Computing/Networking

LAN Technologies Explained

Philip Miller • Michael Cummins

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Phil Miller is the International Customer Services Manager for Nokia Internet Communications and has been specializing in networking, routing, and Internet security for many years. He has designed and supported extremely large single- and multi-vendor networks. He is also the author of the best-selling Digital Press title ***TCP/IP Explained***.

Mike Cummins is a senior consultant for Logical (UK) and has been specializing in networking and internetworking technology for over a decade. During this period he has worked with most leading vendors' equipment, gaining accreditation with many. He has developed and taught numerous technical training courses, and has designed and supported LANs and internetworks based on both single- and multi-vendor equipment.

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supported in an Ethernet environment, they are little different from most other data cabling of their generation in that they are designed to support just a single application. In the Token Ring world, the IBM Cabling System was dominant and also had the advantage that it could support multiple applications such a voice (through additional cables) or other IBM applications such as 3270 or 5250 terminal applications through the use of adapters. This was the first multi-application cabling system on the market and was a revolution in the world of cabling where network managers were becoming increasingly frustrated with the need to change cable types whenever they changed applications.

Structured Cabling Systems

CHAPTER 39

Cabling infrastructures have developed from very humble origins, to what we are familiar with today. When computers were first developed, communications between the Central Processing Unit (CPU) and Input/Output (I/O) devices, i.e., "dumb" terminals, teletypes, etc. was a modest 300 - 9600 bps. A typical cabling environment would be based on multi-pair cable wired in a point to point fashion between host and its peripherals. Should a new connection ever be required, then a cable would be run for the host out to the new location. In the years that followed silicon, the raw material for all CPUs, reduced in price and made the concept of moving some of the processing power out to the terminals more attractive. This concept, known as distributed processing, required advances in cabling technology by a fair order of magnitude. These so called "smart" terminals needed to transfer data at rates significantly higher than before, simply so that the terminal could "feed" its own local processor. Early cable implementations based on multi-pair cable and running some form of serial type communications was quite obviously not up to the task. Many manufacturers were looking to run their systems at speeds between 1 and 4.27 Mbps and therefore deployed proprietary cabling systems, typically based on some form of coaxial cable. This, too, was typically deployed in a star topology, with point to point links back to the central host computer, again under the basis that if a new location was required, then a new cable needed to be laid to accommodate it.

The introduction of the PC in 1980, and the development of the Local Area Network (LAN), required yet another advance in cable technology, with data rates and distances between devices increasing yet again. As we discussed in the previous chapter, Ethernet and Token Ring were both developed utilizing their own specific media type and topology, each with clearly defined rules regarding its deployment. Consider for a moment the "applications" available to an organization at this point (early 1980s). Most large computer systems were based on proprietary cabling and topology (e.g., IBM, ICL, Bull, Wang, Digital, etc.), LANs had arrived with much being made of their standardized approach in an attempt to move away from the proprietary nature of central computer systems, but also using proprietary media options. The telephone system was yet another application in most office buildings, with yet another cable type to accommodate. All of these applications shared one feature, should any moves or changes be required, then the only solution was typically to pull in new cable. It was obvious to most that some form of generic cabling system capable of running any application was needed to provide not only respite from the problems inherent with proprietary cabling, but also a way forward to support the applications of the future, while maintaining support for

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those already available. The need established, the next stage was to develop the cabling system, now known as the Structured Cabling System (SCS).

39.1 Basic Principles

Back in the early 1980s, two manufacturers took up the challenge of developing a generic cabling system. IBM adopted an approach that would see its results based on the cabling infrastructure being developed for Token Ring, with the inclusion of options to support telephony. AT&T on the other hand was a telephony company, already providing telephony solutions to millions of customers. Their approach was very much based on taking the telephony media solution and enhancing it to support data. In either case however, the main principles were very much based on a cabling topology that telecoms companies had been using for years. As early as 1970, telephony companies had begun to move away from a dedicated line per phone approach, across to a new idea known as "block wiring". This approach was very much based on 'flooding' the building with telephony sockets, typically in some form a grid pattern, such that a socket would exist in every conceivable location it might be needed at some point in the future. Each socket would be wired back to a centralized distribution point conveniently located on each floor, with these distribution points then linked back to a Main Distribution Frame (MDF) in the telecoms room, typically adjacent to the PABX. Service to a telephony outlet could then be provided by "patching" between the PABX and the MDF, and then again between the riser link cable and the distribution cable at the floor distribution point.

For this block wiring scheme to be successful, low cost media had to be used to ensure the overall costs of "flooding" the building with distribution cables was not prohibitive. For telephony, this was not a problem as the low speed signalling rates employed with analogue voice did not demand a high specification cable. As both IBM and AT&T found out, the same was not so easily accomplished for data cabling signalling at rates of many millions of bits per second. However, both organizations managed to overcome any early problems to release the first two structured cabling systems on the market, IBM in 1984 and AT&T in 1985. The IBM system was based on STP cable with the MIC connector being used for termination. AT&T on the other hand achieved a successful upgrading of its UTP telephony cable and based their solution on this new higher rated UTP, with the RJ45 8 pin connector as the termination of choice. Since these early heady days in the structured cabling market, many other manufacturers have joined in with alternate solutions based on similar media types or alternatively a third option of FTP (Foil Screened Twisted Pair).

39.1.1 SCS Objectives

All Structured Cabling Systems, no matter what vendor they be from all aim to fulfill the same key objectives. The first and perhaps most important, being the use of a single common cable type capable of supporting all applications desired to run across it. For this to remain cost effective it is also essential that the minimum of additional equipment is required to achieve functional connectivity. In addition to a common media type, SCS are also based on a flood wiring approach to minimize

the impact of moves, additions, and changes (often called MAC). The idea being based on the philosophy that if there is potential for a user to occupy a given area, then there should be a cabling point terminated in that area in advance. By adopting this approach, another objective, that of minimizing the ongoing cost of ownership, can be achieved.

Two further objectives were also critical to the future success of SCS. Firstly, the ability to adopt the topology of the system to match that of any given application. This is essential if a single generic cabling system is to be able to support the many differing applications available. Secondly, and also key is the reliability of the system. Network managers are not likely to deploy a system that makes their task of supporting applications that much harder.

39.1.2 Topology

Structured Cabling Systems are essentially based on a "star" topology, organized in the form of a hierarchical or 'tree' like fashion, as shown in figure 39-1.

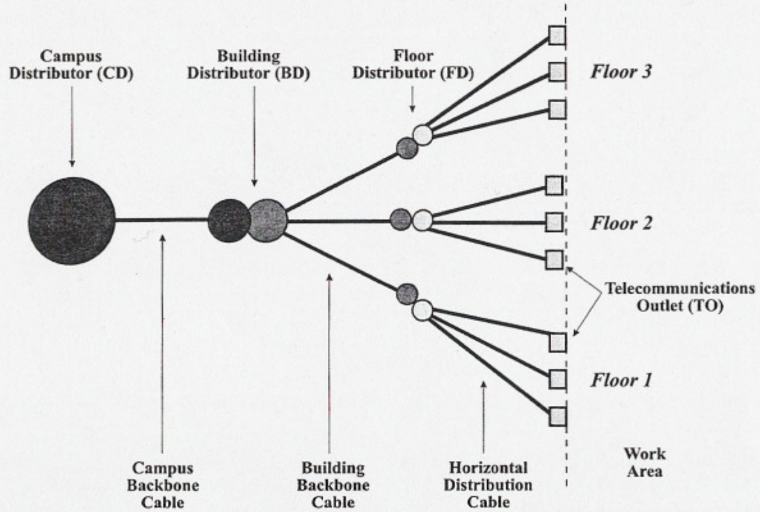

Figure 39-1: SCS Topology

The hierarchy is separated into four levels, combining campus distribution, building distribution, floor distribution, and work area cabling. At the intersection of each area is a distribution point which provides the administration (patching) points for the system. Through careful application of patch cables at these administration points, an end-to-end signalling path can be achieved from any outlet, to any other part of the system. The various elements of the system, shown in the diagram, are often known by differing names. Those shown are taken from the International cabling standard ISO/IEC 11801. Table 39-1 shows a comparison in element names between the International standards and those used by the US standards organization ANSI (American National Standards Institute).

Any SCS implemented, requires only those levels from the standard topology necessary to support the office, building, or campus in question. As a minimum requirement, all systems must comprise at least the horizontal distribution level, terminated at one end at the Telecommunications Outlets (TO), and at the other end, the Floor Distributor. For many smaller buildings, this may be all that is required. However, if the building spans several floors, or the system spans several buildings, then either the building distribution level or both building and campus distribution levels will be required. Figure 39-2 shows a campus wide system, encompassing four separate buildings, each with three floors.

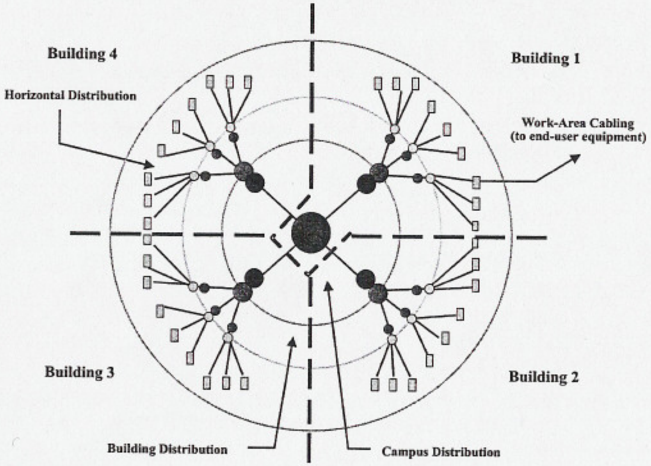

Figure 39-2: Campus Topology

At each point of administration, i.e., the distribution points, provision is made for the presentation of application specific equipment such as computer systems, repeaters, switches, etc., so that they can be patched into the system for user connectivity. This has been omitted from the diagram for the sake of clarity, as has another option, satellite floor distribution points. These are additional distribution points per floor used where cabling distance limitations or user density dictates a single distributor as impractical. When implemented, these are "tied" back to the main floor distributor via an extension to the backbone cabling known as tie-cables.

No specification is given at this stage as to the media employed or the termination systems (patch panels) at the distribution points. This is due to the fact that multiple options are available for either, and in many cases the chosen specification is due to many site specific issues, rather than application specific. An example of this may be where an implementation in an engineering works, or power plant, may prefer the use of fiber cable rather than copper, due to the

immunity to electromagnetic interference (EMI), or safety reasons. It is important to understand the principle behind SCS is the approach, not just the media chosen. This is based on the "flood wiring" of all areas within the building with horizontal distribution cables, terminated at the TO. All of these are then brought back to a single (or multiple) distribution point on each floor. Further, all floors are then inter-connected, as are all buildings, such that any point within the system can connect to any other if so desired.

39.1.3 SCS Components

Many components go to make up a structured cabling system, however, some more than others are core components used in every system. These include the cable, connectors, patch panels and application specific adapters. The last of these, the adapters, may not always be first on the shopping list, but they are key to the operation of the system as a whole. Its one thing having a generic cabling system, over which you may wish to run any given application. It is something else entirely, getting that application to work. Remember, most applications (e.g., Ethernet, Token Ring, Voice, Video, IBM 3270, etc.) were designed to operate over a specific media. For an SCS to function seamlessly, the application must either be modified to support the change in media type (as in the case of Ethernet), or the application must be "fooled" into thinking it is still operating over its media of choice. Hence the need for application specific adapters.

The Balun

It will become apparent, if not already, that the generic media utilized in structured cabling systems, is twisted pair cable. For many applications, such as IBM 3270, this poses a potential problem. That is the signalling characteristics of the application itself. All applications designed to run over coaxial type media, use an un-balanced signalling method where the data signal is measured in reference to a

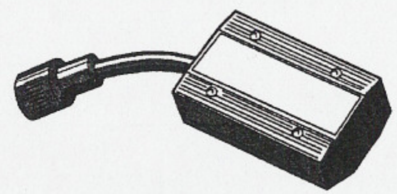

Figure 39-3: A Typical Balun

ground signal. Therefore the finite value of the data signal is of significance. Signalling on twisted pair cable is based on a balanced method, where two conductors are used for signal transmission, one carrying a mirror image of the other. In this instance it is not the value of the signal that is of importance, more the differential between the two, with no reference to ground.

In order to run "un-balanced" applications over a balanced media infrastructure, it is therefore necessary to provide some form of conversion at both the user end, and the host end of the cabling system, such that the application is "unaware" of the twisted pair media in the middle. Such a converter is known as a BALUN, taken from the terms BALanced-to-UNbalanced converter. In addition to signal conversion, the balun also overcomes problems of impedance mismatch (i.e., RG-62 coaxial cable as used in IBM 3270 applications, has an imedance level of 93Ω, whereas UTP has an impedance level of 100Ω).

Baluns have been available for many years, but their use within data cabling systems has been a significant contribution in allowing many terminal based applications to operate over structured cabling systems on twisted pair cabling.

The Cable

As already mentioned, the generic cable specified for structured cabling systems if twisted pair cable. This, however, is not the whole story, as twisted pair cable comes in many different guises, offering different performance characteristics. There is Unshielded or Shielded Twisted Pair (UTP and STP, respectively), as well as Foil screened Twisted Pair (FTP or S-UTP). If this choice is not enough, then there are various categories of UTP (and FTP), each capable of different levels of performance. Then to further confuse matters, it is also totally viable to implement fiber cable instead of twisted pair copper.

One key point that should be made is that although the media options do offer some choice, typically, once this choice is made the same media type is installed across the entire system. This provides the ability to achieve commonality across the entire site, with all basic components being of the same type. This makes supporting MAC work far easier than previous proprietary cable installations. Later in this chapter we will discuss each of the media types in more depth and evaluate the options and limitations they offer.

The Connector

The connector used to terminate the cabling is, of course, dependant on the media chosen with which to implement the system. The choice however, essentially boils down to three, one for UTP and FTP, one for STP and one for Fiber (an additional connector type for fiber is available but is generally being phased out of new implementations). For UTP/FTP installations, the connector specified is the RJ-45 which is an 8 pin modular jack (IEC 603-7) offering the ability to terminate all cores of a 4 pair twisted pair cable. For STP the IBM MIC connector (IEC 807-8) is utilized offering 2 pair (4 core) termination in a hermaphrodite (ungendered) form. Fiber installations offer a choice, although market trends are beginning to eliminate other offerings in favor of the Subscriber (SC) connector. This is a square shaped connector capable of providing high quality termination with highly reproducible results. Older connectors such as the Straight Tip (ST) are still found in legacy installations, but are rarely installed in green field sites today. As with the cabling, the connectors are discussed in more detail later in this chapter.

39.2 Structured Cabling Standards

The whole concept of structured wiring is basically a simple one that provides marked benefits over both dedicated and proprietary systems. It is, however, beneficial that the design and implementation of such "open" systems be laid down

in internationally agreed standards beyond the control of either a single manufacturer, or tied to a specific application. The provides the advantage to the consumer, who is not therefore tied into vendor-specific implementations. The vendors themselves, are simply provided with a predefined set of performance criteria to which their components must adhere. Once these criteria are met, the consumer should, in theory, be able to source product from any vendor and implement it in their system with assurances with regard to minimum performance specification.

39.2.1 U.S. Standards

Early structured cabling systems, like those initially developed by AT&T and IBM, were not governed by any such standards, and the risk of a proprietary implementation was high. However, this was initially addressed by two industry associations in the US, namely the Electronics Industry Association (EIA) and the Telecommunications Industry Association (TIA), who joined forces to produce a document entitled "Commercial Building Telecommunications Wiring Standard" which was published in 1990 as EIA/TIA Standard 568. This document, which although fundamentally flawed by today's standards, not only became the forefather of structured cabling design standards, but defined many of the principles inherent in modern structured cabling systems. These included the basic topology of the system, and the wiring areas within it, as described earlier in the chapter.

In addition to defining the basic topology of a structured cabling system, EIA/TIA-568 also published performance criteria for both copper and fiber-optic cable, and details on cabling system administration. The first edition of this document, published in 1991, also made allowances for cable plant installed to support the main data application of the day, Ethernet. This meant that a structured cabling system could include the use of both 10Base2 and 10Base5 media. This inclusion of coaxial media was only one area where the document was essentially flawed. It is worth remembering at this point that one of the main concepts behind SCS is the use of a generic media type, which 10Base2 and 10Base5 are not. To add to this, the first edition of EIA/TIA 568 did not include performance criteria for different grades of UTP cable. The only criteria included was roughly the equivalent of what we know call Category 3 UTP. This meant that systems could not be designed, in accordance with the standard, for higher speed applications.

39.2.2 Technical Service Bulletins (TSBs)

In an attempt to correct some of the shortcomings of the EIA/TIA 568 standard, Technical Service Bulletins were released to provide addendums to the specification. TSB-36 entitled "Additional Cable Specifications for Unshielded Twisted-Pair Cables" included performance criteria for cables to support applications with signalling rates up to 100MHz, and introduced for the first time a classification of performance called the "Category" system, in which cables are categorized by their performance capability.

Unfortunately, TSB-36 only lays down criteria for the specification of cables and ignores the connecting hardware at either end of the cable. To correct this, TSB-40

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was released entitled "Additional Transmission Specifications for Unshielded Twisted-Pair Connecting Hardware". This document was subsequently superseded by TSB-40A which added such information as connector pin layouts and color coding schemes, guidelines on cable installation practices, and test specifications for the verification of the performance criteria of the connecting hardware. It should be noted that these test criteria are based on laboratory testing and not field testing of installed equipment, which is still a contentious issue.

The specifications within TSB-36 and TSB-40A, along with a lot of new material from organizations such as the EIA/TIA, International Standards Organization (ISO), and other development bodies, have been incorporated into a revised edition of EIA/TIA 568 and has been accredited with "real" standard status by the American National Standards Institute (ANSI). This revised edition is known as ANSI/EIA/TIA 568-A. This latest standard provides an ideal design platform on which a structured cabling system can be built.

39.2.3 Additional US Standards

Although ANSI/EIA/TIA 568-A is perhaps the most significant structured cabling document from the US, others exist that do have great importance is the overall design of building cabling systems. These standards are summarized in the text below:

ANSI/EIA/TIA 569 - Commercial Building Standard for Telecommunication Pathways and Spaces

This document focuses on the correct design of those elements within a building's infrastructure that are relevant to the telecommunications systems within those premises. This includes recommendations for the physical spaces and cabling pathways used by modern cabling systems and telecommunications equipment. These recommendations are essentially based on the following areas.

- Telecommunications Spaces - which include work areas, telecommunications closets, equipment rooms and entrance facilities. This includes sizing, loading, and environmental considerations.
- Telecommunications Pathways - which include horizontal and backbone cable distribution systems (conduits, cable trays, etc.) and pathway grounding requirements. This includes information on the number of pathways to install, acceptable types, and installation procedures.

An in depth description of the contents of this document is beyond the scope of this text, and the reader is urged, if considering a structured cabling system of their own, to obtain a copy of all standards mentioned in this book.

ANSI/EIA/TIA 570 - Residential and Light Commercial Telecommunications Wiring Standard

This document focuses on recommendations for the installation of cabling systems to be used within both residential and light commercial premises. This is based on a recognition that residential premises often have computer equipment similar to

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that found within commercial buildings. It also recognizes the needs of individuals that require remote access through teleworking. It suggests the preparation of telecommunications cabling systems within residential premises for LANs and access to remote networks.

ANSI/EIA/TIA 606 - Administration Standard for the Telecommunications Infrastructure of Commercial Buildings

The main objective of this document is the provision of a series of recommendations for the documentation and ongoing administration of the premises telecommunications infrastructure. This is achieved via the promotion of the use of an administration scheme that remains independent of any application using the system. The recommendations for documentation include:

- Assign a unique identifier to each element within the cabling system
- Create an individual record for each of the identified elements
- Provide a link between all related records.

The standard does not distinguish between electronic or manual recording systems.

System administration is known to be one of the most important aspects of any structured cabling system and it is important to keep records up to date. Remember, if changes are made to the system and these are not recorded in the system administration records, then it is the same as not documenting the system in the first instance. Good system administration also allows for easier tracking of individual components and facilitates easier troubleshooting.

ANSI/EIA/TIA 607 - Grounding & Bonding Requirements for Telecommunications in Commercial Buildings

This document provides recommendations for grounding and bonding issues within a telecommunications cabling system. It is not expected to supersede any requirements laid down in national or local electrical codes/safety regulations, merely provide guidelines to allow telecommunications infrastructure to meet stated performance criteria.

39.2.4 International Standards

In addition to the work done by ANSI and the EIA/TIA committees, the International Standards Organization (ISO) has also done a lot of work on structured cabling systems standards, particularly in conjunction with its sister organization the International Electrotechnical Committee (IEC). These organizations have worked to enhance the recommendations of the original EIA/TIA 568 and TSBs and produced a truly International standard known as ISO/IEC 11801, which is entitled "Information Technology - Generic Cabling for Customer Premises Cabling". This document encompasses all design aspects of a structured cabling system and allows for the system to be designed from a performance perspective much more simply than was previously possible. This document was ratified by ISO/IEC as a standard in 1995 and has been adopted in most countries in the world.

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Due to the nature of cabling systems, it is impossible for an International standard to be specific on every aspect as some aspects remain country specific, e.g., grounding and bonding. Therefore ISO/IEC 11801 is a very generic document, with country specific variations existing. ANSI/EIA/TIA 568A is an example of this, as is EN50173 within Europe. The discussion on structured cabling systems within this text however, is consistent throughout all three of these documents in the main part, with any notable variations highlighted wherever possible.

One area that is very different between ANSI and ISO standards is the terminology used to describe different components within the system. Table 39-1 shows the differences that exist between the two standards in this regard. This is not uncommon, and it must be remembered that as the topology has emerged primarily from a telecoms background, other terminology is also prevalent within the industry, especially with those from a similar telecoms background.

Table 39-1: Comparison of ISO/IEC & ANSI Terminology

ISO/IEC 11801	*ANSI 568A*
Telecommunications Outlet	Telecommunications Outlet
Horizontal Cable	Horizontal Wiring
Floor Distributor	Telecommunications (Wiring) Closet
Building Backbone	Intra-Building (Riser) Backbone
Building Distributor	Intermediate Cross-Connect
Campus Backbone	Inter-Building Backbone
Campus Distributor	Main Cross-Connect

39.3 Areas within an SCS System

The topology of a structured cabling system, as shown in figure 39-1, is further defined in figure 39-4, with the various sub-systems described below.

Structured cabling systems comprise three cabling subsystems; the campus backbone subsystem, the building backbone subsystem, and the horizontal cabling

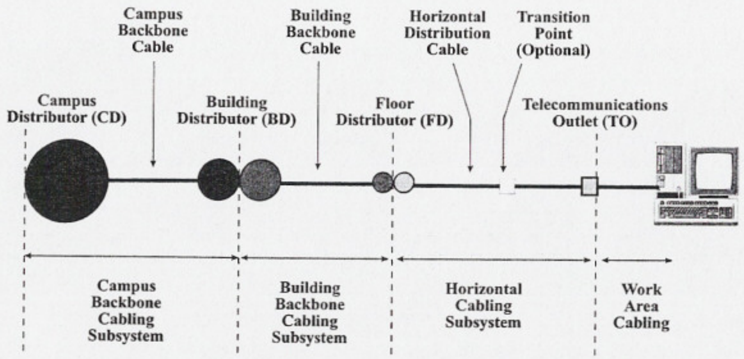

Figure 39-4: Subsystems within an SCS Topology

subsystem. In addition to this there is also the work area cabling, which is necessary but considered outside the scope of the SCS standards due to it being application specific. Each of the cabling subsystems is bounded by a distribution point which provides the mechanism for inter-connecting the subsystems and for linking in application specific equipment i.e., PABX, Bridges, Repeaters, etc.

The horizontal cabling subsystem extends from the floor distributor to the telecommunications outlet, and encompasses the horizontal distribution cables, the connecting hardware at either end, and the cross-connect patching at the floor distributor. The standard recommends that if it is at all possible, all horizontal distribution cables should be continuous, however a single transition point[1] can be included between the floor distributor and the telecommunications outlet.

Several media options exist for the horizontal cabling subsystem, with some differences between the ISO/IEC 11801 and ANSI/EIA/TIA standards. Table 39-2 summarizes these options as well as the differences between standards.

Table 39-2: Horizontal Cabling Media Options

ISO/IEC 11801	*ANSI/EIA/TIA 568A*
2n pairs 100Ω Balanced pair cable Category 3, 4, or 5	4 pair 100Ω UTP/FTP cable Category 3, 4, or 5
n quad elements 120Ω star quad cable Category 4+, or 5+	
2 pair 150Ω STP cable	2 pair 150Ω STP cable
62.5/125 µm optical fiber	62.5/125 µm optical fiber

Two minor differences exist between the ISO and ANSI standards at this level. These are the inclusion of 120Ω star quad cable in the ISO standard, due to some use in Europe, and the fact that that the ISO document talks about balanced pair cables and does not draw a distinction between construction methods. However, in the main part, the two documents agree on important areas such as performance characteristics and cable categorization.

The building backbone subsystem includes the building backbone cable and its termination hardware at either end within the building and floor distributors. In addition, it also includes the cross-connect patching at the building distributor. As with the horizontal cabling, the building backbone has multiple media options, as shown in table 39-3, however, if a copper backbone is installed, the standards expressly forbid any form of splice or jointing within the backbone. This means that transition points are not allowed in this part of the cabling system.

The campus backbone cabling subsystem extends from the building distributor through to the campus distributor and incorporates the campus backbone cable. Also included is the mechanical termination of the backbone cable at either end and the cross-connect patching within the campus distributor. Although the campus backbone subsystem has the same media options available as the building backbone, the use of copper cables in the campus backbone is relatively rare due to

[1] Transition Points are discussed in section 39.3.1.

the increased cable distances involved and the need to provide electrical isolation between buildings. For these reasons, it is far more common to see the campus backbone cabled using fiber optic cable and of course, the fiber terminating hardware at either end.

It should be noted that the standards do not encourage, nor discourage, the use of mixed media for any of the cabling subsystems and therefore this is left to the discretion of the designer and the requirements of the particular installation. It is not uncommon to find both fiber and copper in the backbone, especially the building backbone, with the fiber being allocated for data service distribution and the copper for voice services. Where this is the case, some thought must be given to the application specific equipment required to provide copper to fiber signal conversion, if necessary, at the point of inter-connection.

Table 39-3: Backbone Cabling Media Options

ISO/IEC 11801	*ANSI/EIA/TIA 568A*
2n pairs 100Ω Balanced pair cable Category 3, 4, or 5	4+ pairs 100Ω UTP/FTP cable Category 3, 4 or 5
n quad elements 120Ω star quad cable Category 4+, or 5+	
2 pair 150Ω STP cable	2 pair 150Ω STP cable
62.5/125 μm optical fiber	62.5/125 μm optical fiber
8/125 μm optical fiber	8/125 μm optical fiber

39.3.1 Transition Points

The name Transition Point indicates its function, to transition between one type of cabling to another. This could be from one cable type to another, or from permanent to temporary cabling, or from fixed cabling to a trailing, more movable cable. Some manufacturers provide 25 pair cables, which in theory, could be used for horizontal distribution cables to a fixed point out on the floor, the transition point. At this point they would be terminated, and four pair cables would be used to connect the transition point to the telecommunications outlet. This is useful where pre-wired furniture, or "service posts" are implemented in the office.

Although transition points can aid in the flexibility of the horizontal distribution system, their use should be carefully considered before widespread installation. As with any other point of interconnection, a transition point is a source of increased crosstalk on the cabling link and can have an adverse affect on attenuation. Therefore, as the standards state, all horizontal distribution should be kept continuous wherever possible. In addition, cabling system vendors, especially those offering extensive warranties, may impose restrictions on the use of transition points based on all or any of the following:

- Where, within the cable run, a TP may be placed
- The maximum length of the cable run
- The cable or connectors used

- The maximum transmission speed supported
- The use of TPs at all

39.3.2 Distance Limits

The structured cabling standards set distinct limitations on the maximum length of cable runs for each of the cabling subsystems within the system as a whole. These limits, shown in figure 39-5, are designed as maximum figures and can be reduced for any given design.

The horizontal distribution cables are limited to a maximum of 90m from the floor distributor to the telecommunications outlet. This distance should not be breached, even if transition points are used. It should also be noted that this 90m limit is imposed for all media types, including fiber. In addition to the 90m distribution limit, there is also a limit of 5m imposed for patch cords and work area fly leads. This equates to a maximum transmission distance between application specific equipment placed at the floor distributor, and end user equipment in the work area of 100m, which is equal to the maximum transmission distance for most high speed data applications over twisted pair media.

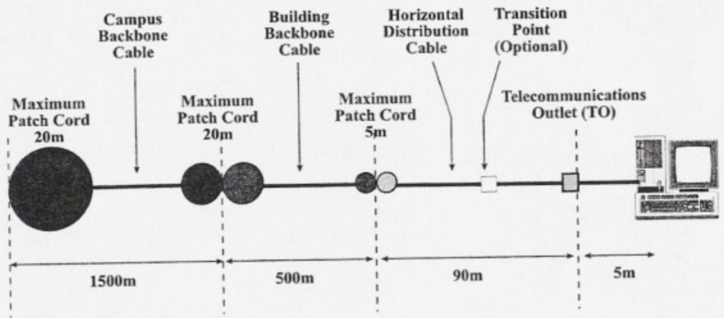

Figure 39-5: SCS Distance Limitations

For the building backbone, the permitted maximum distance of the cable run should not exceed 500m, again irrespective of media type. This distance is measured from the terminating hardware at either end of the backbone cable, and does not include the patch cords. For the building distributor, like the campus distributor, the maximum patch cord length is set at 20m. The campus backbone has a limit of 1500m, which when added to the building backbone equates to an overall backbone length of 2km. This equates to the maximum supported distance for most high speed data applications over multimode fiber optic cable.

Care should be taken when designing a structured cabling system to take into consideration the applications that are intended to run over the system. This is because the maximum distance limits set for the various cabling subsystems can often exceed the maximum supported transmission distances of many common applications. An example of this is Ethernet, which has a maximum transmission limit of 100m over UTP cable. It is perfectly legitimate to design a structured cabling system with a UTP backbone of up to 500m, but Ethernet will not run over it unless the backbone is reduced to 100m, or changed to fiber. This scenario is true for many applications, therefore application standards, or manufacturers guidelines, should be sought and understood before any system is designed.

39.4 Twisted Pair Media Options

As discussed thus far, there are different media options available for structured cabling systems, and some explanation of these media types is probably warranted at this stage. For copper based cabling, the choice is essentially based on whether to implement a shielded or unshielded variety of twisted pair cable, or whether to depart from copper and implement fiber. In this section we will discuss twisted pair media in more depth to understand the options and allow an informed choice to be made, while fiber is discussed in section 39.5.

When considering twisted pair cable (balanced pair in ISO terminology), there are basically three types to consider. There is Unshielded Twisted Pair (UTP), Foil-Screened Twisted Pair (FTP), and Shielded Twisted Pair (STP). The latter, STP, was discussed in the previous chapter and remains unchanged as 150Ω IBM Type 1A, 6A, and 9A. For the purpose of this section, UTP and FTP are categorized in the same way with the only distinction being the inclusion of an overall foil screen beneath the cable jacket. The same is true for connecting hardware, where screening is provided for the termination of screened cable and not for UTP. Therefore when discussing cable and connector hardware performance characteristics, the reader should be aware that these are applicable to both UTP and FTP media.

39.4.1 Cable Construction

Both UTP and FTP are available with either solid or stranded core conductors, with the solid core version designed for distribution cables due to its better transmission characteristics, and the stranded version for patch cords or fly leads. In either instance, the most common form of the media is a four pair variety with each of the

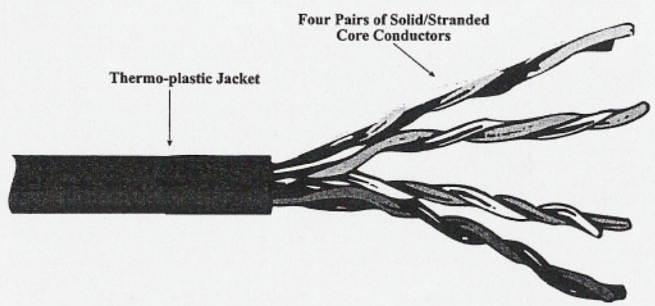

Figure 39-6: UTP Cable Construction

four pairs twisted together to enhance the signalling characteristics of the cable. This construction technique is shown in figure 39-6 below. As already mentioned, FTP differs from UTP only by the inclusion of a foil screening that surrounds the four pairs beneath the jacket. Theoretically, this screening helps to minimize the susceptibility of the cable to outside Electro-Magnetic Interference (EMI), and reduce the levels radiating from the cable itself. This is only true if the cable is installed correctly with all the grounding and bonding guidelines issued by the manufacturer followed. Failure to do so will actually cause the screening to act as a large aerial, attracting all the unwanted interference from the surrounding atmosphere, and causing potentially disastrous consequences to the signals being transmitted. It should also be mentioned that modern cable technology means that it is not specifically a requirement to install screened cable, even though many countries are tightening their regulations with regard to EMI. Most vendors of UTP cabling systems can demonstrate compliance with these regulations for their systems, even though they are based on UTP.

UTP and FTP cables are constructed with the twists in them to provide better transmission characteristics. There are no specific guidelines as to the rate of twist for cables, this is seen as a matter for the manufacturer, merely that the cable performs to stated performance criteria.

39.4.2 Transmission Characteristics

Generally, when considering twisted pair cables, the most important criteria is what is the maximum rate of signalling that can be transmitted over the cable, and over what distance. These may sound like simple enough criteria, but a complex set of parameters need to be considered to determine either. For this reason, the EIA/TIA committee responsible for TSB-36 decided, on the back of work done by the industry, to formalize the categorization of UTP cables such that users and designers would have a simplified choice for their cabling system. This led to the development of the "Category" system we know today in which five categories of UTP/FTP exist. For the purposes of structured cabling, categories 1 and 2 are not good enough to support the majority of applications and are therefore not considered by either this text or the standards themselves. Therefore only Category 3, 4, and 5 cable will be discussed, as will the differences between them. Before this though, it is necessary to have a basic understanding of some of the main transmission characteristics that affect UTP cable, and how their effects can be minimized (elimination is not possible).

Mutual Capacitance
Mutual Capacitance is an effect that occurs when wires are arranged in close proximity to each other, as in the case of UTP cables. In this arrangement, they will exhibit a "capacitive coupling" effect between the pairs such that a coupling of AC signals between the pairs will occur. The net result of this is that "crosstalk" will occur between pairs with the signal on one pair interfering with the signal on another. The only way to minimize the capacitive coupling effect is to reduce the mutual capacitance of the cable to as low as possible. This is achieved via the construction of the cable, using high quality materials and introducing twisting to the pairs. Because the capacitance of the cable is largely due to the construction, it

is imperative that installation guidelines are followed to ensure the internal structure of the cable remains intact.

Characteristic Impedance

Characteristic impedance is the reactance of a cable to an AC signal and is pre-defined for a specific cable type. UTP has an impedance level of 100Ω +/- 15%, which is largely determined by the construction of the cable. Factors such as how many twists per foot are made in each pair, the diameters of the conductors, and the thickness of the insulation are all important in determining the characteristic impedance for the cable. Again, installation such that it damages the cable structure can adversely affect the impedance, causing unwanted signal reflections.

Attenuation

Attenuation is something that affects all signals in all media types and is best described as the gradual reduction of the signal power in relation to distance travelled. Therefore a signal will become "weaker" the greater the distance it must travel. In copper cables, attenuation increases with frequency such that the higher the frequency (Hz), the greater the attenuation, the shorter the distance it can travel. Attenuation is expressed as a ratio of the losses compared with the original signal power, and uses a logarithmic scale known as deciBels (dB). Typically, as it is losses being considered, the attenuation rate is normally expressed as a negative value i.e., -ndB. As attenuation is directly linked to distance, it is a primary factor in determining cable lengths for any given signalling rate.

In order to calculate the level of losses occurring, table 39-4 shows a general guide to equating dB losses to percentage signal losses. It demonstrates that an increase of 3dB effectively doubles the amount of losses, or put another way, each 3dB loss will halve the signal power still left.

Factors that affect attenuation are the quality of the materials used and the method of construction. It is impossible to eliminate, but the effects can be reduced. Evidence of this can be seen in table 39-5 where Category 5 UTP suffers much lower attenuation than Category 3 at the same signalling rates. In fact, Category 3 UTP suffers to such an extent at higher signalling rates, the maximum supported rate has to be limited so as not to compromise the 100m distance limit assigned to the horizontal cabling subsystem.

Table 39-4: deciBel Losses Vs Percentage Losses

deciBels	*Ratio*	*Percentage Power Loss*
0dB	1:1	0%
-3dB	1:2	50%
-6dB	1:4	75%
-9dB	1:8	87.5%
-10dB	1:10	90%
-20dB	1:100	99%
-30dB	1:1000	99.9%

Near End CrossTalk (NEXT)

Near End CrossTalk (NEXT) is the unwanted coupling of signals between pairs within a cable, and is directly related to the mutual capacitive coupling effect described earlier. It is so called because it is always measured at the near end, where the power of a transmission signal is at it strongest. If the signal power is at its greatest then the crosstalk effect is going to be at its worst. Like attenuation, NEXT also varies with frequency, worsening as the signalling rate increases. The other factor NEXT shares with attenuation is the measurement is also made as a ratio in deciBels (dB). In this instance the ratio is between the power of the unwanted crosstalk signal, as measured on an adjacent pair, compared to the power of the original transmission signal. As the comparison is a power ratio, the greater the ratio is, the less the crosstalk is between pairs. This means that unlike attenuation, where low dB values are better, with NEXT, the higher the value, the better the performance. Again, as with attenuation, the ratio values are as shown in the center column of table 39-4.

NEXT causes manufacturers big problems when designing cables, and more specifically connecting hardware as the capacitive coupling effect is at its worst at the point of termination. Within the cable techniques such as varying the number of twists per foot between pairs, and better materials help reduce the effect. For connecting hardware, it is imperative that manufacturers guidelines are followed to ensure NEXT does not exceed acceptable limits.

Signalling Rate

The last characteristic we will consider is the Signalling Rate. The signalling rate is determined by the application making use of the cable infrastructure and varies from one application to another. With digital signals, the signalling rate can be described as the rate of change of the state of the signal, and is measured in Hertz (Hz). For most data applications, this rate of change is in the millions per second range, or MegaHertz (MHz). We have already discussed how this rate of state change in the signal can directly affect the attenuation and the NEXT for any given cable. It is therefore extremely important that it is taken into consideration when selecting cable type for a particular installation. As cable technology enhances, the maximum signalling rate supported will increase, however application developers are also assisting in allowing faster applications to run over existing cable plant by developing fancy encoding schemes that allow the signalling rate to reduce, while the data transfer rate increases. This approach is being used to allow technologies such as 1000BaseT to be developed to run over existing cabling systems.

39.4.3 UTP Categories

As you can imagine, given the number of parameters involved, it is possible to manufacture cable to many different specifications, each with different performance characteristics. This could easily lead to confusion in the market place with users not being aware of the performance capability of their installed systems. To overcome this issue, the EIA/TIA, off the back of work undertaken previously by the industry itself, decided to formalize the specification of UTP cables such that users would be able to easily determine the minimum performance capability of the cable they purchase.

Although five cable categories exist, only categories three through five are considered suitable for structured cabling systems due to the need to support data, as well as voice applications. The difference between the cables in each category is how they perform in relation to the parameters specified in the previous section. Therefore a cable which is less susceptible to attenuation and NEXT is likely to be in a higher category than one with higher attenuation and more crosstalk. Frequency is also a key factor in cable performance, with both attenuation and crosstalk varying with frequency changes. Table 39-5 demonstrates the difference between the three categories of cable in relation to the maximum allowable attenuation and NEXT for each cable category at a range of different frequencies. It should be noted that although only spot frequencies are quoted in the table, the standards do actually dictate that the attenuation and NEXT values for each category should not be exceeded at any frequency between 0MHz and the maximum supported frequency for that category. That is 16MHz for Category 3 UTP, 20MHz for Category 4 UTP and 100MHz for Category 5 UTP.

Based on the specifications stated, the EIA/TIA specified in TSB-36 that Category 3 UTP cables would support a maximum signalling rate of 16MHz. Likewise Category 4 would support applications with a signalling rate up to 20MHz and Category 5 up to 100MHz. This enables designers and customers to know the expected performance of any given installation based on the cables used, or does it?

Table 39-5: Cable Attenuation and NEXT Maximum Values for each Category

	ISO/IEC 11801						*ANSI/EIA/TIA 568A*					
Frequency (MHz)	*Cat 3 (dB)*		*Cat 4 (dB)*		*Cat 5 (dB)*		*Cat 3 (dB)*		*Cat 4 (dB)*		*Cat 5 (dB)*	
	Att	*XT*	*Att*	*XT*	*Att*	*XT*	*Att*	*XT*	*Att*	*XT*	*Att*	*XT*
1	2.6	41	2.1	56	2.1	62	2.6	41	2.1	56	2.1	62
4	5.6	32	4.3	47	4.3	53	5.6	32	4.3	47	4.3	53
10	9.8	26	7.2	41	6.6	47	9.8	26	7.2	41	6.6	47
16	13.1	23	8.9	38	8.2	44	13.1	23	8.9	38	8.2	44
20	N/S	N/S	10.2	36	9.2	42	N/S	N/S	10.2	36	9.2	42
31.25	N/S	N/S	N/S	N/S	11.8	39	N/S	N/S	N/S	N/S	11.8	39
62.5	N/S	N/S	N/S	N/S	17.1	35	N/S	N/S	N/S	N/S	17.1	35
100	N/S	N/S	N/S	N/S	22.0	32	N/S	N/S	N/S	N/S	22.0	32

N/S = Not Supported Att = Attenuation XT = Near End CrossTalk

In fact there is more to it than just the cables. The connecting hardware plays an equal importance in determining the performance capacity of any link, and therefore has been categorized in the same fashion. It is possible to purchase Category 3, Category 4, or Category 5 connectors and patch panels, as well as other connecting hardware arrangements. When implementing a structured cabling system, if a specific performance capability is required then all components, cable and hardware, must conform to the required specifications. The performance of a link is ultimately determined by the lowest category component in that link, i.e., Category 3 connectors will nullify the benefits of a Category 5 cable.

It should also be remembered that cable and connecting hardware is only 50% of what it takes to gain maximum performance from any cabling system. Installation is equally important and it is imperative that manufacturers guidelines are followed to ensure the best return on the investment.

Table 2-6: Connecting Hardware Attenuation and NEXT Maximum Values for each Category

	ISO/IEC 11801						*ANSI/EIA/TIA 568A*					
Frequency (MHz)	*Cat 3 (dB)*		*Cat 4 (dB)*		*Cat 5 (dB)*		*Cat 3 (dB)*		*Cat 4 (dB)*		*Cat 5 (dB)*	
	Att	*XT*	*Att*	*XT*	*Att*	*XT*	*Att*	*XT*	*Att*	*XT*	*Att*	*XT*
1	0.4	58	0.1	>65	0.1	>65	0.4	58	0.1	>65	0.1	>65
4	0.4	46	0.1	58	0.1	>65	0.4	46	0.1	58	0.1	>65
10	0.4	38	0.1	50	0.1	60	0.4	38	0.1	50	0.1	60
16	0.4	34	0.2	46	0.2	56	0.4	34	0.2	46	0.2	56
20	N/S	N/S	0.2	44	0.2	54	N/S	N/S	0.2	44	0.2	54
31.25	N/S	N/S	N/S	N/S	0.2	50	N/S	N/S	N/S	N/S	0.2	50
62.5	N/S	N/S	N/S	N/S	0.3	44	N/S	N/S	N/S	N/S	0.3	44
100	N/S	N/S	N/S	N/S	0.4	40	N/S	N/S	N/S	N/S	0.4	40

N/S = Not Supported Att = Attenuation XT = Near End CrossTalk

The standards also dictate color coding for 4-pair UTP/FTP cables to distinguish between pairs. In addition, 25-pair UTP cables are also available for backbone implementations, in which case a supplementary code is required for the secondary color. For 4-Pair Cables, the first 4 "pair" colors - Blue/Orange/Green/Brown - are each paired with a White conductor. The conductors may have either solid color insulation, or the main color may have a "trace" band or stripe of the paired color - i.e., the first pair may be solid White + solid Blue, or may be White with a Blue tracer + Blue with a White tracer. This latter arrangement makes it easier to keep track of which White belongs with which color.

Table 39-7: UTP/FTP Color Coding

Pair Colors	*Group Colors - 25 Pair cables*
Blue	White (4 & 25 Pair cables)
Orange	Red
Green	Blue
Brown	Yellow
Slate (25 Pair cables only)	Violet

For 25-Pair Cables, five groups of five colors are used. The groups are identified using the colors White/Red/Black/Yellow/Violet, with each group containing pairs using the identifiers Blue/Orange/Green/Brown/Slate. The first group will thus have pairs of White+Blue/White+Orange/White+Green/White+Brown and White + Slate, the second group will have pairs of Red+Blue/Red+Orange/Red+Green/etc., and so on.

39.4.4 UTP Connector

The standard connector for UTP and FTP cables is the eight way modular jack, often referred to as an RJ-45 connector. This connector, shown in figure 39-7 and specified in ISO/IEC 603-7, is available in screened and unscreened varieties for FTP and UTP, respectively. It is based on Insulation Displacement Contacts (IDC) which are crimped onto the individual conductors to ensure continuity from the cable through the connecting hardware.

The RJ-45 is available in jack and socket configuration, which is keyed to ensure correct orientation is maintained. Once the jack is inserted, it is secured in place via a retaining lug on the back, which must be depressed while the jack is removed.

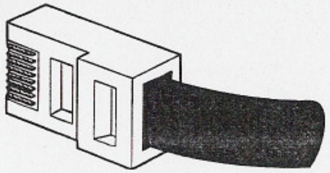

Figure 39-7: UTP RJ-45 Connector

Both ISO and ANSI standards include pin-pair/color layouts for terminating four pair cable in the RJ-45 jack and socket. Two different schemes are included, neither offering any advantage over the other, and both shown in table 39-8. These termination layouts are known as TIA 568A and TIA 568B. The most important factor in implementing a termination layout for connecting hardware is not which you choose, but that the same code is maintained throughout the entire system.

Although it is not strictly necessary to maintain the same code on the patch leads, it is highly recommended to avoid possible confusion. Because it is possible to have systems terminated to TIA 568A or TIA 568B, the standards also include an alternative color code layout for patch leads only. This alternative is also shown in table 39-8. This allows installers to maintain a stock of patch leads and not worry which scheme they are implementing.

Table 39-8: RJ-45 Wiring Codes

Pin No.	*TIA 568A*	*TIA 568B*	*Patch Leads*
1	White/Green	White/Orange	Blue
2	Green/White	Orange/White	Orange
3	White/Orange	White/Green	Black
4	Blue/White	Blue/White	Green
5	White/Blue	White/Blue	Red
6	Orange/White	Green/White	Yellow
7	White/Brown	White/Brown	Brown
8	Brown/White	Brown/White	Slate

Due to the increased handling of patch leads, these should be made from stranded conductor cable, while distribution cables should have a solid conductor for increased performance capability. Which termination scheme is adopted is unimportant, with some manufacturers favoring one over another, while others provide products for both.

39.5 Fiber Optic Media

The use of fiber optic cabling in office cabling systems and LAN applications has been growing steadily over the last ten years, largely due to increased distance

capability and falling costs. These days fiber is the most common media for structured cabling backbone media, especially for data applications. Apart from greater distances, fiber also provides the distinct advantage of electrical isolation between buildings, or locations within a building. This meets the requirements of electrical regulations in many countries around the world.

Two main types of fiber optic cable exist, multimode and singlemode fiber. The difference between the two is the way light is accepted into the cable and then travels along it. To understand this process it is necessary to have a basic understanding of how the cable is constructed.

39.5.1 Fiber Optic Cable Construction

There area two basic elements to optical fiber, the "Core" and the "Cladding" which are shown in figure 39-8. Both of these elements are made from glass during a manufacturing process that makes them inseparable. Although both of these elements are made from glass, they are made from slightly different chemical formulations which impart slightly different optical properties to each element.

The first stage of fiber manufacture is based on a "bait tube" of Cladding glass material which is internally coated with a layer of Core glass. This is achieved by heating the tube while at the same time, introducing an air-borne stream of chemicals which will form the Core glass. As the stream passes over the heat source, it forms a "soot" deposit on the inner surface of the bait tube. This "soot" becomes a layer of sintered glass, which is built up as the heat source gradually traverses the length of the tube. The tube is continuously rotated during the process, to ensure that the coating is formed to a uniform thickness. The core layer does not completely fill the inner diameter of the tube, which is left slightly hollow.

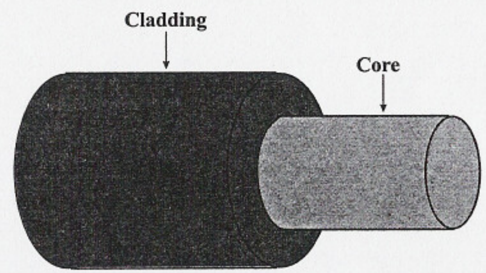

Figure 39-8: Fiber Core/Cladding Construction

The next stage in the manufacturing process is to heat the bait tube to the point at which it softens enough to collapse in on itself, creating a solid billet instead of a hollow tube. This solid billet is known as a "preform", and is essentially a large version of the finished article, with the correct ratio of Core to Cladding diameters. The final stage of manufacture of "raw" fiber (i.e., before it is made up into cable), involves heating the preform billet in a vertical furnace, to the point where it softens sufficiently enough to be drawn out into a thin, flexible fiber. As the fiber is drawn, the ratio of core to cladding diameter remains unchanged, and the finished diameters are reached.

The drawn fiber is then coated with a thin protective layer of polymer material, known as the "primary buffer" before being wound onto a drum. All fiber receives this coating, regardless of the type of cable construction in which it will ultimately be used.

39.5.2 Principles of Fiber Optic Transmission

As previously mentioned, the basis of light transmission through fiber cable is based on the difference in Refractive Indices between the core and the cladding. The Refractive Index is essentially a way of expressing the speed of light through the medium, when compared to that through a vacuum. By giving the Core and Cladding elements slightly different Refractive Indices, light can be made to "bounce" within the Core, and thus provide a light guide function. It is not the value of the Refractive Index which causes the light to "bend" within the Core, but the fact that the Indices of the Core and Cladding are different. As an illustration of this, consider the way in which a straw placed at an angle in a glass of water appears to be "bent" where it enters the water. This phenomenon is caused by the fact that a change of Refractive Index takes place, in this case between the water in the glass and the surrounding air. In the case of water and air, the difference in RI's is quite large, and generally the larger the difference, the greater the refraction (or "bend") in the light path. The difference in RI between the Core and Cladding in optical fiber is more subtle, and amounts to a change of only a few percent.

In truth, the light does not actually bend, but is totally internally reflected when the light rays meet the boundary between core and cladding. To ensure total internal reflection occurs, the light rays must be made to travel at a shallow enough angle so as to allow reflection, or they will penetrate the cladding and be lost. This principle is shown in figure 39-9.

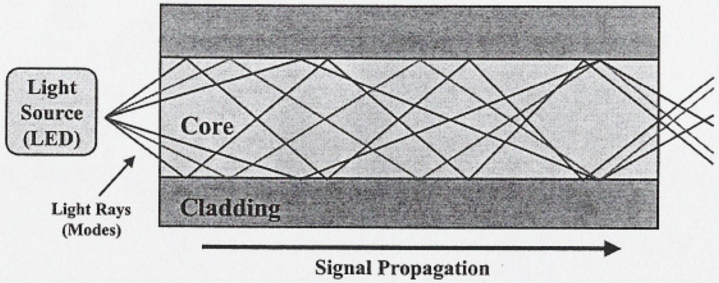

Figure 39-9: Principle of Total Internal Reflection

The method illustrated is known as Multimode - Step Index Fiber, which was the first type developed. The fiber is so named because the light source is omni-directional (typically a Light Emitting Diode - LED) which emits light consisting of

many rays, or modes travelling in slightly different directions. The Step Index refers to a stepped change in the Refractive Index between core and cladding. It can be seen that the various modes enter the fiber at one end and travel on a straight path until they reach the boundary between the core and the cladding. Because of the stepped RI change between the two, if the angle of "attack" is shallow enough, then total internal reflection will "bounce" the light mode back into the core. This will continue down the length of the fiber until the modes of light reach the far end and emanate from the fiber.

While this method of light propagation works reasonably well, it does have limitations which restrict the rate at which successive signal pulses may be sent, and the distance over which they may be transmitted. Light rays travel in more or less straight lines and at the same speed. Therefore those modes that travel further will arrive after those that have a shorter distance to cover. In the example shown, it can be seen that the mode travelling down the center of the core travels a shorter distance than others that "bounce" around. The net result is that the modes arrive spread rather than all at the same time. This effect is known as Modal Dispersion and is a direct cause of signal degradation, and furthermore increases as the signalling rate, or distance covered, increases. To overcome these limitations a new form of Multimode fiber was developed known as Multimode Graded Index fiber.

Graded Index is a clever solution to the problem of Modal Dispersion. It is based on constantly changing Refractive Index from the center to the edge of the core, plus the standard RI change at the boundary with the cladding. This is achieved during the manufacturing process, whereby the chemical formulation is varied as layers of soot are built up inside the bait tube. The net result of the gradual change in RI means that modes will be refracted in many small steps, rather than one large one at the boundary. This has the effect of causing the light to take a curved path through the core. In addition, because the properties of the core glass change the closer to

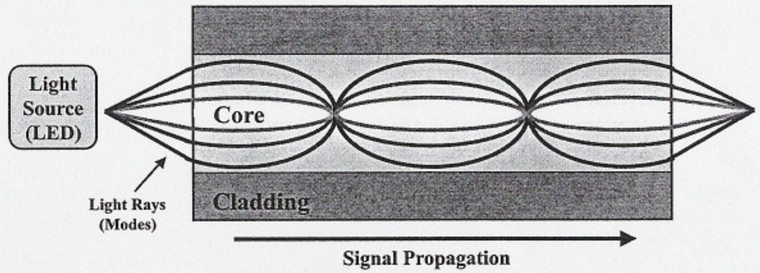

Figure 39-10: MultiMode Graded Index Fiber

the cladding it gets, there is a change in the velocity of propagation of the light mode. This results in the light nearer the cladding "speeding up", while the light travelling straight down the center travels slightly slower. The overall effect of this is that more of the light modes arrive at the far end at the same time, producing a clearer signal, thus allowing faster signalling rates and longer distances. MMGI fiber, is now the standard fiber used for most LAN implementations with distance limitations of up to 2km. The principle of Multimode Graded Index fiber transmission is demonstrated in figure 39-10.

While MMGI fiber remains the most commonly installed type of fiber for structured cabling systems and LAN applications, to achieve the maximum data rates and longest distance, a more specialized version of fiber is required. This "specialized" type of fiber is known as SingleMode (or MonoMode), and is based on Step-Index construction, although the core diameter is typically less than one tenth the diameter of that used in MultiMode fiber. To utilize this form of fiber, a special light source must be used to produce a very narrow, coherent beam of uni-direction light rays, which effectively "floods" the Core with a parallel bundle of modes. In practice, this can only be achieved by a Laser type device, typically in the form of an Edge-Emitting LED (E-LED). These are considerably more expensive than standard high-intensity LED devices, and are normally found only in specialized, long-haul systems i.e., where distances exceed 5 - 10 km.

39.5.3 Fiber Optic Connectors

There are a few different types of connector available for terminating fiber cable, the most popular of which are the Sub-Miniature Assembly (SMA), the Straight Tip (ST), and the Subscriber Connector (SC), all shown in figure 39-11. Of these, the SMA connector is only found in legacy installations and no longer installed in green-field sites. The remaining two, the ST and the SC are both commonplace in the market today. However, the SC, the latest version available, produces much lower losses over a fiber coupling than any of its rivals, and accordingly is the preferred connector in the eyes of the structured cabling standards. It is likely that all over versions will begin to dwindle in popularity as time passes because of this.

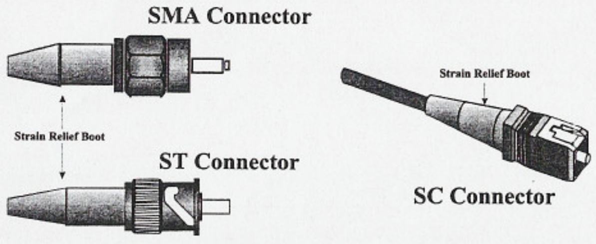

Figure 39-11: Fiber Optic Connectors

The ST connector is based on a bayonet type fitting, while the SC is a push-pull mechanism. Both provide reasonable performance characteristics, with perhaps the SC being more reproducible. The additional advantage of the SC connector is that by being square in shape, connector density on a patch panel, or end-user equipment, is greatly increased over the ST or the SMA connectors.

39.5.4 Fiber Optic Performance Criteria

There are two main performance criteria that need to considered for fiber cable installations, which are Attenuation and Bandwidth. Unlike copper cables, where

crosstalk was a problem, fiber cables are immune from outside interference as the signal carried is based on light and not an electrical current.

Attenuation

Fiber, like copper cable, suffers from a gradual loss of signal power in relation to distance travelled. These losses are exacerbated by factors such as impurities in the fiber, bending losses, mismatch between coupled fibers, and coupling losses due to connectors and splices, all of which must be taken into consideration when calculating the losses of any given fiber link. One big difference between attenuation in copper and fiber, is that fiber attenuation is not linked to signalling frequency, in fact it remains constant across all frequencies.

What is far more important for fiber attenuation is the wavelength of the light source generating the signal. You will therefore find fiber cable attenuation specified not just as dB losses per kilometer, but the wavelength will also be quoted. A particular fiber is also likely to have multiple attenuation figures quoted, one for each wavelength of light source supported by the fiber, i.e., 3.6 dB/km @ 850 nm, and 1.8 dB/km @ 1300 nm. The reason for this is best shown in figure 39-12 which depicts a spectral response curve for a fiber cable, with the different attenuation rates per wavelength change. You will notice that three "windows" are marked at 850nm, 1300nm, and 1550nm, where the attenuation rate is either low or diminishing. Light sources are therefore set to operate at one of these wavelengths to guarantee best performance from the fiber cable. The fibers themselves are optimized to operate at single or dual window operation, again to maximize potential. Multimode fiber is available for 850nm, or 850/1300nm dual window, while singlemode fiber can be found for 1300nm, or 1300/1550 dual window.

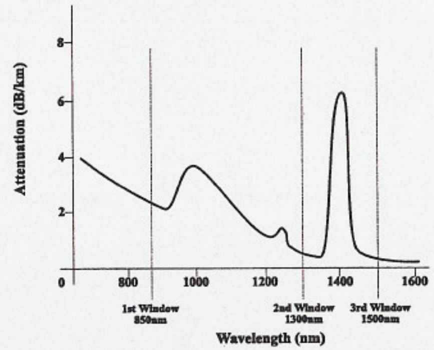

Figure 39-12: Fiber Spectral Response Curve

It is important that the wavelength for operation is known for two reasons. The first is wavelength matching between transmitter and receiver. Failure to match the light source wavelength to the receiver will result in signal failure between devices. The second reason is based on implementation testing, where the installation should be tested for attenuation at the wavelength at which it is intended to be used. Failure to do this may result in results being obtained which bear no resemblance to the losses being experienced by the system.

Bandwidth

Bandwidth is the term used to describe the fiber's "data carrying" capacity and is always expressed in terms of the maximum signalling rate that can be supported in relation to distance. It is important when discussing any type of cable to understand that signalling rate, expressed in Hertz (Hz) is not the same as data rate, expressed in bits per second (bps). The signalling rate is the rate at which the signal is modulated which may, or may not, be the same as the data rate, depending on the data encoding mechanism employed.

For multimode fiber, bandwidth has a linear relationship with distance and is expressed in terms of MHz/km at a specific wavelength. Again, fiber may have two figures quoted if it supports dual window light sources. The linear relationship between bandwidth and distance allows some trade-off if increased distance, or increased bandwidth is required, i.e., if a fiber has a bandwidth of 250 MHz/km @ 1300 nm, a signalling rate of 250 MHz may be used over 1 km, or the signalling rate may be dropped to 125 MHz to support a distance of 2 km, or the signalling rate may be increased to 500 MHz, provided the distance is reduced to 500 meters.

Calculating the bandwidth availability for singlemode fiber is a far more complex subject, due in part to the method of propagation used. In addition to distance, it is also necessary to consider the spectral width of the laser utilized in the light source. A parameter known as the "Chromatic Dispersion Coefficient" is used to describe the fact that even a laser light source cannot generate light modes at exactly the right frequency all the time, and it is this variation in frequency that must be considered. Bandwidth for singlemode fiber is therefore extremely difficult to measure and is quoted in ps/km/nm (picosecond/kilometer/nanometer).

39.6 Application Classes

ISO/IEC 11801 introduced a concept of classification for applications that allowed designers to take a more logical, performance-based approach to structured cabling system design. The application class system is designed to group together different applications based on their signalling rate requirements, in classes that directly correlate to cable categories. This provides the designer with a distinct advantage as it removes the necessity to understand the various encoding methods employed that distinguish application data transfer rates from their signalling rates. Table 39-9 shows the application classes currently defined in ISO/IEC 11801, as well as some examples of applications in each class.

Table 39-9: Application Classes

Class	*Maximum Rate*	*Signalling*	*Example*
Class A	< 100 KHz		Voice, RS-232
Class B	< 1 MHz		ISDN
Class C	< 16 MHz		10BaseT, 4Mbps Token Ring
Class D	< 100 MHz		100BaseTX, 16Mbps Token Ring (Passive)
Optical Class			FDDI (SMF & MMF), ATM 622Mbps

With performance classes defined for applications, and also for cable categories, it becomes possible to map application classes against cable category performance, to define maximum support transmission distances for each application class. Table 39-10 defines the media required to support each distance defined, for each application class. It should be remembered that although it may be feasible to run an application over a given distance, cross reference with the application standards should be made to maintain application compliance.

Table 39-10: Application Class Vs Cable Category Vs Distance

Application Class	*Cable Length* 0 - 90m (Horizontal/Backbone)	90 - 160m (Backbone)	160 - 500m (Backbone)
Class A	Cat 3 - 5	Cat 3 - 5	Cat 3 - 5
Class B	Cat 3 - 5	Cat 3 - 5	Cat 3 - 5
Class C	Cat 3 - 5	Cat 5	Optical Fiber
Class D	Cat 5	Optical Fiber	Optical Fiber

39.7 SCS Patching Options

Having discussed media options, back to structured cabling design and the implementation of end-user equipment into the system. Provision is made at all of the subsystem boundaries to integrate this type of equipment to provide application services. Many applications, especially high speed data applications, often require equipment at each level of distribution to provide signal regeneration and maintain conformance with application standards cabling limitations. Therefore, it is not uncommon to find application specific transmission equipment at each of the distributors with the cabling system. From these locations, connections can be made into the floor distribution and/or backbone cabling as desired. In addition to deciding where application specific equipment should be placed, a decision must be made as to how to present it to the cabling system. Two methods exist, one offering a direct connection, the other an indirect connection. These are discussed in the sections that follow.

39.7.1 Inter-Connect Patching

The Inter-Connect or direct patching method, shown in figure 39-13, utilizes direct patched connections from the ports of the application equipment, to the horizontal and/or backbone patch panels. This is the simplest method of connectivity and is especially convenient when the port presentation is the same on both equipment and patch panel i.e., RJ-45.

With two methods of patching available it is inevitable that each has its advantage, and disadvantage over the other. With Inter-Connect patching the advantage is based on performance. You will notice from the diagram that the number of connections made to complete the link between user equipment in the work area and application equipment in the distributor is kept to a minimum. This aids in minimizing the amount of crosstalk on the link. As crosstalk is worst at points of interconnection, the fewer that exist, the better the results. The downside to the Inter-Connect method is presentation. Where large amounts of equipment, or high port densities exist, there is no doubt that the large number of patch cables can easily become a tangled mess with cables going in all directions.

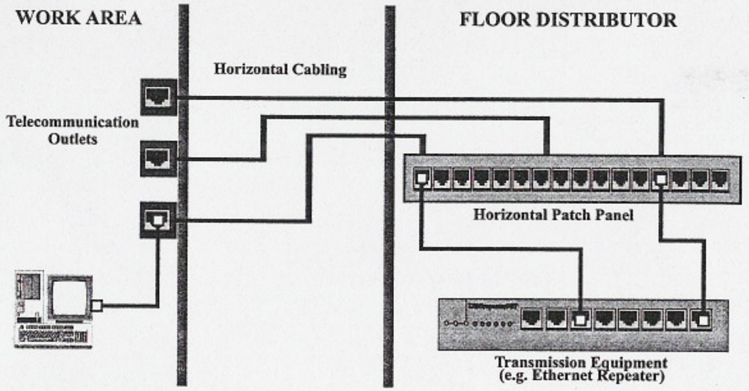

Figure 39-13: Inter-Connect Patching

39.7.2 Cross-Connect Patching

Cross-Connect or indirect patching involves the addition of extra patch panels on which the connections to the application equipment are permanently terminated. In order to make a connection between user port on the cabling system, and application port on the equipment, a patched link between the two patch panels is required, as shown in figure 39-14.

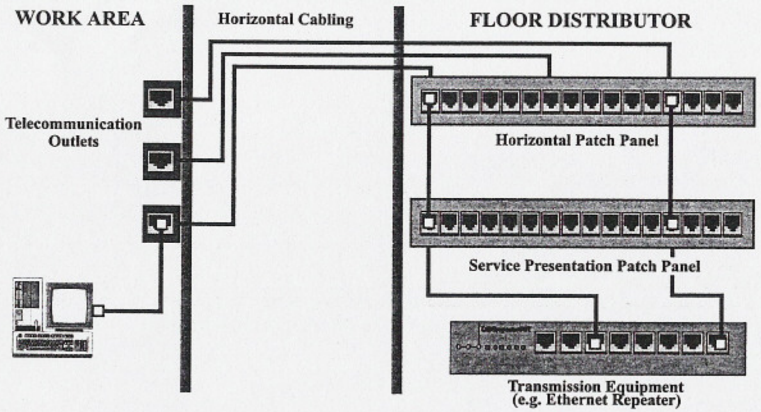

Figure 39-14: Cross-Connect Patching

The main advantage of this method is much neater and tidier cable presentation within the distributor. In addition, if the application equipment comes with a different port presentation than the patching system, then the need for different types of patch lead can be eliminated by terminating the equipment on patch panels. Unfortunately, this does come with a performance penalty, with more crosstalk on the link. However, this is only likely to be significant if the full bandwidth of the cabling is being being pushed to its limits over the maximum 90m distribution distance. Good installation practices can assist in keeping crosstalk to a minimum, and should be adhered to at all times.

39.8 SCS and LAN Applications

Having a structured cabling system is only half the battle, being able to effectively configure the application to run over the infrastructure is just as important. There are many applications that can run over structured cabling, from data applications to voice and video, most of which are beyond the scope of this text. However, in this section we will discuss some of the main points required to achieve effective operation of the three key LAN applications discussed in this book, Ethernet, Token Ring, and FDDI. Many manufacturers provide excellent reference material regarding the mapping of different applications to their cabling systems which are recommended reading if different applications are being considered.

39.8.1 Mapping Ethernet onto SCS

Ethernet, particularly 10/100/1000 BaseT is probably one of the easiest of all applications to map onto a structured cabling system, as the standards were specifically written for twisted pair media and there is no requirement for any special adapters. A typical installation, shown in figure 39-15, requires active equipment to be placed in the floor distributor for user connectivity. This equipment can be a hub/repeater, a bridge/switch, or even a router, depending on

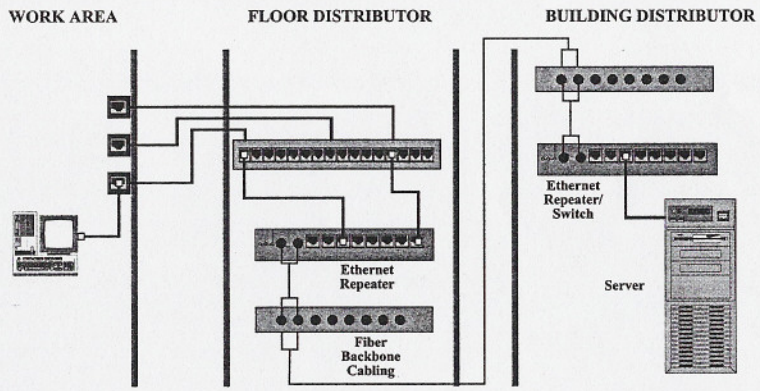

Figure 39-15: Mapping Ethernet on to SCS

the network design being implemented. Invariably today, it is most likely to be a switch of some form providing dedicated bandwidth to the desktop. All of the Ethernet twisted pair media standards indicate a maximum link distance of 100m, matching the maximum distance from floor distributor to user equipment (including patch leads). The active equipment can then be patched to the backbone cabling (fiber or twisted pair) to additional equipment located at the building distributor (typically in the computer room or close to it).

Patch leads are typically available in two forms, straight through or cross-over. The straight through version matches pins at both ends of the cable, while cross-over cables will cross transmit to receive pairs within the cable. With Ethernet using pairs 2 and 3, i.e., the orange and green pairs, this involves swapping pins 1 and 2 with 3 and 6 at one end. Whether to use a straight through cable or a cross-over is determined by the connection that is being made. For example, if the connection is between an end-user PC and a hub port, then straight through patch cables can be used at either end of the distribution cabling. On the other hand, if the connection is from one switch port to another, then a cross-over cable must be used at one end of the connection. For each connection, it is worth checking the type of port being connected. If connecting MDI to MDI[2] , or MDI-X to MDI-X then a cross over is required. If the connection is MDI to MDI-X then a straight through cable can be used.

39.8.2 Mapping Token Ring onto SCS

As a technology, Token Ring has always operated over a star topology cabling system, and therefore maps onto a structured cabling system quite easily. However, Token Ring was developed for 150Ω STP cabling and therefore requires a media filter to be added if the SCS is based on 100Ω UTP. Whether this media filter is an external adapter to the end-user PC or not depends on the type of network interface card (NIC) employed. Older NICs were very much based on STP and would provide DB9 presentation for fly lead attachment. In this instance, an external media filter provides conversion from DB9 to RJ-45 as well as cable type conversion. Newer NICs are available with RJ-45 presentation and a media filter built onto the card. In this scenario, a media filter is still necessary, but comes built in and therefore not required externally. Figure 39-16 shows a typical Token Ring installation, in this case based on active Token Ring MSAUs. It should be noted that passive MSAUs can be transposed for the active ones without changing the cabling configuration.

Care should be taken with Token Ring as to which cable category is required to support which version of the technology. As a basic guide, 4Mbps Token Ring will operate over category 3 UTP, while 16Mbps and above requires category 5 or better.

Patch leads in Token Ring are somewhat simpler than Ethernet in that there is no cross-over cable required for connectivity of end devices. All connections can be made via straight through patch leads. For reference, Token Ring transmits on pins 3 and 6, and receives on pins 4 and 5. Depending on which wiring code (T568A or

[2] MDI and MDI-X ports are described in the Ethernet chapters of this text.

T568B) is employed means that transmission takes place on the green (or orange) pair, and reception is on the blue pair.

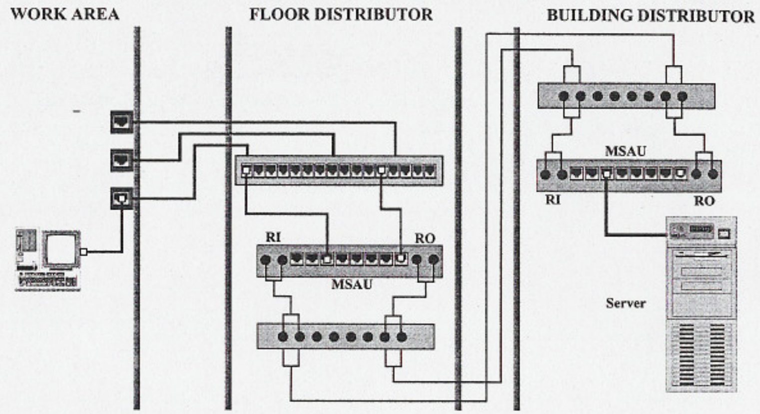

Figure 39-16: Mapping Token Ring on to SCS

39.8.3 Mapping FDDI onto SCS

FDDI, like Token Ring, can be designed around a star topology, but also has the ability to be connected in a dual ring configuration. For structured cabling systems, FDDI implementation is normally based on a star/tree topology providing single attachment to end-user devices. Where dual attachment is required, this is normally confined to the backbone, and not extended over the horizontal

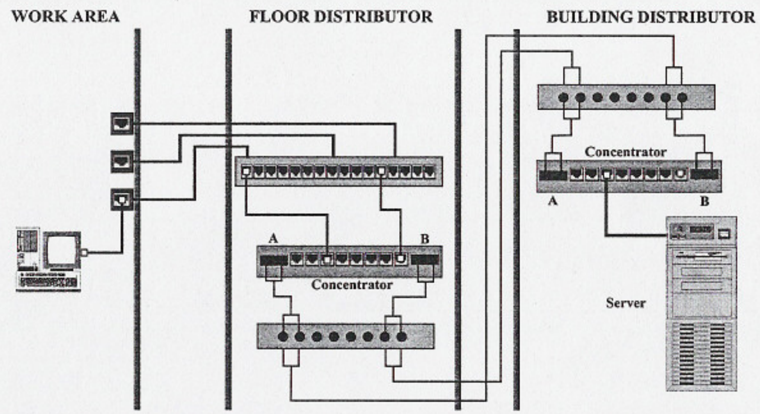

Figure 39-17: Mapping FDDI on to SCS

distribution cabling. This means that FDDI concentrators would need to be placed at the floor distributor, which could be singularly, or dual attached, to the backbone cabling.

It is normal for FDDI to operate over a fiber backbone with either fiber, or twisted pair, for the horizontal distribution. Figure 39-17 shows a typical UTP installation, but it should be noted that fiber distribution cabling could just as easily replace the UTP shown. Where copper cabling is implemented, category 5 UTP is a minimum requirement, over a maximum link distance of 100m.

39.9 Electro-Magnetic Compatibility

In many countries around the world, regulations are being introduced to more strictly control Electro-Magnetic Compatibility (EMC). So what is EMC? The simple answer can be found in the following statement;

"levels of electromagnetic disturbance and intrinsic immunity shall be such that the equipment in question plus all other equipment shall operate as intended"

This statement taken from the EC directive on EMC, tells us that equipment both generates an electro-magnetic disturbance, and can be susceptible to an electro-magnetic disturbance generated by something else. It also states that compliance is achieved through not disturbing anything else, nor being disturbed by some other equipment. Although this compliance is only necessary in EC countries, similar regulations exist in the US, and other areas. So how does this affect cabling systems? The answer to this is somewhat more complex and is attempted in the text that follows.

The regulations typically apply to active equipment, while a cabling system is passive. However, when an application runs over the system it becomes active and regulations apply. So once the system is commissioned it will need to be compliant with local EMC regulations regarding electro-magnetic emissions and immunity from externally generated interference, in short EMC regulations. This raises some questions, the answers to which are still in the process of being defined.

- How do you test a newly installed system to guarantee future compliance with compatibility regulations?
- Whose responsibility is it to ensure compliance?
- What happens in the event of non-compliance?

This situation has led to some misunderstanding and misinformation regarding the suitability of different cable types for building cabling purposes. This has been most notable in the debate about whether or not structured cabling systems need to be installed using screened cables and components. On one side of the debate, the proponents of screened systems will insist that only screened systems will be able to meet the EMC regulations, while vendors of unshielded systems, will insist exactly the opposite. Based on the latest independent research, it is clear that UTP systems are perfectly capable of meeting the requirements of the regulations provided that they are designed and installed according to the proper practices.

What is also clear is that the use of screened systems does not automatically guarantee compliance with the regulations, and indeed if not properly installed a screened system may actually make the EMC situation worse.

One method being developed to allow installers to pre-test a new system in an attempt to ensure future compliance is to test for *balance*. Perfectly balanced cables will have very low emissions and high immunity to electro-magnetic interference EMI. The quest on how to test for balance has led to the development of a test known as Longitudinal to Differential Conversion Loss, or LDCL for short. LDCL is essentially a measure of how much of the power from an interfering signal (the "transverse" element) converts into a signal which affects the signal carried by the cable (the "longitudinal" element). The higher the conversion loss, the more immune the cabling is to external sources of interference (and by implication, the less likely the cable is to radiate interference to other nearby cables and/or equipment).

In addition to new complex testing, installation practices can have a tremendous effect on future EMC compliance. These practices can (and do) affect the performance of cables in respect of interference. The elements most in the control of the installer are:

- Maximum untwisted length of pairs at the termination point (13mm for Category 5 and 25mm for Category 3/4).
- Minimum bend radius (8x cable diameter during cable laying and 4x cable diameter installed in backbox)

One area where application developers can assist in ensuring compliance is with the signalling rate used by their applications. As with NEXT, the emissions from a system, and its susceptibility to EMI, is affected more as the signalling rate rises on the cable. Many developers are designing applications today that utilize complex encoding mechanisms designed to keep the signalling rate down, but the data transfer rate up. FDDI is an early example of this where although the data transfer rate is 100Mbps, the signalling rate on the cable is kept to a maximum of 31.25MHz via the use of MLT-3 encoding. Other applications are following suit to allow faster applications (such as Gigabit technology) to utilize the installed base of structured cabling systems.

Although screened cables are not mandatory for compliance to EMC regulations, nor are they likely to be in the near future, there are some important guidelines worth considering should you decide upon a screened solution. To be fully effective the screening/shielding must be continuous end-to-end within a cabling link and must fully enclose all relevant components. These include connectors, patch panels and cable, and must provide 360° coverage around the component. This continuity is based on end-to-almost-end as equipment to equipment screening should be avoided so as not to introduce earth loops. In practice, most installations maintain continuity throughout the link and stop short at the final connector that attaches to the end user equipment. In addition to the above considerations, it should also be borne in mind that local power and grounding regulations will also apply, in that the screening of the data cabling may be providing a grounding path between areas of a building (or between different buildings), where different ground potentials exist. In such cases, even small potential differences i.e. 1 Volt, may be enough to create a path that carries several Amps of ground loop current. This is well beyond the capability of the very small cross-sectional area of the screening foil and drain wire and will inevitably lead to problems.

39.10 Design Guidelines

Implementing a structured cabling system requires careful planning plus the following of some standards based design guidelines. This section attempts to cover as many of the issues as possible, with options wherever appropriate.

39.10.1 The Design Process

The basis of a sensible approach to the design of a structured cabling system is to start from the edge and work back to the center. This means the place to start is the work area. Things that must be considered along the way include:

- Work Areas - sizing, TO density, fly leads, adapters, etc.
- Horizontal Cabling - media type, transition points, resilience, etc.
- Floor Distributor - location, layout, resilience, security, etc.
- Backbone Cabling - media types, routes, capacity, resilience, etc.
- Building and Campus Distributors - location, layout, security, etc.
- Cabling Pathways - types, routes, etc.
- Power and Earth Bonding
- System Administration

In addition to the basic cabling system, consideration must be given to matters such as power at the distributors, cabling pathways from the distributors and for distribution cabling, the demarcation between the SCS and other cabling systems and, of course, system administration. To maximize the potential of the cabling system, system administration is paramount and begins at the planning stage. There is no point in adding it as an after thought, it never works as well. The system needs to be designed with the ongoing administration in mind. This includes factors such as outlet identification, numbering/naming schemes, color coding, to name but a few.

39.10.2 The Work Area

The work area, horizontal distribution, and floor distributor location may seem like a straight forward element to design, flood wiring each floor to every location, but there are in fact many elements that can be considered in a good design. For example, in theory, a single floor distributor is capable of supporting up to 25,000 square meters of floor space on a single floor, and even more if it is used to support multiple floors. This however, would inevitably lead to an unmanageable system as the floor distributor would be too large and complex. In addition, it is unlikely that all patch leads would be maintained at the limit of 5m. For these reasons the standards suggest a limit of 1000 square meters of floor space as the maximum area to be supported from a single floor distributor. The main advantage of

implementing this in the standards, is that it virtually guarantees distributors are kept relatively simple, an important point when one considers the idea behind structured cabling is that it is supposed to be straight forward, and make MAC (Moves, Additions, and Changes) work easy.

One of the first things to consider in the design of the cabling system is the size of the work area. The standards suggest work area sizing of between $2m^2$ and $10m^2$, but in truth, the size of the work area is going to depend on the use the area is put to, and the likely user density in the future. An example may be a ground floor reception area, where a work area sizing of even $10m^2$ is likely to be too small. On the other hand, a dealer trading floor may require a work area sizing of $2m^2$ or less. This is then a very site specific decision, taken once the use of the areas and the density of the users is well understood.

The number of Telecommunication Outlets (TO) per work area is also something that needs consideration at this early stage. The standards provide some guidelines, but once again flexibility is allowed for the designer. Only a minimum requirement is stated, that of at least 2 TOs per work area, with at least one being fed by balanced pair copper. The second and/or subsequent TOs can be either balanced pair copper or fiber. This is to accommodate the typical user requirement of one data and one voice outlet at the desk. However, there are many occasions where more might be considered. The dealer trading floor is again a good example, this time of where many more than 2 TOs per work area would be required.

Ideally the work areas should be designed to form logical "zones", which can then be arranged to take advantage of one or more of the possible methods of resilience that may be employed. A number of attempts of planning and some calculation may be required to get the right balance of zoning, while always ensuring wherever possible to minimize the floor distributor complexity and administration. Some careful and detailed work at the planning stage will be of great benefit once the system is installed. Some buildings, mainly due to their size, may require multiple floor distributors to service all locations on a floor. This is typically because of the 90m distribution limit, or the overall floor area exceeds 1000 square meters. This can however, prove to be beneficial as it can be utilized to add resilience to the overall design.

The basic design for horizontal distribution cabling provides for no resilience, but there are several options available. Some consideration, however, is required as to the additional expense, and the effectiveness of the resilient solutions. For example, additional TOs could be provided at the work area, but how much benefit is achieved. Should a TO fail, due to breakage or some other factor, who is affected, just a single user and does this justify the expense of the 50-100% increase in materials and labor? On the other hand, who is affected should an entire floor distributor fail? This could be again due to damage, or fire, etc., and would affect the entire floor. In this instance, multiple floor distributors would seem like a good idea, but only if fed by multiple backbones. Figure 39-18 shows some of the options available.

Overlaying, or interleaving, the cabling such that multiple pathways are used can provide a high degree of resilience in the event of a single pathway being damaged.

It does however come at a price, in that installation and material cost are likely to be much higher. The third example, which uses multiple floor distributors and interleaving the cabling is the most resilient design, but extreme care must be taken to ensure ongoing administration is not made too complex in the quest to achieve resilience.

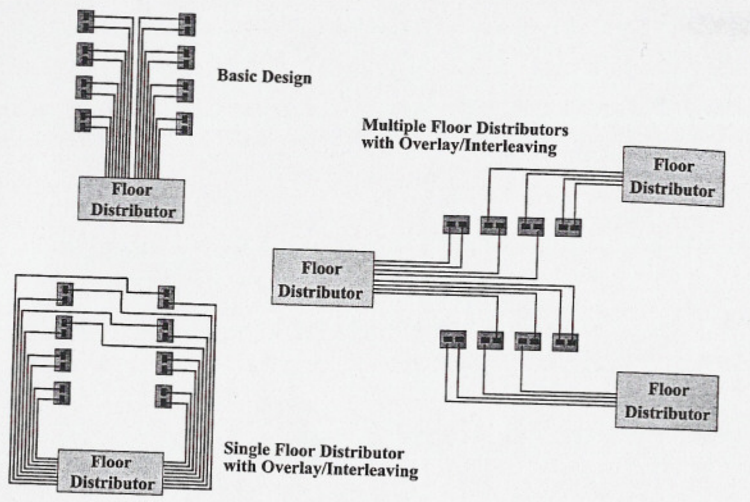

Figure 39-18: Horizontal Cabling Resilience Options

39.10.3 Distributor Layout

The floor distributor requires careful planning as it is perhaps the most important area within the cabling system, it is certainly the place most accessed for moves and changes.

A typical floor distributor contains:

- termination of all horizontal distribution cabling on to patch panels
- termination of building backbone cabling, also on to patch panels
- transmission equipment for inter-connect or cross-connect patching

There are many things to consider when planning the floor distributor including, type of patch panel to be employed, floor distributor housing (cabinet, rack, wall mounting, etc.), sizing, location, and security, to name just some. One of the most important tasks is to determine the size of the floor distributor and its layout. For sizing, care must be taken to include the presentation area for cable termination panels, additional space for patch cable management, space for transmission equipment and power distribution. If cabinets are to be used, the calculations are normally made in a unit known as a "U". Cabinets, patch panels, cable

management and power distribution panels are nearly always quoted as a number of U, where 1U is equal to 1¾ inches or 43mm. Do not underestimate the amount of space required for cable management. Inadequate provision at this stage can lead to a "rats nest" of patch cables later. As a rough guide, 1U of cable management should be included for every 1-2U of patching.

Where multiple cabinets are required for a floor distributor, there are two options as to the layout of each cabinet. The first is based on a functional approach whereby different elements of the system are allocated to different cabinets, i.e., all horizontal distribution cabling in one and all transmission equipment in the other. An alternative to this is a more modular approach whereby each cabinet contains a proportion of all elements, some horizontal distribution cabling, some transmission equipment, etc. The advantage of the second approach is that should a cabinet be lost, i.e., due to a power failure, then a proportion of users would be totally unaffected and able to continue without disruption.

39.10.4 The Backbone

Designing the backbone cabling is not without its difficulties either. For example, which media do you choose? And how much of it do you install? There is no doubt that for higher speed applications, fiber offers the best performance characteristics and distance. However, distributing voice services over fiber in the backbone can be a costly business. So, is two backbones a solution? The answer is possibly.

There are three main considerations when designing a backbone to the cabling system, media type(s), capacity, and resilience. Each of these are discussed below.

Two main options exist for possible media types within the backbone. There is twisted pair or fiber. For LAN applications, fiber is the preferred choice due to its extended distance support at high data rates. However, if the maximum backbone distance is within 100m, or the maximum data rate low/medium, then copper twisted pair remains a viable option. Whichever is chosen, care must be taken to ensure that any active transmission equipment has the necessary interfaces to match the cabling selected. For voice service distribution in the backbone, copper still remains the media of choice, although some manufacturers provide distributed PBXs that can be interlinked via fiber. With this in mind it is still very common to find two distinct backbones installed, a fiber version for data applications, and a low specification twisted pair backbone for voice. This allows low cost twisted pair, typically in high density bundles, to be implemented as a voice backbone, direct from the main distribution frame (MDF) direct to each floor distributor.

$$R = \sum_{1}^{A} f_i n_i / g_i$$

Figure 39-19: Backbone Capacity Formula

Capacity planning for the backbone can be extremely hazardous, especially on a green field site where little is known about the applications to be used. Even in an occupied building, estimating the backbone capacity requirements can be very difficult. Experience is one solution, which can often provide an answer that is more or less accurate. For others, a more scientific approach is required. The formula shown in figure 39-19, and explained below is one answer to this problem.

In the formula, the following key applies:

- **R** is the resultant multiplier to be used to find the backbone capacity.
- **f** is the ratio of lines for a single application to the total number of lines.
- A line is equal to a unit of cabling, i.e., a four pair UTP[3] or a pair of optical fibers.
- **n** is a constant, either 1 if the application shares a common backbone, or 0 if it uses a dedicated backbone.
- **g** is equal to the grouping factor, i.e., the number of users sharing a piece of transmission equipment, such as 24 if a 24 port repeater is being used.
- **A** is the number of applications using the horizontal cabling system.

Although the formula appears quite complex, it is in fact very simple. To calculate R, simply repeat the calculation fn/g for each application, and then sum the results. The following example shows how the formula can be used.

In this example there are 1000 users on a floor of a building, each requiring a telephone and LAN connectivity. For the purposes of this example, all voice services are provided by a dedicated backbone. In addition, of the 1000, 800 are connected via Ethernet using 24 port repeaters, and 200 by Token Ring using 24 port MSAUs. From this we can determine that A is equal to 3 as there are 3 applications, voice, Ethernet, and Token Ring. In addition, the total number of lines is 2000, and the grouping factor for both Ethernet and Token Ring is 24.

With this in mind, the calculation fn/g can be made for each application in turn:

Voice	f = 1000/2000 = 0.5	n=0	g=1
	fn/g=0.5 × 0/1 = **0**		
Ethernet	f = 800/2000 = 0.4	n=1	g=24
	fn/g=0.4 × 1/24 = **0.0167**		
Token Ring	f = 200/2000 = 0.1	n=1	g=24
	fn/g=0.1 × 1/24 = **0.0042**		

R is therefore equal to 0 + 0.0167 + 0.0042 = 0.0209

[3] With Token Ring employing full Ring In/Ring Out connectivity, 2 lines will be needed per rack of equipment. This can be accommodated by halving the grouping factor.

The final part of the calculation is to take the resultant (R) and multiply it by the total number of lines required (2000).

$$2000 \times 0.0209 = 41.8$$

Therefore 42 lines must be provided in the backbone to support all applications that will share a common backbone. This equates to 42 times 4 pair UTP, or 84 fibers (remember, it takes two fibers to form a link). In addition to the 42 lines required, an additional 10-20% should be added for expansion and a further 10-20% for resilience. To complete the above example, assuming 2 pair voice circuits, 2000 pairs of voice grade UTP would also be required, which could be implemented using 10 × 200 pair cables.

The last element for backbone design is resilience. This is extremely important as the loss of a backbone could be enough to put a whole floor, or even a whole building out of action. The simplest and most effective method is to implement multiple backbones, preferably via multiple risers. Where this is utilized, obviously the capacity should be split across all backbones, and it could be implemented with multiple floor distributors to enhance the resilience of the system. Where multiple risers/backbones are employed, it may be worth considering additional capacity in each backbone, such that should one backbone ever be unavailable, the remaining backbones have the additional capacity to provide its services.

One last note about backbone design. Care should always be taken when designing a system backbone, that the desired applications will support the distances involved. Many applications have specific distance limitations for each media type, which do not always match the cabling standards distance limits for backbone cabling.

39.11 Testing and Certification

The main issues surrounding testing is to ensure that the "designed" performance criteria are being met, and verifying that performance margins are satisfied such that current applications will operate correctly, and that there is sufficient performance "headroom" for future applications. The current design standards ANSI/EIA/TIA 568A and ISO/IEC 11801 do not provide detailed information on the testing and certification of installed cabling systems. For some years this left a void whereby it was impossible to "certify" a system, because there was no standard to "certify" it against. This situation is now, in part, no longer so much of a problem due to a publication from the EIA/TIA known as TSB 67 which is entitled "Transmission Performance Specifications for Field Testing of Unshielded Twisted-Pair Cabling Systems". This document has become the de facto standard for testing installed cabling systems since its release in October 1995 and specifies performance criteria for categories 3, 4, and 5 UTP cabling systems.

39.11.1 TSB 67

This document is specifically designed to address the needs for testing installed structured cabling systems and provide a benchmark against which performance can be "signed off". The testing specified is designed to operate using simple to use, and relatively inexpensive, hand-held test equipment, the calibration of which is also included within the document. In addition to performance criteria the document also specifies two different cable configurations for test purposes. These are defined as a Link and a Channel, and both are explained below:

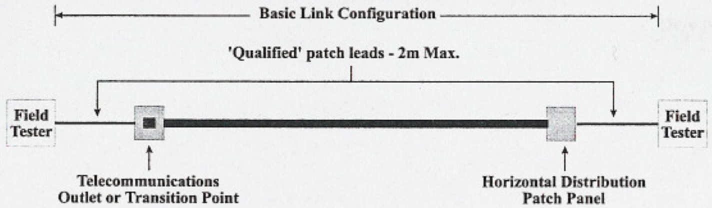

Figure 39-20: Basic Link Configuration

The Link configuration is defined as the cable from the Telecommunications outlet, or Transition Point (if it exists), back to the patch panel at the floor distributor, with the addition of a 2m test lead at either end. This results in the maximum length of a link configuration being 94m. The main idea behind the link configuration is to test the permanently installed cabling, as patch leads and equipment cables can easily be changed, while permanent cabling cannot.

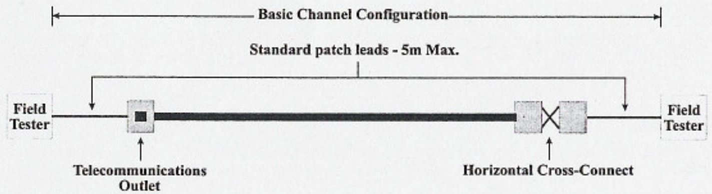

Figure 39-21: Basic Channel Configuration

The Channel configuration, on the other hand, represents the overall data path from application equipment in the floor distributor, to end-user equipment in the work area, and therefore a maximum distance of 100m. Included in the channel configuration are patch leads and equipment cables, in an attempt to correlate channel test results with application standards performance requirements.

For performance criteria such as attenuation and NEXT, TSB 67 specifies different pass and fail criteria for both channel and link configurations. It is therefore important that the correct configuration is selected on the test equipment to match the cable configuration under test. Failure to do so could lead to inaccurate test results that pass a system that if tested correctly would fail.

TSB 67 is fairly limited in its scope, and only specifies four parameters for testing purposes. The parameters included are a rudimentary Wire Map test,

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Length testing, Attenuation, and NEXT testing. Additional parameters, required to ensure support of applications such as 1000BaseT, like Return Loss, Far-End CrossTalk (FEXT), Delay, and Delay Skew are all expected to be included in TSB 95 when it is published towards the end of 1999. The text that follows discusses each of the included parameters and the pass/fail criteria specified in the document.

Wire Map

The primary aim of the wire map test is the verification of correct termination and wire placement within the connectors at either end. For each of the conductors, the wire map test should display the following:

- Continuity
- Short Circuits between two or more conductors
- Crossed pairs
- Reversed pairs
- Split pairs
- Any other mis-wiring

Figure 39-22 shows how some of these faults may be displayed on the test equipment screen.

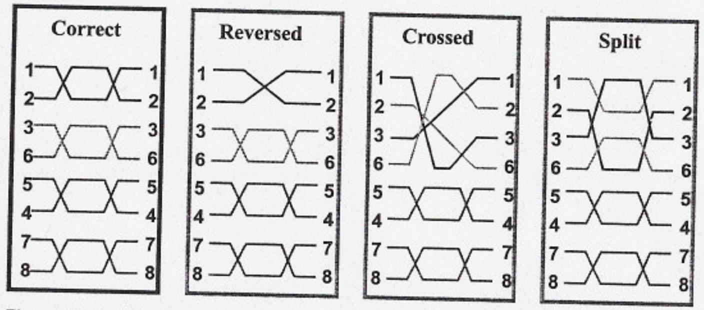

Figure 39-22: Wire Map Test

Length Testing

Length testing is conducted to ensure the installed cabling does not exceed standards based design guidelines. For a Link to pass a length test, it must not exceed 94m in length between test equipment. Likewise, for a Channel configuration to pass then the limit is 100m.

To guarantee accurate length measurements, the test equipment must be aware of the Nominal Velocity of Propagation (NVP) for the specific cable type being tested. The NVP is the speed at which an electrical signal can propagate down the cable, and varies from one cable type to another. This means that a category 5 UTP cable from one vendor, may well have a different NVP than that from another. A cable tester uses a simple equation based on speed and time to establish the distance

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travelled, and therefore the length of the cable. It stands to reason then that for this measurement to be accurate, the tester must know the speed (or NVP) in advance. Most popular cable test equipment will be pre-programmed with the NVP of many common cable types. However, if your cable type is not included, then you must program the NVP yourself. This can be done via a simple test on a pre-determined length of cable (at least 50m for accuracy). Set the test equipment to "Get NVP" mode and the test equipment will ask for the test cable length. It will then measure the time taken for a signal to travel the complete length of the cable. By using the formula of Speed = Distance/Time the NVP can be determined.

Attenuation

TSB 67 specifies attenuation as the loss of power of the signal envelope within a link or channel. Because of the difference between a link and a channel, two different sets of pass/fail criteria have been defined, one for each. The figures quoted in tables 39-11 and 39-12, show the maximum allowable attenuation rates for link and channel configurations respectively. Although the figures quoted are shown for a range of "spot" frequencies, the test equipment should be capable of testing the entire sweep of frequencies from 0-100MHz.

Table 39-11: Maximum Attenuation Figures for a Link Configuration

Frequency (MHz)	*Category 3 (dB)*	*Category 4 (dB)*	*Category 5 (dB)*
1.0	3.2	2.2	2.1
4.0	6.1	4.3	4.0
8.0	8.8	6.0	5.7
10.0	10.0	6.8	6.3
16.0	13.2	8.8	8.2
20.0	n/a	9.9	9.2
25.0	n/a	n/a	10.3
31.25	n/a	n/a	11.5
62.5	n/a	n/a	16.7
100.0	n/a	n/a	21.6

Table 39-12: Maximum Attenuation Figures for a Channel Configuration

Frequency (MHz)	*Category 3 (dB)*	*Category 4 (dB)*	*Category 5 (dB)*
1.0	4.2	2.6	2.5
4.0	7.3	4.8	4.5
8.0	10.2	6.7	6.3
10.0	11.5	7.5	7.0
16.0	14.9	9.9	9.2
20.0	n/a	11.0	10.3
25.0	n/a	n/a	11.4
31.25	n/a	n/a	12.8
62.5	n/a	n/a	18.5
100.0	n/a	n/a	24.0

All the figures quoted in tables 39-11 and 39-12 are based on measurement at 20° Celsius. It should be noted that attenuation rises with temperature on twisted pair cabling and therefore, a factor of 1.5% per degree Celsius for Category 3 cable, and

0.4% per degree for Category 5 cable, can be used to estimate results at temperatures other than 20° Celsius. When comparing the published figures for link and channel attenuation, it is noticeable that on the whole the maximum attenuation rates for a link configuration are approximately 10% lower than those for channel configuration. The reason for this is not only the extended distance of a channel configuration, 100m compared with 94m, but the use of up to 10m of stranded patch cords which have higher attenuation rates than solid core cables.

Near End CrossTalk (NEXT)

As we have seen, NEXT is a measure of how much signal power is coupled to adjacent pairs, thereby leading to distortion of a signal on those pairs. As with attenuation, NEXT increases with frequency, and therefore needs to be tested across a range of different frequencies. The test is performed with a handheld cable tester, which applies a balanced signal to a single pair and measures the coupling effect on the other three pairs.

Table 39-13: Minimum NEXT Figures for a Link Configuration

Frequency (MHz)	*Category 3 (dB)*	*Category 4 (dB)*	*Category 5 (dB)*
1.0	40.1	54.7	60.0
4.0	30.7	45.1	51.8
8.0	25.9	40.2	47.1
10.0	24.3	38.6	45.5
16.0	21.0	35.3	42.3
20.0	n/a	33.7	40.7
25.0	n/a	n/a	39.1
31.25	n/a	n/a	37.6
62.5	n/a	n/a	32.7
100.0	n/a	n/a	29.3

This test is repeated for all pair combinations at a complete sweep of frequencies ranging from 0.15MHz up to the set limit for the cable category (100MHz for Category 5). Tests are performed at 0.15MHz intervals from 0-31.25MHz, and 0.25MHz intervals thereafter. In all tests, the worst case pair must pass the minimum requirements laid out in the document, and summarized in tables 39-13 and 39-14.

Table 39-14: Minimum NEXT Figures for a Channel Configuration

Frequency (MHz)	*Category 3 (dB)*	*Category 4 (dB)*	*Category 5 (dB)*
1.0	39.1	53.3	60.0
4.0	29.3	43.3	50.6
8.0	24.3	38.2	45.6
10.0	22.7	36.6	44.0
16.0	19.3	33.1	40.6
20.0	n/a	31.4	39.0
25.0	n/a	n/a	37.4
31.25	n/a	n/a	35.7
62.5	n/a	n/a	30.6
100.0	n/a	n/a	27.1

It is worth noting that as NEXT is a measure of the ratio between the power of the original transmission signal and the power of the coupled signal on an adjacent pair, the higher the ratio, the less the effect of crosstalk. For this reason, high values for NEXT (expressed in dB) represent better results than a lower value. It also explains why the values in the tables decrease as the frequency increases. This is in direct contrast to attenuation, where lower values were preferable.

For all tests, the test equipment should indicate a Pass or Fail, based on the allowable limits for the cable under test. Should the result be closer to the test limit than the accuracy of the test equipment, then the result should be marked Pass* or Fail*, with the asterisk indicating this to be extremely close to the limit.

Another point of note is that testing should be carried out at both ends of the cable link. The primary reason for this is the NEXT test that only measures the Near End, and thus has to be repeated at the other end. Many modern cable testers have the ability to test both ends simultaneously, primarily because they incorporate a slave tester at one end while the master controls things from the other. This obviously simplifies the testing process, as each cable run only requires a single visit.

There are occasions when short links (less than 15m) may consistently fail NEXT tests for no apparent reason. This is because it is possible for short links to demonstrate additional NEXT due to resonance effects linked to Return Loss and/or Balance of the link. This phenomenon is still under investigation and if encountered the following guidelines should be followed.

- Ensure that the correct components and installation practices have been used.
- Ensure that only "qualified" test leads are used for testing (Link configurations).
- Verify that the NEXT failures are only present in short links less than 15m.
- Verify that the failures are from both directions.

If all these criteria are met, then there is little that can be done apart from running a longer cable. If any of the above criteria is not met, then it is likely that there is another cause to the NEXT failure.

39.11.2 TSB 95

TSB 95, entitled "Additional Transmission Performance Guidelines for 100 Ohm 4-Pair Category 5 Cabling", is designed to address additional test parameters, not included in TSB 67, but now deemed to be important. This is mainly due to new transmission methods employed by high speed technologies such as 1000BaseT. In addition to the parameters already defined within TSB 67, TSB 95 will detail performance specifications for parameters such as Return Loss, ELFEXT, Delay, and Delay Skew. Each of these is explained below:

Return Loss
Return Loss is basically a measure of the ratio between the signal power of a transmitted signal in relation to the power that is reflected. A simple way to think

of this is to compare it to an echo created by impedance variations along the length of a link. At each variation in impedance, some signal power is reflected towards the source; it is the ratio of this compared to the original power that is measured. As with many other parameters, it varies with frequency and must therefore be tested across a sweep of frequencies.

ELFEXT
Far End CrossTalk (FEXT) is similar to NEXT except that the signal is generated at the near end and the crosstalk is measured at the far end. ELFEXT (Equal Level FEXT) is a calculated, rather than measured parameter, which is designed to normalize the results with respect to length. It is calculated by subtracting the attenuation of the disturbing pair from the FEXT this pair has induced in an adjacent pair. The example below demonstrates the calculation and also shows how this normalizes the results with respect to length.

Two links are considered, both made from the same materials and with the same level of workmanship. One link is 60m in length, the other is 90m.

	Attenuation	FEXT	ELFEXT
Link 1	-11dB	-45dB	-45 - (-11) = -34dB
Link 2	-20dB	-54dB	-54 - (-20) = -34dB

Propagation Delay
Propagation Delay is a measure of the time it takes for a signal to propagate from one end of a link to the other. For Category 5 UTP, a typical delay is approximately 5ns per meter. A maximum delay of 570ns is allowable for horizontal cabling in most of the structured cabling standards. This parameter is important because it is the principle reason for length limitation in LAN cabling. Technologies such as Ethernet impose strict delay limitations when implemented over twisted pair cabling.

Propagation Delay Skew
Propagation Delay Skew (or Skew) is a measure of the difference in the propagation delay of the fastest and the slowest pairs in a UTP cable. Although the NVP for all pairs is the same, each pair is a different overall length due to the different twist rates. This means that the signal will have further to travel on the tightest twisted pair compared to the slackest pair. When travelling at the same speed, the signal will reach the far end on the shortest pair first.

Skew is important because some technologies (such as Gigabit Ethernet) make use of all four pairs in the cable. If the skew is significant then signals sent at the same time from one end, may arrive at significantly different times at the far end. If this delay is significant enough, the receiver will be unable to compensate for it and transmission problems may occur.

Current expectations are that although existing category 5 cable systems will need to be re-tested to provide compliance with TSB 95, most are not expected to fail. TSB 95 is currently under ballot and is expected to be released shortly.

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39.12 Future Trends

So what does the future hold for structured cabling systems; a new version of EIA/TIA 568, a 2nd edition of ISO/IEC 11801, category 6 and 7 UTP, ... Many things are in the pipeline, those mentioned are just the short term future, as all are expected by early in the year 2000. Work is well under way on a new release of EIA/TIA 568 which will be known as EIA/TIA 568-B "Commercial Building Telecommunications Wiring Standard". This is a major new release of the standard and will incorporate, or replace, EIA/TIA 568-A, EIA/TIA 568-A addendums 1, 2, 3, 4, and 5, TSB 67, and TSB 95. The main additions will be the inclusion of Category 5E performance levels, 50/125 µm fiber, and the allowance of an alternate fiber connector other than the SC.

A 2nd edition of ISO/IEC 11801 is expected in early 2000 and will include specifications for Category 6 and Category 7 cabling as well as Class E and F applications. This will represent a major step forward in the transmission capabilities of twisted pair cabling. Category 6/Class E will support applications with signalling rates up to 250MHz, while Category 7/Class F will support up to 600MHz. It is likely that Category 6 implementations will be available in either UTP or FTP, while Category 7 systems will probably be based on STP cabling. In the last month or so, the ISO/IEC committee has finally agreed on the connector to be used for Category 7 systems. Two have been chosen, an RJ like solution and a non-RJ like solution. With these in place, there is no reason to assume this standard will be delayed for too long.

So what is next? A good question, that one could guess at and still be way off mark. Will developers push twisted pair cabling beyond the GHz barrier, or will the world finally adopt widespread fiber to the desktop. One thing is for sure, the advances in cabling technology will only increase, as they have to, to stay one step ahead of the application developers.

39.13 Summary

In this chapter we have discussed many aspects of structured cabling from its basic topology, to testing the installed system. With SCS being based on a flood wired approach, using low cost twisted pair cables, the intention is to be able to satisfy any application/user requirements with a single system rather than the complexity of multiple proprietary cabling solutions. SCS has essentially one aim, that is to make MAC work easy for the network manager. This reduces the overall cost of ownership, and facilitates an easier life.

Much of the chapter concentrated on the structured cabling standards for both design and installation testing. These standards are important if the generic nature of SCS is to be maintained, and any proprietary aspect repelled. The design standards concentrate on the layout of the system, including the topology and the various subsystems within it. On the other hand, the installations testing requirements are all based on performance. These days the design is accepted, and only performance seems to be an issue. Tomorrow's standards will concentrate on increasing this while the design is unlikely to change for many years to come.

Appendices