An Overview of Cable and Wire Technology

In this report:

Synopsis

Editor's Note
Users now have a variety of cabling plans to choose from. AT&T's Systimax Premises Distribution System, IBM's cabling plan, Digital Equipment's DEConnect, Bell Atlantic's UITP, and Northern Telecom's Integrated Building Distribution Network are some of the most popular. In addition, the Electronics Industries Association (EIA) charted a project in 1985, sponsored by the Telecommunications Industries Association, to address voice and data communications wiring. This became known as the TR41.8.1 working group, and it is now nearing completion.

Report Highlights
Wiring is now deregulated, and this report brings readers up to date on concerns about this rather complex topic. After providing a brief historical perspective, this report analyzes the different types of cable, describes the various cabling plans now offered, and discusses the different types of equipment available for testing cable installed in a network.

—*By Charles Haggerty*
Associate Editor

Analysis

Historical Perspective

It was not until 1978 that customers were first permitted to install their own inside wiring. Prior to that, the telephone company owned the wire and was responsible for maintaining it.

In 1981 the FCC ruled that new inside wiring installed by the local telephone company would be regarded as an expense, not as an asset. (Inside wiring refers to the twisted-pair wire installed during construction of a building.) In other words, customers would no longer be billed monthly for maintenance. Instead, the telephone companies would charge for installing new inside wiring, but wiring already installed (existing or embedded wiring) would be amortized, or written off, over the course of several years.

The FCC also allowed the telephone companies to sell this existing wiring to users. Some telephone companies then made this offer to users, and some took advantage of it. These users now legally own the wire that they purchased.

In 1983 the FCC distinguished between two types of wiring: simple and complex. Complex wiring is multipair wiring used by a commercial business, not by a residential customer. Simple wiring is the one- or two-strand wiring found in most homes. The FCC detariffed all newly installed complex wiring; simple wiring was not detariffed at that time.

Therefore, complex inside wiring could be regarded as any other customer premises equipment (CPE). Users could, if they wished, purchase and install it themselves. They could hire a firm to provide the installation, or they could hire the telephone company for this purpose. The telephone company had to perform installation work through a separate subsidiary.

In 1984 the FCC allowed customers to augment their existing simple wiring or to purchase more from other vendors besides the telephone companies. The FCC then went on to suggest that all simple wiring be detariffed.

In early 1986 the FCC detariffed the *installation* and *maintenance* of both simple and complex wire. It also proposed that all existing inside wire be detariffed and ownership be transferred to building tenants or owners. Later that year the Commission ruled that existing inside wire would be detariffed on January 1, 1987. (New York Telephone was granted an extension until January 1, 1990.) Ownership would be transferred between that date and 1994, depending on how long it took the local telephone company to recover its costs. Costs already recovered, however, would transfer ownership immediately on January 1, 1987. Riser and horizontal distribution cable was still regarded as the responsibility of the local telephone company.

What this all amounts to is yet one more concern for the telecommunications manager. It is now imperative that the manager have some basic understanding of the different types of cable technology, be aware of the various cabling plans available, and know about the ways of tracking cable topology. These concerns are addressed in this report.

Technical Explanation

Basic Waveforms and Bandwidths

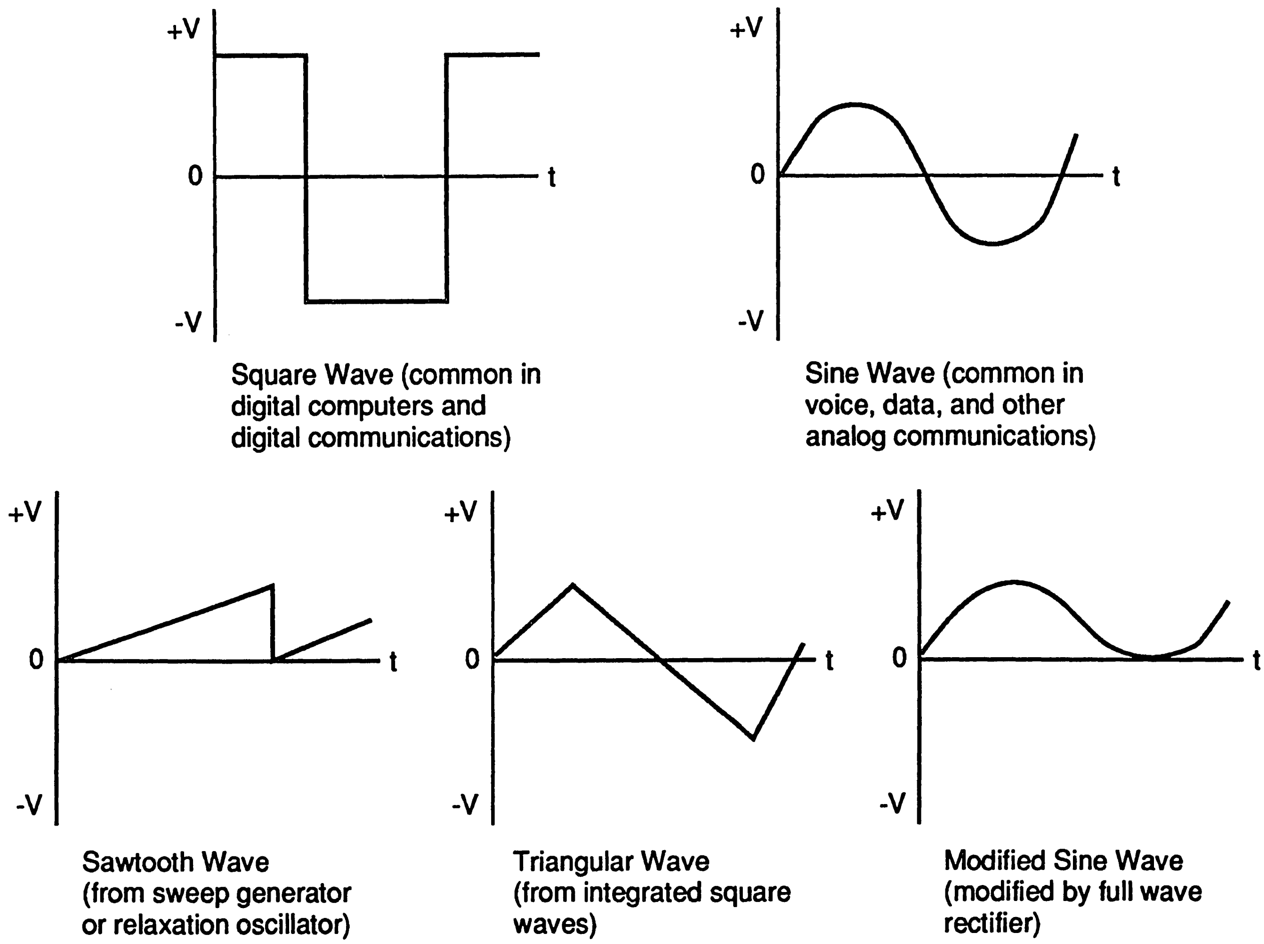
Before discussing the characteristics of the different technologies, it is important to discuss some relevant data communications and electrical concepts underlying the performance claims of different media types.

The traditional ways of expressing communications speeds relate to the frequency and amplitude of electromagnetic signals and voltage levels, which are assumed to be moving in waves shaped like analog sine curves. The amplitude refers to the spread between the highest and lowest point of the typical waves of a particular signal. The amplitude of each wave differs due to transient power surges. Frequency, generally measured in bits per second, is a much steadier parameter that refers to the number of those waves in the given unit of time.

This measurement is directly related to the wavelength (width of the wave), since a shorter wavelength means that more waves can be squeezed into a second. Out of these fundamentals come the following concepts:

- Waveforms—the shape of the wave, which is determined primarily by the generating device and the frequency. There are many waveforms. Figure 1 illustrates some common ones.
- Analog Waveforms—the relatively smooth sinusoidal curves of the electromagnetic waves that bear most data communications traffic. These were originally designed by the telephone company for voice communications, which is satisfied by a relatively narrow range of low frequencies. Smoothly curving analog waves imply slower speeds in the change from one amplitude to another. Analog receiving devices decode incoming data based on the amplitude of the wave, so this form of communications tends to be sensitive to spurious electromagnetic "noise."
- Digital Waveforms—sharp changes in the height of the wave provides the squared-off waveforms of digital transmissions used within most general-purpose computers. These imply high speeds in the change from one amplitude to another but not necessarily high amplitudes. Sensing devices need only check for the presence or absence of a wave of approximate amplitude; if the wave has been increased due to spurious noise, it rarely matters.

Figure 1.
Some Common Electrical Waveforms



Waveforms are based on the relationship of voltage against time.

- T1—the digital communications standard that expects a 24-channel analog signal to be sampled at the rate of 8,000 samples per second. Since each channel sample is encoded as a value stored in an 8-bit digital word, and when all 24 words are transmitted with 1 check bit as a "frame," the resulting transmission speed required is 1.544M bits per second (193 times 8,000).
- Frequency Spectrum—the plot of the amplitude times the frequency is the frequency spectrum of the signal. The frequency of a wave remains constant, as long as the sender and receiver (or perceiver) maintain the same distance or the same relative motion. Amplitude is affected by noise and so tends to vary to some extent.
- Hertz (Hz)—the measurement of frequency as expressed in electromagnetic terminology, i.e., waves per second. This measurement can be applied to light and sound as well as to electromagnetic waves, since all three have comparable behavioral characteristics. Although Hz is almost always equivalent to bps, practically speaking, it is not precisely identical because it is possible to store more than one bit in a single analog wave.
- Channel Bandwidth—the difference between the highest and lowest frequencies for which the individual communications channel or medium (twisted-pair wire, optical fiber, or coax cable) can produce reasonable fidelity.
- Voiceband—defined by the telephone company, voiceband operates at about 300 to 3,000 Hz frequency.
- Baseband—a signal being transmitted in its original analog or digital frequencies, without being changed by modulation.
- Broadband—a channel with a bandwidth greater than that of voiceband, and hence capable of higher data communications rates.

Electromagnetic Wires and Cables

Data communications has, for the most part, been piggybacked onto the voice communications systems of the telephone companies to take advantage of existing networks and their physical network maintenance organizations. Since the voice network was originally designed around analog communications signals, and most modern computers use digital technology, this has meant constant use of MOdulation/DEModulation units (modems) to interface between the two. It has also meant that the computer industry has made wide use of the inexpensive twisted-pair wiring technology used by the telephone company throughout this century for most of its lines. Like the telephone company, too, the computer industry has used the more expensive coaxial cable in the last 30 years for longer distances, heavier traffic, and higher speeds.

Managers responsible for installing networks often find that viable, working cabling is already installed in their buildings. Although the cable type may not be the most expeditious, if it works managers are reluctant to pull it out and replace it with another type. As a result, most present-day networks run on a variety of cable types, and few networks comprise only one type of cabling. The following paragraphs discuss the most widely used types of cable: twisted-pair cabling, coaxial and twinaxial cables, and fiber optic cables.

Twisted-Pair Wiring

Twisted-pair wiring is classified as either shielded or unshielded. In the past, high-speed networks needed to run over coaxial cables. They can operate quite well over unshielded twisted-pair (UTP) wiring. Networks based on UTP are easier to modify and troubleshoot than those based on coaxial or fiber optic cable. Shielded twisted-pair cabling is also easy to work with in terms of testing and modifying networks, but UTP is much cheaper.

Twisted-pair wiring, as the name implies, consists of two individually insulated wires twisted together. It is the oldest type of wiring in widespread use today, and it is still popular because of its low cost and flexibility. Many users are finding ways to increase their use of twisted-pair wiring by using "baluns," converters, and multiplexers to connect the heavy, harder-to-manage coaxial cable to twisted pairs. These types of two-wire circuits usually allow data to flow in only one direction at a time in a half-duplex data communications mode. Four-wire circuits (double twisted pair) are normally required if a device is to send and receive simultaneously in full-duplex data communications.

Twisted-pair wiring is familiar to everyone, since it is the type of wiring telephone companies use in the home. The conducting core of these wires is usually made of copper or aluminum because of the low resistance of these materials. Copper is preferred, but aluminum is sometimes used because of its lower cost. Each of the two wires in the pair is surrounded by its own color-coded polyethylene, polyvinyl chloride (PVC), or a wood fiber, paper-like insulating layer. There may also be a coating of Teflon required if the wire is passing through a plenum (false ceiling) that contains a variety of electrical fixtures and wiring. Anywhere from 6 to 4,200 twisted pairs have been bound together into cables or trunk lines for transmissions between floors of buildings, between buildings, or between cities, but the de facto standard twisted-pair-per-voice-trunk line is a bundle of 25 wire pairs.

Older wires, dating back to the early 1950s or before, were insulated with the wood pulp-based, paper-like material, which was effective as an insulating material if the insulation was kept dry. This proviso is an important one, however, since even well-protected wires in gas-filled underground lead sheaths have developed water damage from leaks at the end seals or cracks in the sheathing. These problems, the development of newer technologies, and changes in the costs of materials led to new types of insulation.

Polyethylene began replacing wood pulp/paper as the typical insulating material as early as the mid-1950s, although the older type of wire is still in place in some out-of-the-way places. Polyethylene has been shown to be an excellent replacement in most respects; it has high insulation strength, a low dielectric constant, low cost, and is easy to manufacture. It is not, however, as fire resistant as a second plastic material, PVC, making the latter a better choice for wiring buildings and switchboards. PVC, on the other hand, has a higher dielectric constant and does not provide the same level of insulation as polyethylene.

The dielectric constant, the measure of the nonconducting properties of the wire and its insulating material, is particularly important in twisted-pair wiring because of problems with the "skin effect." Alternating currents tend to flow near the surface of a conductor rather than evenly throughout the entire wire; this raises the resistance. As the frequency used for the transmission increases, the signal current and the magnetic field that surround it concentrate closer and closer to the outer edge or "skin," raising the resistance more and more. Since the electrical and magnetic fields that surround the signal current are usually larger than the circumference of the wire, higher frequencies are more likely to create "cross talk" with a nearby wire.

This problem is handled in two ways with twisted-pair wires. First, each wire, one positive and one negative, is separately insulated. Second, the twisting of the wire has the effect of grounding the wire and balancing the signal current. Although the result is not as reliable as coaxial and optical cable, it is generally adequate enough to prevent cross talk and other electromagnetic interference.

The wire pair may be bound into a single cord with a polyethylene sheath if the twisted pair is interconnecting modems, devices, and/or wall sockets, but this is mostly for a little extra protection if the cord is stepped on, and for ease of handling. Inside a wall, the extra sheathing is rarely used. In an older building that has been gradually filling up with communicating terminals and personal computers, the wiring closets become clogged with what looks like a confusion of colorful spaghetti. It can be a major task to locate wiring problems, find space for new inserts, or reorganize into a more automated wiring management system.

Joining two twisted-pair wires together is not difficult. The ends of each pair can be manually stripped, twisted together, soldered for more performance, and insulated with tape. Alternately, one of the modern, easy-to-use, press-fit connectors can be pushed onto each end of the two wire pairs, and the two connectors can be joined.

Coaxial and Twinaxial Cables

Coaxial cables, like those used on IBM 3270 Series terminals, involve a pair of conducting elements, but in this case, one of the conducting elements is formed into a flexible, hollow, pipe-like shape, and the second conducting element is a flexible, circular, positively charged "rod" strung through the center of the much larger negatively charged conducting "pipe." The cable is thus a set of two concentric circles which share the same axes, hence the name.

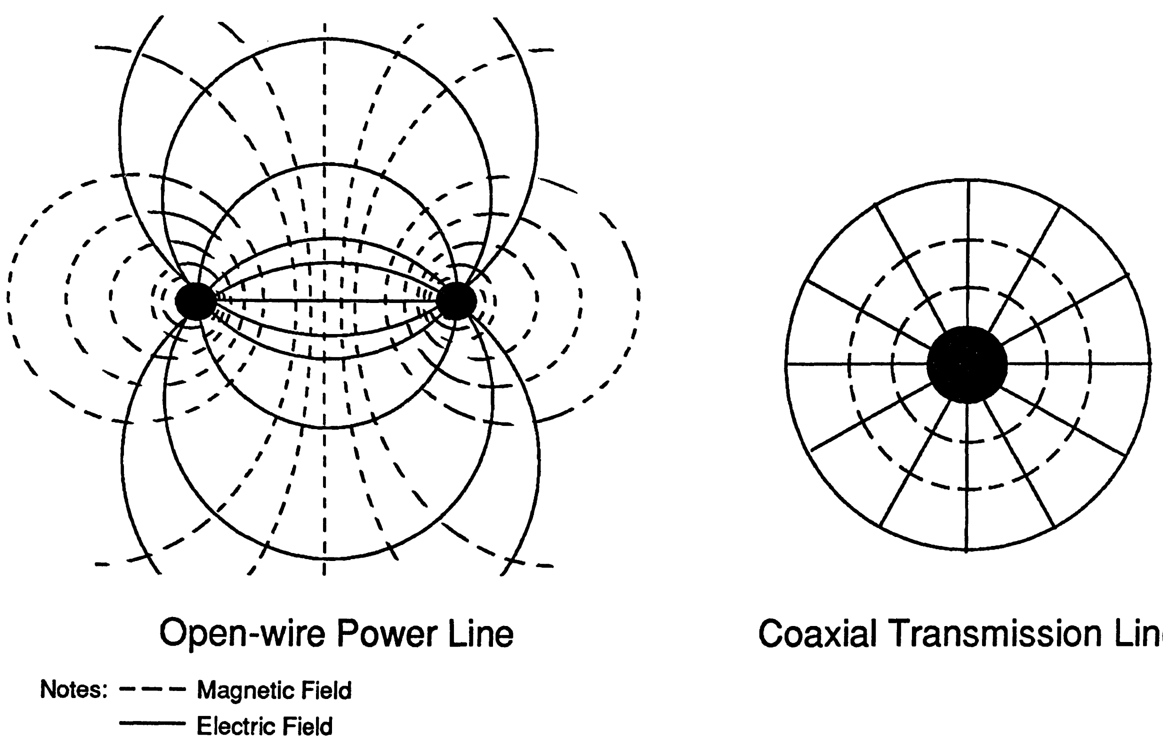
The cable is carefully manufactured so that the inner conductor, or rod, remains centered in the pipe with a high degree of precision by running it through supporting polyethylene disks every inch or so, or by filling the space around it with a spiraled or expanded insulation material. The result is a cable that has self-insulating features due to the way the design offsets the nature of the skin effect.

As noted in the discussion of the twisted-pair wiring, the higher the frequency of the signal current, the more it concentrates close to the skin of the wire. With coaxial cabling, the signal current of the outer conductor gravitates toward the inner skin of the pipe, and the signal current of the inner conductor gravitates toward the outer skin of the rod. Thus, the higher the frequency, the more the two draw together, rather than gravitating outward toward other lines that can generate signal interference. The electromagnetic fields are compact and orderly, as shown in Figure 2, especially when compared with the completely uninsulated "open" wires used in some places for power lines. Coaxial cable still is vulnerable to electromagnetic interference, but this self-insulating characteristic plus the insulating layers added to the cable make coaxial cable better than twisted pair in its capability to handle the higher frequencies of broadband data communications.

Although coaxial cable is a dual conductor, like twisted-pair wire, the two types of lines differ in their balancing relative to the grounding of the line. The twisting that wraps the positive and negative wires around each other balances and grounds the electromagnetic fields surrounding each of the two wires. In coaxial cable, the negative charge is carried on the outside conductor, and there is no grounding. This makes coaxial cable more vulnerable to electronic eavesdropping than twisted-pair wiring. In fact, terminals using coaxial cable require alterations to meet government "Tempest" specifications for security against this type of spying.

There are two variations of coaxial cable that deserve mention. First, Wang has a type of dual-balanced coaxial cable which uses two center conductors; since it is balanced, it does not have the grounding and security problems of standard coax. Second is IBM's twinaxial cable, which is similar to coaxial cable. It runs a twisted pair as the rod through the center of the pipe. In this case, the pipe

Figure 2.
Electromagnetic Fields around Two Types of Wiring



The electromagnetic fields around coaxial cabling occur in a more orderly pattern than they do around the "open-wire" types of power lines.

is still a negatively charged conductor, and the overall cable is unbalanced.

Coaxial cable, in all its forms, cannot be spliced together by the manual strip-twist-and-insulate method. Like twisted-pair wiring, it has press-fit connectors that clamp over the end of the wires and are then screwed together. The inherently heavier nature of the cable and the importance of alignment, however, make the coaxial cable much more difficult to handle in this regard. Users who move terminals around generally prefer twisted-pair wiring.

Outer Sheathing for Electromagnetic Cables

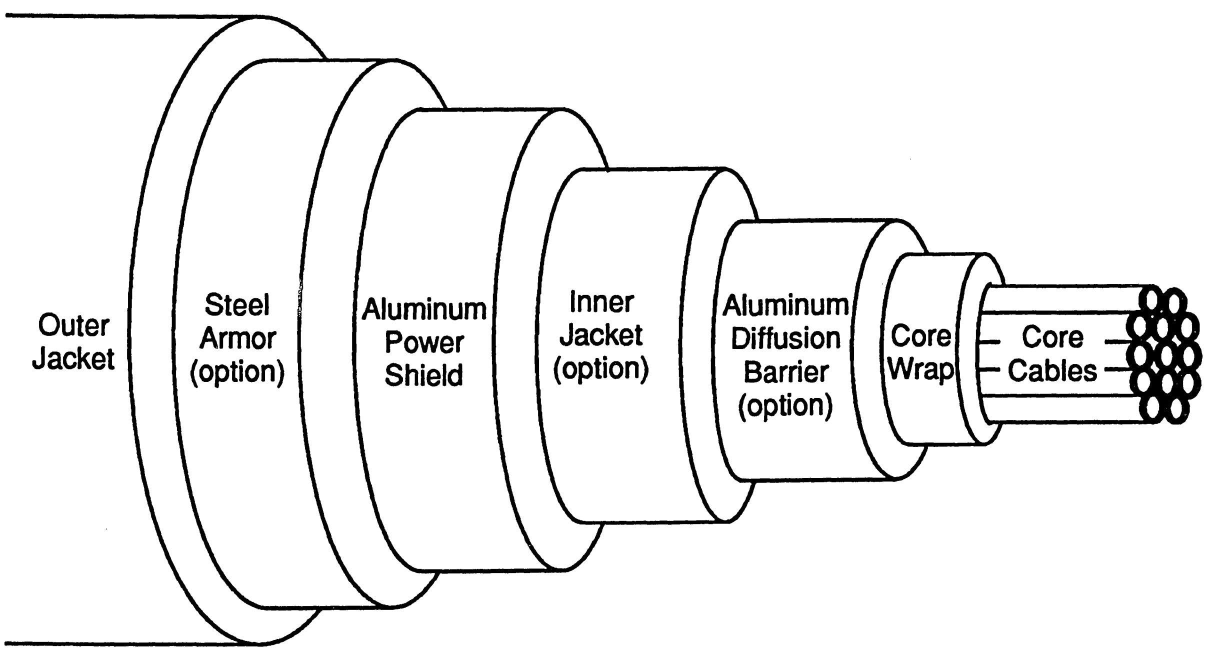
In electromagnetic cables, the type of wire, the number of layers, and the type of sheathing used to insulate the wire have to be evaluated against cost and environmental risk factors. Sometimes it is better to run aerial wire, which is insulated against lightning strikes by means of power shields and diffusion barriers (usually made of aluminum). Sometimes wire must be run through water, which calls for watertight, noncorroding jackets. Other times the cable should be buried underground, where the danger from lightning is less, but water and physical damage from rodents are problematic. See Figure 3 for the typical sheathing layers available.

Fiber Optic Cables

Fiber optics is a technology made possible by the development of especially transparent fibers with low light loss and such ultrasmall, concentrated, reliable light sources as lasers and light-emitting diodes (LEDs) that are capable of high-speed alterations in intensity. A typical transparent fiber is surrounded by a layer of light-bending cladding that is, in turn, surrounded by a protective coating. The light source sends analog waves or digital pulses of light down the fiber to a receiving unit that may be either a repeater that renews the signal or the receiver where the light signal is transformed back into an electromagnetic signal for input to the computer.

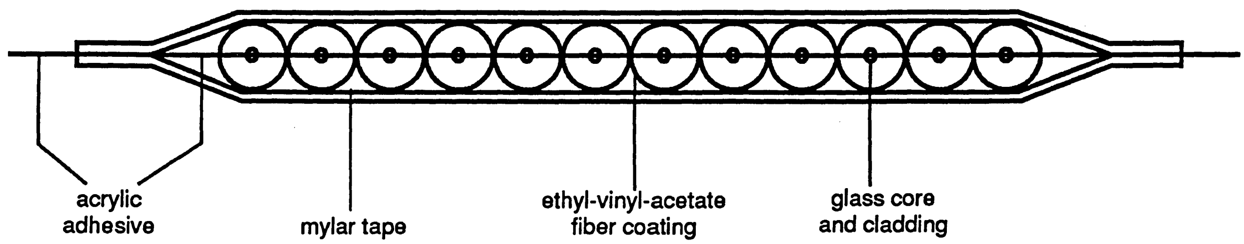
The optical fibers, even with refractive cladding and protective coating, are so thin that it is impractical to have a single fiber in each cable. Instead, they are lined up in a row (which is typically a dozen fibers), glued together and covered top and bottom with tape, forming a fiber ribbon that is

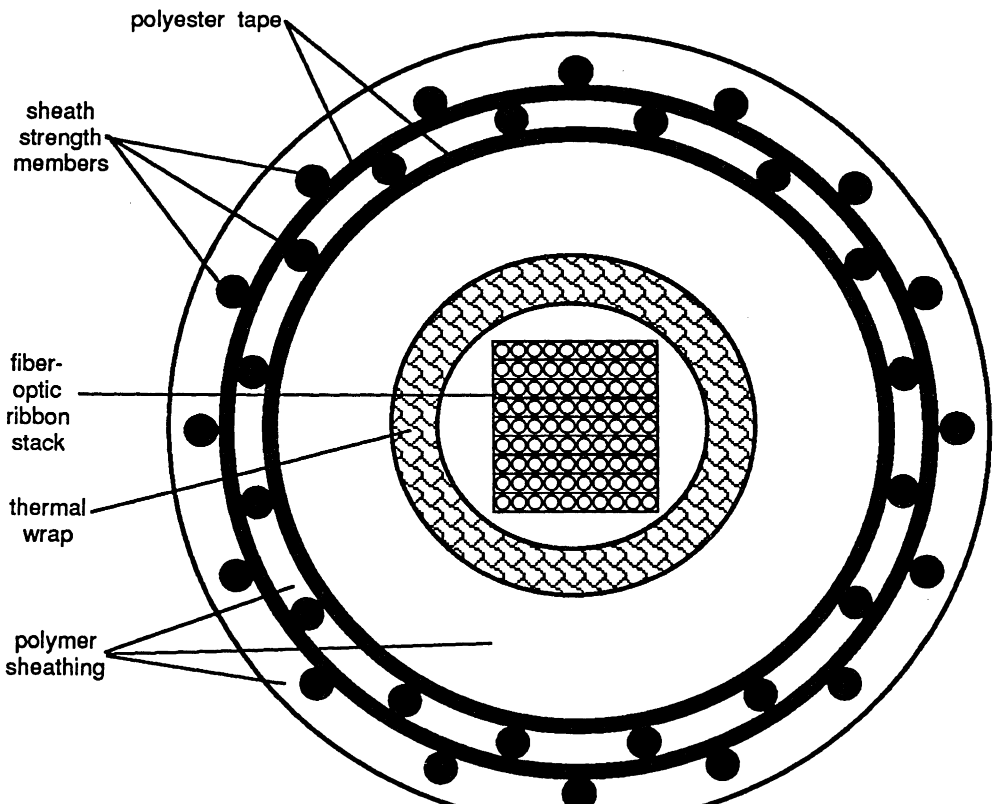
Figure 3.
Sheathing Layers



Sheathing layers in typical multicoax or multiwire cables. Jackets are usually made of polyethylene.

Figure 4.
Fiber Optic Cable





Cross section of 0.5-inch cable with stack of 12 optical fiber ribbons.

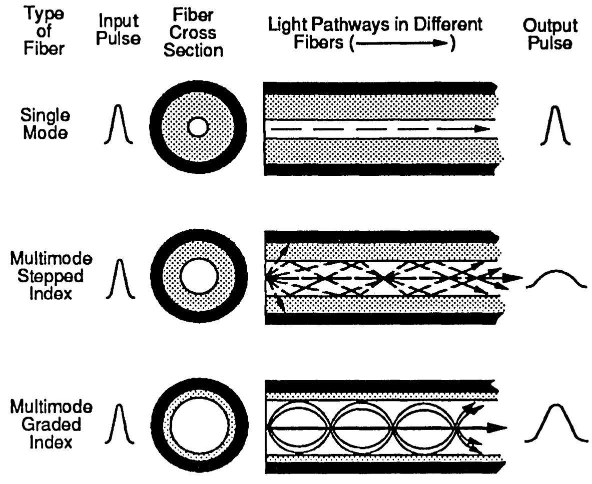
under a quarter inch in width. A stack of these ribbons (again typically 12 in number) is then covered with a thermal wrap, several layers of sheathing, and strengthening wires. The resulting cable contains 144 fibers, each at least an order of magnitude faster than coaxial cable, but still only half an inch in diameter. See Figure 4 for a cross section of a fully sheathed, strengthened, half-inch cable with a 12-ribbon stack; a detailed drawing showing a cross section of 1 ribbon is also included.

There is more than one type of fiber cable. One of the primary difficulties has been to design the cable so that the signal received is a reasonable facsimile of the one sent. On cables with cores wide enough to allow more than one "mode" of light velocity, the mirrorlike refractive properties of the cladding become critical. Waves that do not match the index of refraction are lost; a certain percentage of those that are refracted back to form the datastream conflict with the intended waveform, bounce around, and gradually disperse (modal dispersion) into different time slices than the one in which they started. Like coaxial cable and twisted-pair wiring, this tendency toward attenuation of the signal increases over time and with the length of the cable until the intended shape of the waveform is lost. A repeater must be positioned on the circuit where the waveforms can still be reliably detected and retransmitted. Fewer repeaters lower the overall cost for this part of the system, but this has to be balanced against the price of manufacturing cable that provides greater reliability over distance.

Three basic fiber designs have emerged. They vary as to the nature of the input light source, the size of the core fiber, and the complexity of the index-of-refraction boundary supplied by the cladding and the typical waveform it ultimately presents to the repeater or destination device. Figure 5 compares the three types.

- Single-Mode Fiber: The simplest concept, this also is the most expensive, partly because of the critical tolerances in its manufacture, and partly because it is usually coupled with a laser input device. This fiber has a very small core fiber, a refractive index at the boundary of the core, and cladding that only allows for a single straight pathway through the fiber. The fiber and cladding must be carefully designed and manufactured to create the right kind of refractive index to support this type of single-mode pathway.
- Stepped-Index Fiber: The stepped-index fiber has the thickest core, but it has only a single index of refraction at the core/cladding boundary that bends back the light. Since there is no gradation of refraction, the light rays travel at the same rate; and, since the path lengths will vary depending on the angles of the light rays, the waveform deteriorates rapidly. These problems increase with the transmission speed, so this fiber has a ceiling of about 20M bps for one kilometer. It can, however, be useful for image transfer over short distances. Either a laser or an LED can be used as an input device, but the laser's greater intensity and coherence allow faster speeds.
- Graded-Index Fiber: The graded-index fiber is the most widely used because it supplies adequate speed benefits at more reasonable prices. This fiber has a larger core than single-mode fiber that accepts light rays at a variety of angles. The index of refraction changes across the core/cladding so that the velocity of the light is slower at the center and faster at the edges. The result is that the lightwaves intermittently disperse and rejoin in a controlled, ball-like waveform. While this design, shown in Figure 5, is not as fast as the single-mode fiber, it is, nevertheless, 50 times faster than the stepped-index fiber. As is the case with graded-index fibers, both lasers and LEDs can be used as light sources. The laser provides significantly faster, more coherent lightwaves that can provide speeds as much as 18 times faster than LEDs.

Figure 5.
Optical Fibers and Light



Core fibre is shown as clear circle (O), refractive cladding is spotted and protective coating is shown as solid black. The relative thickness of the protective coating is usually much greater than shown here.

Effect of different optical fibers and their light pathways on waveform of output pulse.

Although the repeaters used to regenerate the optical signal can be spaced more widely apart than those for coaxial cable, they are also more complex and more expensive. They must optically sense the image, change this pulse into an electromagnetic signal to be revivified, and then change it back into an optical pulse to be transmitted. This problem exists only for those cable systems that are transmitting over longer distances and is partially dependent on the speed required.

Fiber Optic Design Considerations

The main distinction between the design of copper wire and optical fiber cables is the difference in the stress-strain behavior of the two cable types. While copper wires, because of their flexibility, can withstand a fair amount of flexural and torsional stress, the same cannot be said of glass fibers, which are essentially brittle beyond a critical microbend factor. Thus, the chief fiber cable design objective is to isolate the fiber from all forms of mechanically or environmentally induced stress. Stress from tension and microbending not only contribute to signal loss, but may cause the fiber cable to break due to local fatigue and loss of strength. When an optical fiber exhibits microscopic deformation, this will cause further signal degradation.

Proper cable design and construction minimize tensile stress and microbends on optical fibers. Under stress-free operating conditions, optical properties of fibers remain stable for typical life spans of 20 to 40 years.

Cable design characteristics must reflect the type of fiber being used (single mode, multimode, etc.), the number of fibers being assembled within a single cable (anywhere from 2 to over 144), the specific installation application (whether to be installed in duct, aerial, plenum, trenched, or underwater cableways; used in military tactical, industrial, or secure communications; installed for long-haul or LAN communications networks, etc.), and other specialized and customized design considerations (e.g., all-dielectric or hybrid metallic and dielectric cables; flame-retardant cables; ultra-high transmission performance; long, continuous sections; submarine cables; armored cables; etc.). Cables must be designed to meet both performance and environmental requirements.

Although different cable manufacturers emphasize one aspect of cable construction over another, the basic design principles are fundamentally the same.

Comparing the Types of Cables

Signal dsitortion is caused by nearby lights, electric motors, power cables, and other sources of electromagnetic and radio frequency interference (EMI and RFI). Unshielded twisted-pair (UTP) wiring offers less protection against such interference than does coaxial cable and shielded twisted pair. On the other hand, fiber optic cable uses a light signal, not an electric one, and so it offers the best protection of all against EMI and RFI. Fiber optic cabling may be more expensive, but it compensates for its expense by realizing savings on retransmission costs.

UTP wiring is easily tapped because it radiates more energy than other cable types. However, any type of copper wire should be regarded as an antenna, so users who need a high level of security should strongly consider fiber optic cabling.

Fiber optic cable is the most expensive, while UTP is the cheapest. Economies of scale, however, may render fiber a cost-effective choice. Its numerous advantages—security, clearness of the signal, less need for repeaters— may mitigate its higher price. AT&T, for instance, believes that the future cable medium for business will be fiber, even though current cost factors have prevented it from being widely used. AT&T suggests that users who can do so should install multimode fiber optic cabling now, even if such cabling will not be used. This gives users lead time that will pay off when the FDDI standard is implemented.

AT&T's belief in fiber's increasingly important role is confirmed by the fact that in 1990 Corning, Inc., increased its production of fiber optic cable by over 50 percent. This increase is part of Corning's market strategy that speculates that the demand for fiber cable is about to increase dramatically.

Much cabling already in buildings is UTP cabling that was installed by the telephone companies over the years. Often, managers tend to regard this as "free" cable and are eager to cut costs by using it. For the most part, there is nothing wrong with this approach. After all, UTP is quite easy to work with, and more installers are likely to have

UTP experience than fiber optic experience. As long as UTP's disadvantages are acknowledged and anticipated, it is not necessary to rip out and replace good cabling. As stated above, many networks will include more than one type of cabling.

One of UTP's current disadvantages is that IBM has refused to support 16M bps token-ring networks on this type of wiring. However, IBM once demonstrated the same lack of support for UTP in 4M bps token-ring networks. When other vendors affirmed their support for UTP in 4M bps token-ring networks, however, IBM followed suit. It seems likely that history may repeat itself. Proteon has announced a 16M bps token-ring product that runs over UTP, as have Ungermann-Bass, Cabletron, and SynOptics. Each of these firms has developed methods for overcoming noise and electromagnetic emissions in UTP cabling. IBM has joined these companies and others in the IEEE 802.5 UTP Study Group, which was formed to study a standard for 4M bps and 16M bps token-ring networks that use UTP.

Fiber Optics' Impact on Other Technologies

Although fiber optic technology debuted only a little more than 10 years ago, it has impacted the relationship of existing technologies. The price of the optical transmitters, receivers, and fiber has dropped rapidly. It is difficult to make a direct comparison, because the equipment needed for fiber optic transmissions costs considerably more than bare wire or cable. Nevertheless, in the last few years it has become increasingly popular for growing companies to redesign and organize building wiring to incorporate fiber optics as part of the system.

There is also a growing tendency to reduce coaxial cable in favor of the older, slower, less reliable twisted-pair wiring. Twisted-pair wiring is much less expensive than coaxial cable, and for the majority of terminals, it is adequate in speed. If local codes demand that the wire be coated with Teflon when routed through the plenum, it costs about $0.10 or $0.15 per foot, whereas coaxial cable costs anywhere from $0.50 to $1.00 per foot for the same coating. When terminals are moved, it is easy to tap or splice twisted-pair wiring, which is light and easy to handle. Twinaxial cable is equally difficult. Despite coaxial cable's higher performance and better resistance to electrical noise, many users have chosen twisted pair. In fact, as a result of user requests, several companies (including IBM) have announced LANs that are based on twisted-pair wiring, even though the vendor was inclined to feel coaxial cable was a better choice to carry the performance load.

There are situations where twisted-pair cables will not do. Computer-to-computer communications, T1 digital transmissions, and other high-speed transmissions require megabit speeds. The traditional approach for these applications was to install coaxial cables. Now, however, it is likely that users will choose optical fibers, providing greater speed and room for significant expansion. The optical fibers have more capacity and take up significantly less room, relieving the congestion in wiring closets. In addition, they are not subject to electromagnetic interference, except in the sending and receiving units that include nonoptical and optical elements.

On the other hand, the high capacity of the fiber optic cable makes any failure a critical event, so the fiber transmission is usually duplexed. The rapid drop in fiber costs has made this a reasonable practice. In addition, some users design distributed as opposed to centralized network routing with two pathways out of every installation, so that if one line goes down, there is an alternate route for all nodes. "Network" is used here in a loose sense, because even when the optical cable goes from building to building, it is meant to be a transparent extension to the local system, and not treated as an FCC-regulated communications line. Of course, the optical fiber can also substitute for a communications line.

In keeping with the rapid development of this marketplace, conservative IBM has already positioned fiber optic cables in several products. Fiber is an optional component of the IBM Cabling System and is the key element of the 3044 Fiber Optic Channel Extender Link. The Cabling System is an organized wiring system, as just described; the channel extender is an interesting product that provides relief to crowded computer rooms by significantly extending the distance (by nearly 1.37 miles) that "local" devices can be located from the mainframe. Fiber is also an imporatnt component of IBM's recently announced ESCON architecture.

With the channel extender at one end of the link, a 3044-C1 unit takes the parallel data from the channel and transforms it into a bitstream suitable for fiber optic transmissions. The actual fiber optic network trunk is a dual cable, up to 6,600 feet long, that terminates in a 3044-D1 unit that deserializes the data and presents it to the attached I/O devices. The whole operation is transparent, so from the computer's point of view the device is a local I/O device, and the configuration of the system has not been disturbed at all.

When a user begins to question what this arrangement is good for and what it can replace, the impact of having "just a longer fast cable" becomes more evident. Consider the following with respect to a building one mile away from the mainframe:

- Performance Benefits from Circumventing the Front End: File transfers, in particular, would be performed at much higher rates, benefiting systems at both ends.
- Subsecond Response Time: This feature, advertised to considerably enhance employee performance for certain types of work, can only be implemented if the terminal is attached to a "local" CPU, because public networks are too slow. The channel extender might solve this problem in some configurations, making a local CPU communicating with the mainframe unnecessary.
- Front-End Relief: If enough terminals could be routed through the 3044 link, the configuration could be partly cost justified by temporarily relieving an overloaded 37XX front end.
- Configuration Flexibility: Suddenly a great many of the mainframe peripherals do not need to be located in the computer room. It is possible to move part of the computer room to relieve crowding.

On the other hand, the link moves all eight possible attachment positions for the channel out to the location of the 3044-D1 unit. If it was decided to reconfigure for performance enhancement or other reasons, the link-attached peripherals would have to be moved as a group (by reattaching the 3044-C1), or some peripherals would have to be physically carried back and forth. This would probably not be a problem, but it needs to be thought about.

Although IBM's mainframe channels operate at speeds of up to 3M bytes per second, the 3044 fiber optic link has a ceiling of 1.25M bytes per second. This limits the link to channel-attached I/O devices that operate in the low- to medium-speed range, primarily terminals, printers, communications controllers, and OEM devices. It can also be used to extend the channel-to-channel connectors used to connect multiple IBM computers together. It is surprising to note, however, that IBM did not engineer the 3044 link to be fast enough to handle the 3380 disks and 3480 tapes, especially since disk crowding is a serious problem in some installations. Higher speed links are already available, such as Data Switch's ChannelNet, which supplies a full-speed channel extender for distances of up to 3.4 miles.

Despite the fact that optical fiber is best used as a digital transmission medium, there are many instances in which coaxial cable's friendliness to analog transmissions will hold it in good stead, in both computer-related and noncomputer-related applications (such as radio). In the computer world, however, it is clear that the coaxial cable market is being diminished.

Protection

Wires and cables need to be protected from two basic kinds of disturbances. First, a continuous transmission line requires protection against impacts or events that might destroy the physical integrity of the line. Second, the signal stream has to be protected from accidental intrusions of the same type of energy used to encode the data. In the case of optical fibers, it would be the intrusion of unintended light; in coaxial cables and twisted-pair wiring, it would be the accidental intrusion of power surges, electrical transients, or other electromagnetic noise.

Physical Protection

The need for physical protection is similar for all three technologies, but there is a difference in the greater fragility of the optical transmission medium. All cables that travel underwater or underground must be suitably insulated against leakage and made of material not easily corroded. Cables strung on poles must continuously withstand the inevitable falling branches, nesting birds, and traveling squirrels, as well as handle fatigue from friction. Even cables buried underground, the safest physical place, must be shielded from rodents.

Transmission Protection

A significant difference between fiber optic technology and electromagnetic technology is that it is easier to shield light from itself than it is to shield electromagnetism from itself. Developing materials that prevent interference from external light sources was not a major difficulty in the development of fiber optics, but insulation is a constant preoccupation with electromagnetism. Light does not easily flow through most types of matter, but electromagnetic energy is quite likely to do so. Thus, light is contained wholly within its transmitting wire and does not interfere with its neighbor at all. Electromagnetic currents not only flow through a wire but also flow around the wire in a field quite capable of distorting its neighbor's data.

The direct and indirect effects of lightning are one of the principal sources of disturbance of communications systems. Direct strikes to aerial or ground wires can cause crushing or melting of the wire and electrical surges in the line, but these effects are not nearly as common as the electrical transients in the line from nearby strikes. The amount of trouble this causes can vary significantly from place to place. In large cities, for example, steel in tall buildings and metallic components of underground utilities divert and reduce transient surges. In addition, communications lines are usually in different ducts than power lines. Away from larger cities, a great deal depends on the amount of thunderstorm activity native to the area, the resistance of the earth, and the proximity of power lines and communications lines.

Interconnection of Different Wiring Types

Switching between Twisted-Pair Wires and Coaxial Cables

It is not surprising to find several twisted-pair wires being multiplexed together onto a single coaxial cable, since the combining of several low-speed lines into a single higher speed line is a common practice in data communications. In an era with more widespread use of terminals and PCs, this type of multiplexing tends to occur with those lines leaving a local area (perhaps a single floor or department) to travel to a computer in another area on the same floor, on another floor, or in another local or remote building. Twisted-pair wiring can also be multiplexed on optical transmission lines.

It is also becoming surprisingly common to use coaxial and twinaxial cables to connect twisted-pair wiring. The primary device used to make this type of connection is a "balun." A balun connects an electrically BALanced element (the twisted-pair wire) with an UNbalanced element (the coaxial cable). It may perform a few other tasks, such as simple filtering and impedance matching, but it is basically a very simple device, because it does not change speeds and code/decode as multiplexers do. A single balun usually costs under $50.

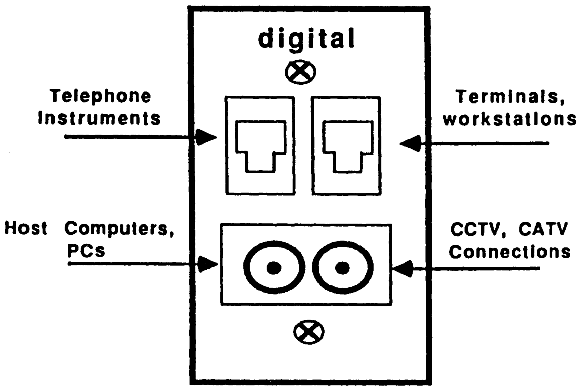
Since baluns are one-to-one devices, different models are required to interface different coaxial subtypes. The most common types interface twisted-pair wiring with IBM 3270-type "standard" coaxial cable, IBM 5250-type twinaxial cable, or Wang dual-coaxial cable. The Wang twisted pair is, strictly speaking, an adapter rather than a balun, since it is a "balanced-balanced" connection, but it makes the same type of connection.

When several coaxial cables are being converted onto a multi-twisted-pair trunk, a balun patch panel is frequently used to control and centralize the wiring connections. These panels usually provide for 24 coaxial inputs and a single trunk with 25 twisted wires as output. One wire is used as a spare. Visually, the panel appears to be multiplexing several lower speed lines onto a single higher speed line, but internally the signal stream from each coaxial input cable is routed to its own separate twisted-pair wire, and both signal streams are flowing at the same speed, maintaining the one-to-one character of the connection.

Interconnection between Optical Fibers and Other Cables and Wires

Interconnecting optical fibers and other types of lines has not yet become popular. In order to link optical fiber with a conductive cable, the electromagnetic signal must be converted to an optical signal and vice versa—not an easy or inexpensive conversion. In addition, the relative newness of the technology means that there are few devices using fiber optic cabling as their transmission line and needing to interface that device to an incompatible transmission system.

Figure 6.
DEConnect Faceplate



The wall jack that the DEConnect cabling scheme uses has four outlets. DEConnect supports a variety of wiring types.

Universal Cabling Schemes

Cabling is now a multivendor proposition. Therefore, it must be evaluated as carefully as phone systems, carriers, and services.

A number of vendors have devised "universal" cabling plans. These plans are variations on the traditional wiring hierarchy that comprises riser cables (vertical cables running between floors), wiring closets (the terminus on each floor), and horizontal cable runs (between the wiring closet and the individual user's equipment).

One of the main concerns in these cabling plans is the use of shielded versus unshielded wiring. Shielded wiring is bulky, expensive, and difficult to handle, but it does offer protection against interference problems. Unshielded wiring is cheaper and easier to work with, but it does not guard against possible interference. Digital Equipment, Bell Atlantic, AT&T, and Northern Telecom use unshielded wire or a combination of shielded and unshielded wires in their cabling schemes. The IBM scheme incorporates several different types of cable. Most of these are shielded cables, but some are unshielded.

IBM Cabling System

IBM introduced its cabling plan in 1983. Provided through third-party contractors, it is a star topology with wiring closets and uses seven different types of shielded or unshielded twisted-pair, coaxial, and fiber optic cable (see Table 1). The system accommodates both voice and data, but each needs different connectors and outlets. The wiring closets enclose distribution racks and 66-blocks. All the system's wiring originates and cross connects in the closet. Any IBM connector can hook up to any other IBM connector, but these connectors are not necessarily compatible with other vendors' equipment. The IBM scheme is suitable for token-rings, PC networks, mainframe-to-terminal connections, and PBX systems. Until recently, though, it was not a suitable arrangement for Ethernet local area networks (LANs). Digital Equipment Corp. has,

Table 1. IBM Cabling System Cable Types

Type	Specification No.	Description
1	4716748	Two pairs of AWG#22 conductors with braided cable shield.
1 plenum	4716749	Same as 4716748 but with TEFLON or equivalent dialectors.
1 plenum	4716734	Two pairs of AWG#22 conductors with corrugated metal shield suitable for serial or underground installation.
2	4716739	Two pairs of AWG#22 conductors with braided shield accompanied by 4 pairs of AWG #22 telephone conductors.
2 plenum	4716738	Same as above, but with TEFLON or equivalent dielectric.
3	ANSI/ICEA S-80-576-1983 Bell 48007	Four pairs of AWG#24 telephone wire.
5 nonplenum	4716744	Two 100- /140-micron optical fibers suitable for indoor, aerial, or underground (in conduit) installation.
6	4716743	Two pairs of AWG#26 stranded conductors to be used as patch or jumper cables in wiring closet or from wall outlet to device.
8	4716750	Two pairs of AWG#26 solid conductors in parallel for use under carpeting.
9	6339583	Two pairs of AWG#26 stranded or solid conductors.

however, introduced its Shielded Twisted Pair Ethernet Adapters, which allow its Ethernet LANs to use IBM's cabling system to connect PCs and workstations. Generally, the IBM plan is rather confusing and elaborate. Nonetheless, it appears to be the best cabling solution for data applications, although its market acceptance has been less than enthusiastic.

AT&T's Systimax PDS

AT&T introduced its Premises Distribution System (PDS), now called the Systimax PDS, in 1985. Functionally, this is a star topology with wiring closets, but it only uses two types of wire: unshielded four-pair twisted wire for station runs and fiber optic cable for the backbone. The wall jack is an eight-pin universal modular unit that accepts voice or data.

As noted earlier, AT&T is committed to the future implementation of fiber. AT&T recommends fiber to users who need high bandwidth and a high level of security. For other users, however, AT&T installs twisted pair.

The Systimax PDS is divided into six subsystems that AT&T claims will support all building configurations. Sections can be implemented for small applications and then upgraded as requirements demand. Customers can change their systems incrementally instead of scrapping a system every time needs change.

In May 1990 AT&T enhanced its Systimax PDS scheme with a new cable that supports speeds of at least 20M bps at up to 328 feet from the wiring closet.

Opinion is divided as to whether IBM or AT&T cabling is best for data transmission, but Systimax PDS has been met with a more favorable reaction from users. The AT&T scheme is most cost effective for installations of more than 100 lines, although even for these networks Systimax PDS may not be the cheapest alternative. However, Bell Labs supports this cabling scheme, a fact that could well sway many prospective users.

Digital's DEConnect

DEConnect is the only cabling plan that was requested (indeed, demanded) by users. This is a bus-based scheme, but each floor of the building is star wired, and each floor has a wiring closet intersecting the central Ethernet trunk. Wires run from the closet to the individual wall plates.

Voice and data are completely segregated with DEConnect. Standard twisted-pair wire supports voice, four-pair twisted wire supports asynchronous data, RS58 "thin wire" coaxial cable supports Ethernet LANs and video, and coaxial cable transmits video. The wall jack has four outlets: one for a PC or workstation, one for a terminal, one for video coaxial cable, and one for a telephone (see Figure 6).

DEConnect works best, though not exclusively, with Digital equipment. It is especially suitable for Ethernet applications. The data interface conforms to EIA RS-423, but adapters make it compatible with RS-232-to-RS-423 signaling.

Bell Atlantic UITP

Bell Atlantic's Universal Information Transport Plan (UITP) was introduced in 1986. Like most traditional plans, UITP employs risers, wiring closets, and horizontal station runs. Data traffic runs on a separate high-speed network; shielded twisted-pair wires are used for data transmission in risers and for high-speed workstations. Voice and low-speed data are transmitted over unshielded four-pair twisted wire. There are two types of modular eight-pin jacks used at the faceplate.

Northern Telecom IBDN Plan

Northern Telecom introduced its Integrated Building Distribution Network (IBDN) in 1987. IBDN includes both nonshielded twisted-pair and fiber optic wiring in the horizontal runs from the wiring closet to the individual terminals and in the risers. This scheme employs a single outlet, unlike the other plans discussed in this report, contributing to the plan's price competitiveness.

The IBDN scheme uses a modular telephone-type wall jack. This plan is designed to support Northern Telecom's Meridian SL-1/SL-100 PBX systems as well as PBXs from other major vendors such as AT&T, Rolm, and Mitel. The vendor also claims that IBDN will support IBM and Wang computer systems and Ethernet systems operating at 10M bps. Data is supported through an RS-423 interface.

In March 1990 IBM announced its Open Plan structured cable building service. This scheme is based on Northern Telecom's IBDN plan; it supports multivendor environments and is designed to provide cost reductions in reconfiguring networks.

Keeping Track of Cabling

It is imperative that communications managers keep accurate records concerning their installation's wires and cables. Someone must know when all the cabling was installed, where it goes, and what it is used for. The seemingly endless miles of cabling must be documented and the documentation kept available. Fortunately, methods exist for facilitating this process.

In the past it was necessary for an army of clerks to manually enter cable paths and wire connections on paper reports, which were then stored in voluminous collections. Retrieval involved looking up the sought-after route or connection. In addition to being time consuming and expensive, this type of cable management was prone to error.

A standard labeling scheme is the first step in avoiding confusion. The purpose is to easily and quickly track all devices. Any labeling scheme should include all the elements in the cabling hierarchy, including the equipment room, the equipment, and the cabling itself. It is often convenient to identify different parts of the cabling system by using colors, prefixes, or codes. A simple scheme is offered by Curtic Manufacturing Co., which has introduced its Cable Organizer. This is a 10-slot cord manager with recessed label slots, two bundler clips for grouping loose cables, six runner clips to secure cables safely, and 10 blank labels.

Labeling and grouping cables, while necessary steps, are not sufficient. They should be backed up by a tracking system. Small installations with relatively uncomplicated cabling runs can probably make do with a paper-and-pencil tracking plan, but more extensive or elaborate plans should use a computer-based system. Managers should consider converting existing paper tracking systems to online databases.

There are a number of automated databases and spreadsheet plans that may be used, and users can also develop their own.

Cable Test Equipment

Cables are durable and need little or no maintenance. When a cable fault does occur, however, it is necessary to pinpoint the problem and correct it quickly. Better still, it is smart to anticipate potential problems before they occur by testing cables before installation and periodically thereafter.

According to *Computer/Electronic Service News*, there are four types of cable testers:

- 100-LED breakout boxes (or 25-LED cable testers)
- Portable automatic cable testers
- Variable connector testers
- Intelligent cable testers

The *100-LED testers* require test points to be manually activated. The technician must designate a ground return lead. Using a 100-LED tester to test cabling already embedded in walls, ceilings, or under floors can be difficult and time consuming. In addition, it is necessary to use a remote test module with the 100-LED tester. One end of the cable is connected to the tester, the other end to a remote testing module. The big disadvantage of this type of tester is that all 25 leads must be checked individually. This means 25 trips back and forth between the 100-LED tester and the remote module. For a ground return lead, it is sometimes possible to use an electrical wire or earth ground as the return path. Testers often use the building's plumbing as long as it does not contain sections of nonmetal pipe. Ground reference pins on both the 100-LED tester and the remote module must connect to the return path.

The *portable automatic cable testers* are popular because they can automatically check all leads without using jumpers. The operator need not be on-site to do the testing.

Variable connector testers are not limited to testing 25-pin cables. They usually have a number of adapters and can test a greater variety of cables than can the 100-LED or portable testers. Unfortunately, the basic units are considerably more expensive than the other two types discussed, and the adapter modules add to the cost.

The *intelligent cable testers* are so termed because they can actually learn a cable's specific configuration. These testers retain a cable's signature in memory and can compare it with the signatures of other cables. Thus, these testers can run go/no-go tests. These intelligent testers are highly useful; their only disadvantage is that their size excludes them from field service testing.

NuData, of Little Silver, NJ, sells a useful cable tester called the Cable Vision Model 9510 Universal Cable Tester. Powered by rechargeable batteries or an AC adapter, this unit has a 20-character by 16-row LCD screen that shows cable pinouts and identifies in plain English what kind of connectors are on the cable. Menu-driven operation and help screens simplify testing. Users can test a cable by plugging it into the test device and pressing a key. Any errors found will be displayed on the screen along with repair information. Nu-Data has a wide selection of adapter boards available, including universal adapter boards for unusual connectors.

Microtest, of Phoenix, AZ, offers its Cable Scanner product for local area networks (LANs). This battery-powered tester measures cable lengths; locates cable in ceilings, walls, and floors; locates faults, cable breaks, shorts, and crimps; and determines if a repeater is needed. The Cable Scanner determines if cabling is the fault of a network failure, and then the 32-character display pinpoints the location of the problem. A Microtest Cable Tracer is included with the Scanner. After the Cable Scanner has located the fault, the Cable Tracer helps the user find where in the ceiling or wall the cable lies and what kind of cable it is. Microtest has recently announced a twisted-pair adapter enhancement to the Cable Scanner. This adapter lets users attach the Scanner to telephone-style connectors and then toggle between pairs of wires to test for faults.

Microtest also recently announced its Quick Scanner, a handheld LAN troubleshooting device that uses cable radar and time domain reflectrometry to locate faults in coaxial or twisted-pair cabling.

Standardization

Local area networks (LANs) are becoming larger in scope and complexity, indicating the need for a standard in buildings and campus environments. In 1985 the Computer Communications Industries Association (CCIA) asked the Electronics Industries Association (EIA) to develop building standards for office-oriented businesses with a maximum extension of 9,840 feet and between 100 and 50,000 users. The result has been the formation of the TR41.8.1 working group to address voice and data communications wiring. This project has attempted to coalesce the information necessary for telecommunications wiring. A companion project is addressing residential and smaller office environments, while another project considers the building architecture necessary to support the recommended wiring.

This last project recommends that the horizontal wiring be configured in a star topology. It requires each floor in a building to have a wiring closet. The IEEE 802.3/Ethernet bus structure and the 802.5 ring structure can accommodate star wiring by means of concentrators or multiport devices. Horizontal wiring distances are defined as 295 feet between the wiring closet and the wall outlets, with an allowance for an extra 9.8 feet in the work area.

The following cables are recognized by the TR41.8.1 working group for horizontal wiring: four-pair 100-ohm unshielded twisted pair; two-pair 150-ohm shielded twisted pair; and 50-ohm coaxial cable.

The working group has recommended accommodations for a variety of user applications. In addition, the likelihood of making extensive changes in the future should be kept to a minimum. Therefore, it is recommended that there be at least two outlets at each workstation. One outlet should be supported by four-pair 100-ohm unshielded twisted pair. The other outlet should be supported by one of the following horizontal media: four-pair 100-ohm unshielded twisted pair; two-pair 100-ohm shielded twisted pair; or 50-ohm coaxial cable.

For backbone wiring, the working group has also recommended a star configuration and use of the following cable types: 100-ohm unshielded twisted pair; 150-ohm shielded twisted pair; 50-ohm coaxial cable; and 62.5-/125-micron optical fiber.

Users should choose backbone wiring based on the required services, flexibility for future services and requirements, site size, and ease of installation. Some sites may require multiple backbones.

Safety Considerations

Wire is often installed inside ducts; it is more attractive and makes reconfiguration easier. Conduits have often been made of metal, but recently installers have been using PVC conduits. Some critics of PVC material have suggested that it is a fire hazard, but PVC conduits were approved by the National Electric Code (NEC) in 1987 (Article 437, Rigid Nonmetallic Tubing, PVC-Type 1, used for electrical conduit). PVC conduit has also been approved by the National Safety Code (NEC Handbook, 1987, Article 347-3). Furthermore, it appears that those criticizing PVC conduit have a self-serving interest because they manufacture metal conduit.

The dangers of low-level elecromagnetic radiation, although not adequately understood or evaluated, are receiving serious attention. A series of articles in *The New Yorker* magazine in 1989 indicated that such dangers may be quite real. The study of electrical and magnetic radiation emanating from cable has chiefly concentrated on power line cables and transformers. However, extremely low frequency (ELF) radiation from communications wiring also presents a field of inquiry. To date, unfortunately, few findings have been published. ■