



Introduction to Optical Fibre Principles



Wavelength and Spectra

- **Wavelength:**

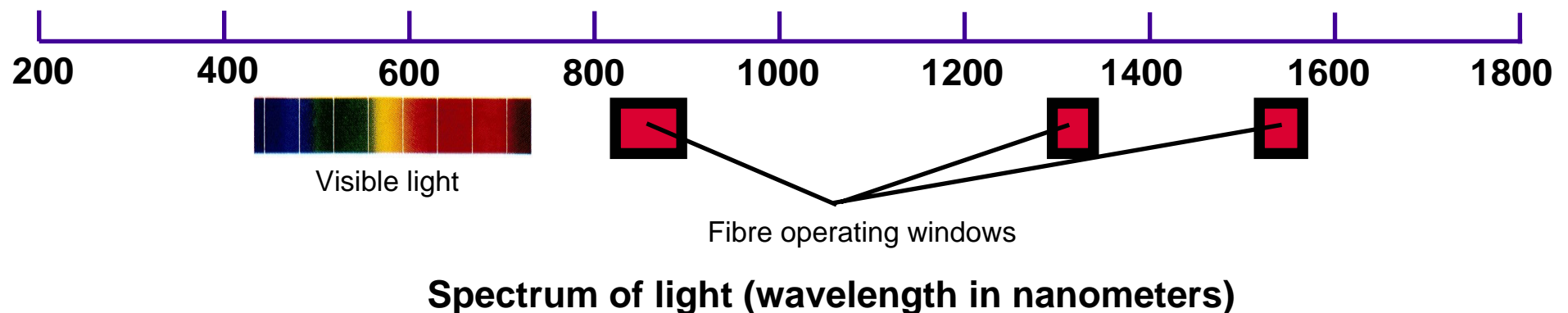
- f* Light can be characterised in terms of its wavelength

- f* Analogous to the frequency of a radio signal

- **The wavelength of light is expressed in microns or nanometers**

- **The visible light spectrum ranges from ultraviolet to infra-red**

- **Optical fibre systems operate in three IR windows around 800 nm, 1310 nm and 1550 nm**





Advantages and Disadvantages

Advantages

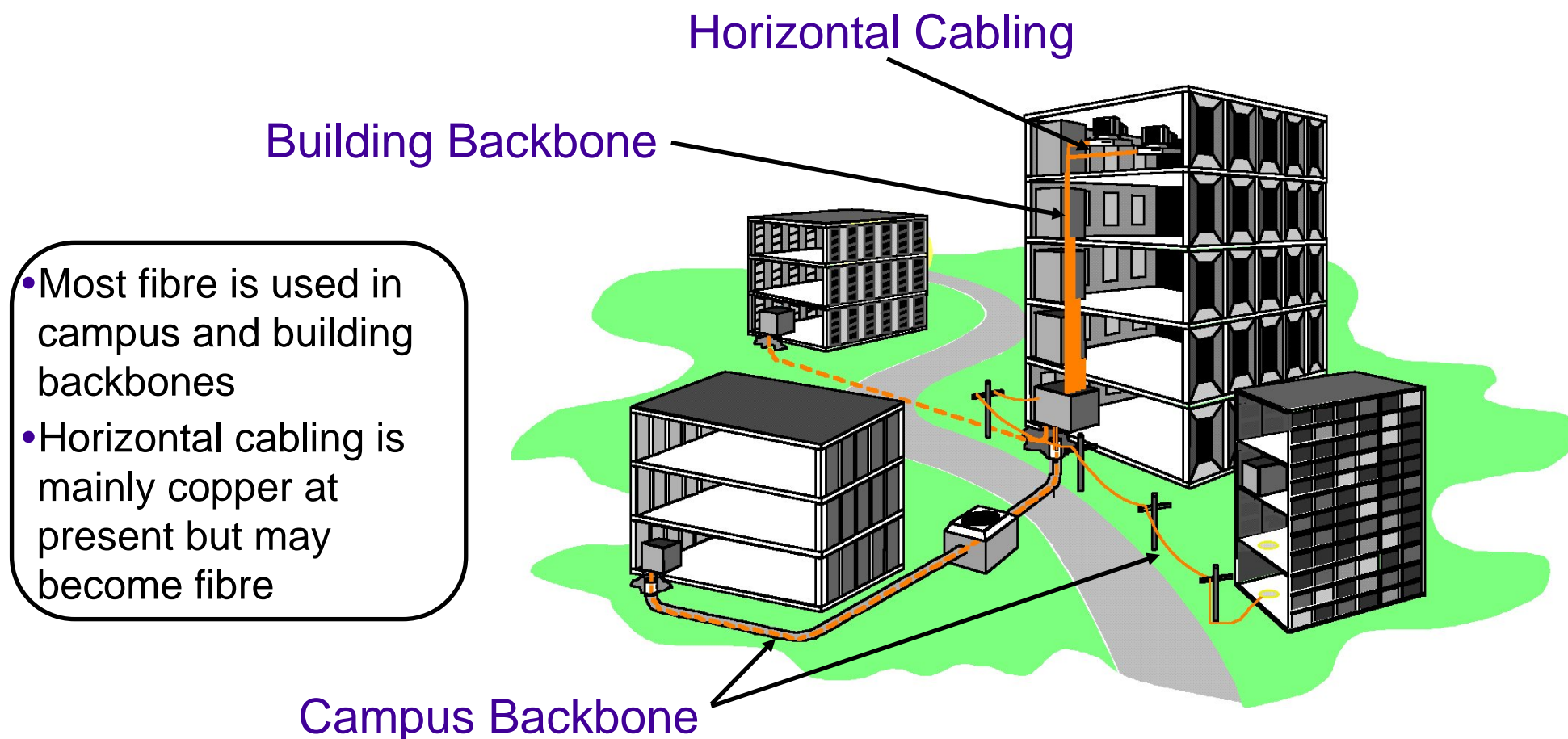
- Low attenuation, large bandwidth allowing long distance at high bit rates
- Small physical size, low material cost
- Cables can be made non-conducting, providing electrical isolation
- Negligible crosstalk between fibres and high security, tapping is very difficult
- Upgrade potential to higher bit rates is excellent

Disadvantages

- Jointing fibre can be more difficult and expensive
- Bare fibre is not as mechanically robust as copper wire
- Fibres are not directly suited to multi-access use, alters nature of networks
- Higher minimum bend radius by comparison with copper

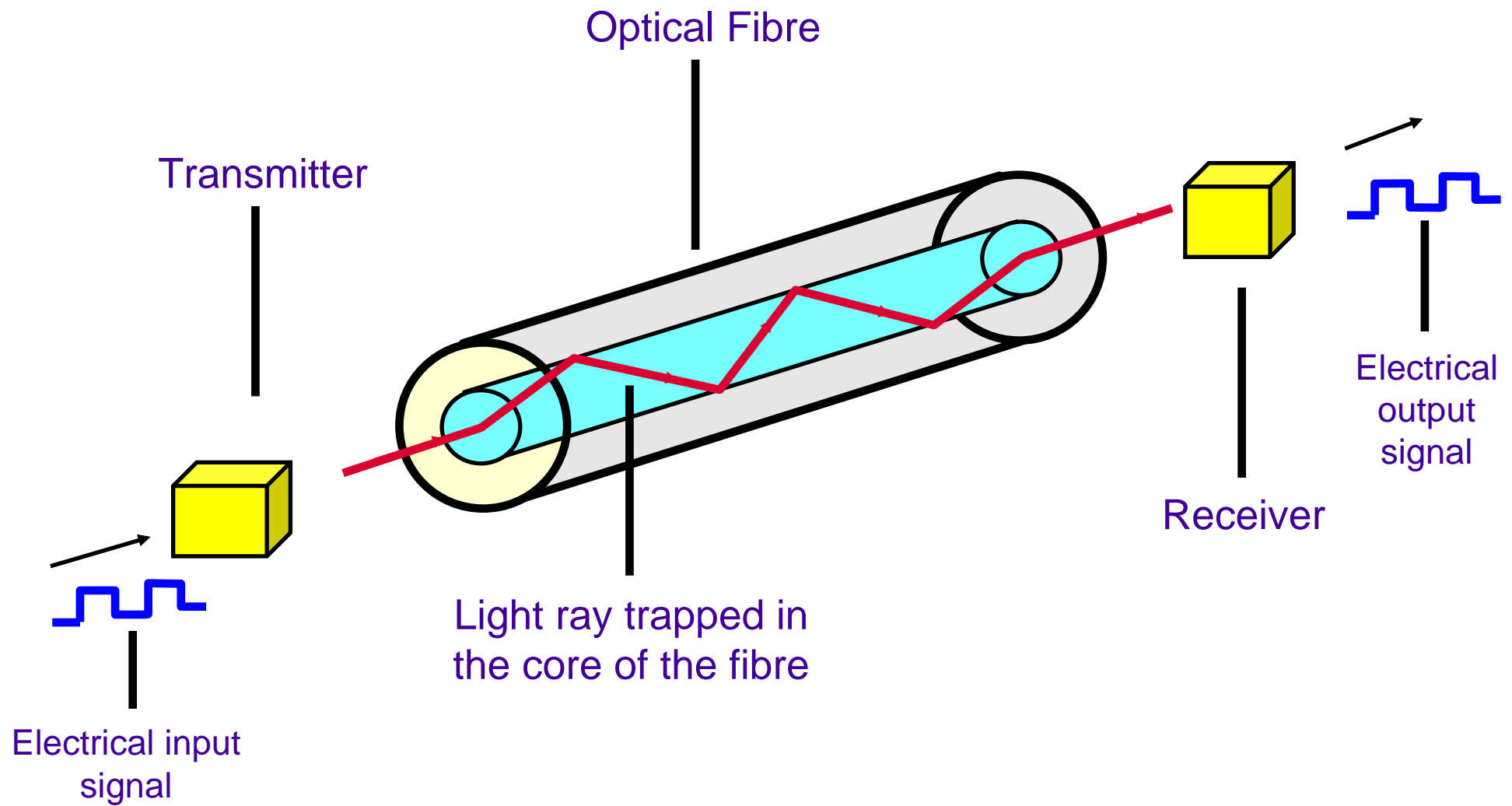


Applications for Fibre in Buildings





How does Light Travel in a Fibre?





Decibels and Attenuation

Basic decibel power equation relates two absolute powers P_1 and P_2 :

$$\text{Power ratio in dB} = 10 \log_{10}[P_1/P_2]$$

In a fibre or other component with an input power P_{in} and an output power P_{out} the loss is given by:

$$\text{Loss in dB} = 10 \log_{10}[P_{\text{out}}/P_{\text{in}}]$$

By convention the *attenuation* in a fibre or other optical component is specified as a positive figure, so that the above formula becomes:

$$\text{Attenuation in dB} = -10 \log_{10}[P_{\text{out}}/P_{\text{in}}]$$



Absolute power in Decibels

- It is very useful to be able to specify in dB an absolute power in watts or mW.
- To do this the power P_2 in the dB formula is fixed at some agreed reference value, so the dB value always relates to this reference power level.
- Allows for the easy calculation of power at any point in a system

Where the reference power is 1 mW the power in an optical signal with a power level P is given in dBm as:

$$\text{Power in dBm} = 10 \log_{10} [P/1\text{mW}]$$

For example 2 mW is +3 dBm, 100 μ W is -10 dBm and so on. Negative dBm simply means less than 1 mw of power. 1 mW is 0 dBm



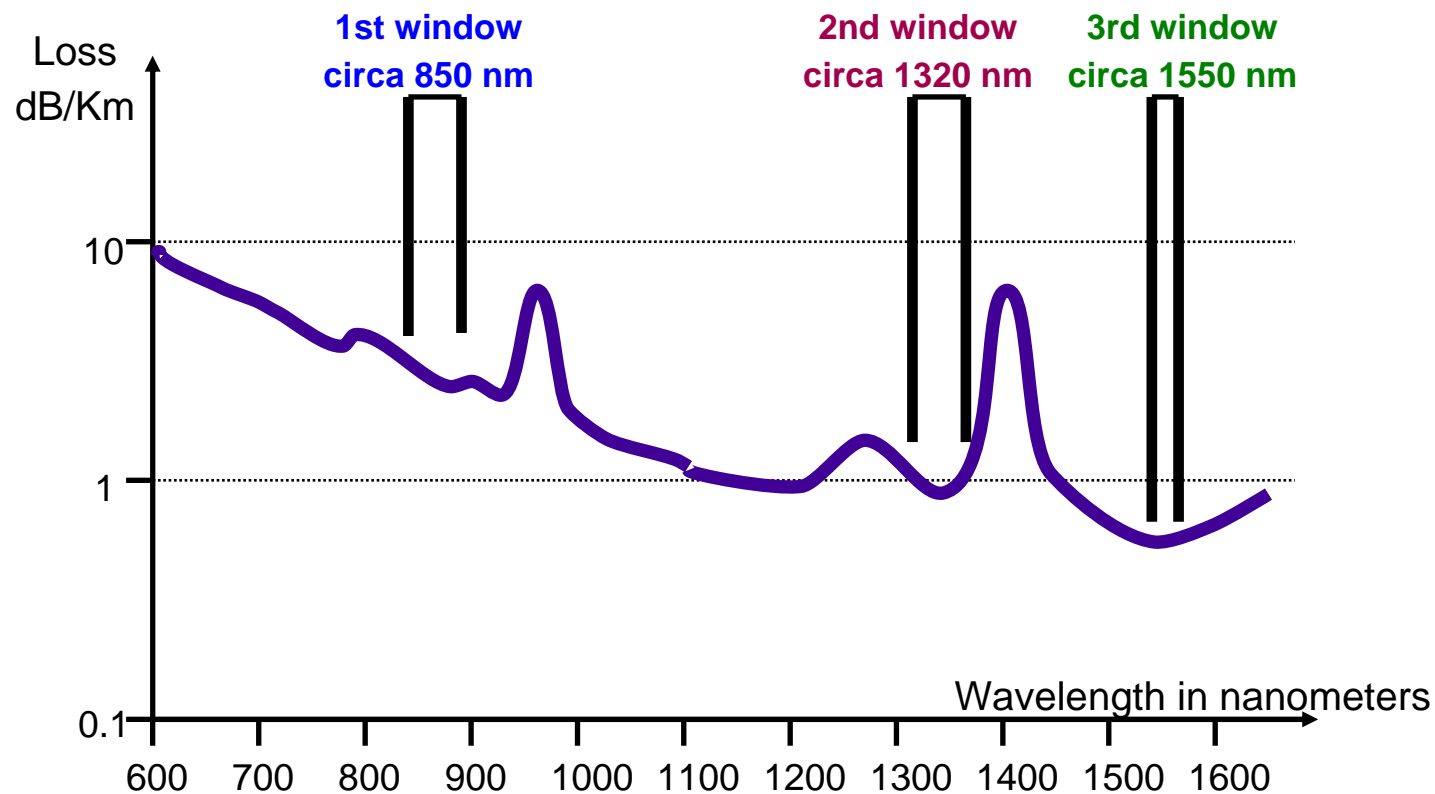
Watts to dBm Conversion Table

Power (watts)	Power (dBm)
1 W	+30 dBm
100 mW	+20 dBm
10 mW	+10 dBm
5 mW	+7 dBm
2 mW	+3 dBm
1 mW	0 dBm
500 μ W	-3 dBm
200 μ W	- 7 dBm
100 μ W	-10 dBm
50 μ W	-13 dBm
10 μ W	-20 dBm
5 μ W	-23 dBm
1 μ W	-30 dBm
500 nW	-33 dBm
100 nW	-40 dBm



Attenuation in Fibre: Transmission Windows

- Three low loss transmission windows exist circa 850, 1320, 1550 nm
- Earliest systems worked at 850 nm, latest systems at 1550.



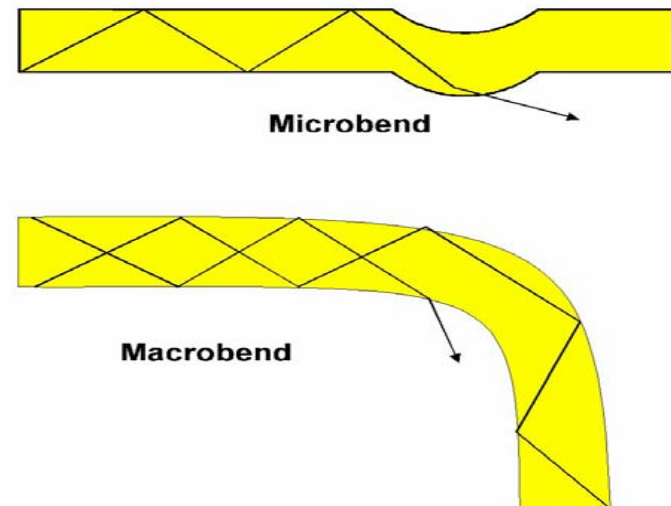


Bending Loss in Fibres

- At a bend the propagation conditions alter and light rays which would propagate in a straight fibre are lost in the cladding.
- Macrobending, for example due to tight bends
- Microbending, due to microscopic fibre deformation, commonly caused by poor cable design

Microbending is commonly caused by poor cable design

Macrobending is commonly caused by poor installation or handling



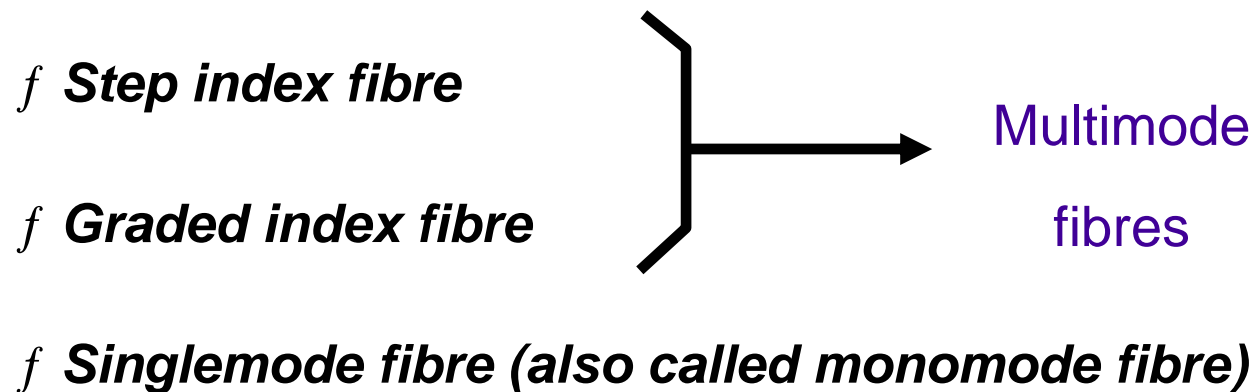


Fibre Dispersion and Bandwidth



Types of Optical Fibre

- Three distinct types of optical fibre have developed
- The three fibre types are:





Dispersion in an Optical Fibre

- Fibre type influences so-called "Dispersion"
 - The higher the dispersion the lower the fibre bandwidth
 - Lower fibre bandwidths mean less information capacity
-

Modal Dispersion:

Reduced by using graded index fibre

Eliminated by using singlemode fibre

Material Dispersion:

Reduced by using Laser rather than LED sources

Reduced by operating close to 1320 nm



Multimode Fibre Bandwidth (I)

- Combination of modal and material dispersion limits fibre bandwidth
- Dispersion is rarely specified, bandwidth is more useful
- Typically stated as MHz.km
- For example TIA/EIA-568-A specifies 500 MHz.km minimum for backbones in the 1300 nm window
- Bandwidths range from about 400 MHz.km to 1000 MHz.km.
- 50/125 μm fibre will have higher bandwidth than 62.5/125 μm fibre

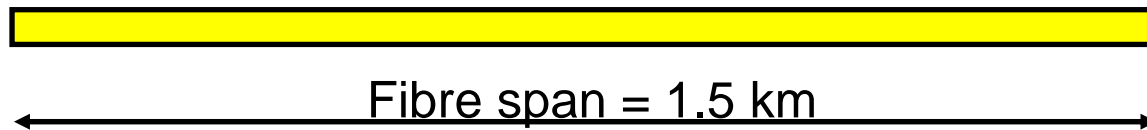


Multimode Fibre Bandwidth (II)

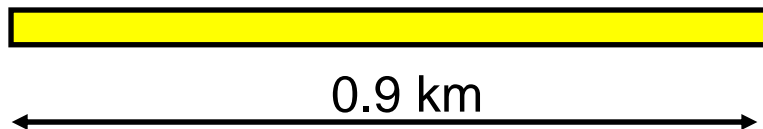
- To find the bandwidth of a fibre span, divide the bandwidth in MHz.km by the fibre span in km.
- The longer the fibre span, the lower the overall bandwidth.

Example:
MHz.km

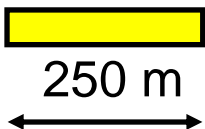
Assume a fibre bandwidth of 600



Overall bandwidth = 375 MHz



Overall bandwidth = 666 MHz



Overall bandwidth = 2400 MHz



Multimode Fibre Bandwidth and Bit Rate in LANs

- Relationship between available bandwidth and maximum bit rate is complex
- For LANs and building cabling systems rule is:

$$\text{Maximum bit rate in MB/s} = \frac{\text{Fibre bandwidth in MHz.km}}{2 \times \text{Fibre span in km}}$$

- Rule is conservative, assumes zero dispersion penalty is required
- For example for a 500 MHz.km over 2000 m the maximum bit rate is 125 MB/s
- In practice use a fibre that exceed the standards for a given LAN to ensure adequate bandwidth



- **Optical fibre systems utilise infrared light in the range 700 nm to 1600 nm**
- **Fibre has a number of significant advantages**
- **Building fibre systems operate around 1320 nm**
- **Multimode fibres suffer from modal and material dispersion**
- **Material dispersion is minimised by operating near 1320 nm**
- **Singlemode fibre eliminates material dispersion**



Fibre Types and Fibre Termination

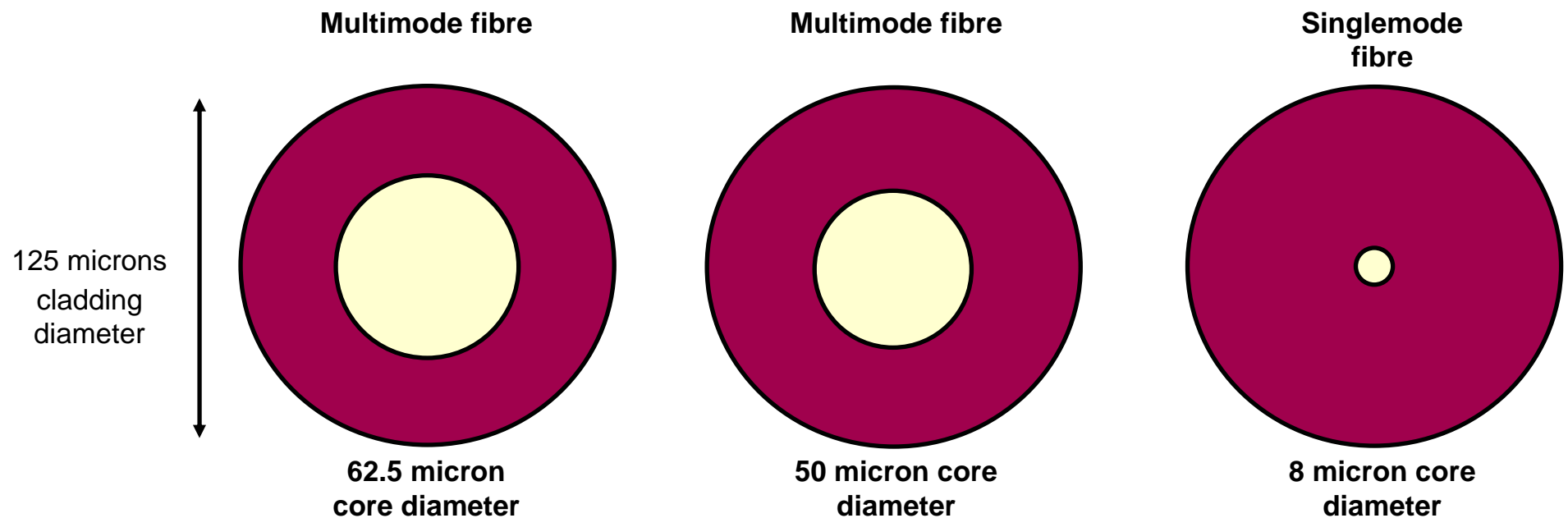


- **Fibre types**
- **Basic fibre protection**
- **Basic cable construction**
- **Typical cables for different applications**
- **Fibre termination in buildings**
- **Fibre connectors, fusion and mechanical splices**



Fibre Types

- Three generic fibre types dominate the building cable market
- Multimode is most popular but singlemode is now being installed more frequently
- Multimode is more tolerant of source and connector types
- Singlemode offers the largest information capacity

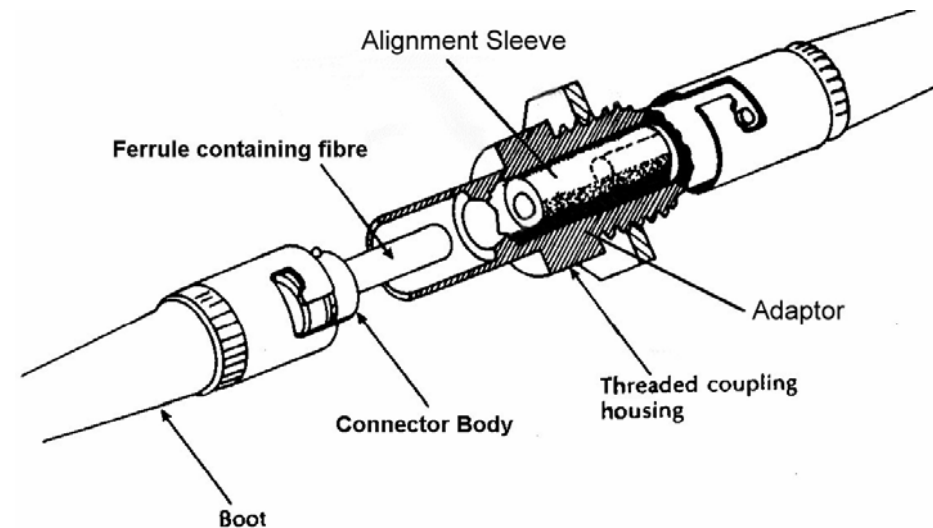




Standards for Fibre Joints in Buildings

- For connectors maximum mated pair connector attenuation is 0.75 dB
- Different colour coding for multimode and singlemode connectors
- Maximum splice loss for fusion or mechanical is 0.3 dB

Mated pair of ST type
Optical Connectors

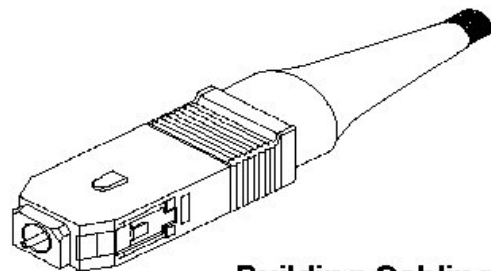




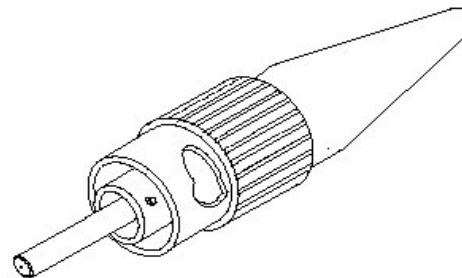
Building Cabling Connectors and Standards

- Presently the ST-compatible connector is the most commonly used connector for termination.
- The TIA/EIA-568-A, Standard specifies the Duplex SC (568SC) connector interface at all terminations at patchpanels and outlets.
- Standard provides a migration path option for users of ST-compatible connectors.
- The primary advantages of the 568SC connector are:
 - f* It is a duplex connector, which allows for the management of polarity.
 - f* It has been recommended by a large number of standards.
 - f* Most SC connectors offer a pull-proof feature for patch cords.

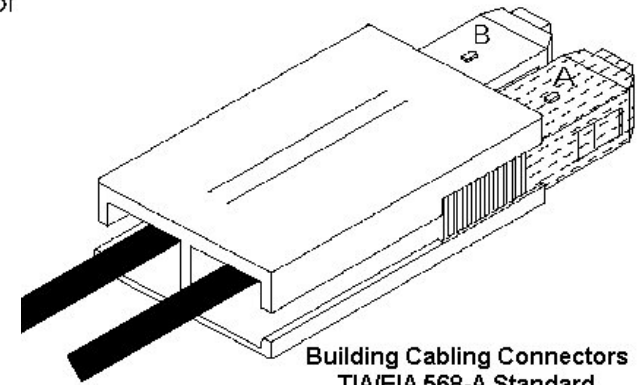
SC Connector



ST Compatible Connector



568SC (Duplex SC)



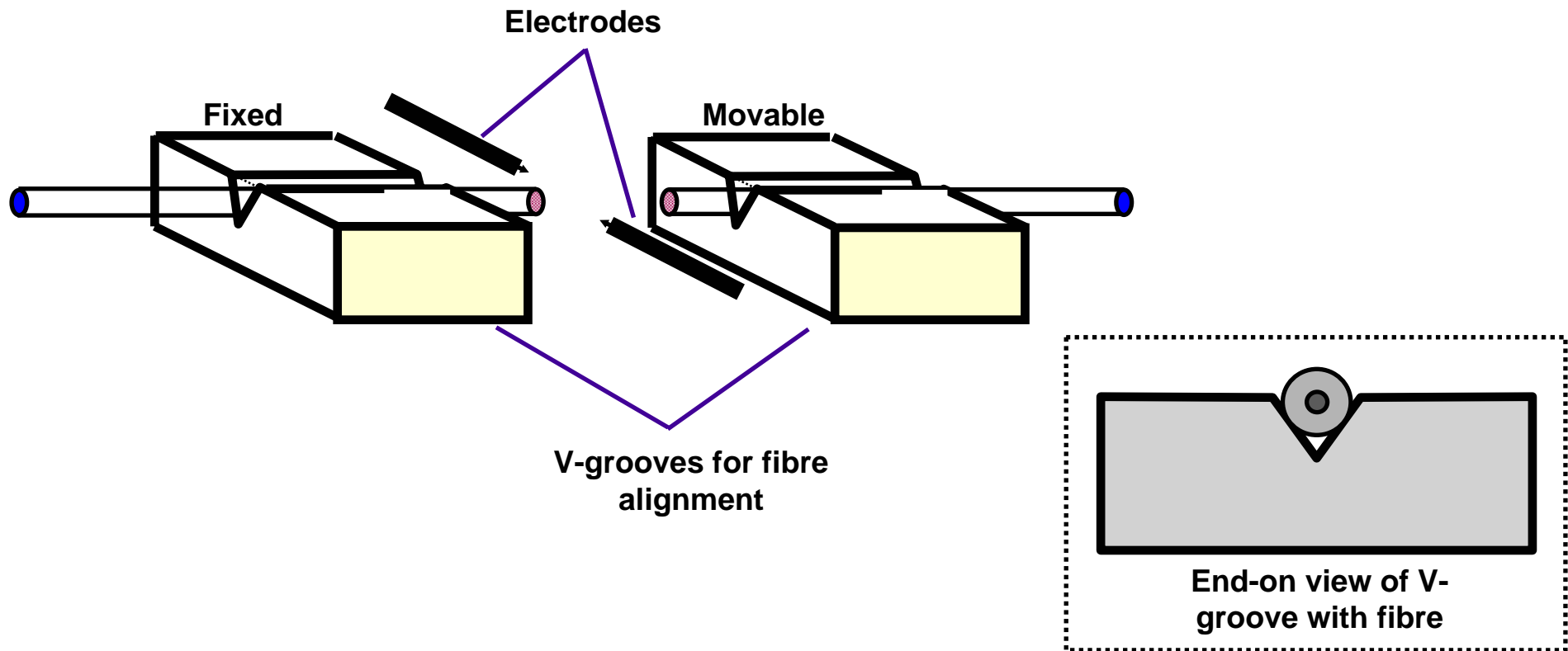
Building Cabling Connectors

Building Cabling Connectors
TIA/EIA 568-A Standard



Fusion Splice Principles

- Cleaved fibre ends are fused permanently together using an electric arc
- During splicing fibres are held in V-grooves for alignment
- A variety of splicers have developed to cater for multimode and singlemode fibre





Fusion Splicers: Northern Telecom Compact

- Fixed V-groove alignment
- Loss 0.05 dB (SM) and 0.02 dB (MM)
- Integral 4" LCD panel
- Automatic alignment of fibre cores
- 8 default splicing programmes
- Automatic proof test (220 grams) carried out after each splice
- Maximum splice loss for fusion or mechanical is 0.3 dB

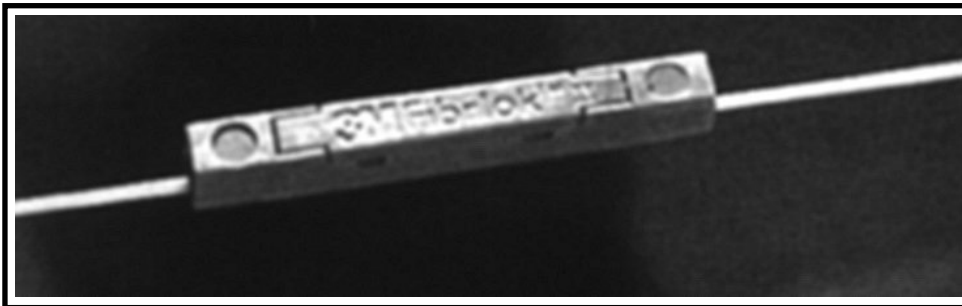


Northern Telecom Compact Splicer

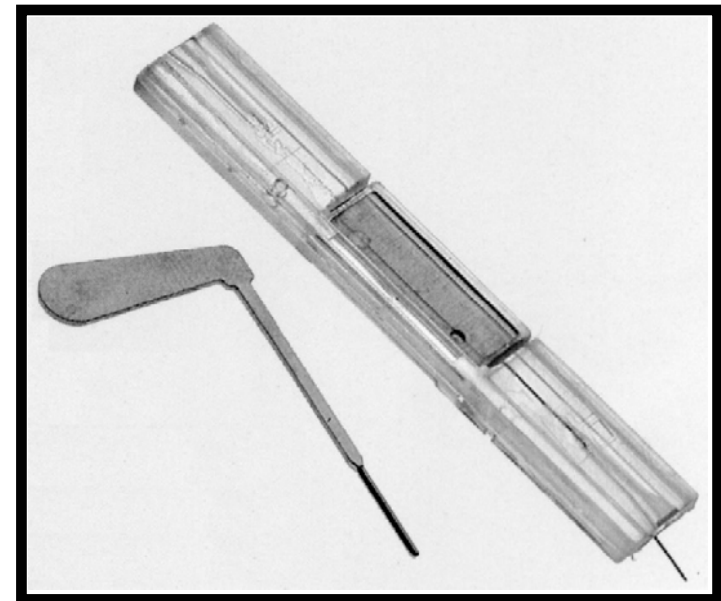


Mechanical Splices

- Wide variety of methods have been developed.
 - Impetus is to provide a "semi-permanent" low loss splice without complex equipment or local power sources
 - Loss now down to <0.05 dB.
-



3M Fibrlok II Splice



AMP Corelink Splice



Planning Fibre Systems: Standards & Power Budgeting



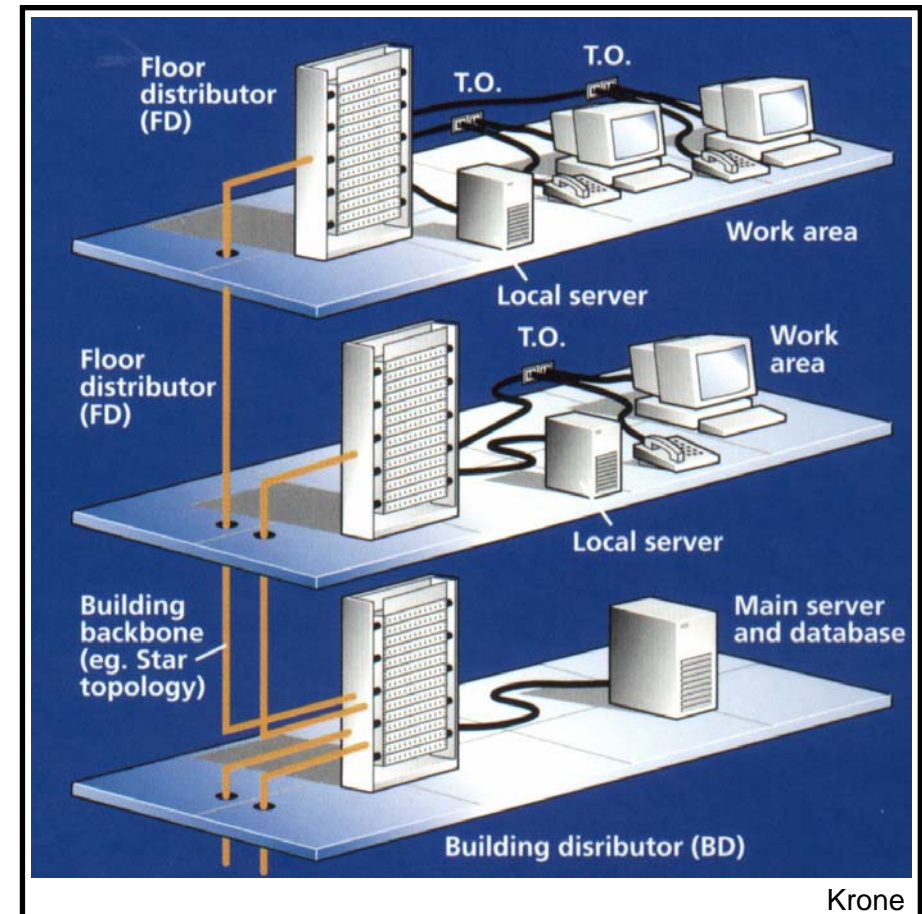
- **Relevant standards**
- **Power budget definition**
- **Power margins**
- **Sample exercises**



EN 50173: Functional Elements

A number of functional elements are defined:

- Campus Distributor (CD)
- Campus Backbone Cable
- Building Distributor (BD)
- Building Backbone Cable
- Floor Distributor (FD)
- Horizontal Cable
- Transition Point (optional) TP
- Telecommunications Outlet (TO)

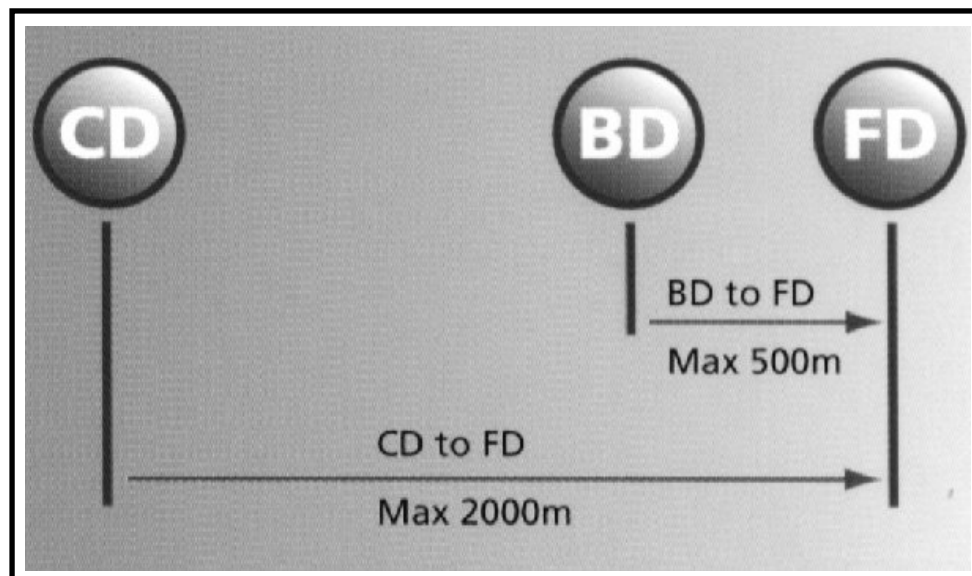




Maximum Distances

Maximum Multimode Fibre Distances as per EN 50173

Singlemode fibre increases CD to FD to 3000 m



Krone



EIA/TIA 568-A and Fibre

EIA/TIA 568-A 1995 Commercial Building Telecommunications Wiring Standard

- **Recognises 62.5/125 micron fibre for horizontal cabling**
- **Recognises 62.5/125 micron fibre and singlemode fibre for backbones**
- **Section 12 covers fibre specs**
- **Connector style recognised is SC but ST is allowed**
- **Maximum mated pair connector attenuation is 0.75 dB**
- **Different colour coding for multimode and singlemode connectors**
- **Maximum splice loss for fusion or mechanical is 0.3 dB**



Summary of EIA/TIA 568-A Fibre Specifications

Specification	Horizontal 62.5/125 μm	Backbone 62.5/125 μm	Backbone Singlemode
Atten @ 850 nm	3.75 dB/km	3.75 dB/km	-
Atten @ 1300 nm	1.5 dB/km	1.5 dB/km	0.5 dB/km (outside) 1.0 dB/km (inside)
Atten @ 1550 nm	-	-	0.5 dB/km (outside) 1.0 dB/km (inside)
Bandwidth (850 nm)	160 MHz.km	160 MHz.km	Not spec.
Bandwidth (1300 nm)	500 MHz.km	500 MHz.km	Not spec.
Fibres/cable recommended	Minimum 2 fibres/cable	6-12 fibres/cable	6-12 fibres/cable



Power Budgeting



Power Budget Definition

- Power budget is the difference between:

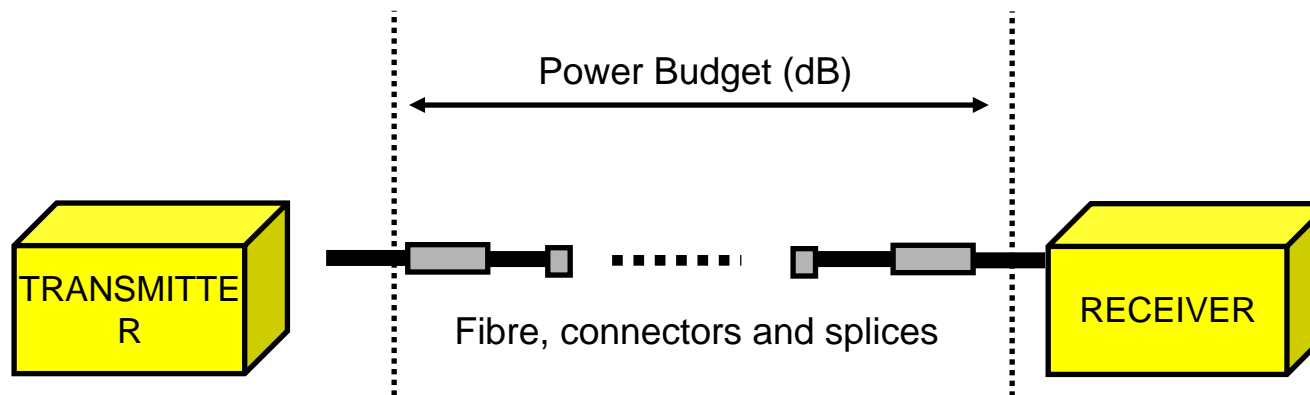
- f* The minimum (worst case) transmitter output power

- f* The maximum (worst case) receiver input required

- Power budget value is normally taken as worst case.

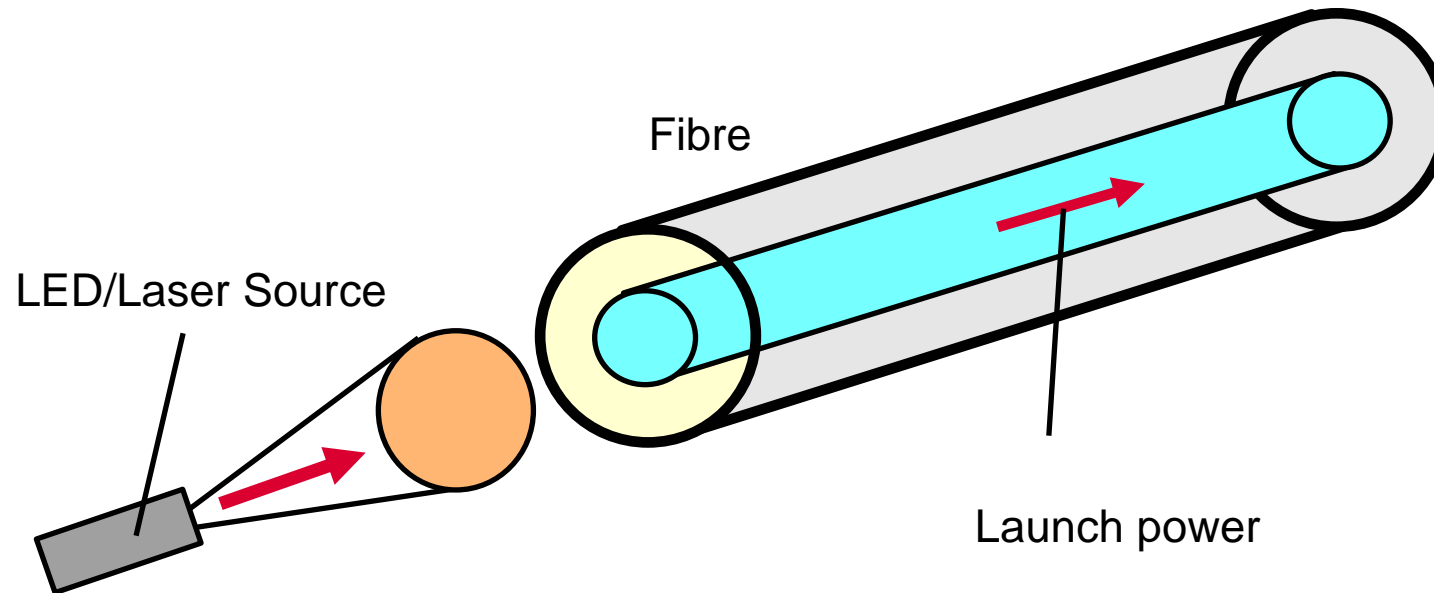
- In practice a higher power budget will most likely exist but it cannot be relied upon

- Available power budget may be specified in advance, e.g for 62.5/125 fibre in FDDI the power budget is 11 dB between transmitter and receiver





Launch Power



- Transmitter output power quoted in specifications is by convention the launch power.
- Launch power is the optical power *coupled into the fibre*.
- Launch power is less than the LED/Laser output power.
- Calculation of launch power for a given LED/Laser and fibre is very complex.



Power Margin

- **Power margins are included for a number of reasons:**
 - f* **To allow for ageing of sources and other components.**
 - f* **To cater for extra splices, when cable repair is carried out.**
 - f* **To allow for extra fibre, if rerouting is needed in the future.**
 - f* **To allow for upgrades in the bit rate or advances in multiplexing.**
- **Remember that the typical operating lifetime of a fibre system may be as high as 20 years.**
- **No fixed rules exist, but a minimum for the power margin would be 2 dB, while values rarely exceed 8-10 dB. (depends on system)**



Sample Power Budget Calculation (FDDI System)

Power budget calculation used to calculate power margin

Transmitter o/p power (dBm)	-18.5 dBm min, -14.0dBm max
Receiver sensitivity (dBm)	-30 dBm min
Available power budget:	11.5 dB using worst case value (>FDDI standard)
Number of Connectors	6
Worst case Connector loss (dB)	0.71
Total connector loss (dB)	4.26
Fibre span (km)	2.0
Maximum Fibre loss (dB/Km)	1.5 dB at 1300 nm
Total fibre loss (dB)	3.0
Number of 3M Fibrlok mechanical splices	10
Worst case splice loss per splice (dB)	0.19
Total splice loss (dB)	1.9
Total loss:	9.16 dB
Power margin (dB)	2.34 — Answer



Sample Exercises



Exercise 1

- The design for a building optical fibre link is as below. Calculate the power budget using the TIA/EIA component losses.
 - Operates at 850nm
 - Transmitter launch power
 - Max -15dBm
 - Min -18dBm
 - Receiver Sensitivity
 - Max -30dBm
 - Min -28dBm
 - 62.5/125 μm fibre
 - 4 Lengths, 500m, 300m, 150m and 800m.
 - Connector pairs
 - 2
 - Splices
 - 1



Exercise 1 cont'd

- Calculate the bandwidth of the system.
- What improvements would be made to the system if the operating wavelength is 1300nm.



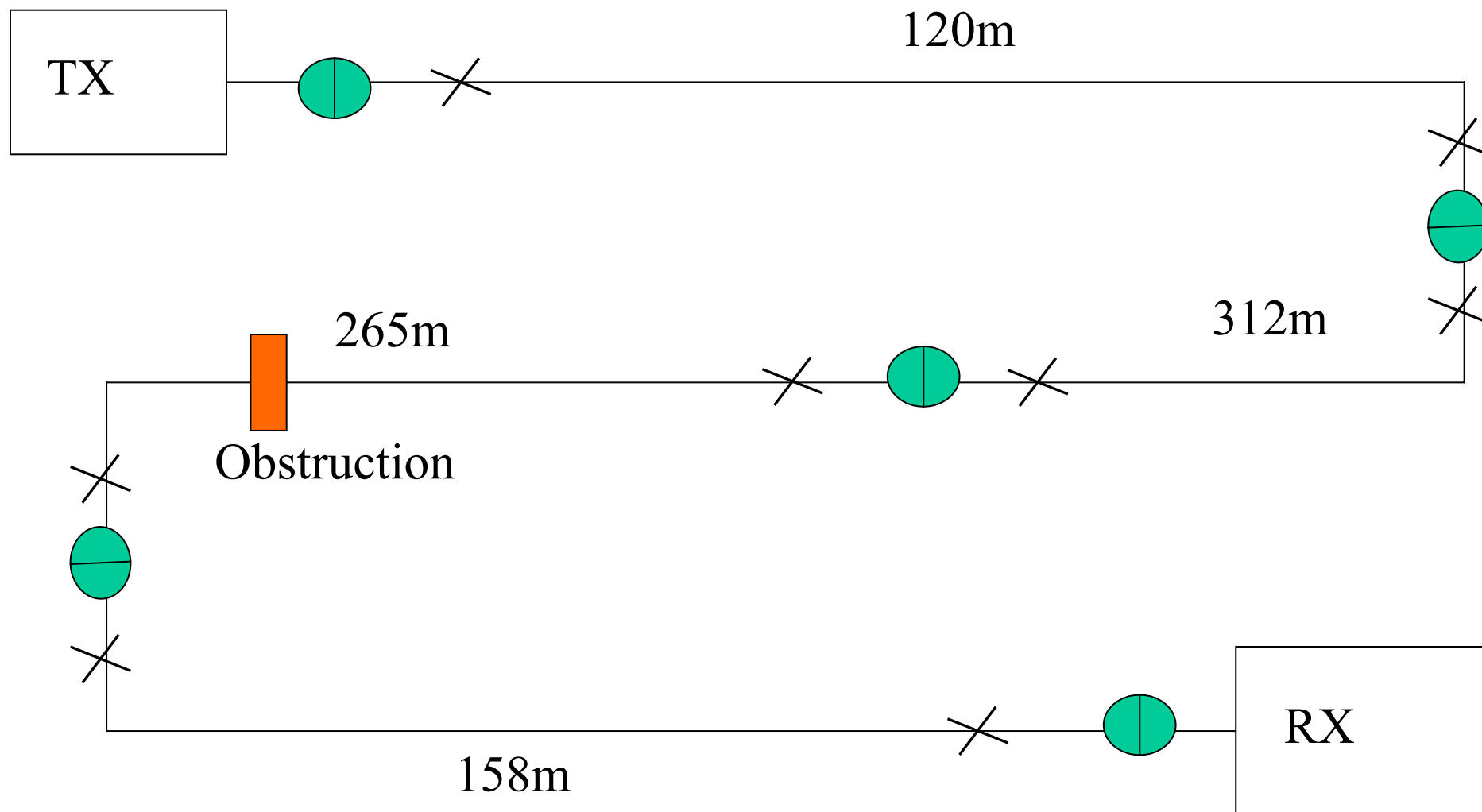
Exercise 2

- An optical link in a building and campus is to be the full 2000m length. Due to some restrictions the fibre must be installed in a number of shorter lengths. Calculate what are the minimum fibre lengths that can be installed if splices are used and then if connectors are used. A power margin of 2dB must be maintained.
 - Operates at 1300nm
 - Transmitter launch power
 - Max -8dBm
 - Min -10dBm
 - Receiver Sensitivity
 - Max -30dBm
 - Min -28dBm



Exercise 3

- The FDDI link between locations shown below needs to be extended and re-routed due to unforeseen building alterations.
 - The cable must be rerouted to avoid an obstruction
 - The new cable pathway around the obstruction is approximately 150m long
 - System is operating at 1300nm. Power budget is 11dB according to FDDI standard
- 1. Assuming all existing cable remains draw a new system diagram and determine if the system will work using TIA losses.
- 2. Assuming new cable can be pulled in (replacing the whole 265m length) what is the improvement in the power budget compared to one above.





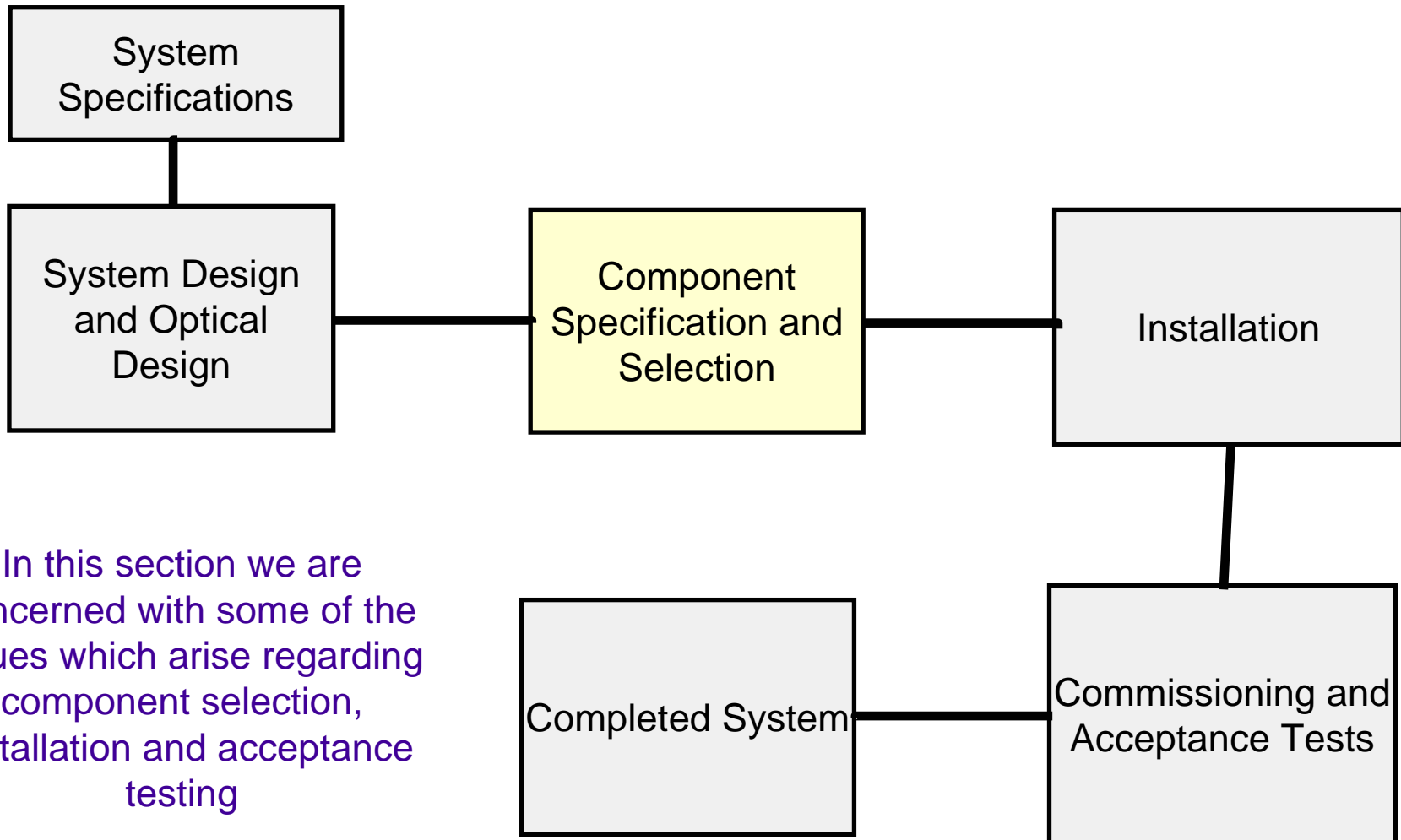
Specification and Other Issues



Component Specification and Selection



The Path from Specification to Completion





Component Selection

Component	Comment
Transceivers	FDDI, Fibre channel etc.. Laser v LED
Fibre	Core size and multimode v singlemode
Cables	Construction and fibre count
Enclosures	Rack and patchpanels, cable management
Cable fixings	Tray types, outdoor ducts
Connectors	ST , SC or small form factor (SFF) connectors
Termination method	Direct connection or fusion spliced v mechanical spliced pigtails
Ancillary	Adapters, pigtails, patchleads, fibre organisers etc..

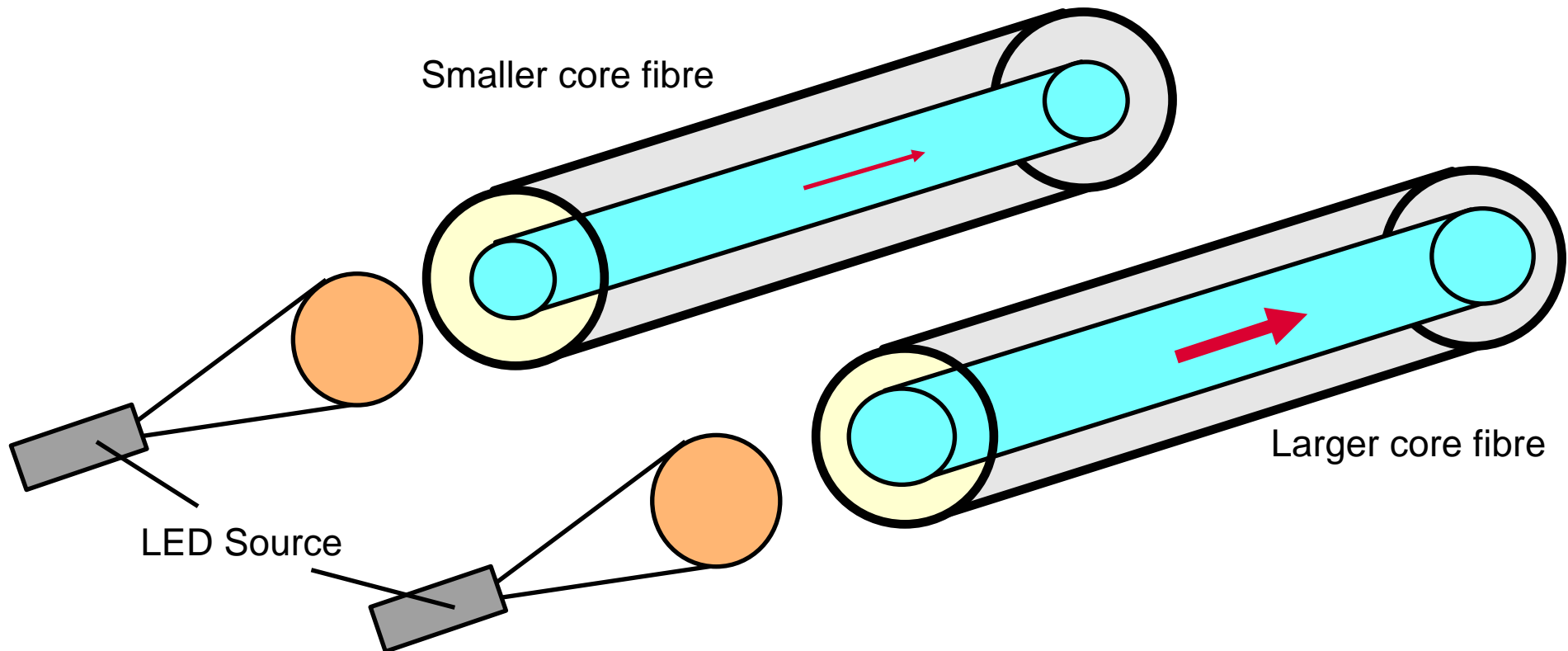


Multimode Fibre Choices

- Backbones can utilise multimode 50/125 μm , 62.5/125 μm or singlemode fibre
- 50/125 μm fibre have a lower input power by comparison with 62.5/125 μm fibre using the same LED transceiver: ***power budget impact***
- 50/125 μm fibre has a larger bandwidth than 62.5/125 μm fibre, typically 60% larger.
- 62.5/125 μm fibre will support in excess of 1 Gb/s up to 300 m. 90% of all building backbones are < 300 m long.



Coupling from LEDs into Multimode fibres



- Optical power coupled into the fibre depends on core diameter and numerical aperture
- Assume a 4.7 dB source coupling loss for the same LED source into 50/125 μm fibre compared to a 62.5/125 μm fibre



Multimode V Singlemode Fibre Choices

- LED transceivers cannot be used with singlemode fibre
- Singlemode uses Laser based transceivers, but will support all backbone lengths at multi-Gb/s
- Mix of multimode and singlemode possible,
- Mix allows LED/multimode today with upgrade to Laser/singlemode later without retrofit



Component Selection: Fibre Optic Cables

- Most effective method is to review installation and operating environment
- Aids include the FIA guidelines "Fibre Optic Cable Selection Guide, Document No. FIA/FCC/1/95"

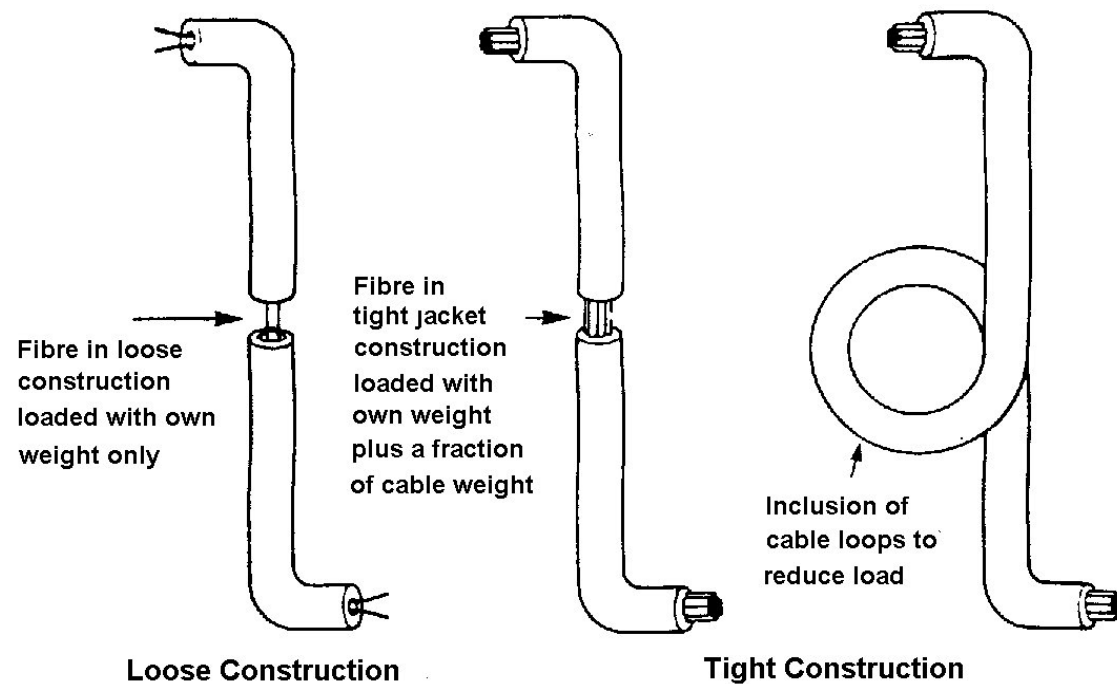
Other points to note are:

- For direct burial and external duct installation loose tube cable means lower fibre stress
- Internal horizontal runs need flexible cables so tight jacket cables are the norm
- Vertical runs need special care (see next overhead)
- All fibres must be uniquely identifiable
- Multimode and singlemode fibre may be accommodated in the same cable



Vertical Cabling

- Vertical runs need care. Tight jacket cables tend to result in the uppermost fibre span being loaded by cable weight, this favours loose tube
- For tight jacket cables use short horizontal runs or cable loops to reduce fibre load
- Loose tube cables has a problem with moisture protection gel oozing out of the cable tubes under gravity in external vertical cable runs





Multimode and Singlemode Fibres in Cables (I)

- Multimode AND singlemode cables may be installed together
- Singlemode is kept as dark fibre until used
- Provides future upgrade path
- Ratio of MM to SM fibres:
 - f* Optimal ratio depends on forecasted customer needs
 - f* Typically for customers forecasting gigabit applications the present advice is 30% singlemode
- Cables may be separate or composite, choice depends on a number of factors



Multimode and Singlemode Fibres in Cables (II)

Separate Cables:

- MM and SM are segregated in two separate cables
- Easier segregation, fewer installation errors
- Ease of segregation is particularly important in outdoor applications
- Occupies more physical space than a composite cable
- Separate patchpanels can be used to avoid confusion

Composite Cables:

- SM and MM share a single cable
- Occupies significantly less space
- May be more prone to installation errors,
- May require single patchpanel, causes confusion
- Limited availability and higher costs

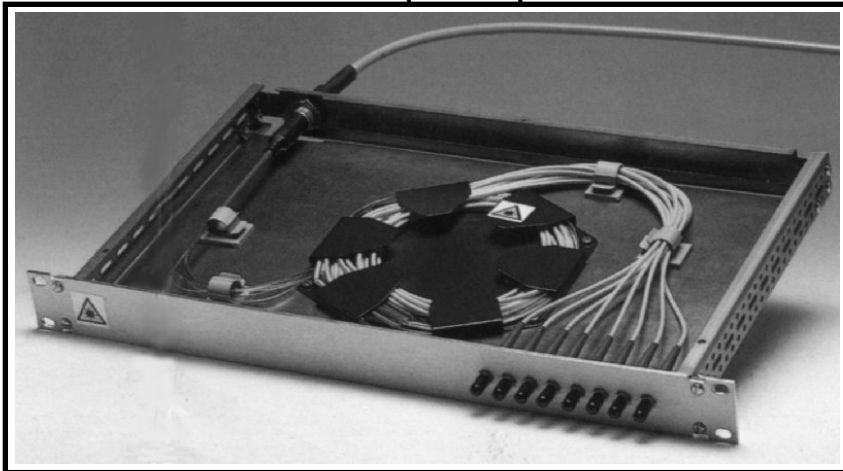


Enclosure Specification and Selection

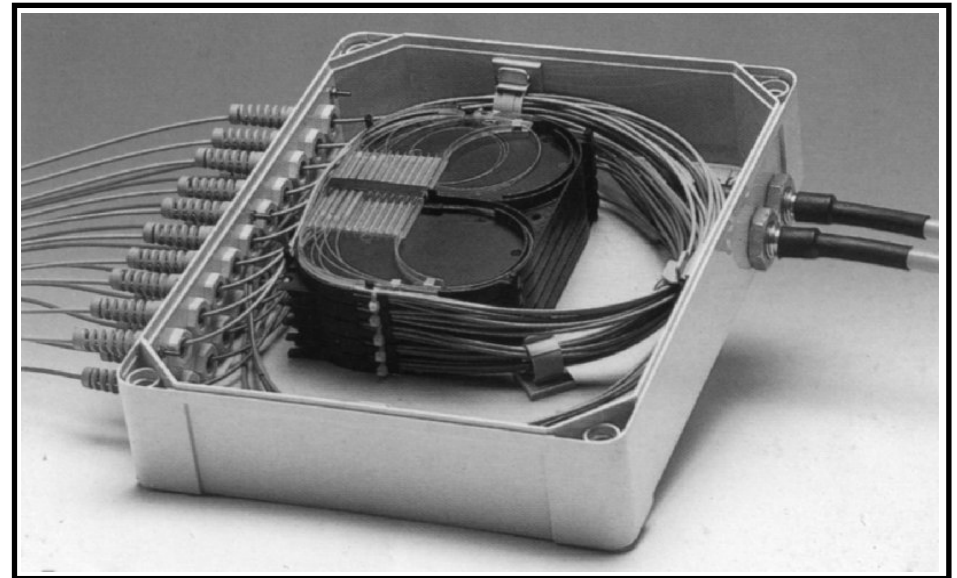
For enclosures selection is influenced by:

- Environmental factors such as temperature and humidity as well as vibration and moisture.
- Mounting requirements: rack based or wall mounted
- Location and access requirements. User interference, security
- Ease of maintenance and repair. Future upgrade potential

Focas 19" patchpanel



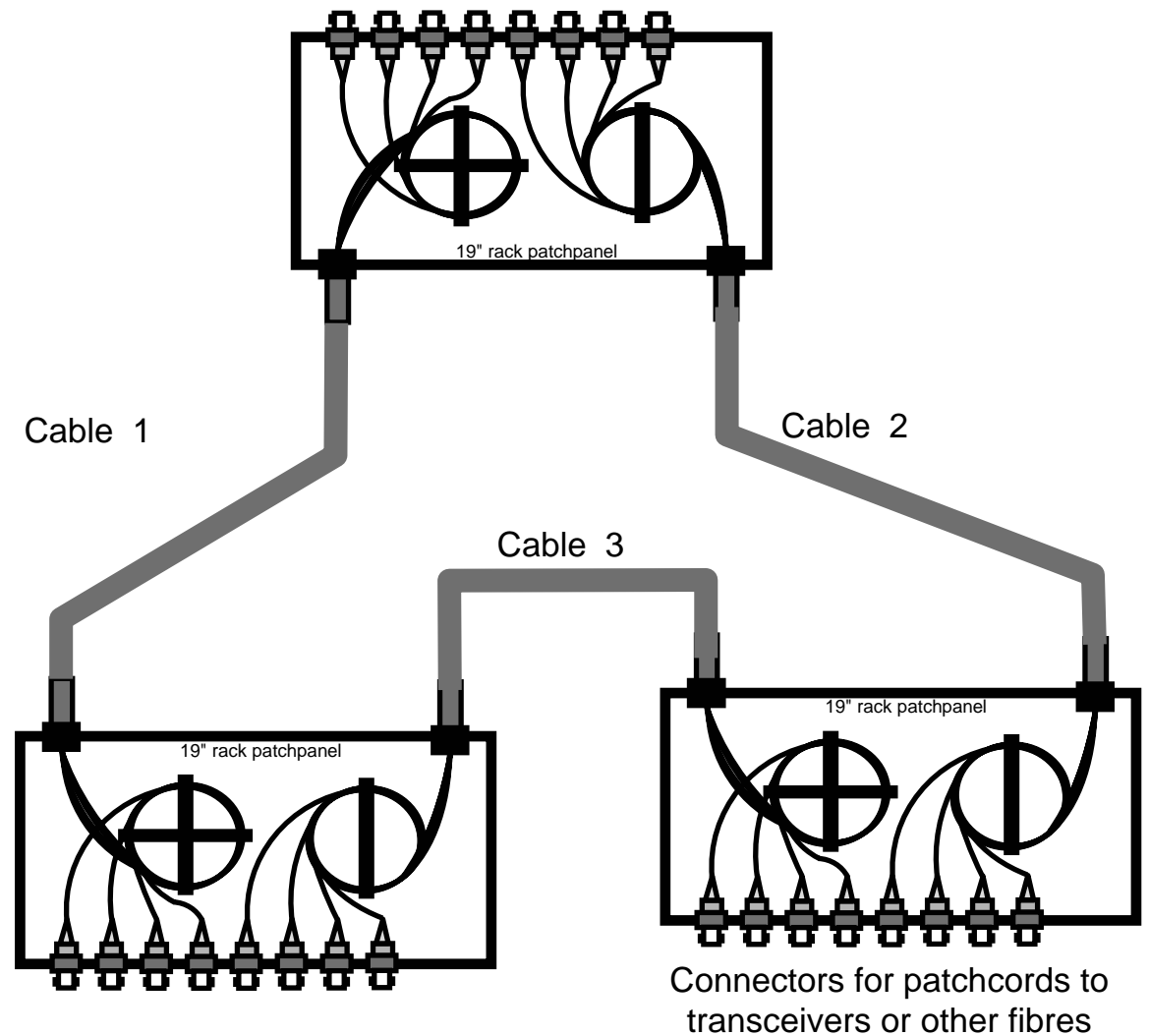
Focas wall mounting splice enclosure





Cable Termination

- In most building and campus installations fibre cabling is installed between patchpanels
- Intermediate splices and enclosures may be needed, where a cable enters/leaves a building
- At patchpanels a number of termination options exist:
 - f* Preconnectorised fibre pigtails fusion spliced to incoming cable fibres
 - f* Preconnectorised fibre pigtails mechanically spliced to incoming cable fibres
 - f* Direct connectorisation of incoming cable fibres





Direct Connectorisation versus Spliced Pigtails

- **Economics:**

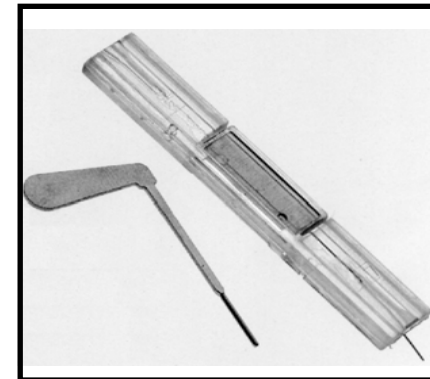
- ƒ Quickfit connector kits cost €1500 to over €3000, connectors cost about €5
 - ƒ Spliced pigtails involve the pigtail cost (€5) and the splice cost (€1-2 for mechanical but almost zero for fusion).

- **Loss specification may influence decision. Splicing involves an extra "unnecessary" loss by comparison with direct connectorisation**

- **But preterminated pigtail connectors done in "ideal" factory conditions are likely to show lower loss than those done in the field**



AMP Lightcrimp Quickfit
Connectors



AMP Corelink
Mechanical Splices



Fusion Splicing versus Mechanical Splicing

- **Economics:**

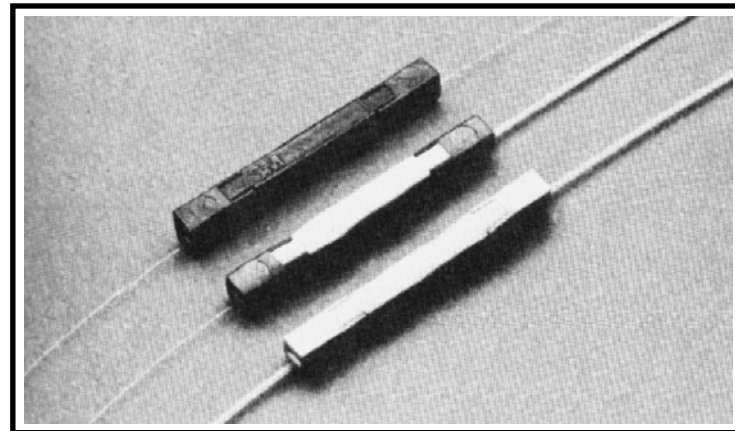
- f* Mechanical splices have low tooling costs, but each splice is more expensive (€1-2)
 - f* Fusion splicing involves expensive equipment (€7K to €40K), but very low cost splices
 - f* Organisations undertaking jointing infrequently should consider mechanical splicing

- **Loss specification may influence decision. Repeatable losses below 0.06 dB will require fusion splicing**

- **Installation conditions, labour costs etc.. greatly influence choice between fusion and mechanical splicing. UK surveys have proved inconclusive**



Northern Telecom Compact
Splicer



3M FibrLok II
Mechanical Splices



Pigtail Specification & Selection

Specification	Comment
Length	1 m typically but beyond 1.5 m excess fibre is untidy
Fibre	Multimode 50/125 or 62.5/125 or singlemode
Buffer	250 μm or 900 μm (blown fibres may be different)
Connector	ST or SC type (see connector specification & selection)
Colour code	Ideally a range of colour codes should be available, but not always so
Test Cert.	Test certificate should accompany all pigtails, stating factory insertion loss test results



Patchcord Specification & Selection

Specification	Comment
Length	Variable but 1-3 m is typical
Fibre	Multimode 50/125 or 62.5/125 or singlemode
Diameter	2.5 mm is typical but newer designs are smaller
Connector	ST or SC type (see connector specification & selection)
Duplex/simplex	Patchpanels normally use simplex, desktop-to- wall outlet use duplex. Duplex at a patchpanel is tidier and less error prone
Markings	Cable should indicate fibre spec (see above)
Test Cert.	Test certificate should accompany all patchcords, stating factory insertion loss test results



Connector Specification & Selection

Applies to loose connectors and connectors on pigtails & patchleads

Specification	Comment
Type	SC is the industry standard but ST very common. Small Form Factor (SFF) connectors are becoming more common
Ferrule	Plastic metal or ceramic. Ceramic gives the lowest loss, plastic is a poor choice (high loss and susceptible to damage)
Polish	Not a big issue in building cabling
Strain Relief	Simple plastic strain relief on buffered fibres, more complex on patchcord fibres
Colour code	Directional coding and multimode/singlemode coding needed