of studio-quality HDTV from a studio to a television transmitter. The network operator has four types of transmitters available, which operate at rates to OC-3, OC-12, OC-48, and OC-192. Which one offers the capacity you need without too much excess?

Chapter Quiz

1. What is the analog bandwidth of one standard NTSC television channel?
   a. 56 kHz
   b. 1 MHz
   c. 6 MHz
   d. 25 MHz
2. How many lines per frame do standard analog European television stations show, and how many full frames are shown per second?
   a. 525 lines, 25 frames per second
   b. 625 lines, 25 frames per second
   c. 625 lines, 30 frames per second
   d. 1125 lines, 25 frames per second
3. The HDTV standard in the United States transmits 19.3 Mbit/s after digital compression. How much compression is used, and what would the data rate be without it?
   a. 4-to-1 compression, 80 MHz
   b. 10-to-1 compression, 200 Mbit/s
   c. 13-to-1 compression, 270 Mbit/s
   d. 75-to-1 compression, 1500 Mbit/s
   e. none of the above
4. What key development made the quality of analog fiber-optic transmission adequate for cable television trunks?
   a. highly linear distributed-feedback lasers
   b. inexpensive single-mode fiber
   c. dispersion-shifted fiber
   d. digital video compression
   e. optical amplifiers for 1550-nm systems

5. What is the most important advantage of fiber optics over coax for distributing cable television signals from head-ends to optical nodes?

a. Fiber optics are hard to tap, so they reduce signal piracy.

b. Fiber repeater spacing is much longer, avoiding noise and reliability problems with coax amplifiers.

c. Fiber can be extended all the way to subscribers.

d. Fiber cables are less likely to break.

6. How are analog video signals distributed to subscribers on present cable television systems?

a. All subscribers receive the same signals, which require set-top decoders to show premium services.

b. Signals from set-top controls are used to switch designed signals to the home.

c. Equipment at the head-end switches selected services to each subscriber.

d. One pair of optical fibers runs directly from head-end to home.

7. What must cable systems change to transmit HDTV signals instead of NTSC analog video signals?

a. All coaxial cable must be replaced with fiber-optic cable reaching homes.

b. Analog transmitters and set-top boxes must be replaced with digital versions.

c. Only the transmitters at the head-end must be changed to HDTV format.

d. Only the set-top boxes and the cable type must be changed to HDTV format.

e. No changes are necessary because cable transmission has always been digital.

8. What frequencies are used for signals from the subscriber to the head-end in hybrid fiber-coax?

a. 50 to 550 MHz

b. 0 to 1 GHz

c. 550 to 750 MHz

d. 5 to 40 MHz

e. none of the above

9. How do cable modems work on hybrid fiber/coax networks?

a. They switch signals directly from the head-end to individual subscribers.

b. They transmit signals in one direction only.

c. They function like a local-area network, addressing high-speed signals to one of many subscriber terminals served by the same network.

d. They digitize video images for videoconferencing but cannot be used for other purposes.

e. They are incompatible with hybrid fiber/coax.

10. Which format is used for digital television displays?

a. 1080 lines, 1920 pixels, 60 interlaced frames per second

b. 1080 lines, 1920 pixels, 30 progressive scan frames per second

c. 720 lines, 1280 pixels, 60 progressive scan frames per second

d. 480 lines, 640 pixels, 60 interlaced frames per second

e. all of the above

11. How many analog video channels are required to transmit a full HDTV digital signal?

a. 1

b. 2

c. 4

d. 5

e. 6

12. A fundamental difference between cable-television and telephone networks is that

a. cable networks can't carry two-way telephone traffic.

b. only cable networks can carry high-speed data.

c. cable networks do not use circuit switching.

d. only cable networks use single-mode fiber.

e. there are no differences left.