Transmission Media

Two main groups:

-**Wire based media** (*hardwire*, or guided), either :

-*electric*, like **twisted pair** cable TP, **coaxial** cable

-*optic*, like **fiber optics**

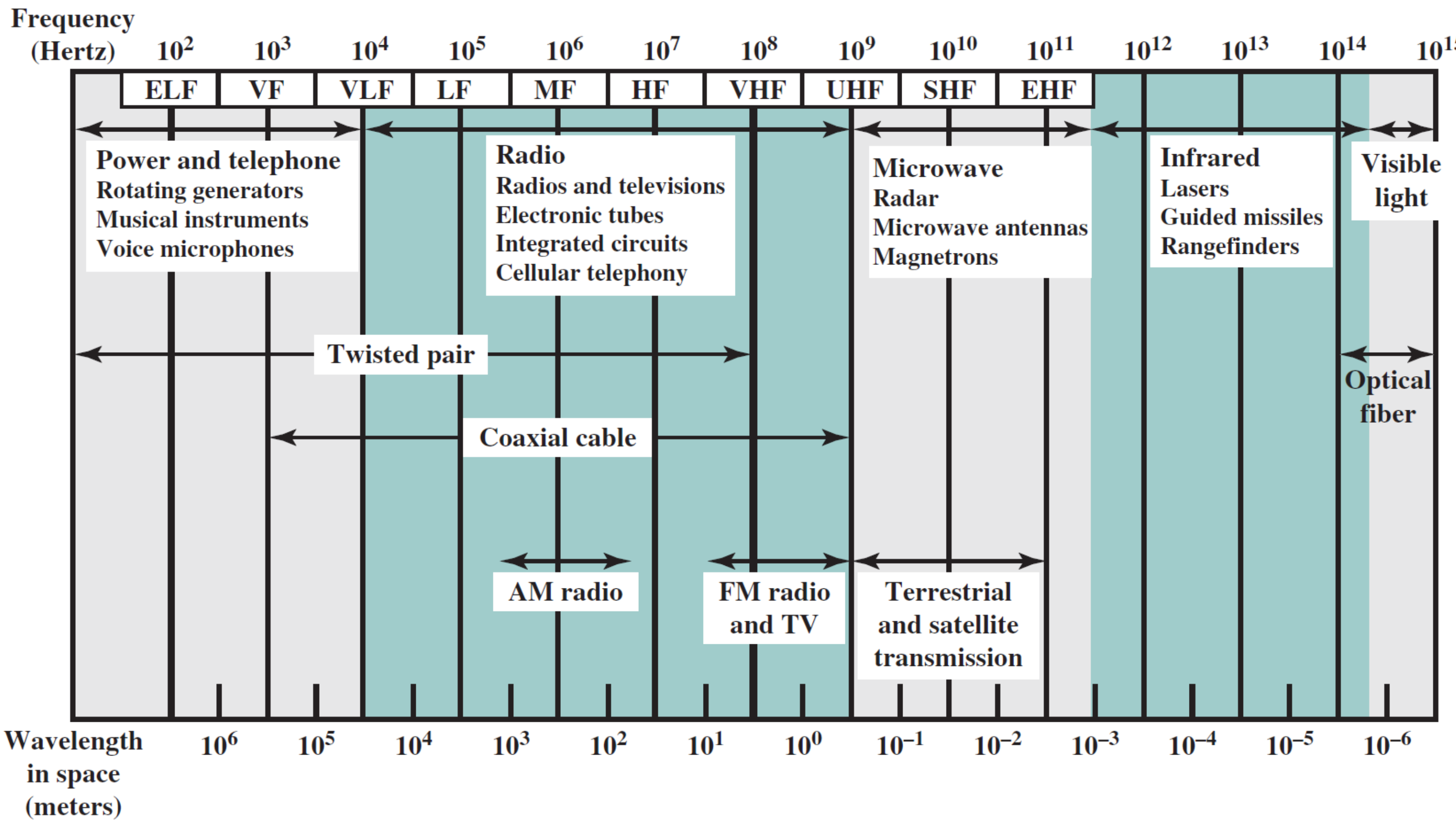
-**Wireless** (*softwire*, or unguided), like **infrared rays**, **radio waves**, **microwaves.**

Characteristics and quality determined by medium and used signal.

For guided media (wire based), the medium is more important!

For unguided media, the bandwidth produced by the antenna is more important!

Main key concerns are: **data rate** & **distance**



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

Electromagnetic Spectrum & used frequencies by each media's transmission technique

Design Factors

Bandwidth

Higher bandwidth gives higher data rate

Transmission impairments

Attenuation limits possible covered distances (acts more for guided media)

Interference (acts on both categories); for guided media use of proper shielding

Number of receivers

In guided media: more receivers (multi-point transmissions) introduce more attenuation

Hard-wire media

Specific Parameters for the Electric Cables

-*Fire security*- the internal cable structure and external coating need to offer proprieties for: zero halogen emission, low smoke fume emanation, flame retardant

-*Impedance* – cables for data transmission present impedance in the range of 50-150Ω, but usually 100Ω impedance

-*Propagation speed* for the electric signal - a ratio of the light speed. An average value of 66%·c, implying a signal speed on a copper based cable of 200.000Km/s

-*Signal loss* - cable needs to allow small values for the signal loss (attenuation is measured in dB)

Hard-wire media

Specific Parameters for the Electric Cables

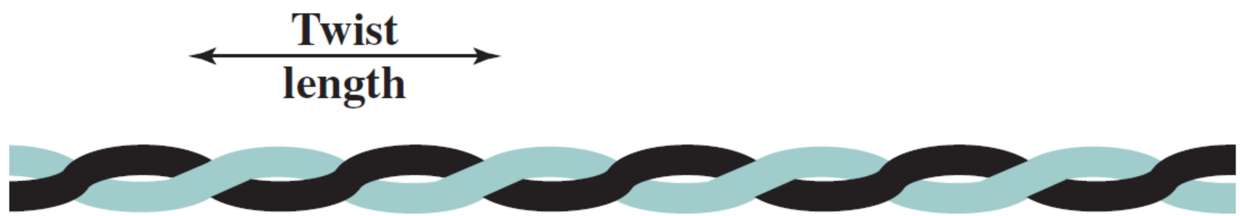
-*Cross-talk* is a measure (in dB) of how a cable affects the behavior of a neighbor cable. For effect limitation is used the shielding. Also used the balanced differential transmission

-*Section (geometry)* of the conductor – measured not in mm, but in AWG (*American Wire Gage*); 26AWG for telephony cables

- In Europe, the ISO/IEC-11801 standards family defines general and specific cabling design documents.
  - It comprises the ISO/IEC 11801-1:2017 Information technology — Generic cabling for customer premises — Part 1: General requirements and includes ISO/IEC 11801-2, ISO/IEC 11801-3, ISO/IEC 11801-4, ISO/IEC 11801-5, ISO/IEC 11801-6. The ISO/IEC 11801-1 specifies the requirements for coaxial, twisted-pair copper and optical fiber.
  - In the USA and Canada, ANSI/TIA-568-C standard is used instead of ISO/IEC 11801.

Twisted pair

Consists of two metallic copper wires, twisted after a given step.



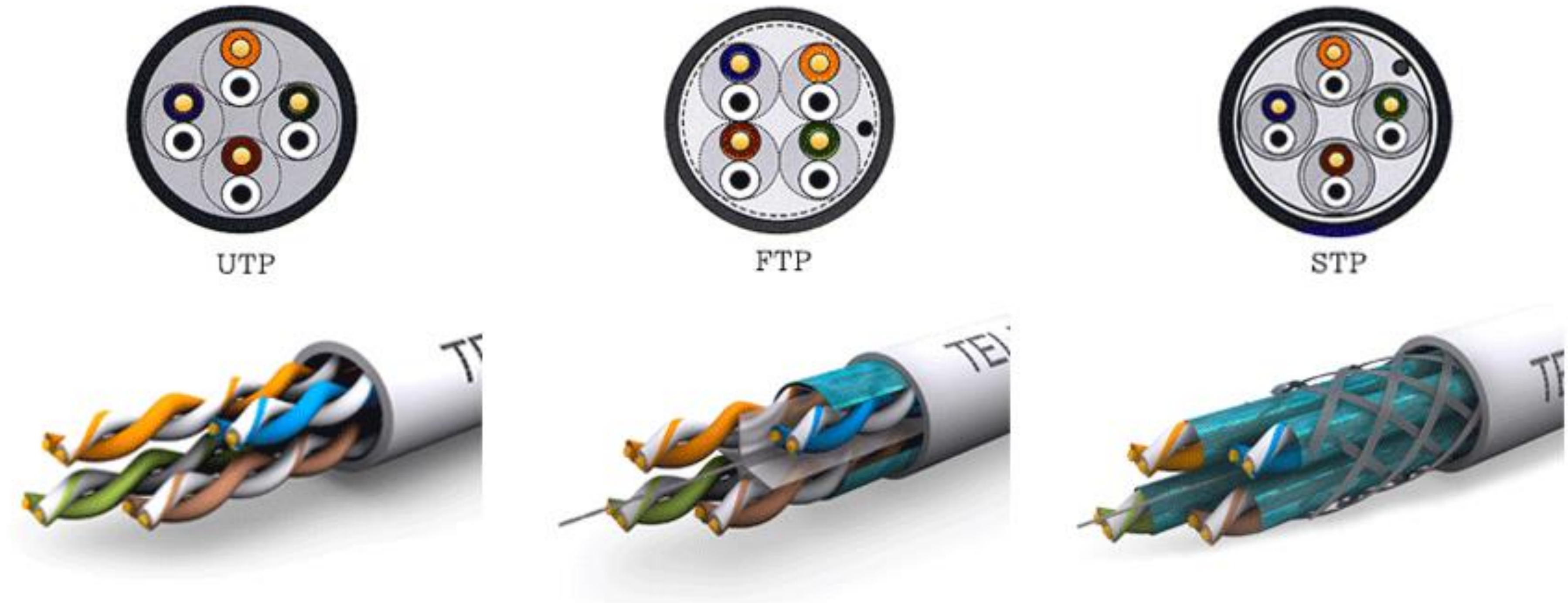
—Separately insulated
—Twisted together
—Often "bundled" into cables
—Usually installed in building during construction

Twisted pairs are of the following kinds:

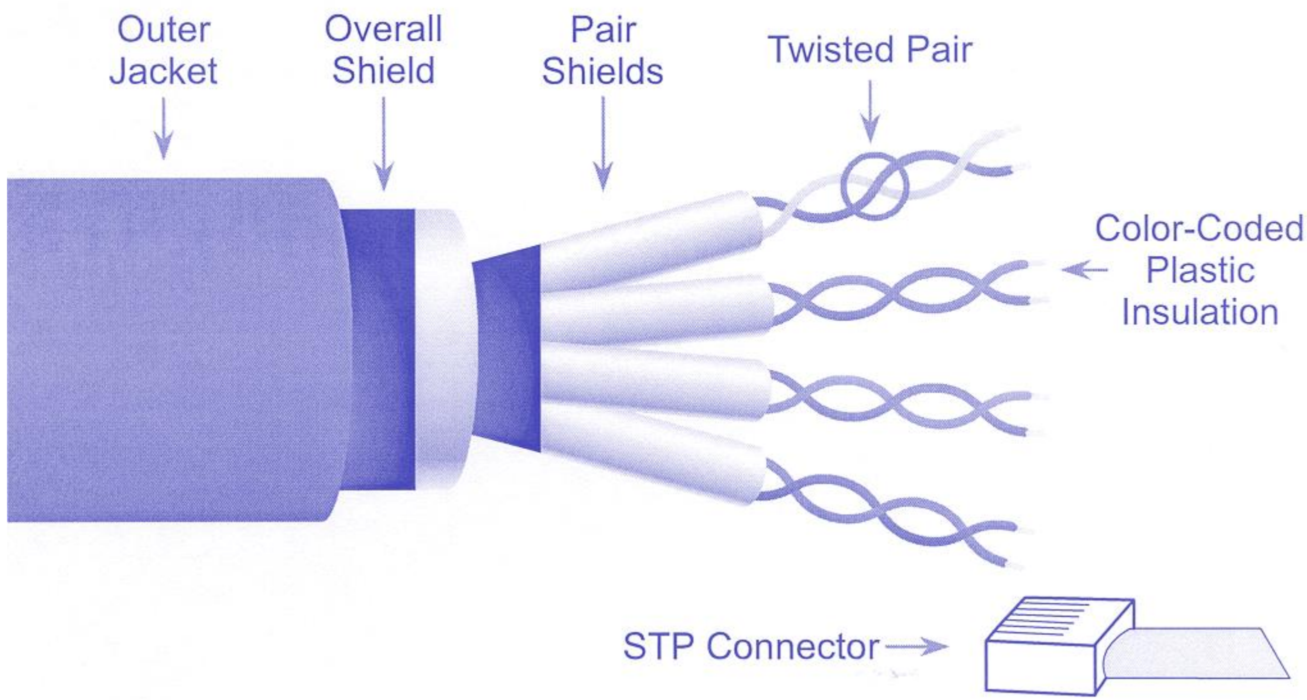
-STP (*Shielded Twisted Pair*), presenting protective shield for each pair and a global shield (metal braid) for whole cable; reduces interference but increased weight

-FTP (*Foiled Twisted Pair*), or **ScTP** (Screened TP), providing an unique global shield

-UTP (*Unshielded Twisted Pair*), being the non-shielded variant, only the separate pair insulation

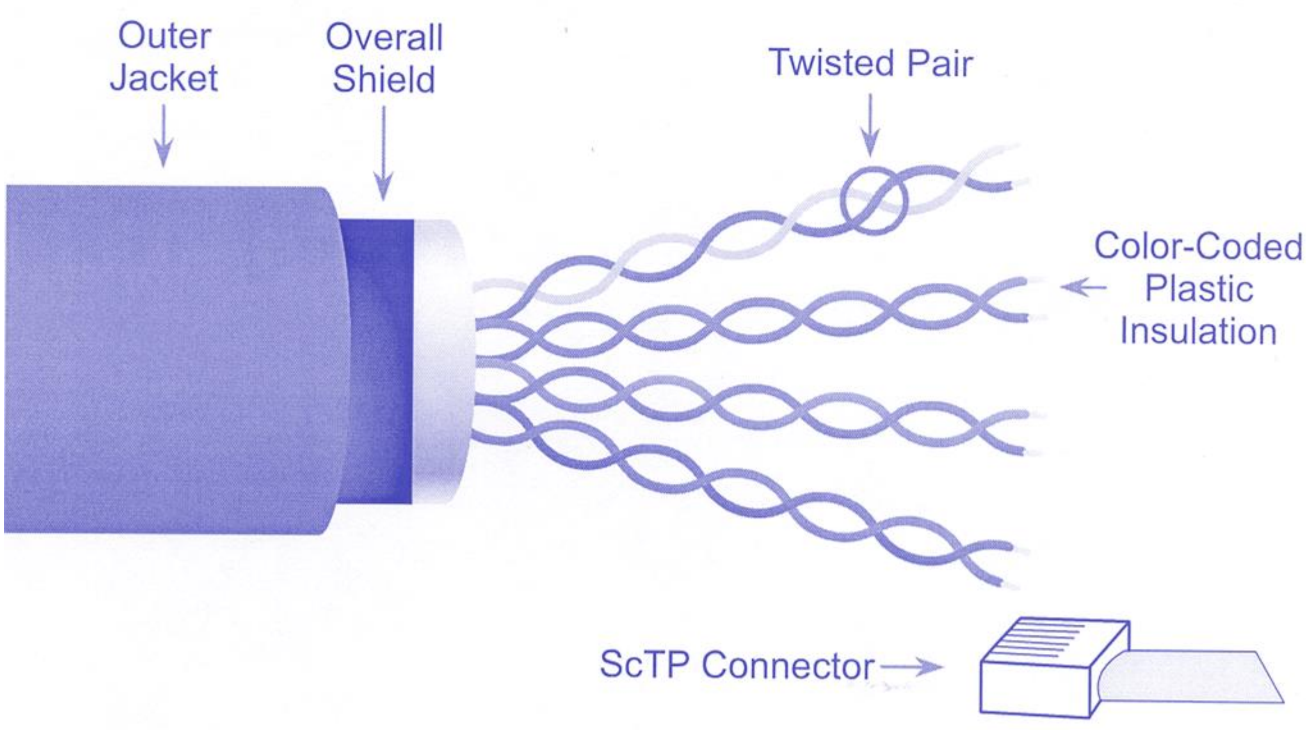

UTP
FTP
STP

STP (Shielded Twisted Pair)



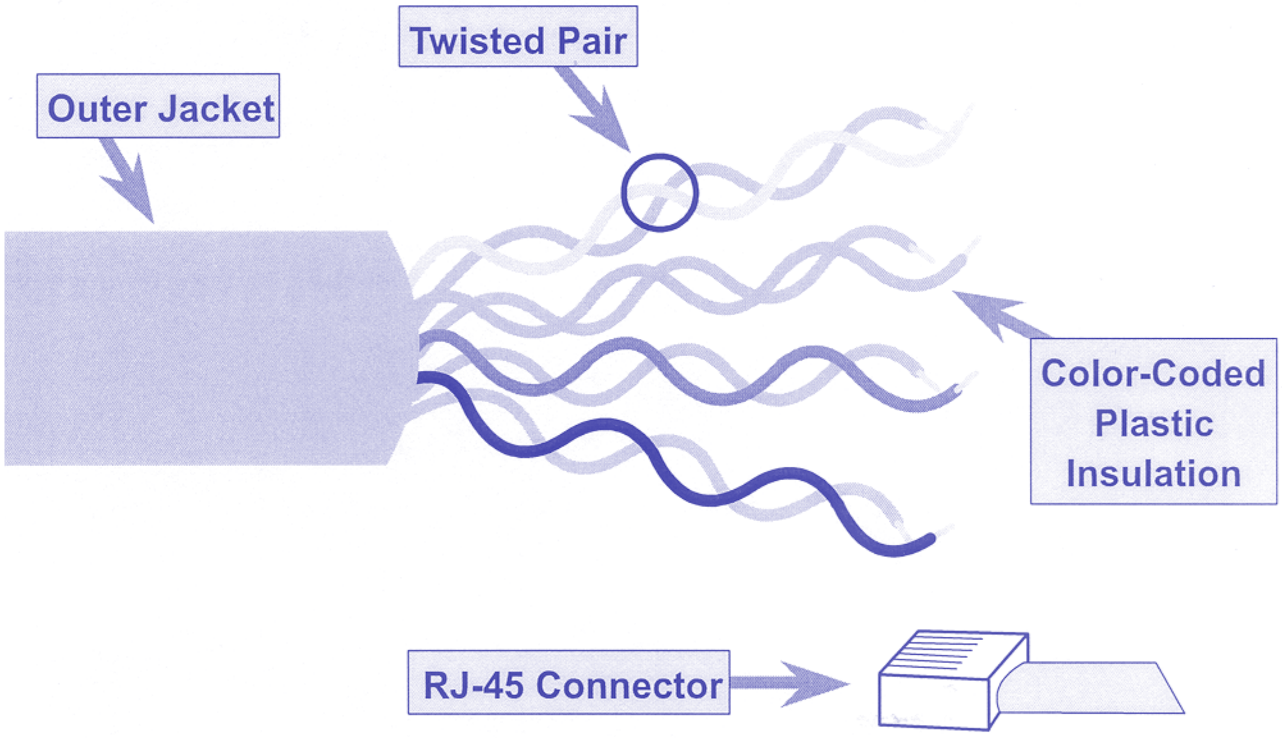
maximum cable length: 100 m (short distance)

ScTP (Screened Twisted Pair)



maximum cable length: 100 m (short distance)

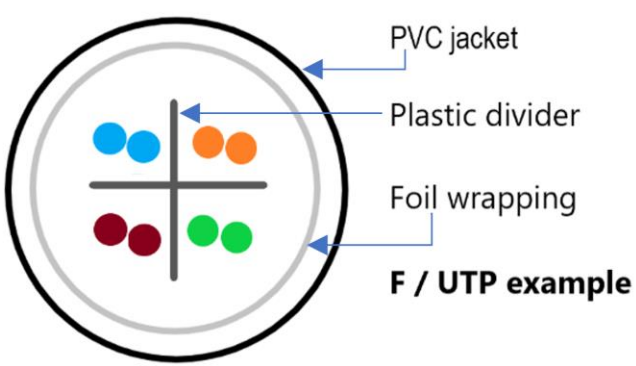
Unshielded Twisted Pair (UTP)

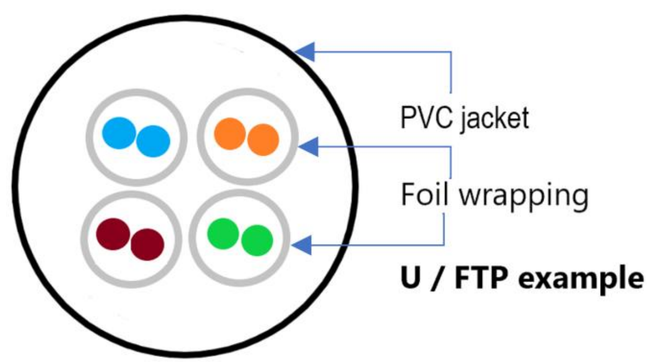


maximum cable length: 100 m (short distance)

The cable naming convention from ISO/IEC 11801 presents the different types of cable construction, based on their screening: XX / XXX. Examples of cable naming are: U/UTP, U/FTP, F/UTP, S/UTP, SF/UTP, F/FTP, S/FTP, SF/FTP etc.

XX			**/**	**X**		**XX**
overall screen				**element screen**		**balanced element**
F = foil screen	S = braid screen	SF =braid and foil screen		U = unscreened	F = foil screened	TP





UTP: most common medium; used in:

-Telephone network

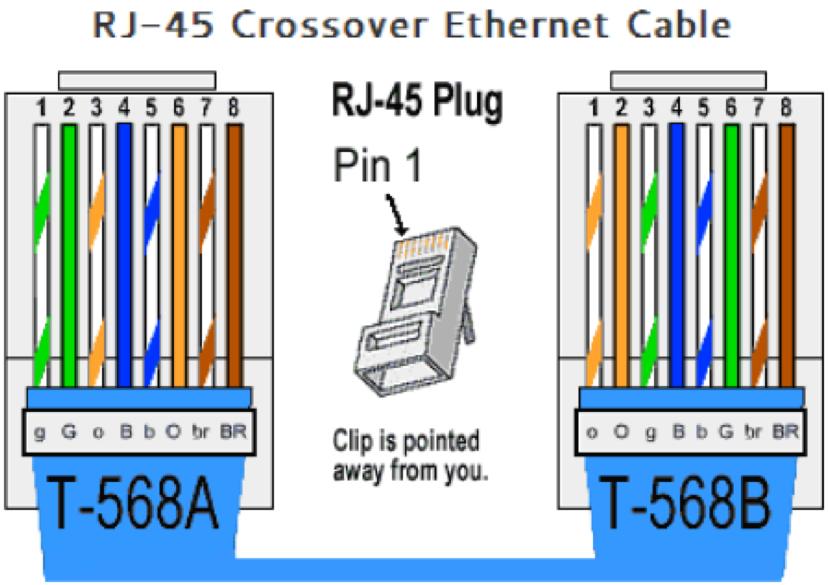
Between house and local exchange (subscriber loop)

-Within a company's buildings

To private branch exchange (PBX)

-For local area networks (LAN)

Ethernet at 10Mbps or 100Mbps



Advantages:

-cheap

-easy to work with (to install on walls)

Problems:

-susceptible to EM interference and noise

-need for amplification (order of kilometers)

-near end crosstalk

UTP Categories

-Category 1 - *Telecommunication*, the cables for the analogue telephony

-Category 2 (*Low Speed Data*), the cables for analogue and early digital telephony, offering data transmission services at low speeds

-Category 3 (*High Speed Data*) defines cables used for LANs up to 10-16Mbps; the usual voice grade

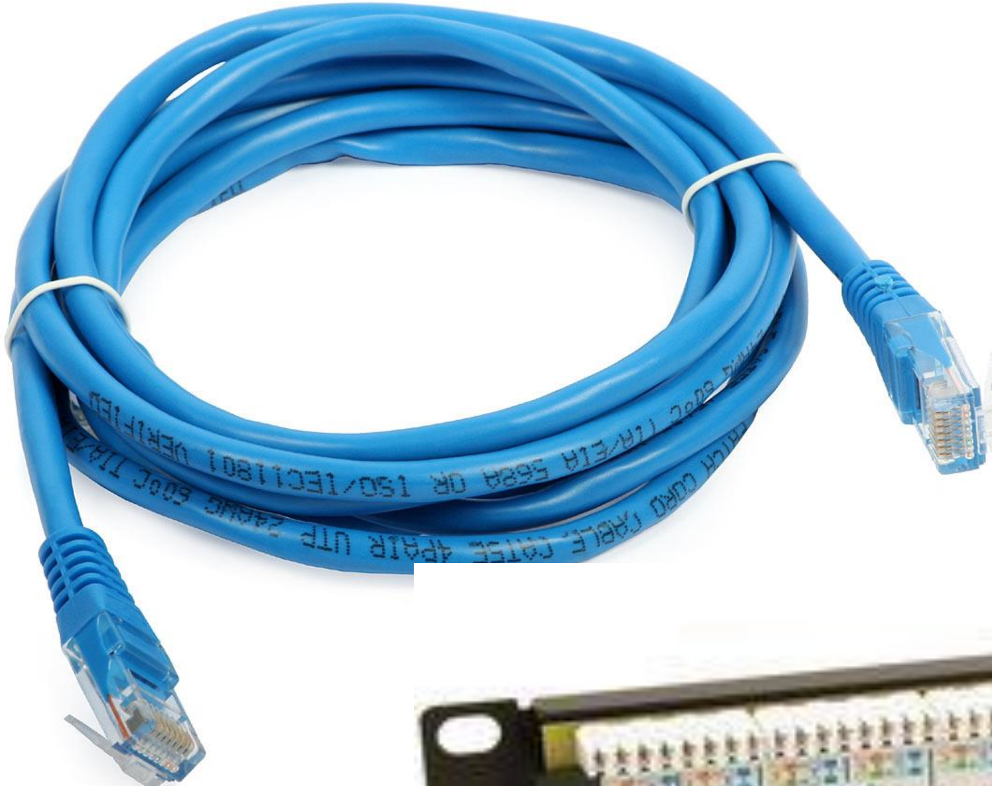
-Category 4 (*Low Loss*, *High Performance Data*) defines cables with higher performances, used at communication speeds of tens of Mbps (20Mbps)

-Category 5 and 5e (*Low Loss*, *Extended frequency*, *High Performance Data*), are used in today's networks working at hundreds of Mbps; Commonly pre-installed in new office buildings.

-Categories 6 and 7 (*low attenuation and higher noise immunity*)

UTP Categories

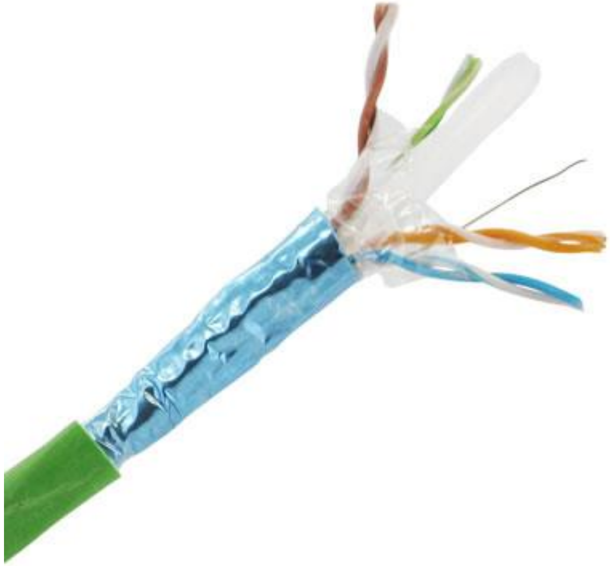
Class	Bandwidth	Category
Class A	up to 100 kHz	Category1
Class B	up to 1 MHz	Category2
Class C	up to 16 MHz	Category3
Class D	up to 100 MHz	Category5e
Class E	up to 250 MHz	Category6
Class EA	up to 500 MHz	Category6a
Class F	up to 600 MHz	Category7
Class FA	up to 1000 MHz	Category7a
Class I and Class II	up to 2000 MHz	Category8.1, 8.2



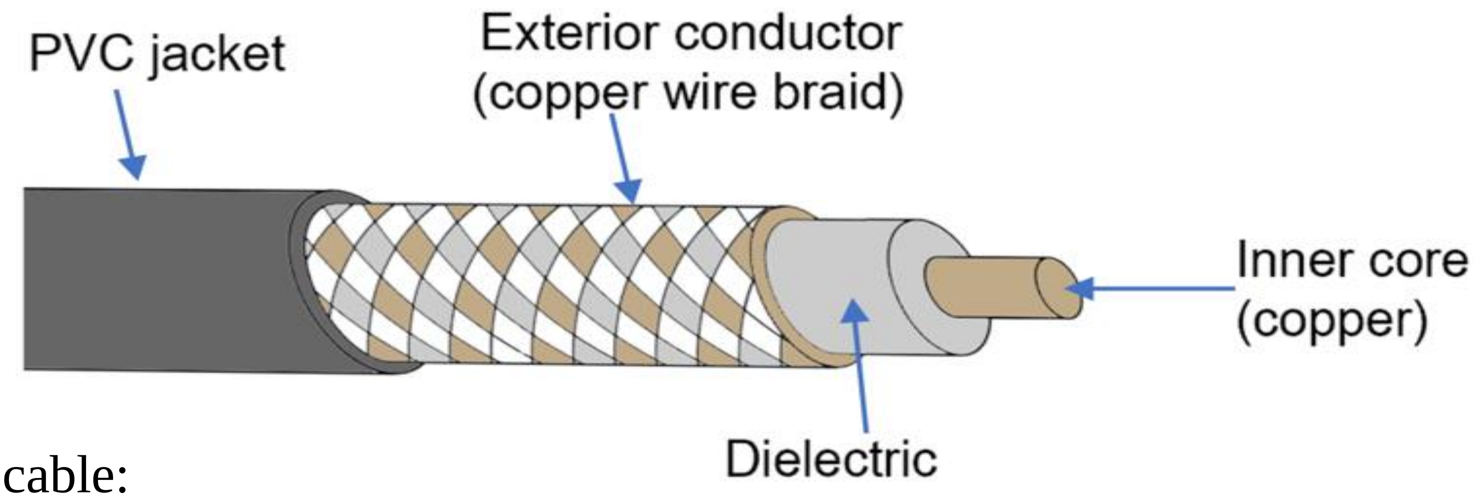

1 2 3 4 5 6
7 8 9 10 11 12


FLUKE networks


1.WireMap
2.Pair&Length
3.Coax/Tel
4.Setup
Cable Tester & Wire Tracker
WIREMAP



Coaxial cable



Coax cable:

-base-band cable, 50Ω impedance, used in Ethernet LANs

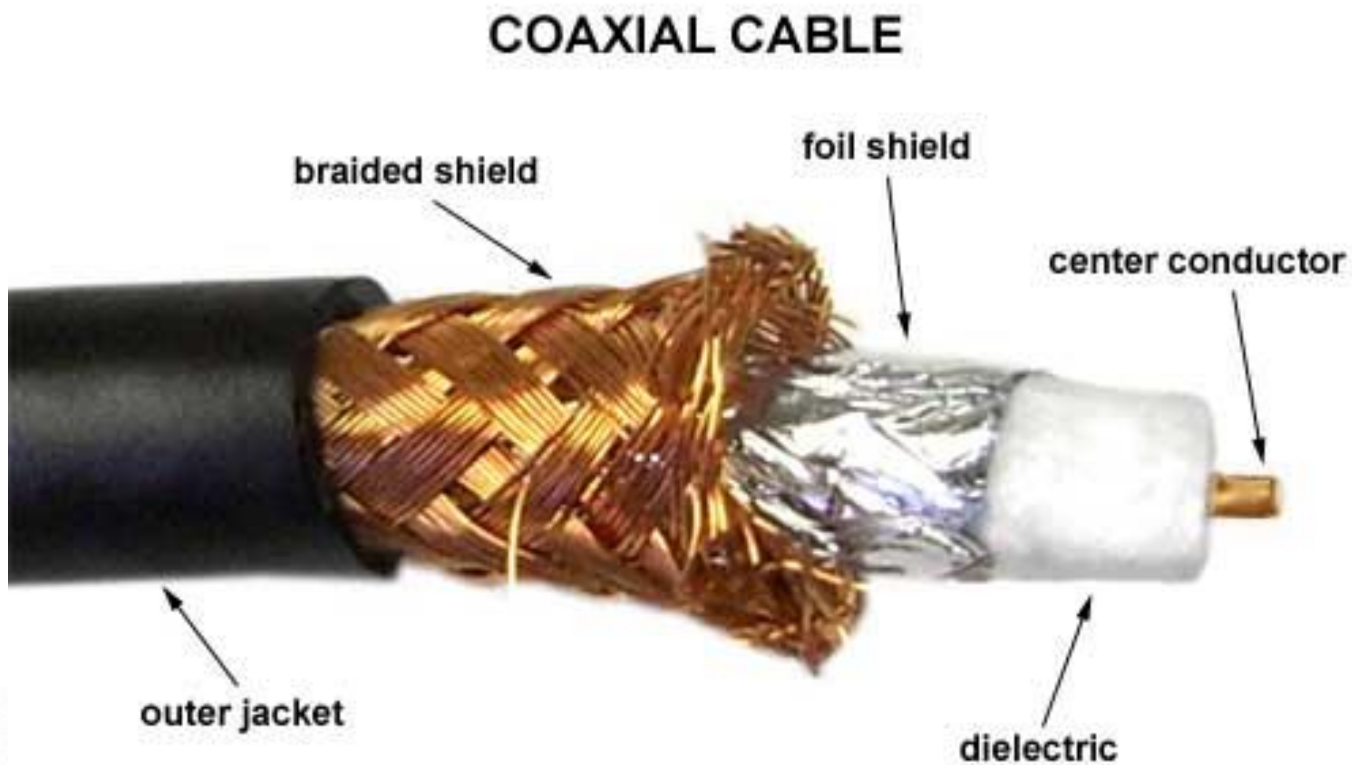
-thick Ethernet (RG213), difficult to install

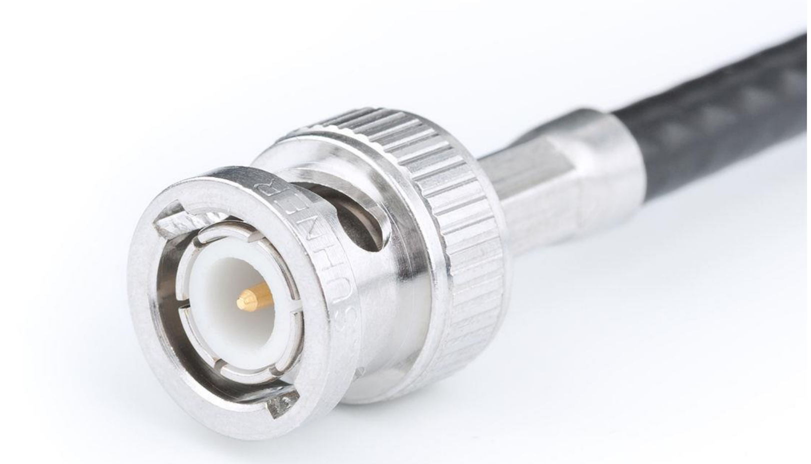
-thin Ethernet (RG58), excellent versatility

-broad-band cable, 75Ω impedance, used less for LANs, more for CATV or long distance telephone transmissions

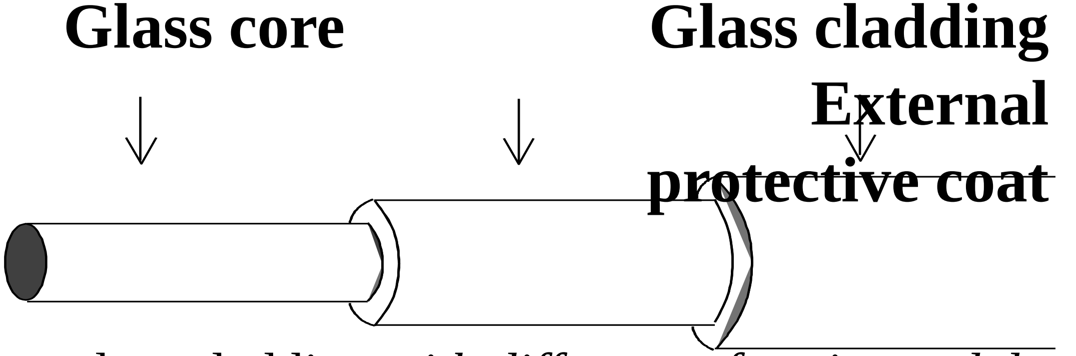
Advantages: goes up to 500MHz, repeaters every 1-2 km

Drawback: is a shared broadcast medium, not for full duplex (switched) transmissions => will be replaced by UTP (LANs) or by fiber optics (long telephony trunks)


COAXIAL CABLE
braided shield
foil shield
center conductor
outer jacket
dielectric



Fiber optic



An inner glass core, covered by a glass cladding *with different refractive and density proprieties*; for protection and easier cabling – colored plastic coat (see next slide also)

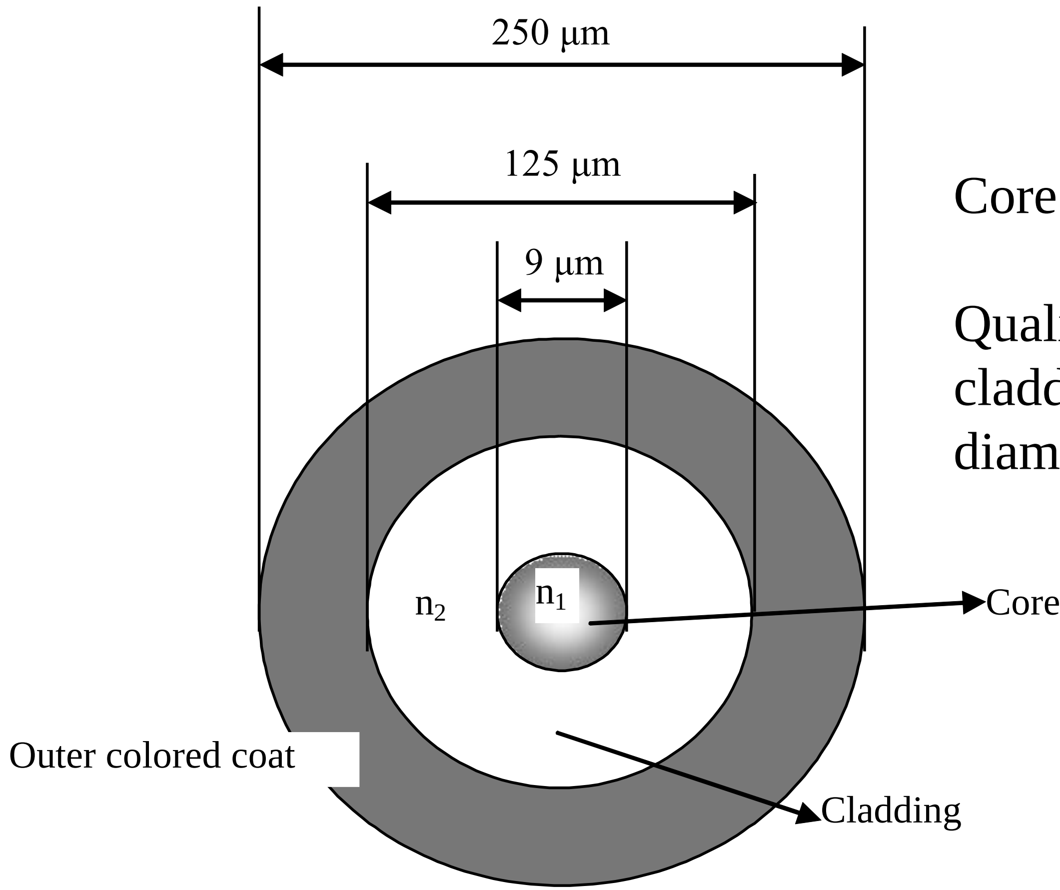
Advantages:

-low attenuation, fiber optic links with lengths in the order of ten of Kilometers

-total immunity to electromagnetic field effects (carriers are the neutral photons)

-transmission data rates in the order of Giga bps

-easy for cabling, presenting low weight, small diameter (125/250μm) and being flexible



Core diameter less than 10 microns

Quality of fiber given by ratio between cladding diameter and whole fiber diameter

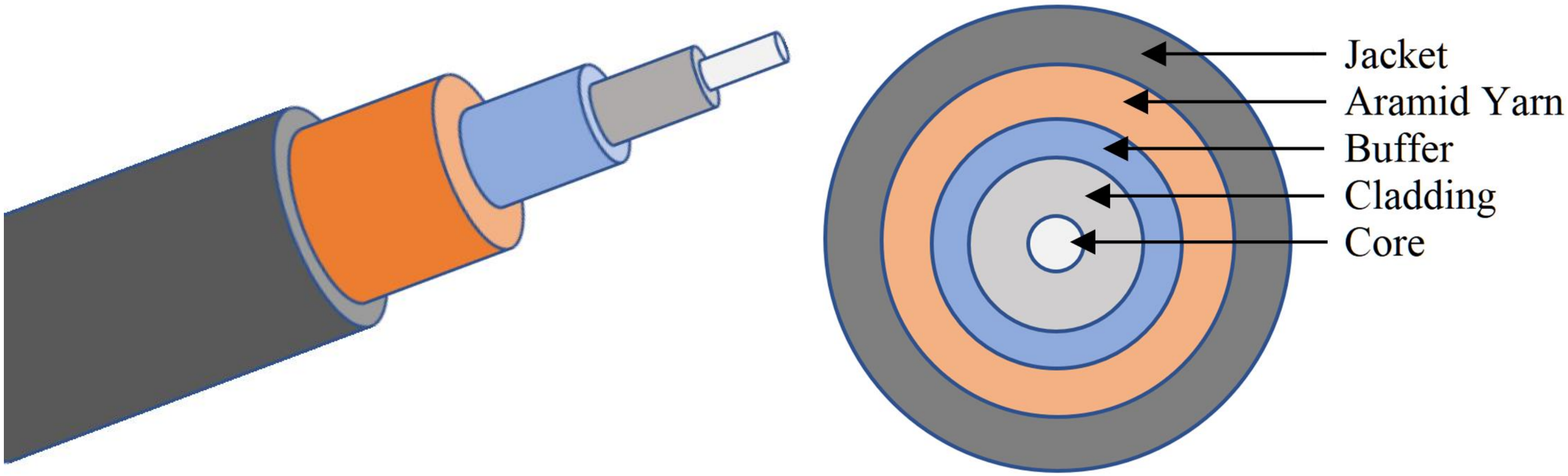


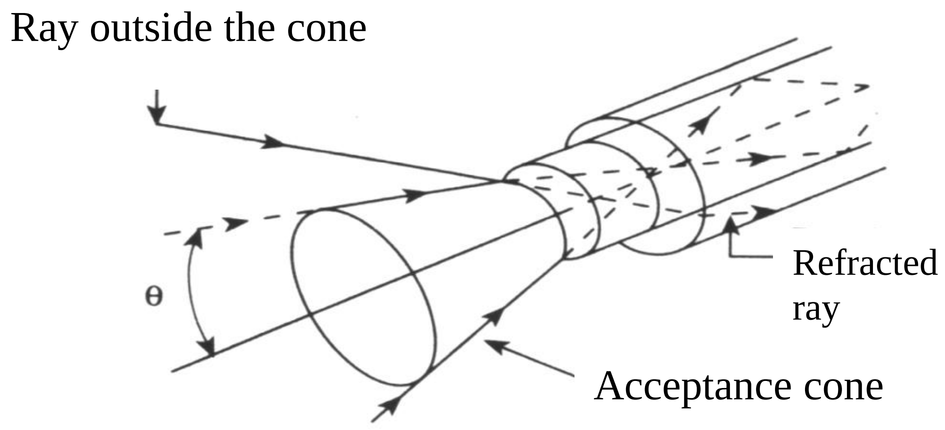
Figure 2.1 a. *Optical fiber layers* b. *Optical fiber transversal section*

Optical transmissions theoretical issues

Optical transmissions governed by Snell's law: the critical angle for an ideal transmission is: $\boldsymbol{\theta_c = \arcsin(n_2/n_1)}$, n_1 and n_2 are the refractive indexes of the adjacent glass layers (core, respectively cladding);

The lower refractive index of the cladding (with respect to the core) causes the light to be angled back into the core

All attack angles for the light rays up to the critical angle will give minimum refraction and maximum of reflection => acceptance cone



Light propagation modes:

-**step-index multimode**, refraction index constant for the fibre core, doesn't matter distance to core's centre; implies different path lengths for light rays, making reception difficult; present a thicker core (hundreds of µm) => cheaper fiber

-**graded-index multimode**, refraction index decreasing from the core centre to edges; offer a better focusing of the rays, so a lower attenuation and easier reception

-**single mode** (mono-mode), the core diameter ~ light ray wavelength (5-8µm) => direct path for light ray, no loss, no attenuation, but more expensive

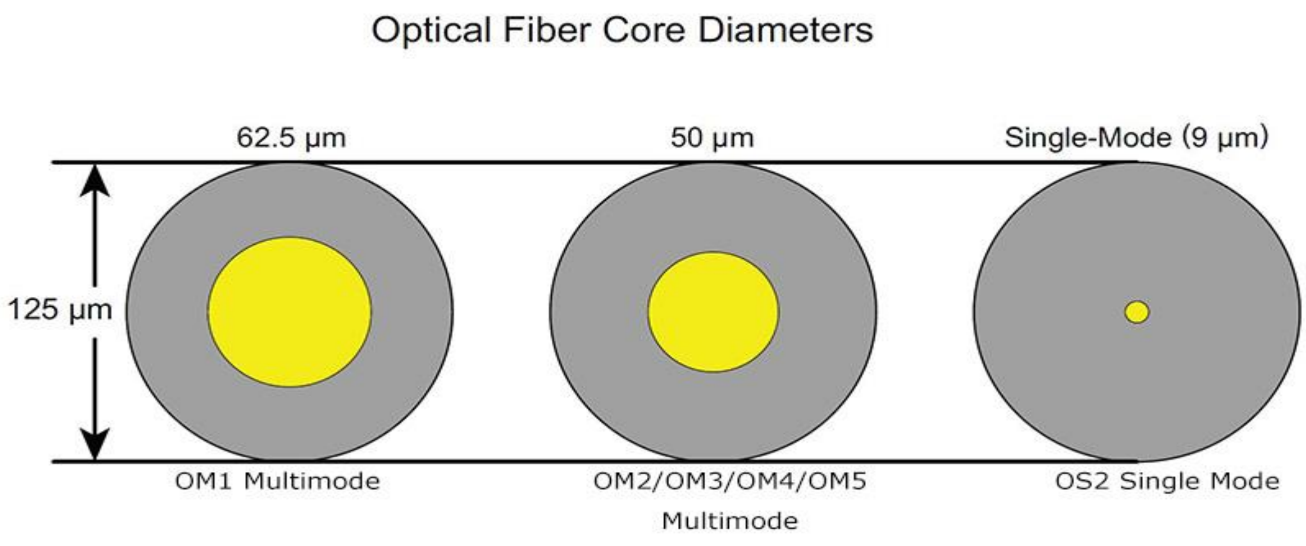
Condition for single-mode fiber:

$$\lambda_c > \frac{2\pi a}{2,405}\sqrt{n_1^2 - n_2^2}$$

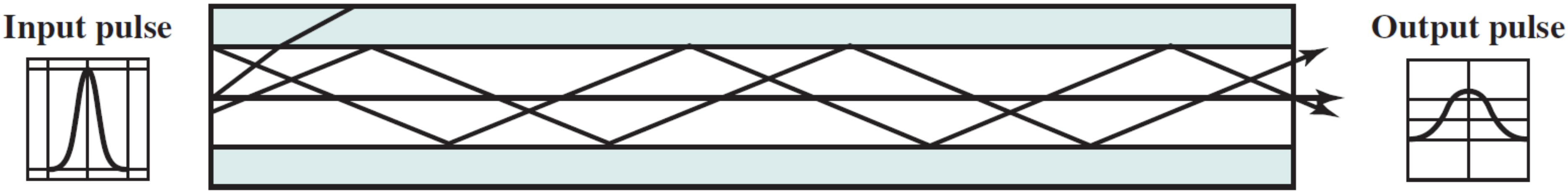
λ_c - light ray wavelength;

2a – fiber diameter;

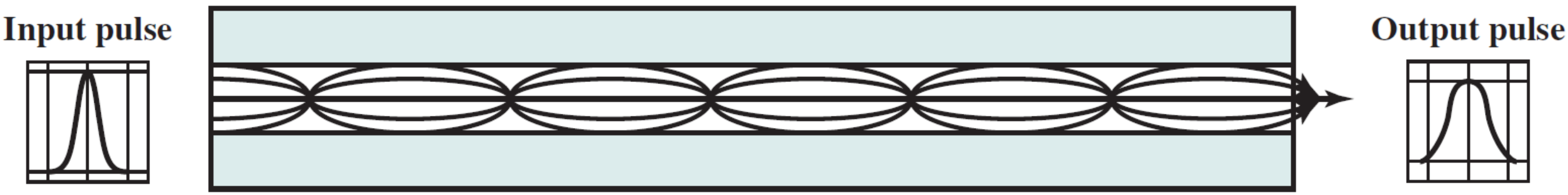
n_1 and n_2 are refractive indexes of the core, respectively cladding



Light propagation modes



(a) Step-index multimode



(b) Graded-index multimode

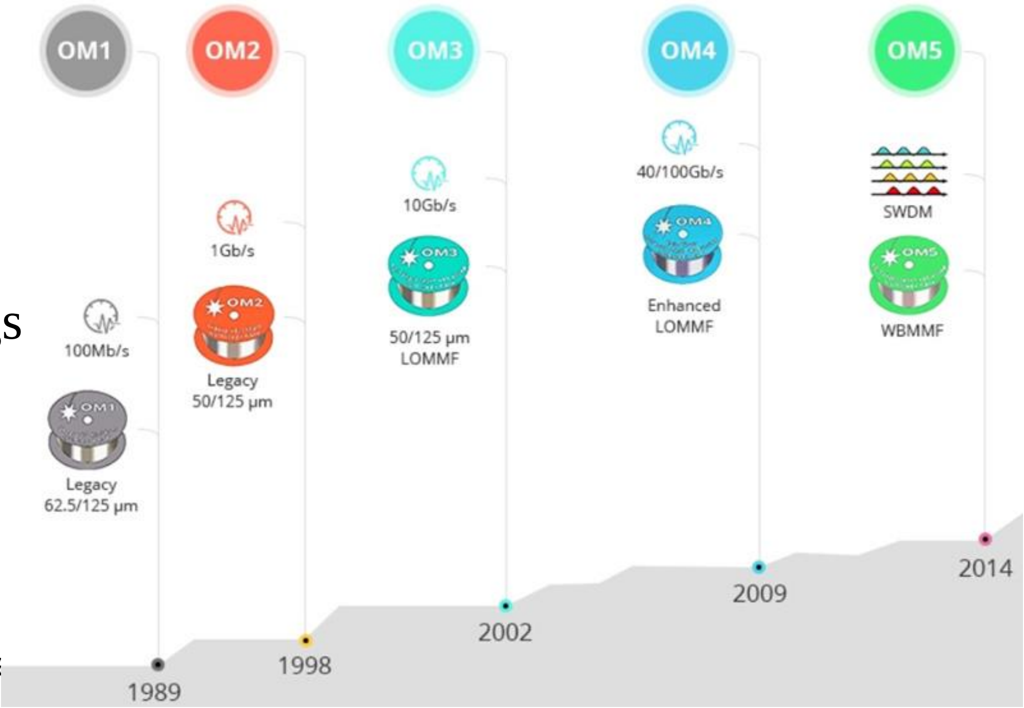
(c) Single mode

Multimode Fiber

MMF Cable Type	Diameter	Jacket Color	Optical Source	Bandwidth
OM1	62.5/125µm	Orange	LED	200MHz*km
OM2	50/125µm	Orange	LED	500MHz*km
OM3	50/125µm	Aqua	VSCEL	2000MHz*km
OM4	50/125µm	Aqua	VSCEL	4700MHz*km
OM5	50/125µm	Lime Green	VSCEL	28000MHz*km

https://community.fs.com/blog/advantages-and-disadvantages-of-multimode-fiber.html

- mostly used in communication over short distances (hundreds of meters):
  - inside a building or campus networks
  - backbone applications in buildings
  - enterprise and data center applications



Single-mode Fiber

Name	OS1	OS2
Standards	ITU-T G.652A/B/C/D	ITU-T G.652C/D
Cable Construction	Tight buffered	Loose tube
Application	Indoor	Outdoor
Maximum Attenuation	1.0dB/km	0.4dB/km
Distance	10 km	200 km
Price	Low	High

-used in communication over long distances (kilometers):

Advantages over multimode fiber:

- longer transmission distance
- greater bandwidth capacity
- increased transmission speed
- limited data dispersion & external interference
- less signal attenuation

Fiber Optic Cable Type		Fiber Cable Distance					
		Fast Ethernet 100BA SE-FX	1Gb Ethernet 1000BASE-SX	1Gb Ethernet 1000BA SE-LX	10Gb Base SE-SR	40Gb Base SR4	100Gb Base SR10
Single mode fiber	OS2	200m	5000m	5000m	10km	/	/
Multi-mode fiber	OM1	200m	275m	550m (mode conditioning patch cable required)	/	/	/
	OM2	200m	550m		/	/	/
	OM3	200m	550m		300m	100m	100m
	OM4	200m	550m		400m	150m	150m
	OM5	200m	550m		300m	400m	400m

https://community.fs.com/blog/single-mode-cabling-cost-vs-multimode-cabling-cost.html

Transmission devices:

-light *emission* using **LEDs** (light emitting diodes) or **laser (diodes)** (for single-mode transmissions)

-*reception* of light and conversion into electrical signal using **photodiodes**

For fibers: to be used wavelengths upper than the visible light (> 750nm)

Attenuation depends on the light ray wavelength => definition of 3 windows for the optical transmissions:

-850nm centred window, used for multi-mode ‘cheap’ transmissions; up to 150MHz signal frequency, attenuation of 3.5dB/km

-1300nm centred window, used for graded-index multimode and single-mode transmissions; attenuation under 1dB/km, working frequencies: 0.5-1GHz

-1550nm wavelength centred window, single-mode laser based transmissions, attenuation under 0.5dB/km, working frequencies up to 100GHz

Use of fiber optic cables:

-long haul trunks (10 – 100km without amplifiers)

- used also for LANs or digital subscriber loops; usually as point-to-point links, shaped as ring or star

Junctions / Splices

Points where two fibers are connected to obtain a longer link or a fibre gets attached a terminal connector (permanent connection)

Mechanical junction: fibers ends are cut, cleaned and polished, then aligned into a mechanical device

Junction by fusion: fibers ends are heated-up close to melting point, than pasted and heated-down suddenly

Junctions introduce extra attenuation (0.1 to 0.4 dB)

Connecting devices – optical connectors:

Non-permanent connections or variable configurations

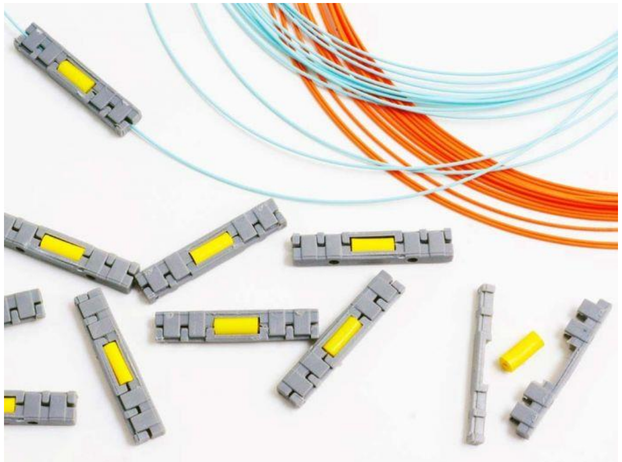
Usually prefabricated connectors, one side presenting a junction with fiber, the other connector side being free

Connectors are:

-passive, using taps with LED/Photodiode; do not affect cable transmission

-active, using transformers from light/electric to electric/light signals and electric signal amplification

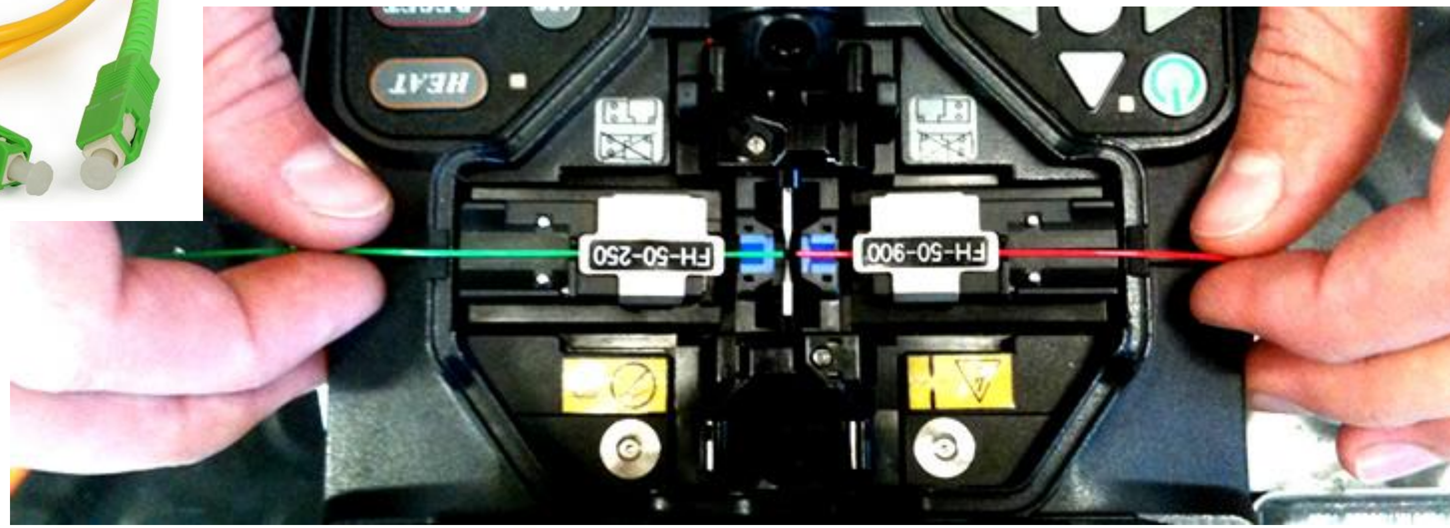
Connectors introduce extra attenuation, higher than junctions (0.2 to 0.5 dB)



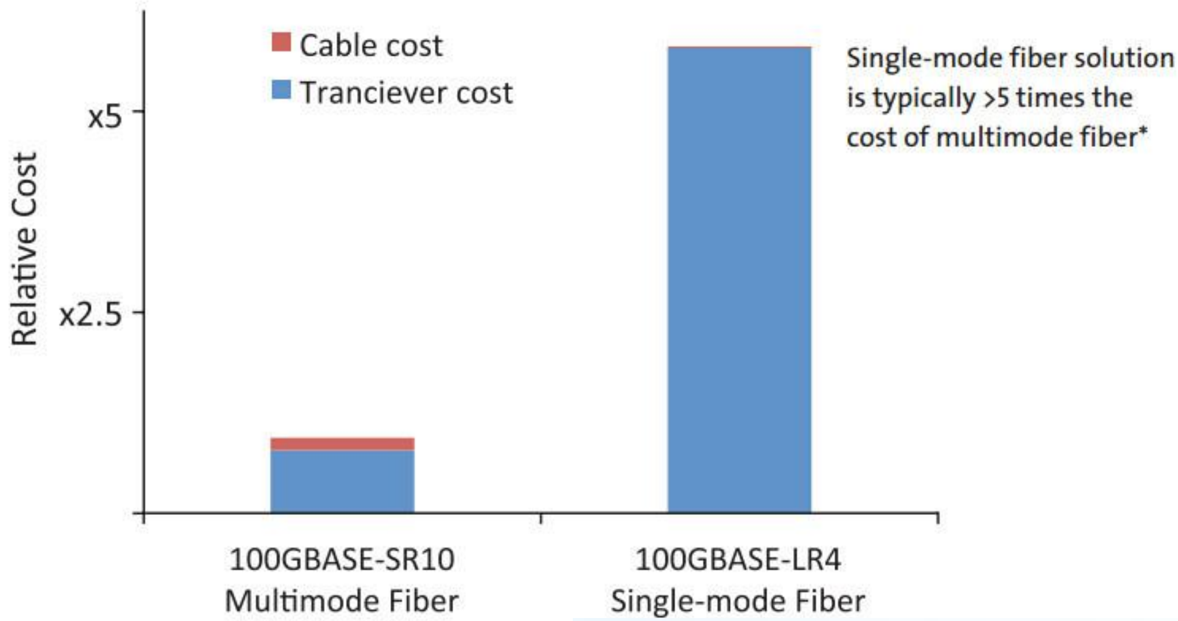
splices: (loss <= 0.3dB) mechanical and fusion

SFP

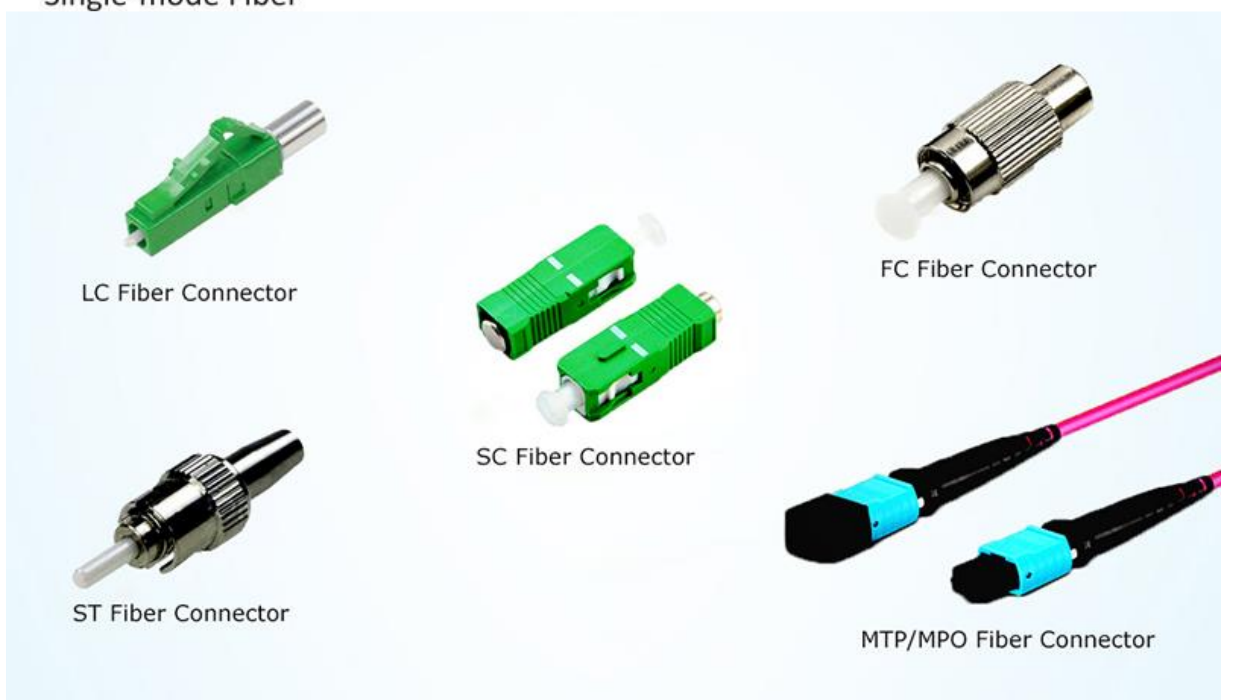
Media converter



Optical Transceiver Cost and connector types



https://community.fs.com/blog



Fiber Optic vs TP and Coax

Information in this table, considering especially the costs, is relative and is subject to change; so it is pure informal and is accurate for year 1999-2000

Attribute	TP	Coax	FO
Data rate per km	10-100-n Mbps	100Mbps	n Gbps
Accessibility to be tapped	Easy	Easy	Difficult
Signal radiation	Yes	Yes	no
Grounding problems	Yes	Yes	no
Static problems	Yes	Yes	No
Sparkling	Yes	Yes	no
Bit error rate	10^{-9}	10^{-6}	10^{-10} +
Size &Weight /data rate	Medium	Large	small
Cable cost per meter	50p	70p	70p
Installing + maintenance costs	N	N	2N

Soft-wire (wireless) media

For unguided media: higher frequencies give higher transmission data rates

Antenna based transmissions:

- -directional, antenna-to-antenna focused beam, requiring antennas alignment
- -omnidirectional, beam spread and may be received by many antennas

LANs using wireless media present flexibility, easiness in installing and maintenance

Main media:

- -terrestrial microwaves
- -satellite microwaves
- -broadcast radio waves
- -infrared rays

Terrestrial microwaves

Use frequency domain of 2-40GHz, offers up to 500MHz analog signal bandwidth, up to 100Mbps digital signal data rate

Use of parabolic 'dish' => 'line-of-sight' transmissions of a focused electromagnetic beam => existence of a theoretical maximum distance between antennas:

D = 7.14 **sqr**(K•h),

Where **h** is antenna's height and **K** an adjustment factor for waves reflection due to the earth curvature (a 4/3 value may be acceptable)

For long hauls => a succession of relay towers

Satellite microwave

Transmissions (directional, station – satellite – station(s)):

-optimum frequencies domain: 1-10GHz, due to low natural noise interferences (solar, wind, human devices); the most are point-to-point transmissions, referred as 4/6GHz band (the uplink based on 6GHz, the downlink frequencies centred on 4GHz. Today in use 12/14GHz (especially by small earth-stations) and 19/29GHz, offer higher bandwidth, but is need for overcoming attenuation problems.

Satellite: a **microwave relay station**, receiving on one frequency band (*uplink*) and retransmits on another (*downlink*), avoiding interferences. These frequency channels – **transponders**.

Problem: satellite remains stationary with respect to the fixed (usually) earth-stations => equal rotation period as the earth's (launched for 35,784km height)

Satellites on the same orbit, need for an angular displacement of 4° (4/6GHz band) and 3° (12/14GHz band) for no interferences between.

Applications:

-television distribution (Public Broadcasting Services – programs broadcasted to stations and then to users , also Direct Broadcast Satellite – video transmitted directly to user); today use of costless VSAT (Very Small Aperture Terminal) systems

-long distance telephone transmissions

-private networks (each using separate sub-channels)

Broadcast Radio

Being omni-directional transmission, radio antennas are not dish-shaped and may be mobile; generally radio waves use frequencies in the range of 3kHz – 300GHz; broadcast radio (telecomms radio) covers VHF and part of UHF band: 30MHz – 1GHz.

Advantages:

-good wave propagation, low reflection and refraction due to ionosphere

-line-of-sight transmission obeys same law as terrestrial microwave; an usual value for radio repeaters: 20km

Drawbacks:

-multipath interference, due to reflections from land, water, natural and human-made objects.

-radio transmissions allow up to 20Mhz analog signal bandwidth and up to 10Mbps digital signal data rate

Infrared

Infrared comms are based on modulated infrared light, using transceivers; use of THz frequency range; only line-of-sight transmissions => rigid station alignment or passive surface reflections => no interferences, due to impossibility to penetrate surfaces => good enough analog signals bandwidth or digital data rate (LANs at 16Mbps).

No licences for use of infrared channels.

Elements of Structured Cabling

A **structured cabling system** (SCS), featuring the open architecture, is a set of cabling and connectivity products that integrates the voice, data, video, and various management systems of a building.

A **BMS** (Building Management System) consists of:

-safety, life & fire alarms

-security and access control (SAC)

-energy systems (EMS)

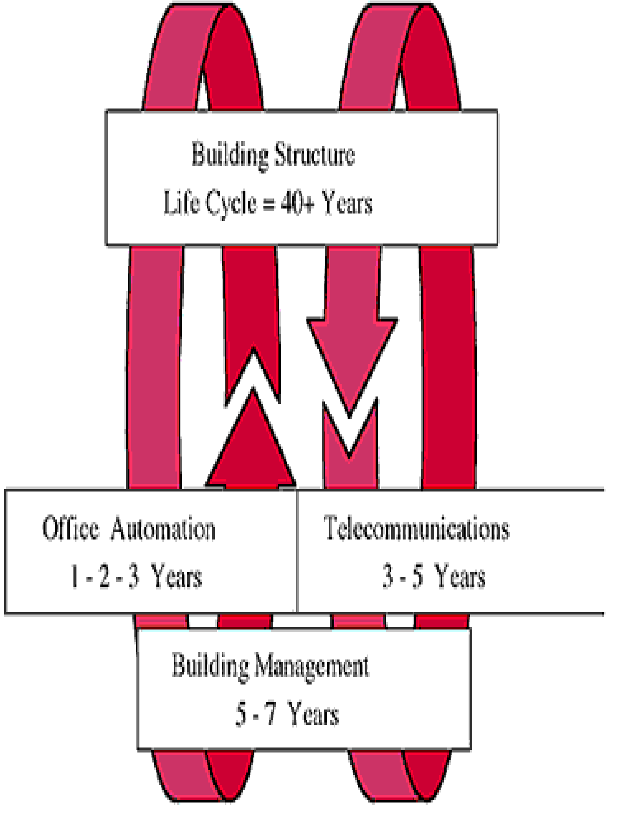
-heating, ventilation and air conditioning (HVAC)

Usually were cabled separately and voice & data cabling isn't addressed during construction.

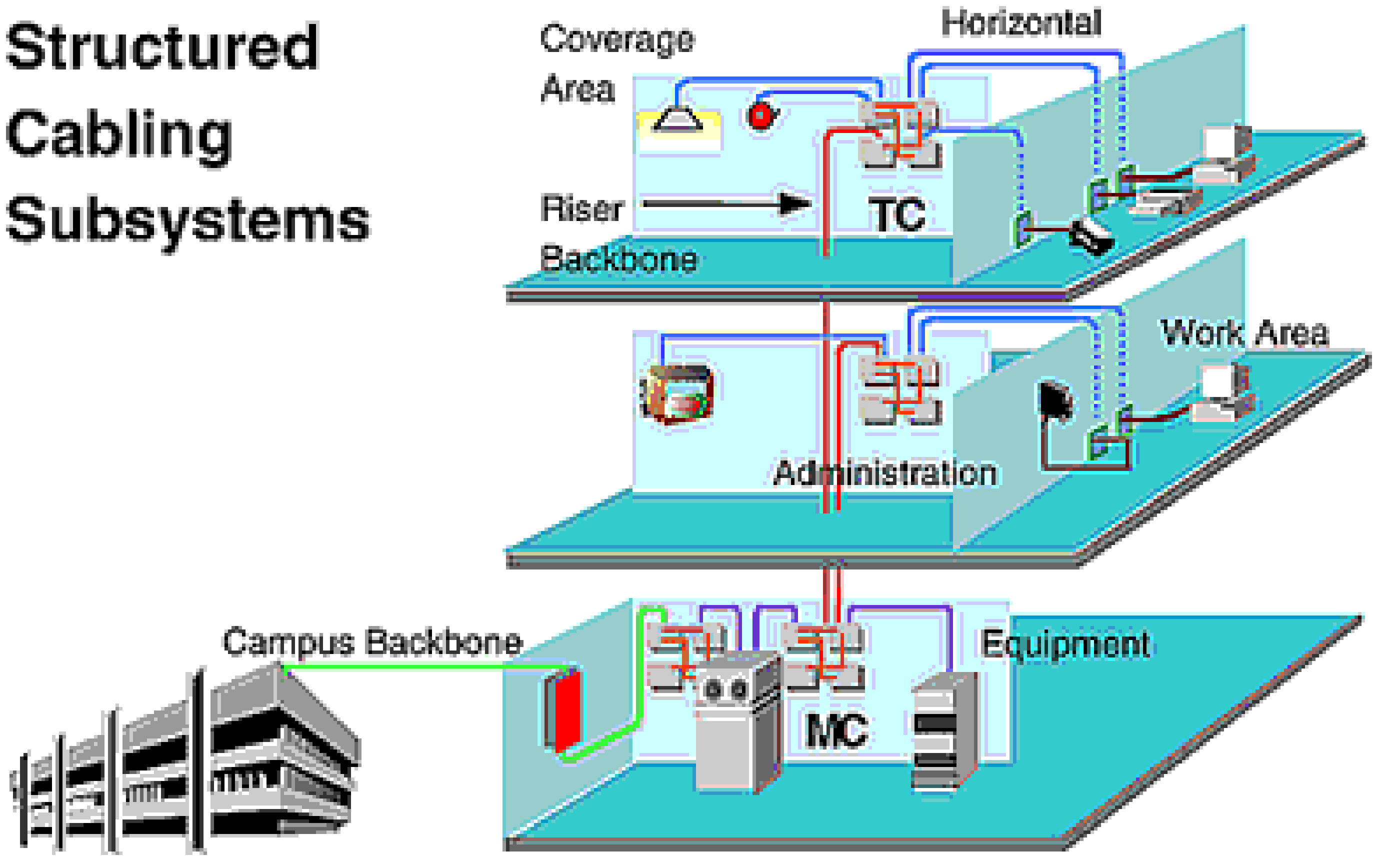
Planning and installing the SCS from this phase => lower construction, labour and operational costs.

With proper planning, it is not necessary to provide new cabling every time systems are changed or upgraded.

(after International Engineers Consortium).



The **Electronic Industries Association/Telecommunications Industry Association** (EIA/TIA) and **International Standards Organization/ International Electrotechnical Commission** (ISO/IEC) have created industry standards for cabling voice and data systems (EIA/TIA 568, 570, or ISO/IEC 11801).
These standards address the cabling and cable-delivery methods (pathways and spaces) and are based on a **structured subsystem architecture** of cabling elements.



TIA/EIA Standards

TIA/EIA-568A	Commercial Building Telecommunications Cabling Standard
TIA/EIA-569A	Commercial Building Standard for Telecommunications Pathways and Spaces
TIA/EIA-570A	Residential and Light Commercial Telecommunications Wiring Standard
TIA/EIA-606	Administration Standard for the Telecommunications Infrastructure of Commercial Buildings
TIA/EIA-607	Commercial Building Grounding and Bonding Requirements for Telecommunications

Sample case study: EIA/TIA 568A *(Commercial Building Telecommunications Cabling Standard);* applicable to campus, medium companies, etc.

Used when designing a company LAN.

The standard specifications concern:

-the minimal requirements for cabling a building with a given number of offices

- -the cabling topology and the allowed distances
- -the components of the cabling system
- -the transmission media and their characteristics
- -the vertical cabling
- -the horizontal cabling
- -the cable identification manner
- -the necessary documentation of the project.

Are defined a number of subsystems:

-building entrance facilities

-equipment room

-backbone cabling (vertical cabling)

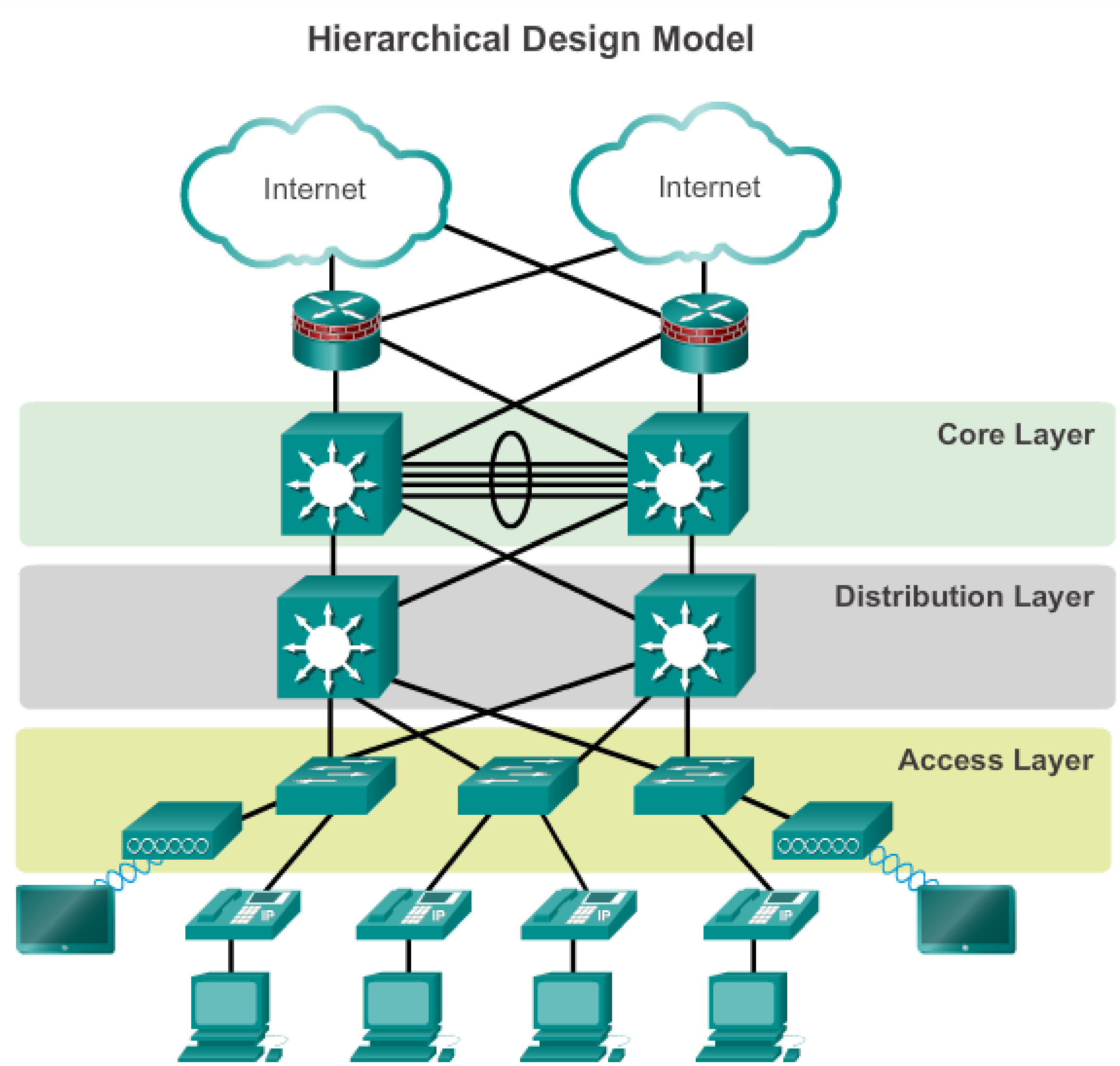
-telecommunication closet

-horizontal cabling

-work area’s components

Minimum Requirement
-maximum linear covered distance of 3.000m
-maximum surface of the cabling area of 1.000.000 sqm.
-maximum number of employees of 50.000
-minimum validity of the project of 10 years.

Cabling Topology
Topology: **hierarchical star** (star topology allows flexibility, the ring or bus topologies easy to be shaped as a star.
Center of the star is the **main cross connect** (MC), designed for the whole cabled area.
Second hierarchical level, the **intermediate cross connect** (IC), belongs usually to one building from the cabling area.
The third level is the **telecommunication closet** (TC), associated to a floor from a building, or to a group of working rooms.


Hierarchical Design Model
Internet
Internet
Core Layer
Distribution Layer
Access Layer
IP
IP
IP
IP

Constitutive Cabling Components

-main crossconnect (MC)-star center, a distribution center of main cables for other buildings or other cabling levels

-**intermediate crossconnect** (IC)- local to each building, a ‘one by floor’ distribution closet

-**telecommunication closet** (TC) – cabling toward workstations, more on a floor; contains the patch panels

-**intrabuilding backbone** – cabling between ICs and local TCs

-**interbuilding backbone** – cabling between MC and other buildings

-**equipment room**, local to a cabling level; contains passive equipments (switching panels, cable ducts, measurement equip.), or active equip. like telephone central point, audio-video, LAN switches

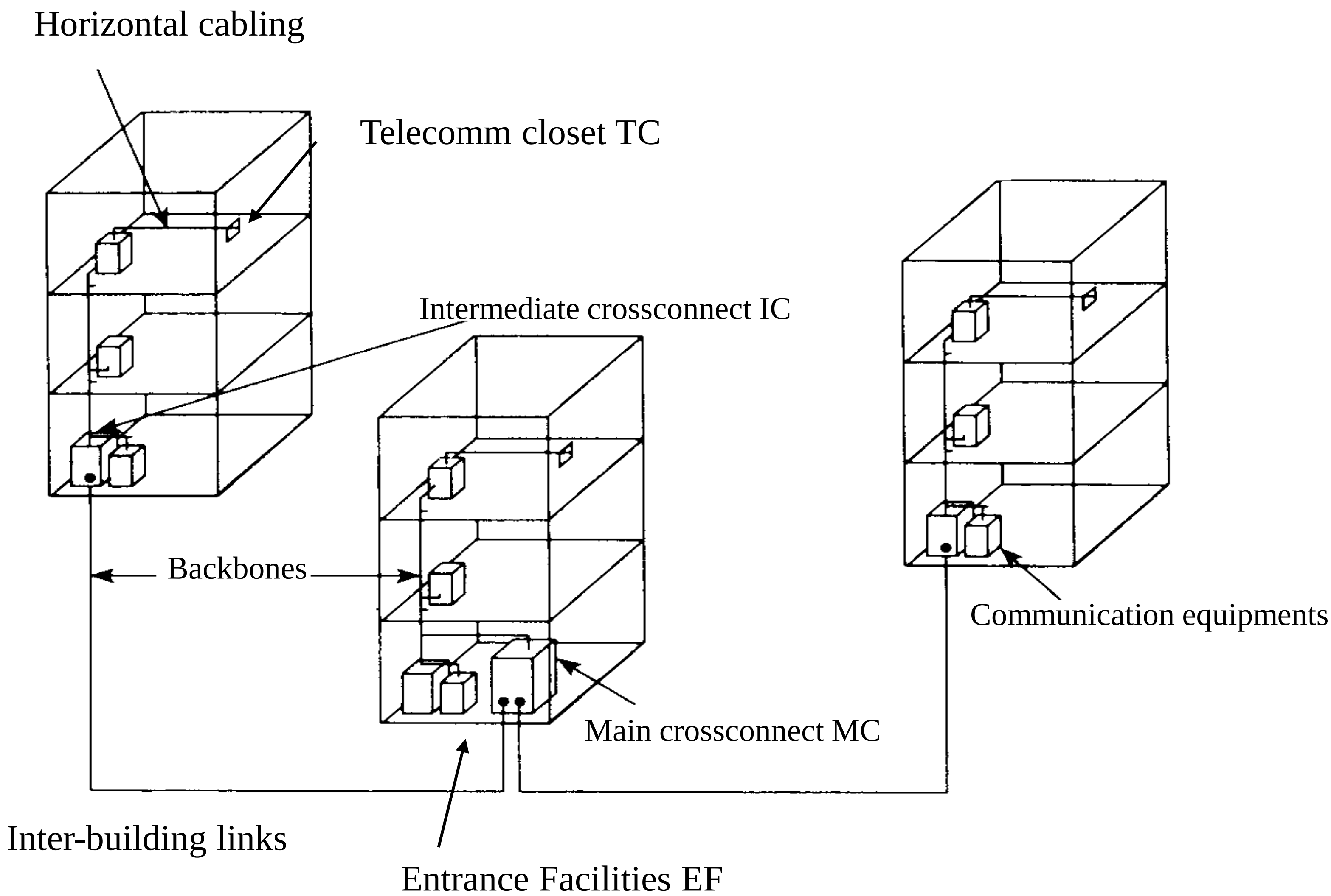
- **interbuilding entrance facility**, interface between outside cabling and inside backbone, especially grounding facilities

-**work area**, identifies workstations, associated patch + drop cables, adapters

-**patch panels**, switching panels for coax or UTP, or barrel panels for fiber optic

-**telecommunication outlets**, connect workstations to the cabling system

-**cabling adapters**, both passive or active


Horizontal cabling
Telecomm closet TC
Intermediate crossconnect IC
Backbones
Communication equipments
Main crossconnect MC
Inter-building links
Entrance Facilities EF

Transmission Media

Media accepted:

-**coax cable** of 50ohm, known as normal Ethernet cable (less used today)

-**multimode fiber** optic with the 62,5/125 μm diameters

-**single-mode fiber** at 8,3/125μm

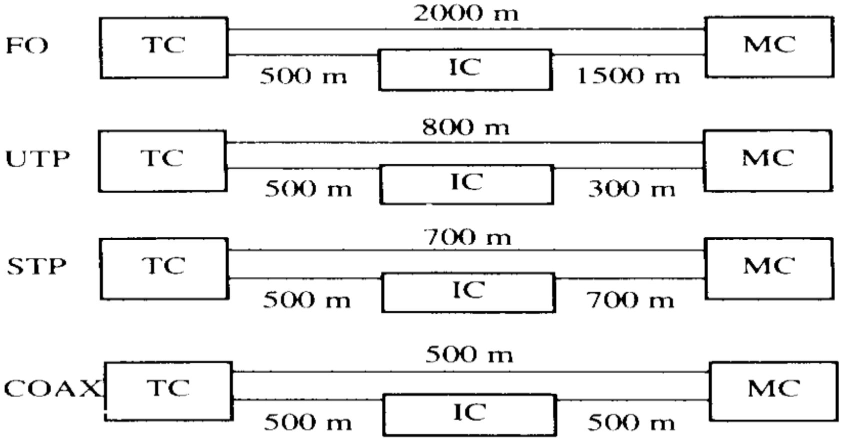
-**twisted pair cables**, either:

-UTP (*unshielded twisted pair*) with an impedance of 100Ω

-STP (*shielded twisted pair*) with impedance of 150Ω.

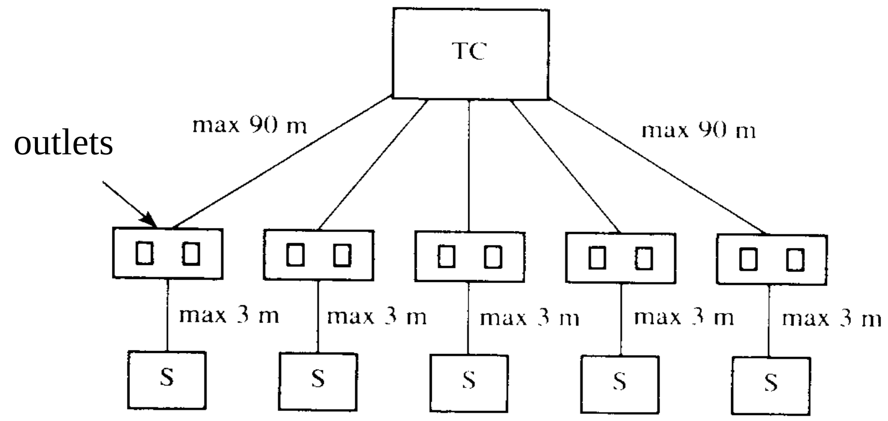
Vertical Cabling

Concerns inter & intra building backbones, specifying the maximum cable lengths, either directly from a TC to the MC, or using an IC



Horizontal Cabling

Specifies connections (cables, their allowed maximum lengths, connectors) between the workstations and the local distribution closet (TC); the figure shows the drop cables from the workstation to outlet and the runs from outlets to local TC.



Some types of used connectors:

-RJ45 connector for 4-wire UTP cables

-fiber optic connectors as ST and SC

-BNC connectors for coax

-hermaphrodite connector for STP

Installation Directives

-cable installation (maximum admitted force/cable, mechanical manner of connecting the wires)

-under-carpet horizontal cabling (distance between power and data lines, necessary shielding)

-ground protection for the electric wires or the specific protection for the fiber optics

Cable identification

For each cable a label with an alphanumeric string, containing information about:

- the area within the building where cable is located
- the number of the floor where is located the local distribution closet
- the numerical identifier of the workstation
- the numerical identifier of the local distribution closet.

Project Documentation

Use of standard terminology and notations.

Must include:

- the logic drawing of the cabling system
- the table for the vertical runs identification
- the table for each local distribution closet, for a complete cable identification.

Logic drawing of cabling