# Fibre Channel Fundamentals

by Tom Weimer

## Abstract

**Channel.** Connection between computer and peripheral.
**Network.** Interconnection among computers.


Fibre Channel, a new interconnect technology for high-performance computer peripherals and networks, has a number of advantages over similar technologies. Fibre Channel enables **channel** data transfer speeds about 2½ times faster than high-end SCSI (Small Computer System Interface) and carries **network** and channel traffic over the same lines with equal efficiency. It can also carry audio and video data, supports a range of transmission media and distances, is very reliable, scalable, and easy to integrate into existing systems.

Implementing Fibre Channel requires components already familiar to IT professionals: host cards, cables, and driver software, with optional switches, hubs, and bridges, combined in network-like topologies. Its dual network/channel capability makes Fibre Channel ideally suited to the new concept of the Storage Area Network (SAN), an expandable, high-speed network of storage devices, separate from but accessible by a traditional computer network such as a LAN.

Fibre Channel completely separates the *delivery* of data from the *content*. It is concerned only with delivery, and is blind to content. It is therefore very flexible in the types of data it transports. Fibre Channel is designed to carry many upper-level data protocols, the most significant being SCSI and IP, which are "mapped" onto Fibre Channel's physical delivery service.

This report describes Fibre Channel technology, key features, and applications, and compares the scope and performance of Fibre Channel and SCSI.


### Contents



## Fibre Channel—A Data Transport Standard

Fibre Channel is a set of standards that define a high performance data transport connection technology which transports many kinds of data at speeds up to 1 Gigabit per second (100 Megabytes per second), through copper wire or fiber optic cables, across distances up to 10 km. It is similar to the Ethernet networking protocol or the portions of the SCSI protocol that dictate the physical characteristics of connections and data transmission. Fibre Channel distinguishes itself from these and other protocols by its ability to handle high speeds, varieties of data types and cable media, and long distances.

The name "Fibre Channel" can be misleading, because the technology is not limited to fiber optics or peripheral device ("channel") applications. Not only does it support low-cost copper wire, but Fibre Channel carries channel, network, or video data traffic with nearly equal efficiency.

It works by defining only a method for transmitting data from one node to another, regardless of the type of data transmitted. The nodes can be two computers exchanging network data, a computer sending file data to a peripheral device such as a disk array or a printer, or two peripherals such as a disk array and a tape library performing backup operations.

Separate "mappings" define how to format many upper-level protocols (ULPs) for Fibre Channel delivery. The most important standardized mappings are for

SCSI and IP, but there are many others, and proprietary mappings can be developed allowing Fibre Channel to carry any kind of data traffic.

Using the Fibre Channel standards as guidelines, many companies have developed or are developing products that provide Fibre Channel connectivity and devices that communicate over Fibre Channel. Products such as host adapter cards, cables, switches, hubs, and **bridges** provide physical connections. Fibre Channel Disk drives, RAID (Redundant Array of Independent Disks) systems, and tape libraries are some devices currently available.

**Bridge.** Hardware that converts signals between Fibre Channel and other connection protocols like SCSI and Ethernet.

## Key Features of Fibre Channel

Fibre Channel defines a data transport service that is:

- Fast—most current implementations operate at 1 gigabit per second (Gbps), or 100 megabytes per second (MBps). Planned speeds of 2 Gbps and 4 Gbps (200 and 400 MBps) are already approved and in development.
- Long-distance—up to 10 km between fiber optic connections makes remote mirroring or backup possible, and less expensive copper wire cables for near-vicinity connections can still span up to 30 meters.
- Scalable—users can start with a basic setup and expand in many ways as a system's requirements evolve
- Reliable—superior data encoding and error checking, and the improved reliability of serial communications
- Dependable—redundancies ensure that storage or network access is always available
- Flexible in many ways—
  - Carries any kind of data traffic. Mapping protocols have already been defined which enable sending SCSI, IP, ATM, HIPPI, and other higher-level protocols
  - Supports a variety of system **topologies**: simple point-to-point between two devices, economical arbitrated loop to connect up to 126 devices, or powerful switched fabric providing simultaneous full-speed connections for thousands or millions of devices.
  - Can be carried over various fiber optic or copper cables, and different cable types can be mixed in a single topology
  - Compatibility with older technologies like SCSI and Ethernet, using hardware **bridges** (also called "routers")
- Standardized—unlike proprietary solutions, Fibre Channel is emerging as an industry-wide standard, so many different vendors can develop products which all work together

**Topology.** The physical layout of device connections.

**Bridge.** A device that converts Fibre Channel signals for use with another protocol.

## Why We Need Fibre Channel

Fibre Channel was developed in response to increasing need for high-speed, high-volume data transfers in storage and network services. As a result of constant improvements in computer processor and peripheral device speeds, network and channel interconnects such as Ethernet and SCSI have become the limiting factors in system performance.

Developers began to realize, as long as ten years ago, that a new interconnect protocol would be needed to handle increasing system traffic. The American National Standards Institute (ANSI) formed a group of committees whose objective was to design a high-performance I/O protocol that:

- Transfers large amounts of data at very high speeds
- Is independent of the data transmitted, so it carries both network and channel types of traffic, and
- Supports a variety of physical carrying media, such as fiber optics and copper wire

To accomplish all this, the standards group needed an interconnect technology that was:

- Serial—to overcome the speed, distance, and reliability limitations inherent in parallel protocols like SCSI
- Asynchronous—to handle both network and channel traffic in the same protocol

## How Fibre Channel Works

Fibre Channel standards specify the physical characteristics of the cables, connectors, and signals that link devices. They also describe three general topologies for connecting devices. Finally, since Fibre Channel only provides a data transport mechanism, they define how to map upper-level protocols such as SCSI and IP to the Fibre Channel data format.

### Physical Components—Cables, Ports, and Links

Fibre Channel carries data over many types of electrical and optical cable. In many cases, this permits converting cables already installed for other interconnects into Fibre Channel cables.

**Link.** A connection between two devices, regardless of the connecting medium.
**Port.** The Fibre Channel interface on a device, with separate “transmit” and “receive” connections.

A connection between two devices is called a **link**. Cables connect to **ports** on the devices to form a link. Each port has two connections, one dedicated to transmitting data, the other to receiving. In a simple link between two devices, A and B, one cable connects the transmit side of the port on device A with the receive side of the port on device B, and another cable connects device B’s transmit side with device A’s receive, as shown in the following diagram.

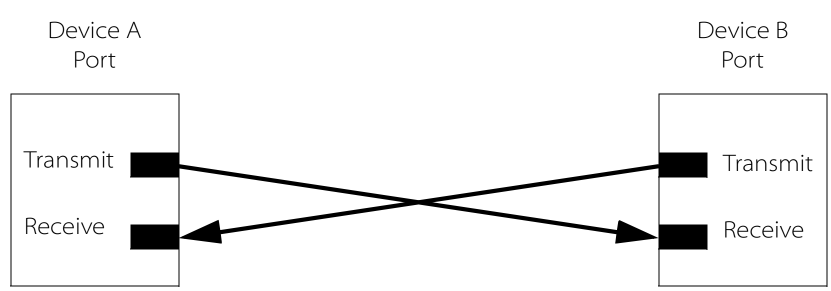



Illustration of a connection between two Fibre Channel nodes
(point-to-point topology shown)

Several kinds of acceptable copper wire and multi-mode or single-mode fiber optic cables have been approved for Fibre Channel. Ports are specific to one kind of cable or signal, but adapters exist to convert from one signal type to another. The table below summarizes the most common link types capable of running at the current top speed of 100 MBps.

**Fibre Channel Media Options**

| Signal type | Cable type | Distance |
|---|---|---|
| Electrical | Twin-ax copper cable | 0-30 m |
| Optical | Multimode fiber, short-wave laser | 2-500 m |
| Optical | Single mode fiber, long-wave laser | 2 m-2 km* |

* Another single-mode fiber, longwave laser configuration can transmit up to 10 km, but is not yet in common use.

Fibre Channel is a serial data transfer protocol, meaning it transfers data one bit at a time. As a result, each direction of a link only requires one optical fiber or one pair of copper wires, so Fibre Channel cables are very small and simple. They also use simple, common connectors: twin-ax electrical links use standard DB-9 or HSSD serial connectors, and fiber optic links use standard SC connectors or new, smaller Galaxy connectors.

## Topologies

Fibre Channel provides three topology options for connecting devices: point-to-point, arbitrated loop, and fabric (sometimes called "switched" or "switched fabric").

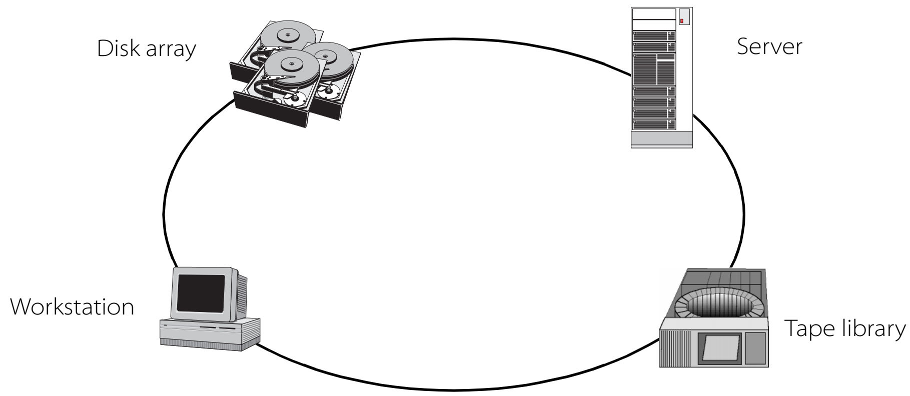
**Point-to-point.** The most basic Fibre Channel topology, consisting of two devices with a direct, dedicated connection.

The simplest topology is a **point-to-point** connection. It consists of just two devices, most likely a host computer and a storage device or other peripheral. One device's "transmit" connection is directly linked by a Fibre to the other device's "receive" connection, and vice versa, as shown below. This arrangement provides a dedicated high-speed connection between two devices.


Point-to-point topology

**Arbitrated Loop.** A topology in which devices are linked sequentially in a closed loop.

**Arbitrated Loop** topology rivals point-to-point in simplicity, but permits greater connectivity among devices. Devices are connected in a closed loop, each device's transmit port linked directly to the next device's receive port. This is illustrated in the diagram below.



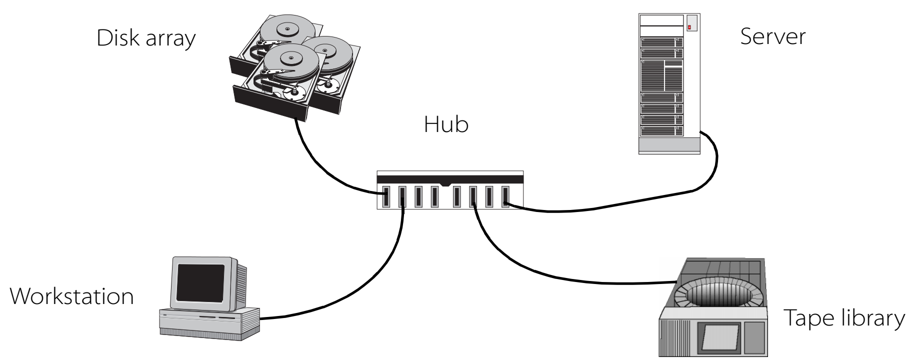

Simple arbitrated loop topology

Arbitrated loop is by far the most prevalent topology currently in use. It provides an economical yet high speed connection for up to 126 devices. It is called "arbitrated" because the loop supports one active connection (between two devices) at a time, so devices negotiate for control of the loop when more than one device requests a connection.

No sophisticated hardware is required to set up arbitrated loop. The only necessary components are Fibre Channel devices or bridges, host adapters and driver software for host computers, and cabling. Fibre Channel hubs and dual loops, however, boost reliability and availability for arbitrated loop topologies.

**Hub.** A device which centralizes connections and guarantees continuity for arbitrated loop topologies.

A **hub** provides centralized routing for a Fibre Channel arbitrated loop. Instead of connecting devices directly together, each device is connected to a port on a hub. The hub completes the connection from device to device, as shown below.

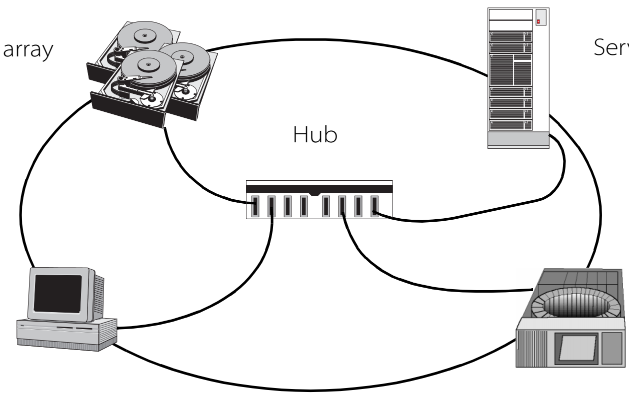



Arbitrated loop topology with a hub

The main advantage of a hub is that each hub port has a port bypass circuit (PBC). If a port detects that a device is absent or not responding, it closes the PBC, allowing the loop to remain intact. This prevents a failing device or connection from bringing down the entire loop. It also allows hot-plugging, the ability to add and remove devices while the loop is active. If you run out of hub ports, you can add hubs by "cascading" or connecting hubs together.

**Dual loop.** A special arbitrated loop topology which connects devices on two separate loops.

Hubs provide loop security against failing devices or ports, but should a hub itself malfunction, it can bring down a loop. Using a **dual loop** can help protect against this. In a dual loop, each device has two separate Fibre Channel ports, and each port attaches to a separate loop. If one loop goes down because of a cable or hub malfunction, the devices are still available through the second loop. Each loop may or may not go through a hub. The diagram below illustrates a dual loop configuration, where one loop is routed through a hub.




Dual arbitrated loop topology, with one loop routed through a hub

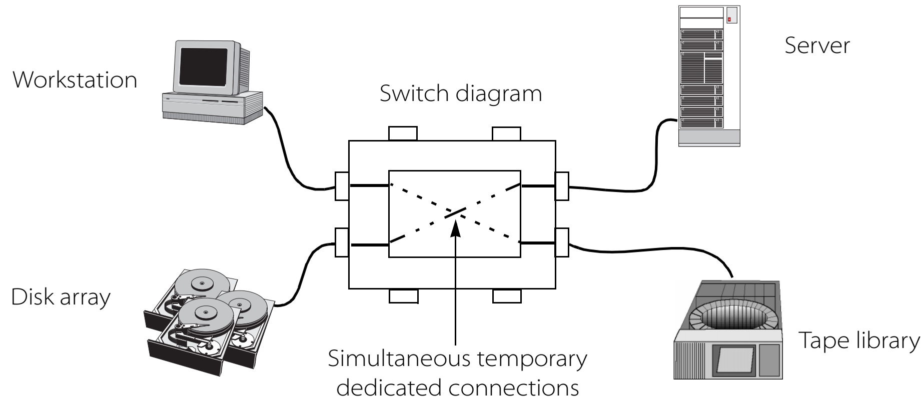
The four devices in this topology would each have two separate Fibre Channel ports. Many Fibre Channel storage devices now include two ports to support dual loop configurations. Although in this illustration each device is attached to both loops, a device could be on just one loop, so if a device has only one Fibre Channel port, it can be part of a single loop while the other devices are on both loops.

The configuration possibilities of arbitrated loop are almost endless and can be tailored to virtually any need short of a large network. It is becoming an especially popular method for mass data storage because of its flexibility, its ability to provide many levels of redundancy, and the ease with which new capacity can be added. Its most important and revolutionary application has been in storage area networking (SAN), which is discussed in more detail below.

**Fabric.** A switched topology providing full-speed simultaneous connections for up to 16 million devices.

The most powerful Fibre Channel topology is the **fabric**, or switched fabric. In addition to ports on each device, a fabric requires one or more hardware switches, making it more costly to implement than point-to-point or arbitrated loop. However, it boosts connectivity to a logical limit of 16 million devices per fabric, and unlike arbitrated loop, each fabric connection has the full speed of a point-to-point connection.

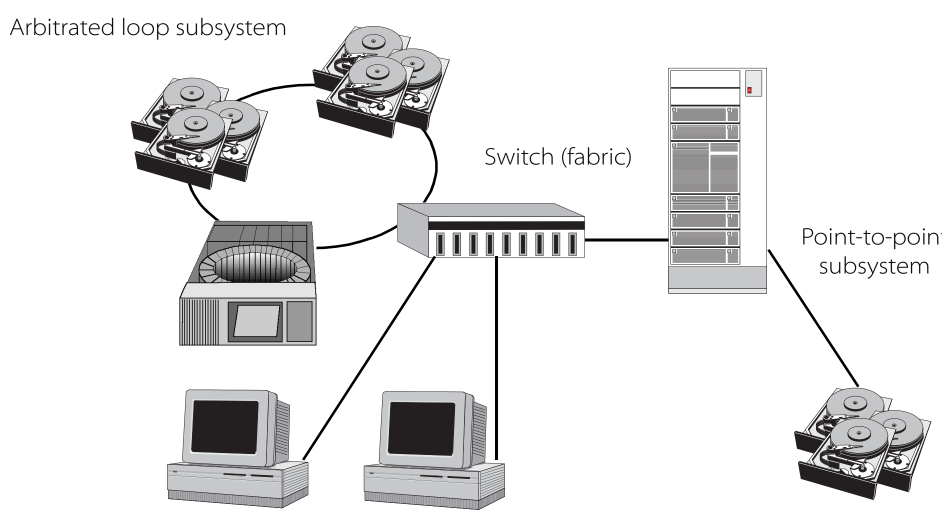
A fabric works similarly to a phone system. One device “dials up” another by supplying its fabric address. The switching hardware then creates a direct connection between the two devices, which stays open until the devices terminate the connection. Connections between other devices can be active simultaneously. The diagram below illustrates a simple switch topology.




Simple switched fabric topology

The number of simultaneous connections allowed depends on the capacity of the switching hardware. If more capacity is needed, more switches can simply be added. The 16 million device limit is due to limited addressing space, not hardware, just as available phone numbers in North America are currently limited to 10-digit combinations.

The three Fibre Channel topologies can be combined in almost any way imaginable. The diagram below illustrates a Fibre Channel fabric with subsystems using arbitrated loop and point-to-point topologies. The subsystem devices are available to any device in the fabric, but they might be attached as a subsystem if most of their communication will be with other devices in the subsystem.




Combining topologies: a fabric with arbitrated loop and point-to-point subsystems.

### Upper-Level Protocol Mapping

Fibre Channel does not substitute for any protocol which defines how to format or interpret data in a particular way to control devices, such as IP (Internet Protocol) or the higher levels of SCSI. It defines only the physical characteristics of interconnecting devices, how to connect them, address them, and how to package data for transmission.

To insure device interoperability, standards have been developed to map some of these higher-level protocols to a format that Fibre Channel can transmit. For example, one protocol defines how to translate SCSI command descriptors, which would normally be sent in parallel, into serial Fibre Channel format, and back to parallel SCSI when they are received by the target device. The following network and channel protocol mappings have been specified or proposed:

- Small Computer System Interface (SCSI)
- Intelligent Peripheral Interface (IPI)
- High Performance Parallel Interface (HIPPI) Framing Protocol
- Internet Protocol (IP)
- Link Encapsulation (FC-LE) using International Standard (IS) 8802.2 (network)
- Single Byte Command Code Set Mapping (SBCCS) to implement ESCON and block multiplex interfaces
- Audio Video Fast File Transfer
- Audio Video Real Time Stream Transfer
- Avionics

Proprietary mappings are also possible but not covered by the standards.

## Building a Real Fibre Channel System

The elements of a Fibre Channel system are much the same as for other common interconnect methods, whether network or I/O channel. The basic components are host bus adapter (HBA) cards, cables, and software drivers. The HBA is equivalent to a SCSI host adapter card or a network interface card (NIC). The process for connecting a Fibre Channel device, such as a disk or tape library, to a host computer in a simple point-to-point link would be:

- Install the HBA in the host computer
- Connect cables to the Fibre Channel port on the HBA and the port on the device
- Install driver software on the host computer

To network several computers or devices, you would need a host adapter for each computer. You can add other products to expand the capability of a Fibre Channel system:

- hubs or switches to support loop or fabric topologies
- Fibre-Channel-to-SCSI or -Ethernet bridges, to connect legacy devices and networks to Fibre Channel systems
- Extenders or repeaters to enable longer fiber optic or electrical cable lengths

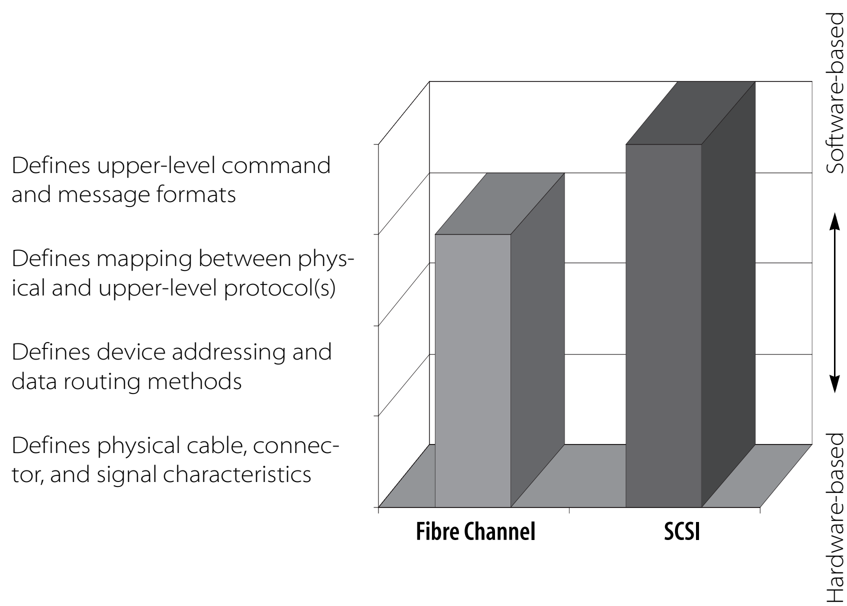
The type of host bus adapter you need depends on the bus type of your host computer. PCI bus Fibre Channel host adapters are widely available. HBAs are also available for other common bus types such as SBus, EISA, MCA, PMC and VME. Some HBAs can support any Fibre Channel topology, and some can support only certain topologies.

Driver software typically comes with the HBA and is written for specific operating systems, so it is important to make sure an HBA vendor has a driver for your operating system when looking for a card. Driver software exists for most popular operating systems, such as Windows 95/NT, Sun Solaris, HP-UX, IBM AIX, Sequent DYNIX/ptx, SGI IRIX, SCO Unixware, and Macintosh. Almost all HBA vendors have drivers for Windows 95/NT, and many have them for Solaris, but finding a card for other operating systems might require some research.

Although there are some fiber-optic-ready host adapters, most HBAs come with an electrical DB-9 or HSSD serial connector, so using them with fiber optic cables requires a Media Interface Adapter (MIA) to convert between electrical and optical signals. MIAs can also be used to convert electrical Fibre Channel devices for use with fiber optics.

## Fibre Channel's Relation to SCSI

It is important to recognize that Fibre Channel does not replace SCSI. SCSI is an expansive standard which defines physical connection and transmission methods, as well as high-level command and message sets for peripheral devices. Fibre Channel covers only the physical aspects of connecting devices and transmitting data signals. It completely separates the *delivery* of data from the *content*. SCSI, in contrast, can be thought of as two separate protocols, a lower-level protocol which covers physical connections and upper-level protocol which defines a command and messaging system for a wide range of peripheral device types. The figure below illustrates the functional similarities and differences between SCSI and Fibre Channel.




Comparing the scope of Fibre Channel and SCSI protocols

Upper-level protocols like SCSI are laid over Fibre Channel's physical transport services. Because Fibre Channel and SCSI's physical layer use different addressing and control methods, SCSI data has to be modified to a format that Fibre Channel can deliver. This process is called "mapping." Fibre Channel defines standard mappings for SCSI and many other upper-level protocols. When mapped SCSI data arrives at its destination, it is then remapped back to SCSI format.

The upper-level commands and message system of the SCSI protocol remain the most popular way to control peripheral devices. Device manufacturers and software developers have invested a lot of time and money in programming for the SCSI standard, and the number of SCSI devices currently in use is countless. With Fibre Channel mapping and Fibre-Channel-to-SCSI bridges, SCSI devices and technology retain their functionality but can now take advantage of the superior data transfer speed, reliability, and flexibility that Fibre Channel provides.

**Parallel.** Sending multiple bits of data at a time by using multiple wires in a connection.

Why go to all this trouble of mapping, remapping, and bridging? Why not just use standard SCSI cables and connections? Because Fibre Channel provides faster, more reliable data transport to more devices over greater distances than SCSI connections. SCSI's physical transmission speed, distance, and scalability are limited by its **parallel** nature. The many electrical wires in a SCSI cable generate interference which hampers signal reliability. This interference gets worse at higher data transfer rates, longer cable lengths, and when wires are added to boost parallel capacity. Fibre Channel does not have these problems because it is a serial technology. The following table compares the performance characteristics of Fibre Channel and physical SCSI.

**Comparison of Fibre Channel and SCSI Data Transfer**

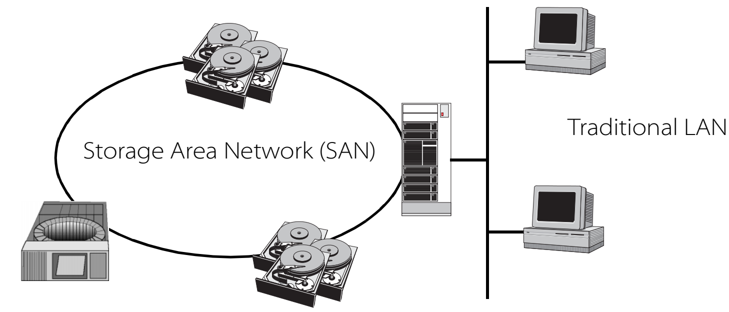
| | Fibre Channel Arbitrated Loop | Ultra SCSI | Ultra/Wide SCSI |
|---|---|---|---|
| **Clock speed** | 1,062.5 MHz | 20 MHz | 20 MHz |
| **Bits/cycle** | 1 | 8 (1 byte) | 16 (2 bytes) |
| **Data transfer speed** | 100 MB/sec | 20 MB/sec | 40 MB/sec |
| **Planned improvements** | 200 MB/sec and 400 MB/sec | 40 MB/sec and 80 MB/sec | 80 MB/sec and 160 MB/sec |
| **Distance covered** | Up to 10 km between devices connected by fiber optics, 30 m for copper wire | 25 m for entire differential SCSI bus, 12 m for low-voltage differential | 25 m for entire differential SCSI bus, 12 m for low-voltage differential |
| **Maximum Number of devices** | 126 | 8 | 16 |

## Application—Storage Area Networks

Although Fibre Channel defines a common interconnect method for all types of data traffic, including network and peripheral device communications, most development for Fibre Channel technology right now is for data storage devices. One reason for this is that the early development of Fibre-Channel-to-SCSI bridges makes it possible to add Fibre Channel storage devices to a system while maintaining compatibility with older SCSI storage devices. Bridges for Fibre-Channel-to-Ethernet compatibility have only recently become available.

The networking capacity of Fibre Channel has led to a new concept in network data storage: the Storage Area Network (SAN). The high performance network capacity of

Fibre Channel can combine with its peripheral I/O nature to create a network of storage devices, separate from the common LAN, with one or more servers acting as a gateway to storage access.




Example of a Storage Area Network (SAN)

A SAN provides high-speed data storage and retrieval which is scalable and highly available. Another advantage of SANs is that data transfer between storage devices can take place without clogging the LAN. This greatly simplifies issues such as mirroring and backup. Scheduling backups over a network has become increasingly difficult as enterprise-wide applications demand virtually uninterrupted access to data storage. With a storage-dedicated network, tape backups can be run almost anytime with little impact on network performance.

The SAN concept also provides reliable data access. With a dual arbitrated loop, the SAN can be connected to two servers, providing redundant access to all storage in case the one server goes down.

## A Note on Cost

It is difficult to compare the cost of implementing Fibre Channel to other existing technologies, because it offers a set of features not available from any other data transport service. Many aspects of Fibre Channel technology, such as its serial nature, ability to carry network and channel traffic, speed, and flexibility, make it an inherently economical technology for high-speed, high-volume applications. Fibre Channel should be considered for any application that requires a combination of high data throughput, long transmission distances, low maintenance, and high reliability.

Legacy technologies such as SCSI and Ethernet currently enjoy economies of scale, due to their mass popularity, which Fibre Channel won't see for a few years yet. As Fibre Channel gains popularity and more systems adopt it, the prices of Fibre Channel components will drop dramatically.

Fibre Channel is an ideal technology for gradual integration. Bridges to other technologies make it possible to implement Fibre Channel in stages, where it is most needed first, while maintaining links to older technologies. Rather than completely replacing entire systems, Fibre Channel devices can easily be added as older devices wear out or become obsolete.

## For More Information

Much information on Fibre Channel is available on the Internet. The following companies or organizations have websites covering various aspects of Fibre Channel technology. Most of these sites also contain links to further information on Fibre Channel technology, products, news, and frequently asked questions (like why "Fibre" is spelled "-re" instead of "-er"). The sources are listed approximately by the amount of general Fibre Channel information they contain. Sites further down on the list focus more on specific Fibre Channel products or applications.

- The Fibre Channel Association (FCA)
  Industry association
  http://www.fibrechannel.com/

- The Fibre Channel Loop Community (FCLC)
  Industry association
  http://www.fcloop.org/

- Gadzoox Networks
  Fibre Channel hubs and switches, emphasis on storage networking
  http://www.gadzoox.com/

- Crossroads Systems
  Fibre-Channel-to-SCSI bridges and routers
  http://www.crossroads.com/

- Emulex Corporation
  Fibre Channel hubs and host adapters
  http://www.emulex.com/fc/

- Ancor Communications
  Fibre Channel switches and host adapters
  http://www.ancor.com/