STRANDED AND SOLID CONDUCTOR ETHERNET CABLES

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Figure 1. UTP (Unshielded Twisted Pair) cross-section.

CATEGORY-TYPE CABLES

Late in 1990, the Institute of Electrical and Electronics Engineers (IEEE) published a new set of standards introducing data-capable twisted-pair cabling for use in 10 Mbps Ethernet systems. Supplanting the coaxial cabling and bus topology of previous networking systems, this new 10Base-T standard established a star topology built around a central “data traffic controller” (a hub or a switch), to which each workstation in a Local Area Network (LAN) could be connected independently via a single dedicated UTP (Unshielded Twisted Pair) cable. The star topology and 10Base-T technology made installing and troubleshooting Ethernet systems much easier, and it made managing them much more efficient. Since that time, twisted-pair cabling has emerged as the dominant network cabling scheme, and has contributed to the vast expansion in Ethernet use that still continues today.

There are now a dizzying number of twisted-pair cable types available, corresponding to a dizzying array of standards detailing the configuration and performance specifications needed to support the increasingly faster data rates and larger bandwidths of incoming technologies. Introduced as ordinary telephone wire in 10Base-T, the evolution of this familiar and well-understood copper medium can be seen in a list of Category-type (“CAT”) cables introduced to meet these new requirements.

Category	Cable Types	Bandwidth/ Data Rates	LAN Applications	2006 Status
CAT-1	UTP	1 MHz (Less than 1 Mbps)	Telephone & Doorbell Wiring	Outside Plant and Backbone
CAT-2	UTP	4 MHz (4 Mbps)	IBM Token Ring Networks	Outside Plant and Backbone
CAT-3	UTP	16 MHz (16 Mbps)	Voice & data on 10Base-T Ethernet	Min. standard for residential phone use
CAT-4	UTP, ScTP	20 MHz (100 Mbps)	16 Mbps Token Ring Networks	Obsolete
CAT-5	UTP, ScTP	100 MHz (100 Mbps)	10Base-T, 100Base-T (Fast Ethernet)	Obsolete
CAT-5e	UTP, ScTP	100 MHz (100 Mbps)	10Base-T, 100Base-T	Current TIA/EIA standard
CAT-6	UTP, ScTP	250 MHz (10 Gbps)	1000Base-T	Current TIA/EIA standard
CAT-6A	UTP	500 MHz	10GBase-T	Under Development

For CAT-3 cables and above, each cable type in turn comes in two flavors—as a solid-conductor cable, and as a stranded-conductor cable. Although both types within each category are made to meet the same cable configuration and electrical performance specifications, their physical properties place different restrictions on cable segment length, and limit their use to specific areas within Ethernet systems. As a result, the two cable types are used very differently, and their roles are very seldom interchanged.

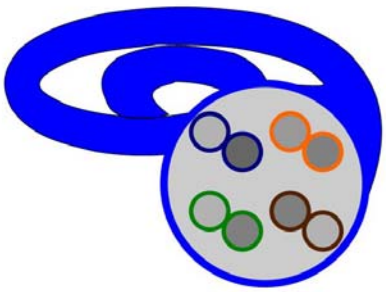
Figure 2. Solid-conductor cable

SOLID CABLE CONDUCTORS: ALONE, BUT NOT STRANDED

Each of the conductors tucked away inside a solid Category-type cable is made up of a single, solid conducting wire. For cables used in networking applications, these conductors usually consist of bare copper wires with diameters between 22 and 24 AWG (American Wire Gauge units, or approximately 0.51 - 0.64 mm). Category 5e UTP cables always have nominal conductor diameters of 24 AWG (0.0201 in., or 0.511 mm), and higher-performance cables like Category 6 UTP employ the larger 23 AWG copper wires (0.0226 in., or 0.574 mm in diameter). In addition to being physically stronger and easier to work with, these larger wires have superior electrical characteristics that remain stable over a wider range of frequencies. These characteristics make CAT-6 cables better suited to new and emerging fast Ethernet applications.

In general, solid conductor cables have a lower DC resistance and a lower susceptibility to high-frequency effects based on their larger diameters alone. We will see in the next section that these properties allow solid conductor cables to support longer transmission runs and higher data rates than their stranded cable counterparts. But perhaps the most distinguishing characteristic of solid Category-type cables is the fragility of their conducting wires, and their resulting overall inflexibility. We can see from the dimensions above that “larger” here is a truly relative term, and that all of these wires are very fine when compared to the lengths of cables and the size of the beings who handle them. Because of their small size, they can’t hold up to very much bending or flexing without breaking, or suffering surface irregularities that can change their conducting properties. For this reason, these cables are well-packed inside a strong outer sleeve that resists bending, making them less flexible and not well suited to normal everyday use in connecting work area components. Their overall stiffness makes them most useful for use as horizontal or backbone cabling within a system's infrastructure.

STRANDED CABLE CONDUCTORS: STRANDED WITH A TWIST

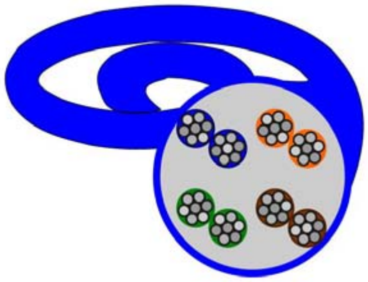

Figure 3. Stranded-conductor cable

Stranded-conductor cables are the more common Category-type cables, and the ones we most often work directly with. Inside the twisted pairs of a stranded cable, each individual conductor is made up of a bundle of smaller-gauge wire strands. These are arranged so that several wires (commonly 6 or 18) surround a single wire at the bundle's center (Figure 3 shows six-around-one, or seven strands total). The outer wires are wrapped helically around the central wire through a process called stranding. The stranded wires together form a single conductor with an overall diameter about the same as that of a conductor in a solid cable, but with a much smaller conducting area (based on the smaller diameters of the conducting wire strands).

The stranding of the wire conductors serves to protect them, and gives stranded cables their flexibility. For a given conductor length, the more times each strand twists around the central conductor, the better the protection and the greater the overall flexibility of the cable. This idea is quantified by the *lay* of the conductor strands, or the distance required for a single wire strand to twist all the way around the conductor, making one complete rotation about its central wire.

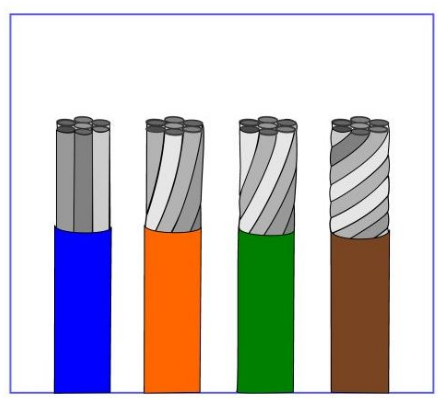

Figure 4. Straight lay and helically-stranded cables.

To see how this works, first consider a "nonstranded stranded conductor"—a conductor in a *straight lay* cable where there is no twisting of the outer wire strands (Figure 4). If this cable is bent, each strand is bent almost as if it were alone inside the cable. The outer strands are free to move around in response to the mechanical stresses introduced, potentially changing the cable's conductor configuration and transmission characteristics each time it is flexed. Continued bending in opposite directions without the uniform 'cushioning' of the outer wire strands weakens the central conducting wire, and shortens the lifetime of the cable.

But a helical stranding of the wires around the center wire causes all the individual elements of the stranded conductor to pull toward its center when the cable is bent, keeping the configuration of all the elements constant. Their paths around the central conducting wire ensure that the stresses on individual wires are averaged over the lay length, and that the total stresses are distributed over all the strands to minimize the stresses on the center conductor. The more twists given to the wire strands (the shorter their lay length), the more support provided to each of them and to the central conductor.

The conductors in stranded Category-type cables used for networking and Ethernet applications are usually made of bare or tin-coated copper wires. Tin-coated conductors are made by dipping the individual wire strands in a bath of molten tin before their assembly into a single conductor. In addition to protecting the conducting surfaces from oxidation, the tin coating makes the fine wire strands easier to solder onto patch panels and wall jacks, and prevents the fraying of individual wire strands.

A note on wire sizes

The diameter of copper wire is most often given in AWG (American Wire Gauge) sizes, which are based on a conductor's cross-sectional area. In the AWG system, a conductor's size is related to its diameter if it is a single, solid conductor and to its overall diameter if it is a stranded conductor. Stranded conductors are often specified by the number of strands and the corresponding AWG size—i.e., a 7/38 stranded conductor consists of 7 wires (6 around 1) having an overall diameter of 38 AWG (0.1524 mm, or 0.018241 in.). Because of the way these wires were traditionally made, larger AWG-size numbers correspond to smaller wire diameters (because they had to be drawn more times). As maddening as this backward specification of size might seem, it is interesting to contemplate the continued use of such an antiquated system for technologies that change so rapidly.

COMPARISON OF ELECTRICAL PROPERTIES

As we move toward increasingly faster Ethernet systems requiring increasingly larger frequencies and data rates, the electrical activity inside a copper transmission medium can get a bit mysterious. Fortunately, though, the basic electrical properties causing these mysterious phenomena still remain the same. For solid and stranded conductor cables, the changes seen in transmission performance when going from one conductor type to the other fall under the broad category of attenuation effects.

ATTENUATION

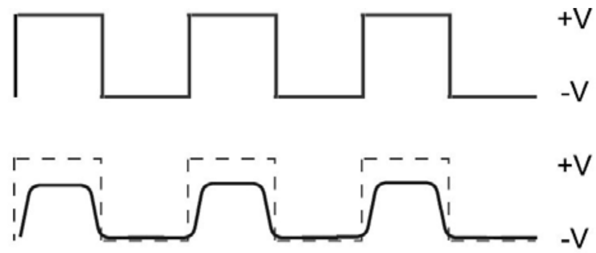

Figure 6. Attenuation of a signal transmitted through a copper wire. Top shows original signal shape and amplitude, and bottom shows the weakening of the transmitted signal due to attenuation.

Attenuation is the general loss of a transmitted signal's strength (amplitude) as it moves from one end of a cable to the opposite end. Also called insertion loss, attenuation is measured in decibels (dB)—the same units we use to measure the amplitudes of sound waves. In measuring the attenuation in a cable, lower dB values indicate better performance and less signal loss—the transmission environment is less "noisy". Higher dB values are analogous to voltage loss inside the cable; if a signal becomes too attenuated, it will be unintelligible before it can be picked up at the other end of the cable.

ATTENUATING CIRCUMSTANCES

1. Conductor diameter

Stranded conductors exhibit higher attenuation than solid conductors through their smaller conducting diameter. A conducting wire's gauge size is based on its cross-sectional area, and this area determines the DC resistance for a given conducting material like copper. This resistance causes some of the transmitted signal's energy to be dissipated as heat as it moves along inside the cable, so that longer cable lengths mean more heat loss, and more attenuation of the transmitted signal. For this reason, stranded conductor cables cannot be used for long cable runs, and both solid and stranded conductor cables have specified length limits.

2. Higher frequencies

At higher frequencies, conducting materials like copper experience a continuous decrease in their conducting cross section, called the skin effect. As the frequency of a transmitted signal increases, the skin effect pushes electrons outward toward the surface ("skin") of the conductor. As the frequencies continue to increase, the skin depth continues to decrease, so that a cylindrical, solid conducting path will become hollowed out, with electrons flowing only along the outer surface of the cylinder. In this way, the smaller and less-defined circumference of stranded conductors results in higher attenuation losses (as much as 20% higher) in stranded cables than in solid-conductor cables.

3. Conductivity

If the outer surfaces of stranded conductors are coated with tin, the skin-effect problem is compounded because the bulk of the electrons are forced to flow along the tin layer, and tin has a higher resistance than copper. At the same time, the formation of copper oxides on the surfaces of untinned conductors can also increase the resistance on the conducting wire's surface, resulting in the gradual deterioration of performance just the same.

CHOOSING THE RIGHT CABLE

New Installations & backbone cabling

Because incorporating any cable type into a building's structure is expensive and best managed by keeping long-term applications in mind, the superior electrical performance and longer runs possible with solid conductor cabling make it more suitable for permanent building installations. Its stability over higher frequencies means that longer time periods are possible between cable reinstallations, and its comparative frailty is not a problem when it is protected from damage by the building itself. Long cable runs (up to 90 m, or 290 ft) can be placed inside walls, up through ceilings, or across underground pathways connecting adjacent buildings. Since solid-conductor cable is most often used for these permanent cabling applications, it often referred to as network cable.

Horizontal cabling

Solid-conductor cables are also used for “horizontal” runs (same-floor runs) spanning the distances between telecommunications rooms and work areas. In addition to performing better over long distances and at higher frequencies, the single, larger conducting wires of solid cables are much easier to terminate than the multiple fine wires of stranded conductor cables. Also, the relative stiffness of solid-conductor cable makes it preferable for use with 110-type punchdown connectors on the backs of wall jacks, or with the 66-type punchdown blocks on plywood boards. In contrast, the softness and flexibility of stranded Category-type cables make working with punchdown connectors or IDCs (Insulation Displacement Connectors) very difficult.

Patch cables

The nature of the attenuation losses discussed above means that, for the most part, there is very little difference between the electrical performance of solid and stranded cables for very short segment lengths (according to the TIA/EIA 568-B Standard, for lengths below 10 meters). In modern hierarchical wiring schemes, the length limitations of stranded cables are easily met (3 m, or 9.8 ft), and the increased flexibility and durability of stranded cables make them perfectly suited for interconnecting work area outlets with workstation PCs and other end-user devices. In contrast, solid conductor cables are far too fragile for frequent bending and handling, and far too difficult to manage in connecting closely spaced components.

The conductors inside a stranded cable are protected by the wire strands surrounding them, so that very little of the conducting surface area is exposed to damage if the cable is accidentally cut or smashed, and the conductor is not weakened by repeated flexing and bending. Without this protection, the conducting surfaces within a solid-conductor cable are more susceptible to nicks or other irregularities that affect transmission performance and often accompany their early demise.

Finally, the more pliable nature of stranded cable makes it easier to work with and handle, allowing it to be more easily routed through tight spaces between interconnected equipment, or along the paths of other patch cables. It is designed to be readily switched among wall outlets, patch panels, and equipment, and when properly handled it will not suffer flex damage or broken conductors with frequent moving around. These further practical advantages and the longer lifetime of stranded conductor cable make it ideal for use in assembling the “pre-connectorized” patch cables used for connecting work area outlets to end-user devices.

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Glossary

Attenuation Measured in decibels, attenuation is a measurement of the change (loss) in transmission signal strength between two points on the cable. Attenuation is measured in decibels (dB).

Bandwidth The highest frequency for which a positive power sum ACR (Attention to Crosstalk Ratio) remains greater than zero. The highest frequency range used by a communication system.

Baseband A Baseband network is one that provides a single channel for communications across the physical medium e.g. cable, so only one device can transmit at a time. Devices on a Baseband network are permitted to use all available bandwidth for transmission. The opposite of ‘Baseband’ is ‘Broadband’. A typical example of a ‘Broadband’ network is Cable TV.

Data rate The actual data throughput of a cable. Encoding and compression schemes can push the data rate above the actual bandwidth of a cable by sending data along the cable in a more efficient way; this makes data rate a better measure of a transmission system’s capabilities.

dB (decibel) A measurement of the gain or loss in signal strength within a communications circuit. Decibel numbers are - This is the decrease in signal strength (expressed as negative dB) from one end of a cable to the other.

DC Resistance A function of the cross sectional area of the conductor. Resistance in the wire limits the signal and dissipates the energy as (a small amount of) increased heat. The longer or thinner the wires the greater the resistance.

FREQUENCY The number of cycles completed in a unit of time, usually expressed in Hertz (Hz), or cycles per second. For data cabling, MHz is often used; the 'M' stands for "mega" and means that you can add 6 zeros to the number given. Thus a cable rated at 100 MHz would have to complete 100,000,000 cycles each second.

HIERARCHICAL WIRING SCHEME A cabling architecture that uses successive cable "layers" to connect a main cable (the backbone cabling) to intermediate and horizontal cables within a building (i.e., wiring closet cables), and to connect these in turn to individual network workstations and components via patch cords.

HUB A repeater that can broadcast messages to all workstations in a network.

MBPS Megabits per second

MAC ADDRESS "Media Access Control" address, or the physical address of an Ethernet node.

PUNCH DOWN BLOCK Punch down blocks come in 110 and 66 varieties.

SCTP "Screened Twisted-Pair" cable. ScTP has the same 4-pair (8-conductor) configuration as UTP cable, but employs a single piece of metal film or braid shielding surrounding the entire 4 pairs. This extra shielding combines with the twisting of the wire pairs wires to further protect against signal degradation.

SSTP Fully shielded twisted-pair cable. SSTP is a 4-pair (8-conductor) cable having a metal or braid shielding around each pair, and another shielding around the entire group of 8 wires. The additional shielding provides further protection against signal degradation caused by outside sources of interference.

STAR TOPOLOGY A topology allowing only one device at each end of a wire, requiring repeaters for more than two devices.

SWITCH A repeater that redistributes messages based on hardware MAC addresses.

TOPOLOGY The physical format of a network.

UTP "Unshielded Twisted Pair" cable. The most common LAN networking cable in the US, UTP cables do not employ any additional electrical shielding, relying instead on the electrical balance provided by their twisted-pair wiring scheme for the prevention of cross-talk between conductor pairs, and for the cancellation of electromagnetic and radio frequency interference (EMI and RFI) from outside sources.