Introduction

- This course is designed to provide knowledge on:
  - Principles
  - Theories
  - Technologies
- Involved in modern telecommunication networks
- Attendees will gain a top level understanding of the telecommunications networks
- Thus enabling attendees to operate efficiently and effectively in the industry.

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Course outcomes

- Understand the physical terms used in optical networks
- Identify the appropriate :
  - Fibres types
  - Active and passive elements
  - Testing methods
  - Device limitations and impacts on network design
- Interpreting power, OSA, OTDR and BER results to determine network quality
- Determine the correct digital payloads
- Heath and Safety guidelines to protect yourself and your co-workers

Bandwidth growth and demand

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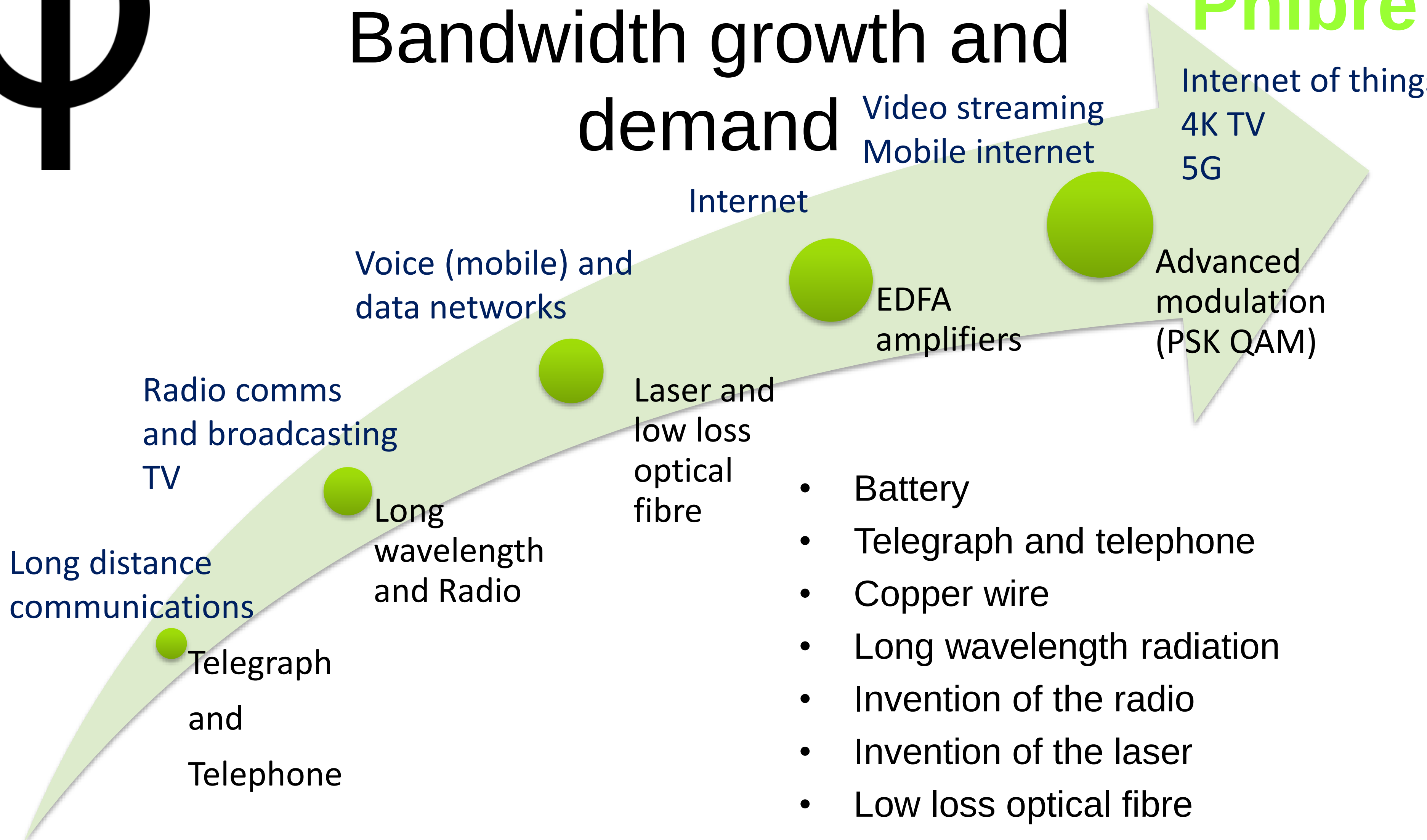
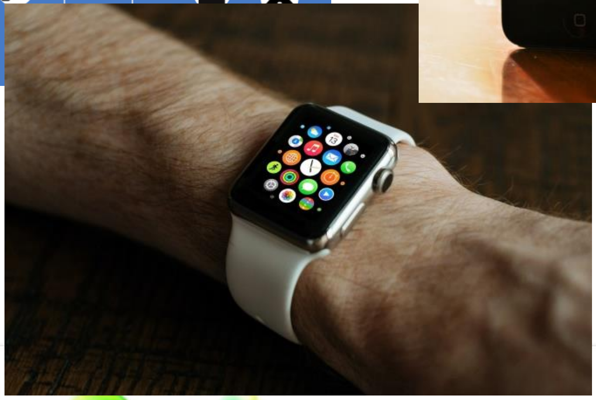
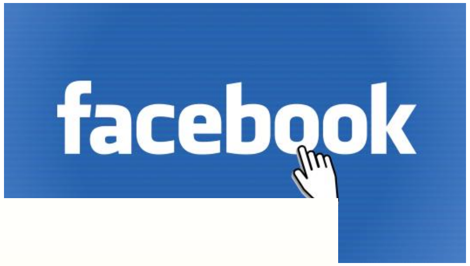


- Battery
- Telegraph and telephone
- Copper wire
- Long wavelength radiation
- Invention of the radio
- Invention of the laser
- Low loss optical fibre
- EDFA
- Coherent transmissions systems

Fibre demand and capacity

- Capable to transfer **10 Petabits (10x10^{15})** of data between New York to London in 3.1 *microseconds*. [as of 2017]
- Relates to the transfer **25,000 Blu-Ray** in one second
- Electrical cables are only capable of 10Gb/s for 100m



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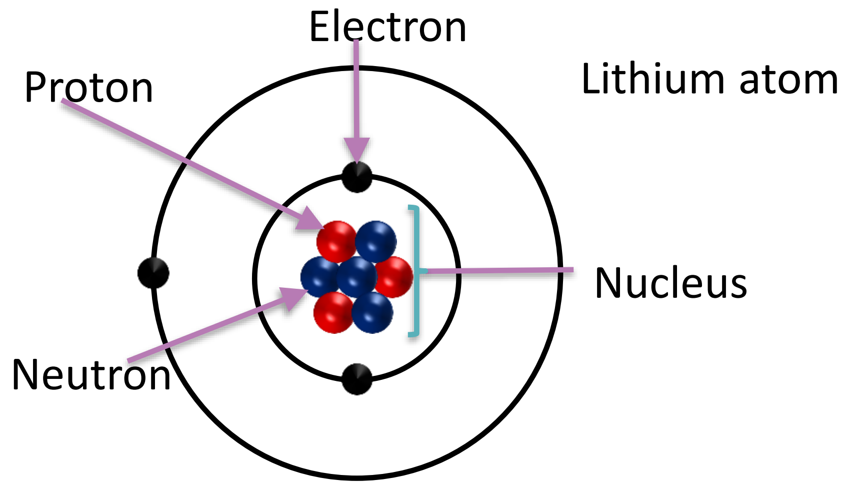
Optical Fibre Benefits

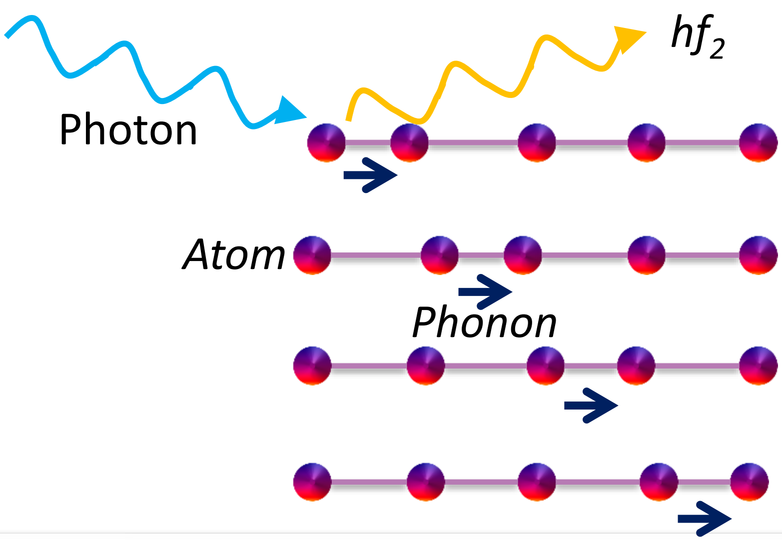
- Transmission over long distances
- Low attenuation loss
- Lower latency, compared to Satellite communications
- Higher bandwidths
- Small cable cross-sectional areas
- Able to handle high optical power levels
- Fibres can be used as sensors
- Immune to electromagnetic interference
- Not affected by environmental conditions
- Data security
- Ease of installation
- Material cost is lower compared to electrical cables

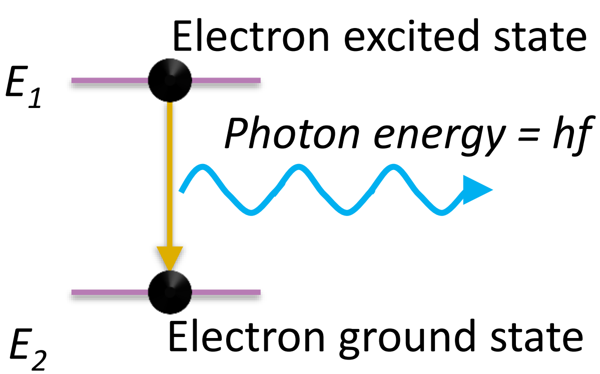
BASICS

Understanding Elemental Particles

- Electrons
- Protons
- Neutrons
- Photons
- Phonons

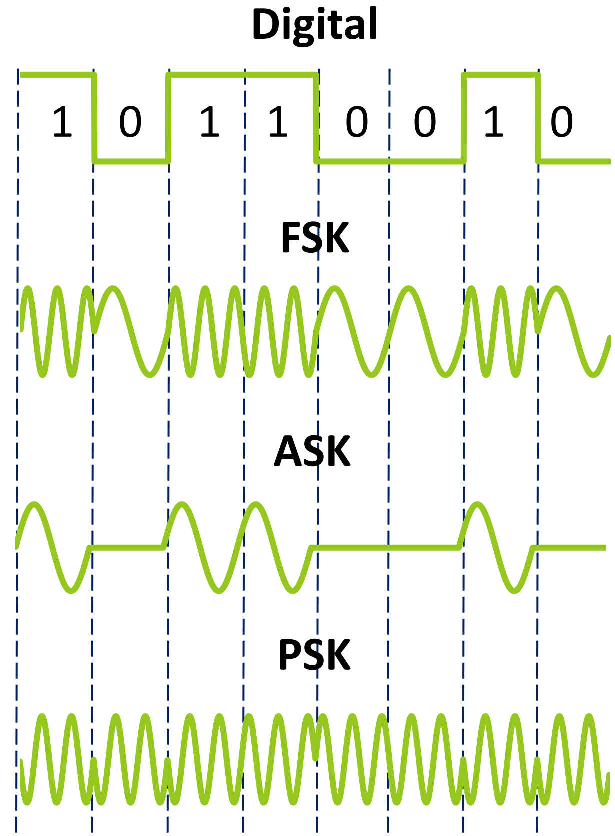


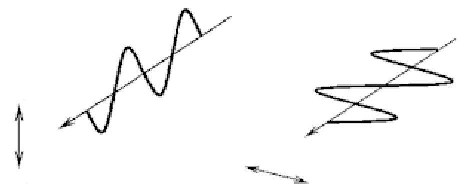




Modulation formats

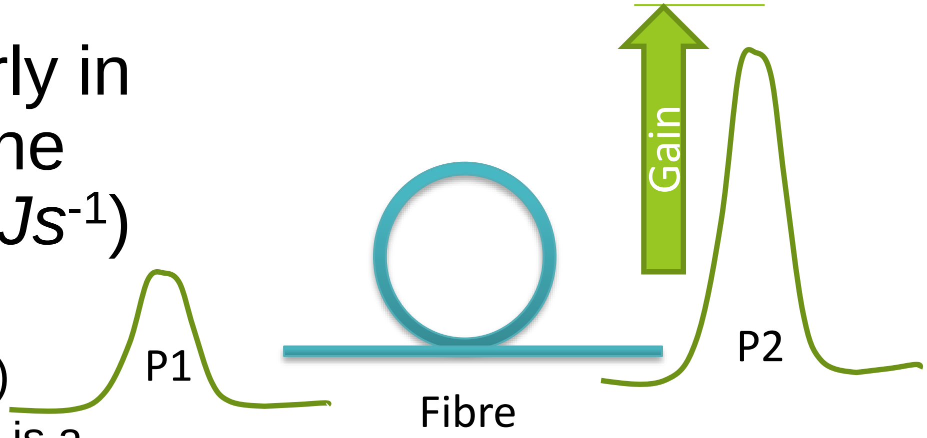
- EM spectrum is made up of a range of properties
- EM can be controlled to impart information onto the signal.
- Modulation is the process of altering one or more properties of a periodic waveform of a carrier signal with a data signal.
  - Frequency
  - Amplitude
  - Phase
  - Polarisation





Units of power

- Power is measured linearly in WATTS (*W*), defined by the units Joules per second (Js^{-1})
  - Log scale
    - dB (Relative measurement)
      - **The decibel** noted as **dB** is a logarithmic unit used which is used express the ratio between two values
    - dBm (Absolute measurement)
      - Where **Decibel-milliwatts** denoted as **dBm** is an abbreviation for the power ratio in decibels (dB) of the measured power referenced to one milliwatt (mW)



Power in dBm	Power in mW
+20	100
+10	10
+3	2
0	1
-3	0.5
-10	0.1
-20	0.01
-30	0.001

$$P_{dB} = 10\log_{10}\left(\frac{P_1}{P_2}\right)$$

$$P_{dBW} = 10\log_{10}\left(\frac{P_W}{1W}\right)$$

$$1W = 1000mW$$

$$P_{dBm} = 10\log_{10}\left(\frac{P_{mW}}{1mW}\right)$$

Introducing the physical properties involved in optical networks

PHYSICAL TERMS USED IN OPTICAL NETWORKS

Physical terms related to optical fibre

- Providing principles used and explanation of the physical mechanisms used to enable optical networks to transport large amounts of data between sites

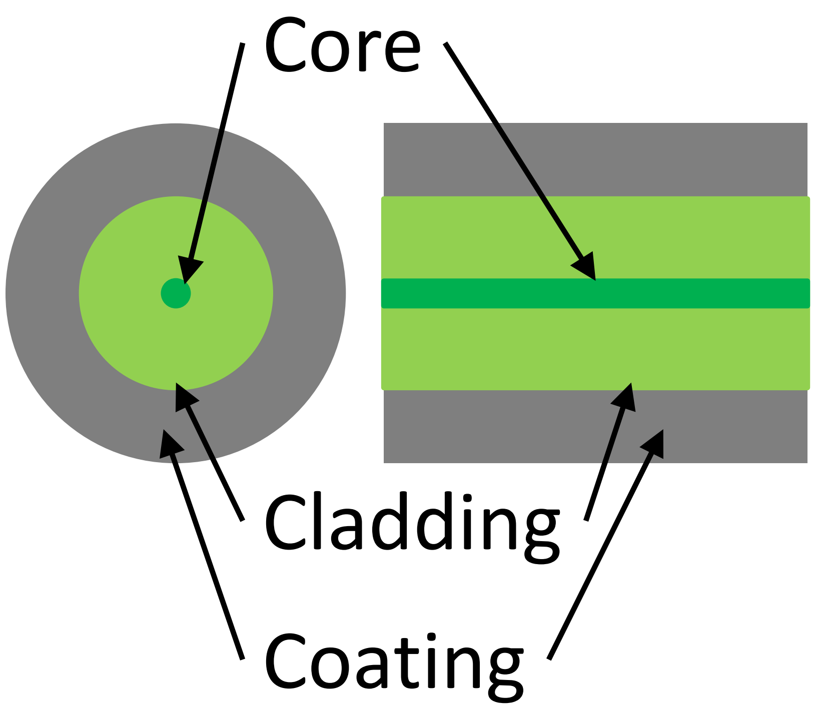
- The next section will introduce and explain the relevance of these terms

– Section 1
  - Reflection
  - Refraction
  - Critical angle
  - Cone of acceptance
  - Total Internal reflection
  - Transmission modes
  - Chromatic dispersion
  - Polarisation dispersion

– Section 2
  - Transmission windows
  - Attenuation and loss
  - Nonlinear medium
  - Rayleigh scattering
  - Simulated Raman scattering
  - Simulated Brillouin scattering
  - Nonlinear phase modulation

What is an optical fibre

- A waveguide that is used to guide light until it reaches its intended destination
- Optical fibre is made up of three parts
  - Core
    - Is the part where light transvers through the fibre
  - Cladding
    - The cladding is designed to reflect light back into the core. So the reflective index, is lower than the core.
  - Coating
    - Plastic coating provides mechanical strength and prevents damage while being handled
- The core and cladding act together to keep the light within the core

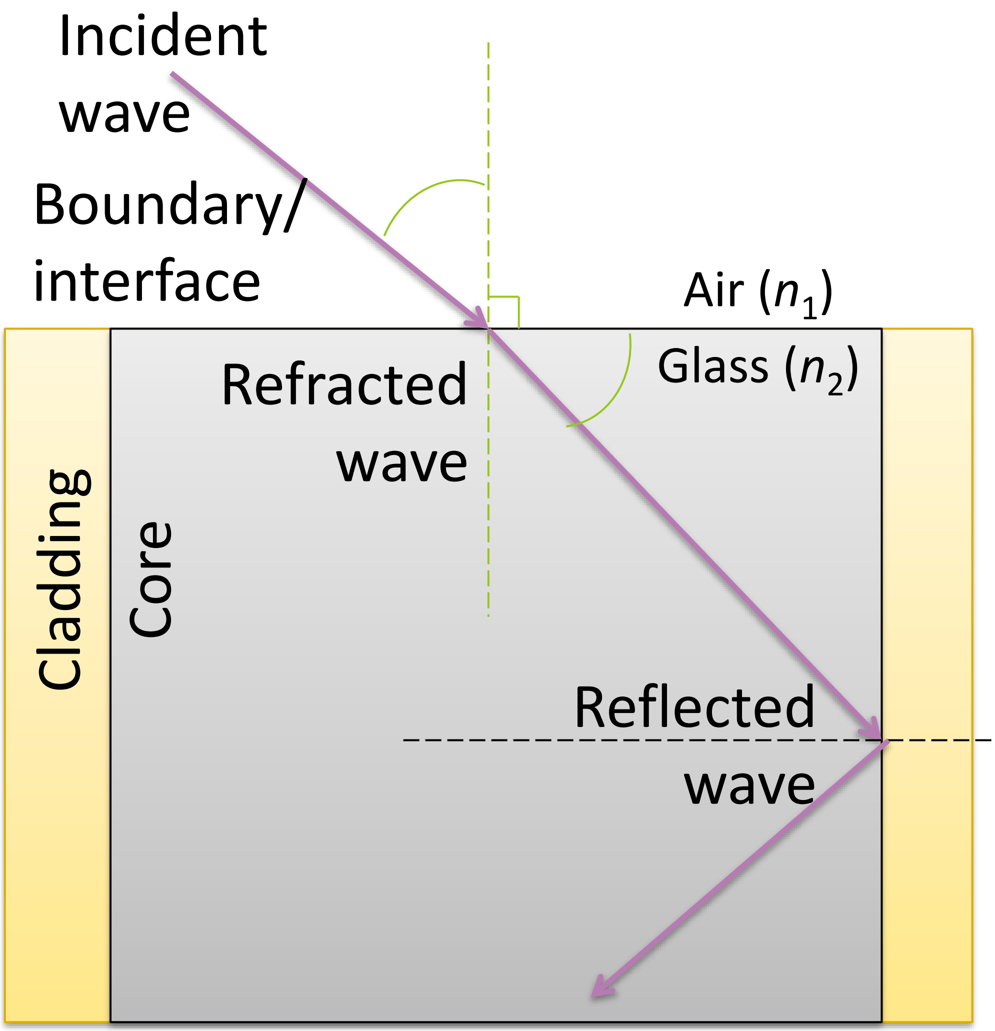


Reflective index

- Is a number that describes how light travels through a material
  - Glass in our case
  - Given the notation - n
- The reflective index value difference between two materials determines if light travels through a material (refracted light) or not (reflected light)

Refraction and Reflection

- Refraction
  - when the direction of light changes when it transverses from one medium to another.
- Reflection
  - Light changes direction of light back into the medium from which it originated.
- Critical Angle
  - Angle of interaction will determine either refracted or reflected will occur.
- **Numerical Aperture (NA)**
  - Characterizes the range of angles of light which enter and exit an optical fibre
- Cone of acceptance
  - Max angle that determines whether a light wave will propagate through optical fibre or pass into the cladding



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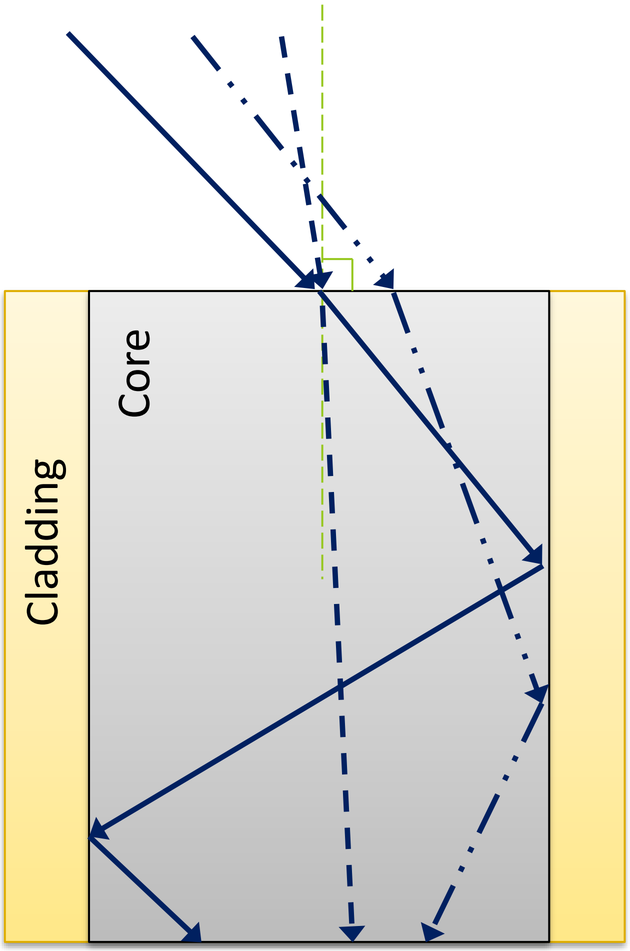
Modes in optical fibre

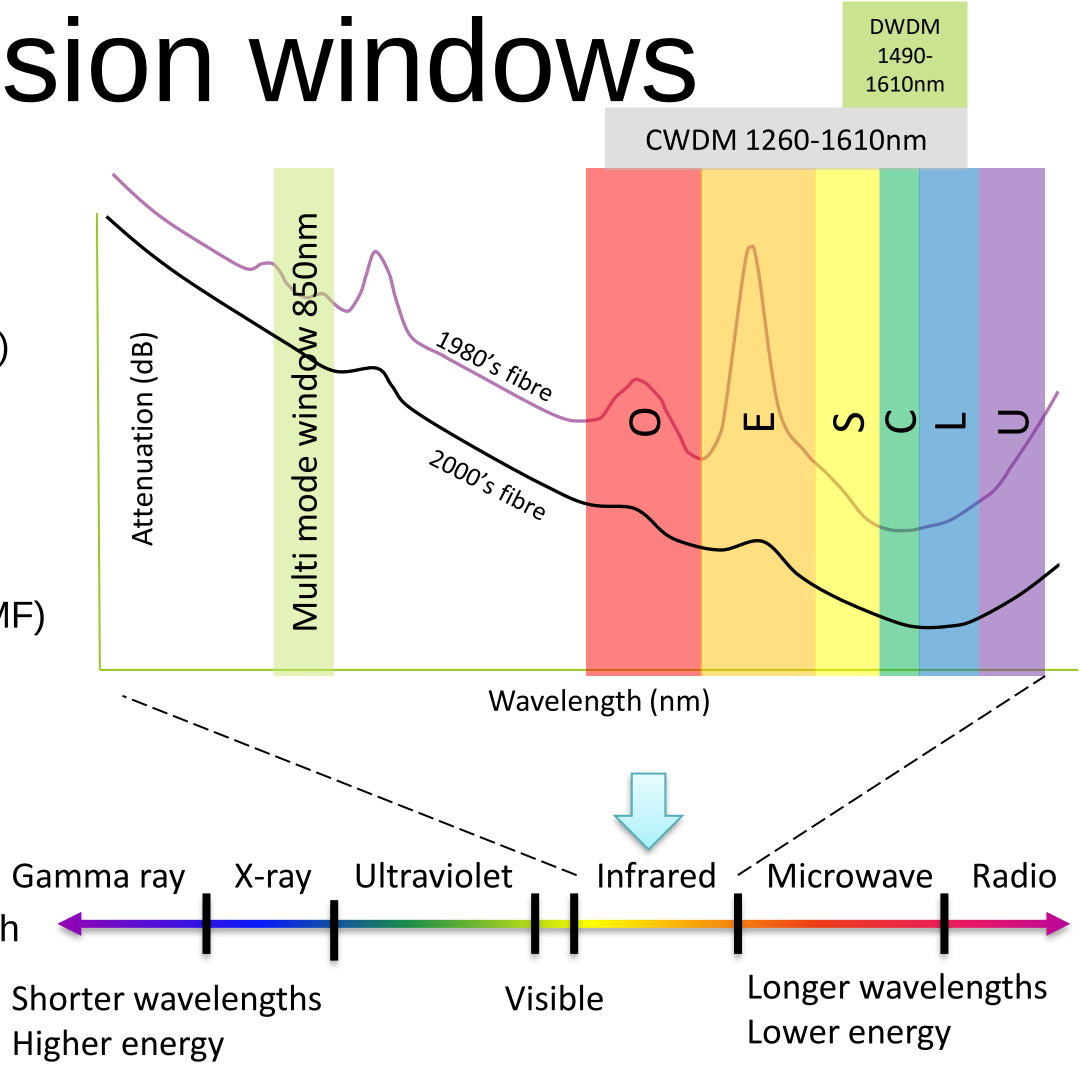
- Important concept for multi mode fibres
- Modes refer to the different ways of which light can propagate through an optical fibre
- Think of it as differing light waves bouncing back and forth within the core.
- A signal can consist of multiple light rays, which can take differing paths through the fibre.



GENERAL PROPERTIES OF OPTICAL FIBRES

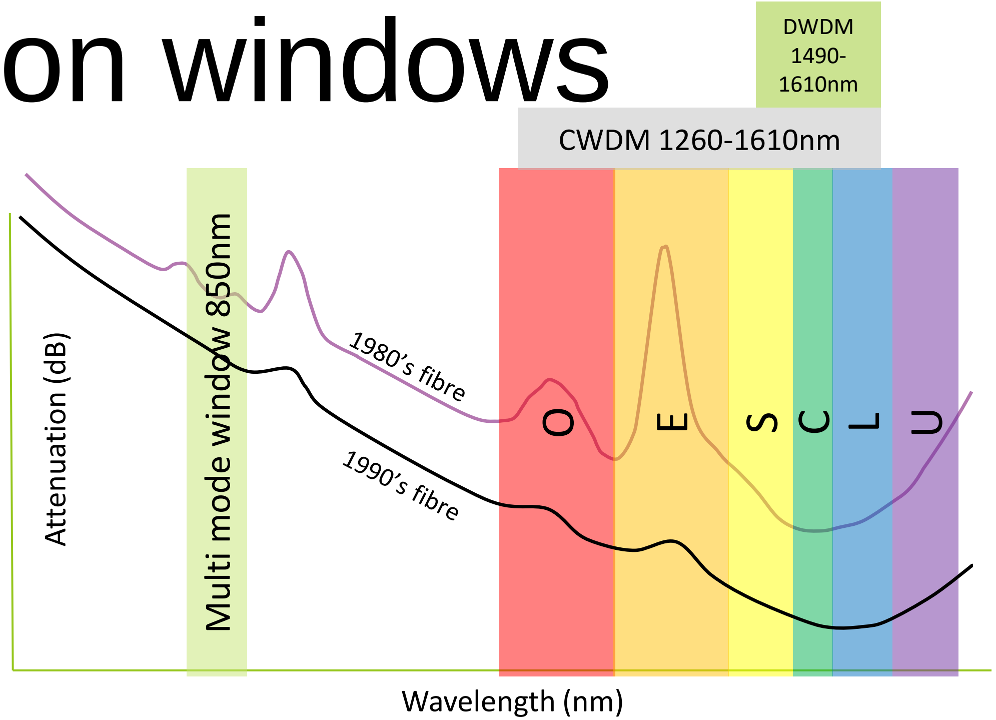
Transmission windows

- **Multi mode**
  - First optical fibres used these frequencies
  - Used with multimode fibres (850nm)
- **Original**
  - 1310 nm
  - Used for campus sized networks
  - Higher attenuation
  - Used for shorter links (SMF and MMF)
  - Lower cost of lasers (LED)
  - Single and multimode fibres
- **Extended**
  - Contains the OH absorption peak (1383 nm)
  - Mostly used for CWDM systems with modern fibres (ITU-T G.652 C/D)
- **Short**
  - Is used as an extension of the C-Band
  - Used for Optical Supervisory Channel on most systems (1510nm)



Transmission windows

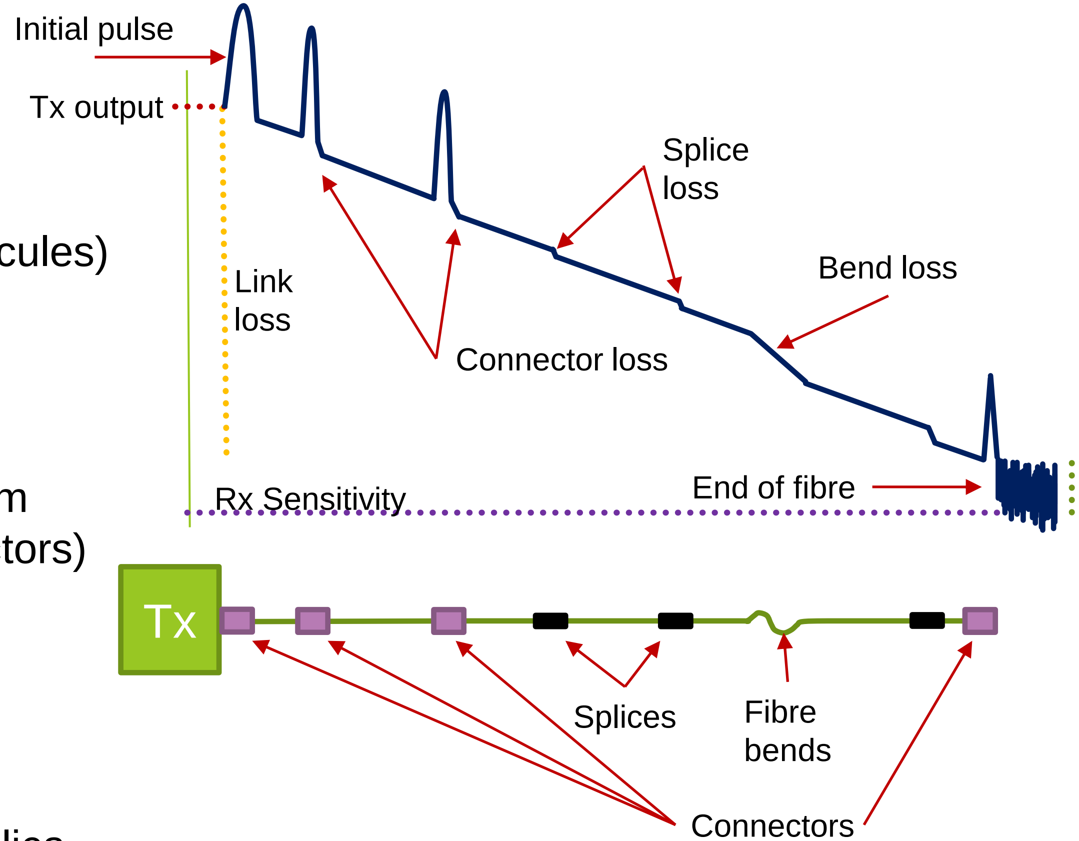
- **Conventional**
  - 1550nm wavelengths
  - Lowest attenuation band for optical fibre
  - Window with for single mode fibres
  - Used for long distance communications
- **Long**
  - Band is used as another extension of the C-Band
  - Now being exploited to provide extra fibre capacity
- **Ultra long**
  - Not commonly used, as it has higher attenuation than C &L
  - An extension of L-Band



Wavelength Range	Description	Short hand notation
1260 to 1360 nm	Original	O band
1360 to 1460 nm	Extended	E band
1460 to 1530 nm	Short wavelengths	S band
1530 to 1565 nm	Conventional	C band
1565 to 1625 nm	Long wavelengths	L band
1625 to 1675 nm	Ultra long wavelengths	U band

Attenuation and loss

- **Fibre attenuation**
  - Material absorption
  - Impurities in core (water molecules)
  - Waveguide imperfections
  - Scattering off atoms
- **Fresnel reflection**
  - Light scattered back at medium boundary (splices and connectors)
- **Loss caused during fibre manufacturing**
  - Core irregularities
- **Rayleigh scattering**
  - Small density fluxulations in silica core (alters reflective index)



$$\text{Attenuation(dB)} = 10 \times \log_{10}\left(\frac{\text{Input intensity (W)}}{\text{Output intensity (W)}}\right)$$

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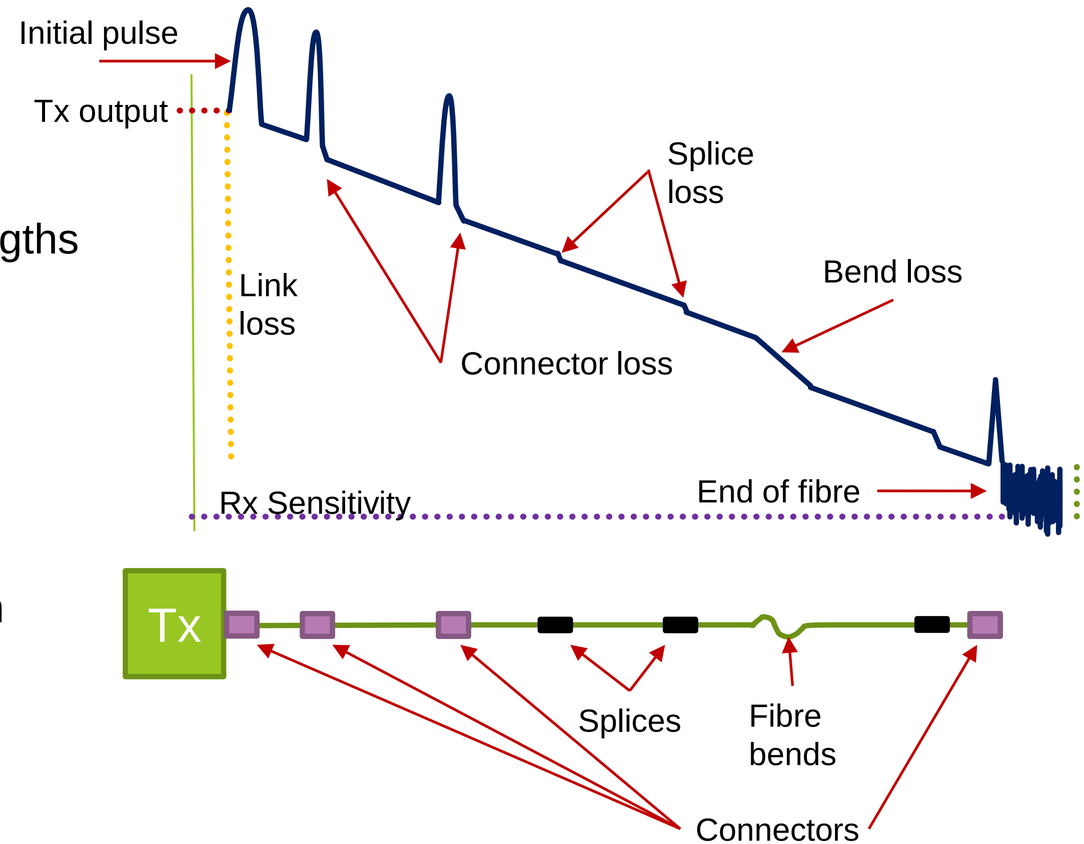
Attenuation and loss

- **Bend loss**
  - Tight bend radius
  - Higher loss at longer wavelengths
- **Splice losses (Fused fibre)**
  - Poor Cleave
  - Incorrect fibre alignment
  - Contamination
  - Reflective Index mismatch
  - Fibre core diameter mismatch
- **Connection losses**
  - Air gap
  - Contaminants on connector
  - Damaged connector face (scratch)
  - Mismatched cores (fibre types)
  - Misaligned fibre cores

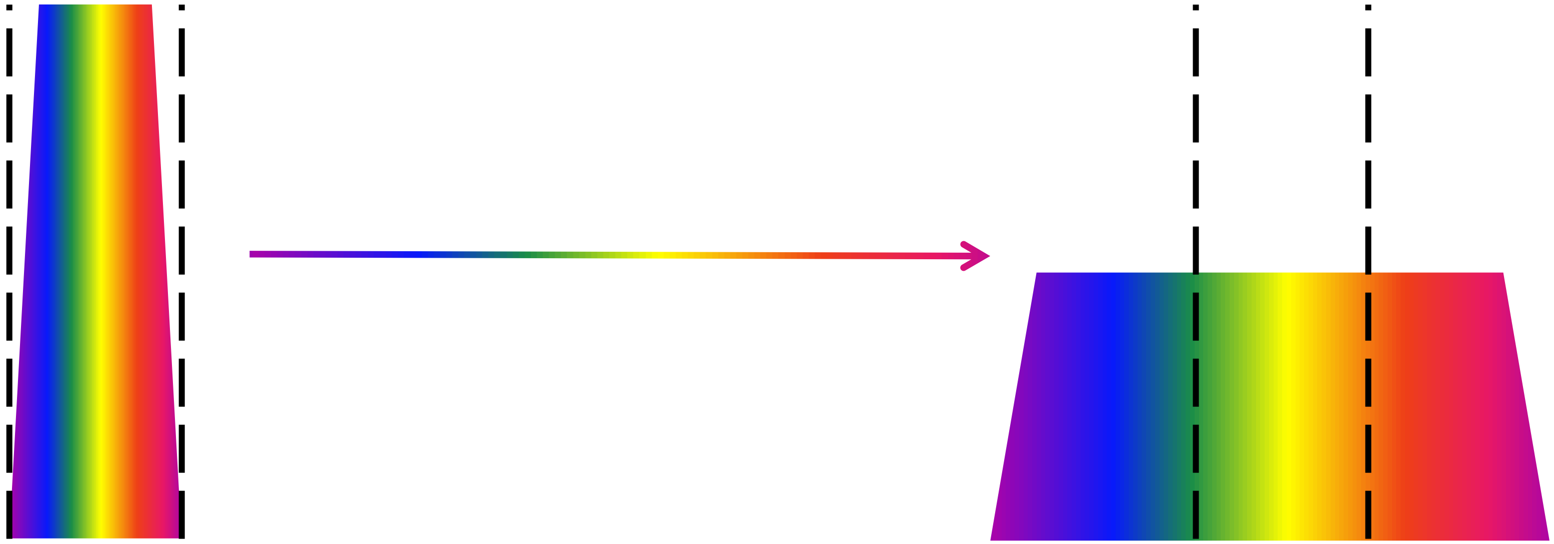


$$\text{Attenuation(dB)} = 10 \times \log_{10}\left(\frac{\text{Input intensity (W)}}{\text{Output intensity (W)}}\right)$$

DISPERSION

Dispersion

- The broadening of an optical pulse in time
- An optical pulse is not just one wavelength, but is made up of a number of different wavelengths called a “wave packet”
- Each of the wavelengths travel at slightly different speeds
- Leading to the optical pulse broadening as the signal travels through fibre

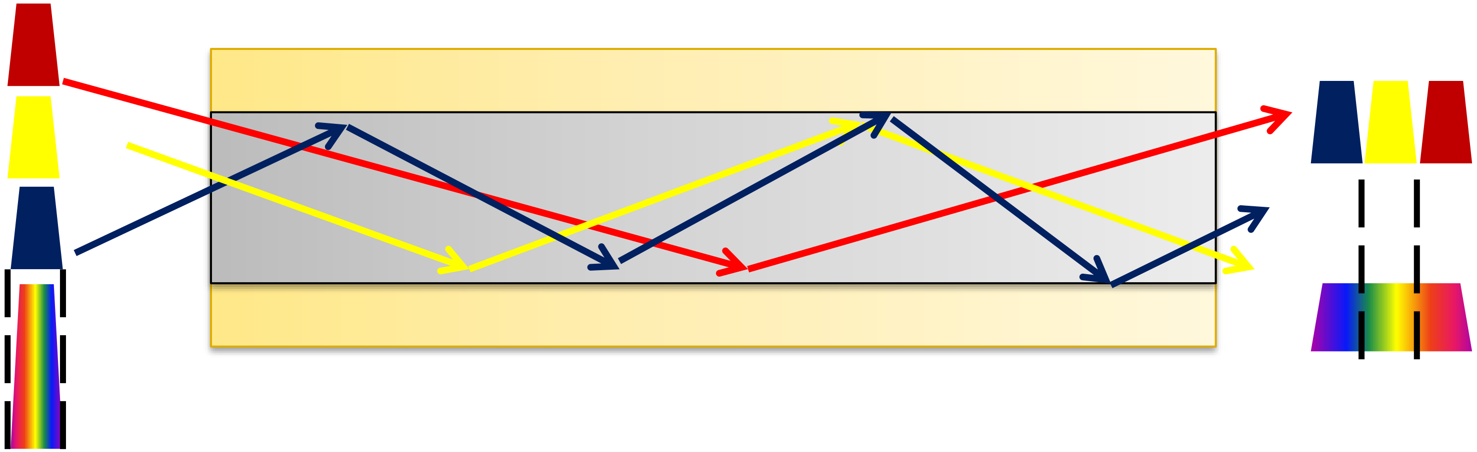


Bit period boundary

Modal Dispersion

- Relevant to multimode fibre
- Pulse width widens with distance
- Results in signal broadening of the optical signal
- Second main limitation to transmission propagation after attenuation

- Modes travel at different speeds and distances, which result in the modes spreading over the bit periods and into the preceding and following bits
- Leading to **Inter-Symbol Interference (ISI)**
  - When power from different bits leak into each other
  - ISI introduces bit errors into the data stream



Bit period boundary

Inter Modal Dispersion

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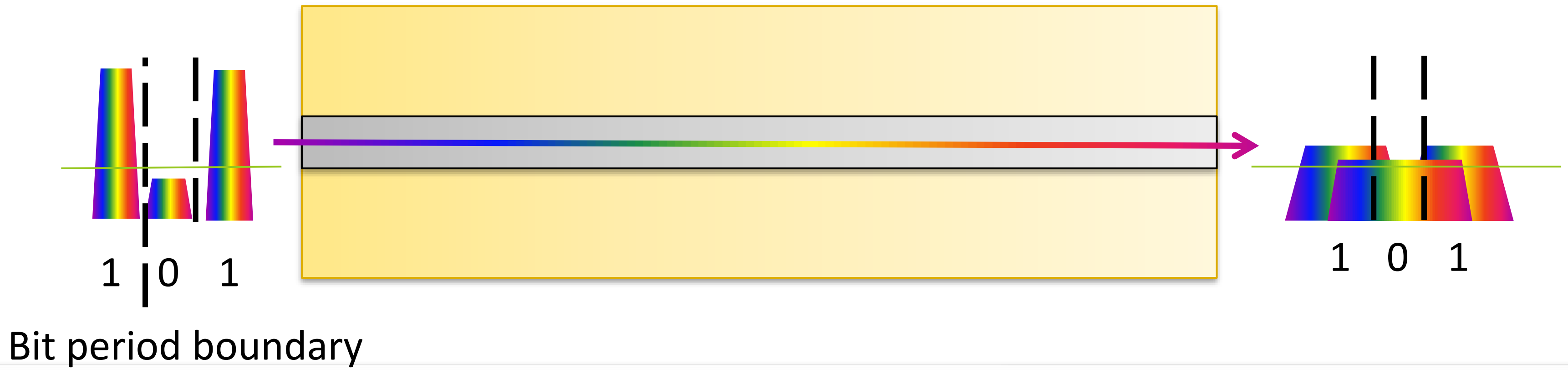
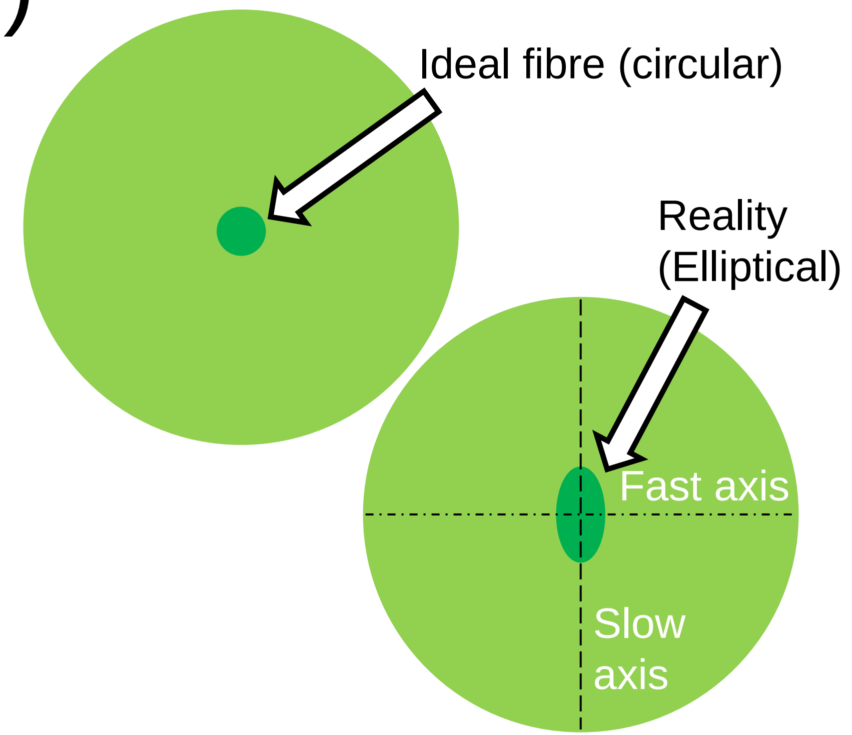
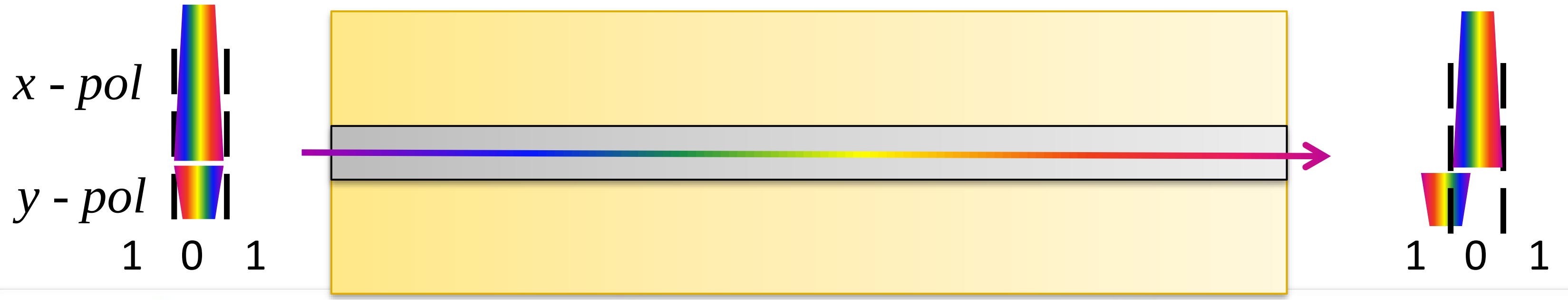
- Relevant to single mode fibre
- Results in signal broadening of the optical signal
  - Pulse width widens with distance
- The causes of dispersion can be broken down into:
  - Material
  - Waveguide
  - Polarisation
- The pulse spreads over the bit periods and into the preceding and following bits
- Leading to Inter-Symbol Interference (ISI)
- Transmission rate increase relates to 4x increase in chromatic dispersion



Polarisation Mode Dispersion (PMD)

- Describes the different between the arrival of two polarisations of a single pulse
- Causes of PMD is random in nature
- Laser transmits an optical signal in two polarisations
  - Small variation from perfect cylindrical symmetry
  - Results in boarding of pulse, beyond bit boundaries
  - Pulse spread is often called **Differential Group Delay (DGD)**
  - Major limiting factor in modern optical communications





TYPES OF OPTICAL FIBRE

Fibre and cable manufacturing

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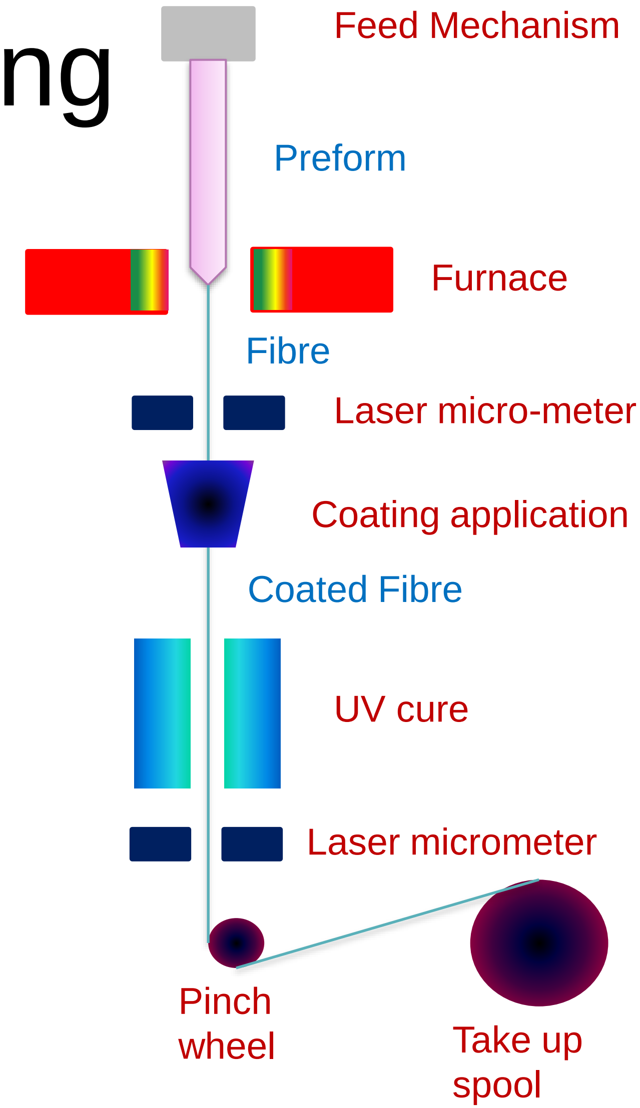
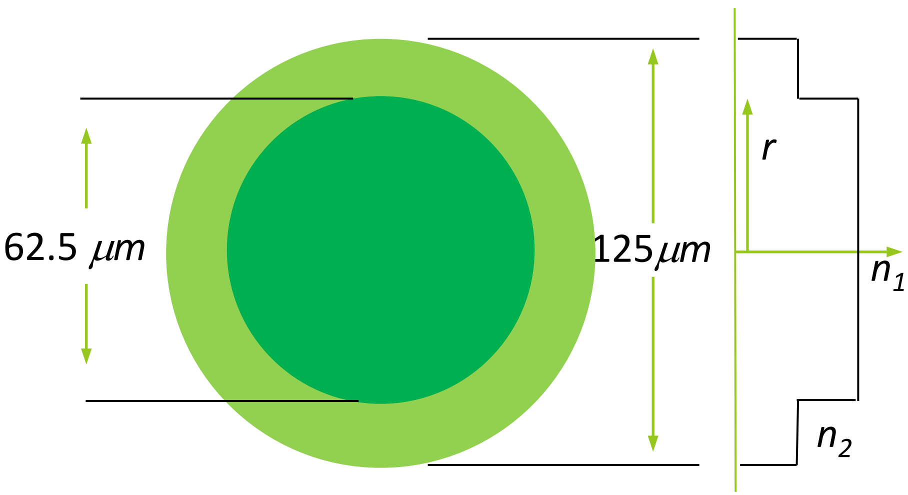
- Drawing
  - Fibres are made from large diameter “preform”
    - Made from a modified chemical vapour deposited to produce pure silicon preform
  - Preform is placed inside a drawing tower
  - The lower tip is heated, and pulled into a thin thread of glass, that forms an optical fibre
- Coating
  - Buffer coating
    - UV cured Urethane acrylate composite
    - Applied during the drawing process @ 60mph – 2000km of fibre a day
    - Metallic armour can be applied in some cases
- Cable construction
  - Separate operation
  - Buffer layer is further covered by a tough resin
  - Possible jacket layer can also be applied
  - Sheathings and armour can be applied

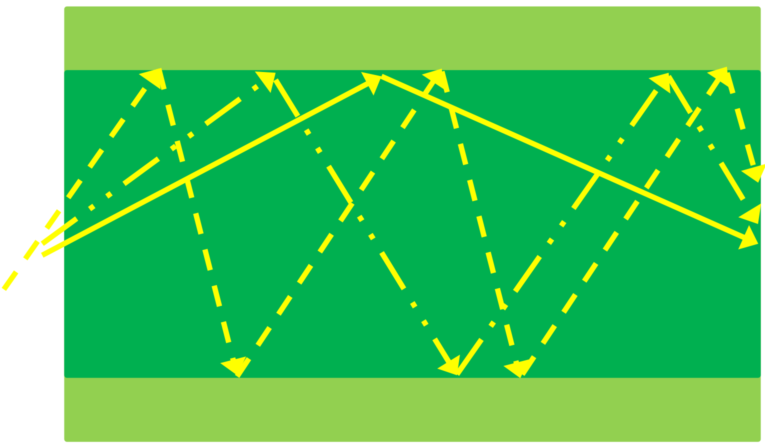


Step Index

- Also called multimode fibre
- Uniform core and cladding refractive indexes
- The change in the refractive values confines the multimode signal within the fibre
- Used for low rate or short distance telecom links
- 850nm and 1300nm wavelengths

- Signals are susceptible to multi mode dispersion
- Differing modes travel different distances and arrive at different times
- Main limitation and increases with:
  - Transmission rate
  - Transmission distance





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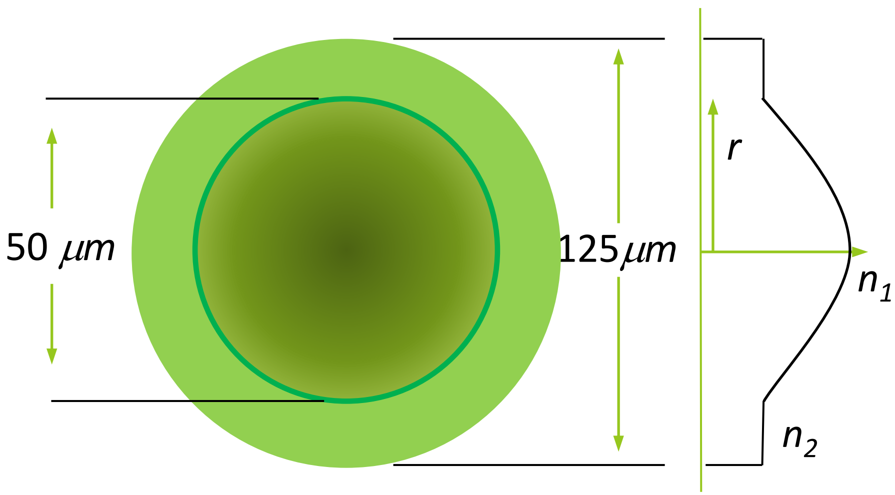
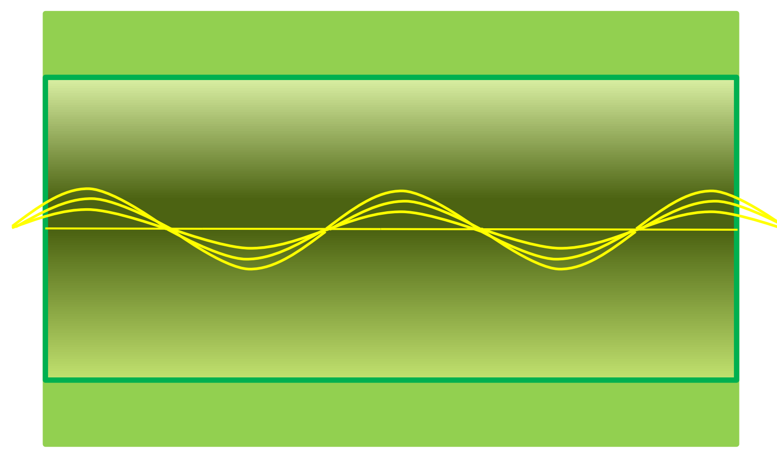
Multimode fibre (MMF)

- a.k.a Graded Index Fibre
- Defined in ITU-T G.651.1 standard
- Refractive index decreases from the centre outwards
- Cladding has a uniform reflective index
- Results in light waves bending into the core, due to the non-uniform nature
- Used for low rate and short distance links
- Modes still travel different distances, but dispersion is lower compared to step index fibre
- Multimode fibre can handle faster data rates and longer transmission distances.
- Primary fibre used for multimode fibre communications.
- 850nm and 1300nm wavelengths





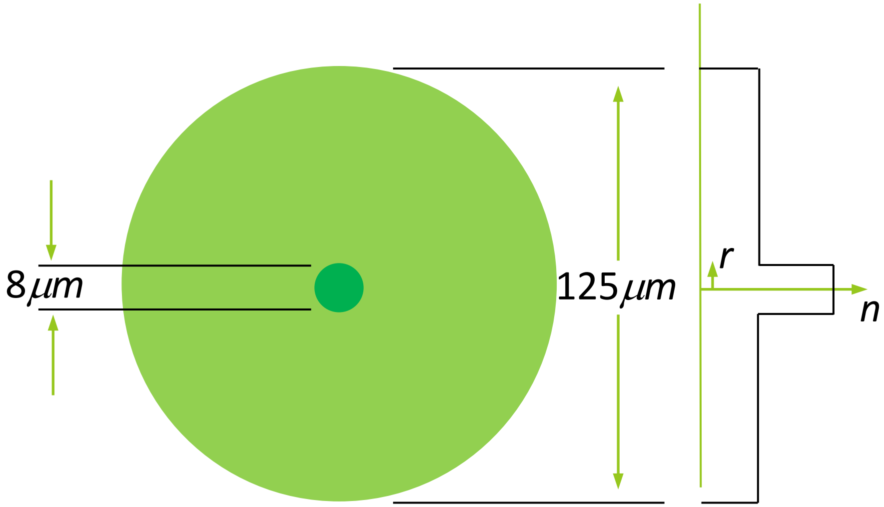
Multimode Fibre Index

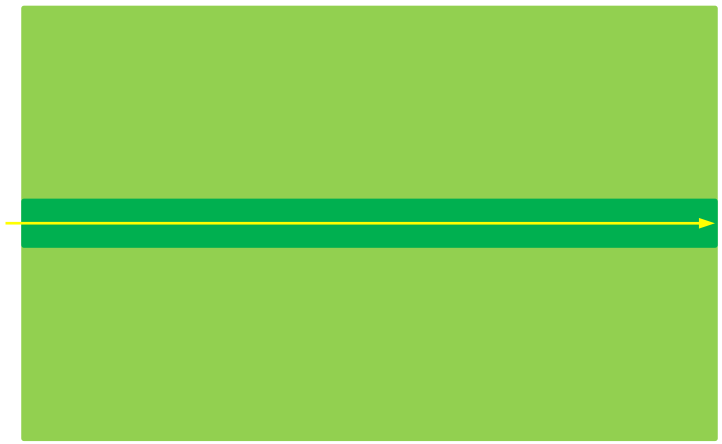
Multimode optical fibres can be identified by an Multimode optical fibre (OM#) and one single mode (OS#) designation ITU-T G.521. The denotation determines the type of interconnect and is detailed in **ISO/IEC 11801 standard**.

Denotation	Core Diameter (μm)	Overfield Launch (MHz) laser bandwidth	Transmission wavelength (nm)	Reach in metres for 10Gb/s (m)	40GBase – SR4 and 100G SR10 (m)	Designed for
OM1	62.5/125	200/500MHz	850/1300	33	N/A	1G
OM2	50/125	500/500	850/1300	82	N/A	1G
OM3	50/125	2000	850/1300	300	100	10GB/s transmission
OM4	50/125	4700	850/1300	400	150	10, 40, 100G
OM5	50/125	3500/500	850-950	400	150(40G), 100(100G)	10,40,100G
OS1 (SMF)	9/125		1310/1550	1dB/km		10, 40, 100G
OS2 (SMF)	9/125		1310/1550	0.4dB/km		10, 40, 100G

Single mode fibre (SMF)

- Core diameter of 7-10 μm
- Small core results in only one mode (ray of light) propagating through the fibre
- Transmission window of 1260 – 1600 nm
- Benefit of the small core
  - No intermodal dispersion
  - Higher transmission capability
  - Higher transmission rates >100Gb/s
  - Requires smaller line width lasers
- SMF has been the dominate type of fibre used for This type is the most used form type of fibres long distance transmission requirements
- There are several variants of signal mode fibres





Single mode fibre (SMF)

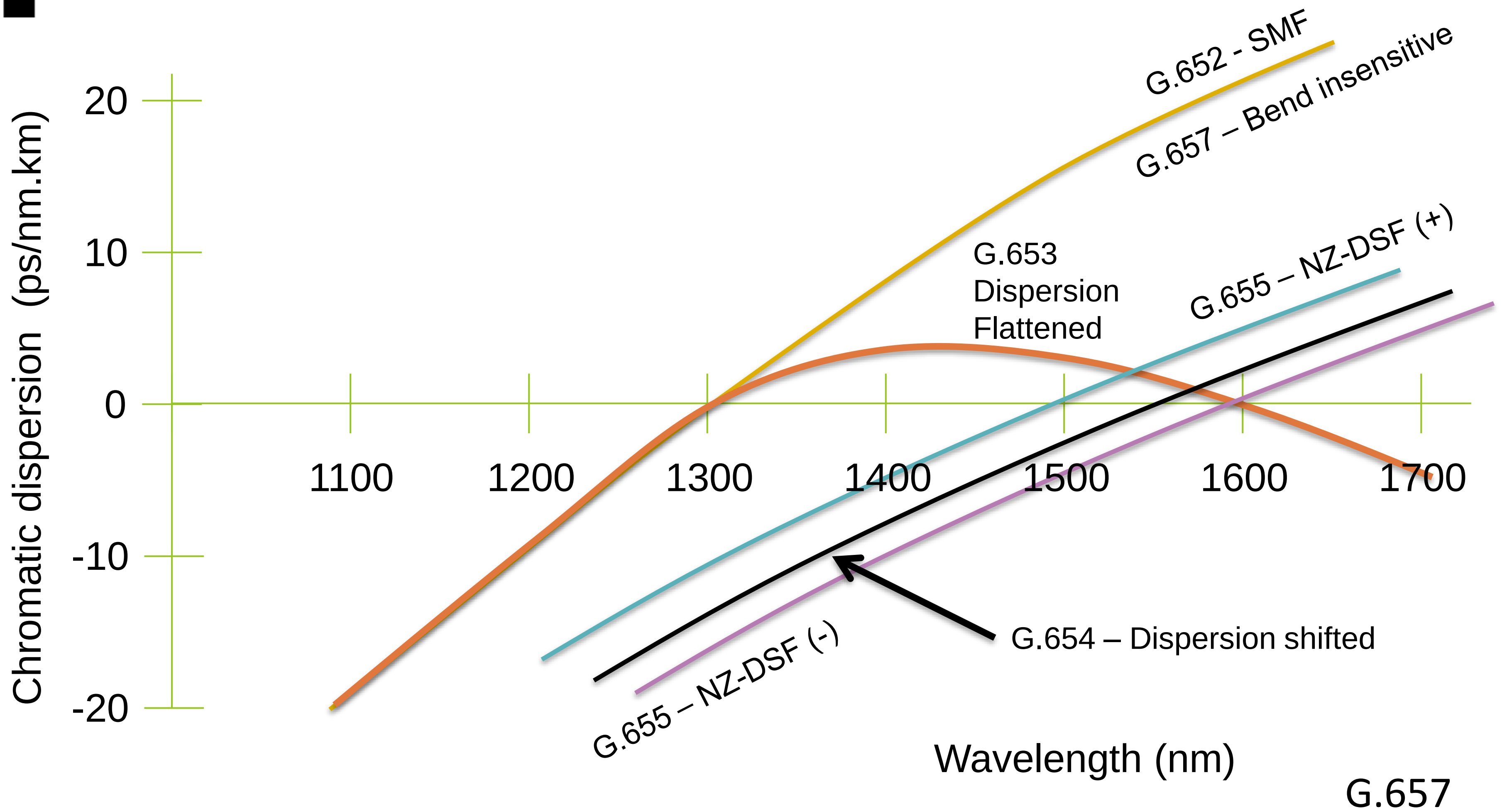
- **Standard SMF**
  - **G.652 A (IOS/IEC OS1)**
    - The original single mode fibre
    - Low cut off wavelength of 1260nm
    - High CD coefficient
  - **G.652 B (IOS/IEC OS1)**
    - This stand improved on the original by reducing the attenuation and polarisation mode dispersion
  - **G.652 C (IOS/IEC OS2)**
    - This standard reduces the high attenuation of the lower water peak (1383nm)
  - **G.652 D (IOS/IEC OS2)**
    - This standard reduces the attenuation and PMD values at 1550nm

- **Dispersion shifted fibre (DSF)**
  - **G.653**
    - Has a zero dispersion wavelength at 1550nm.
    - Reduction in dispersion has the unwanted affect of creating non linear (NL) effects in the fibre at higher powers in a CWDM and DWDM networks
    - Low NL threshold limits number of channels used on the fibre
    - CD is higher for signals in the 1310 range
    - This standard of cable is not commonly deployed these days
    - Was extensively deployed in the 1990’s and are still used today

Single mode fibre (SMF)

- **Cut off shifted optical fibre**
  - **G.654 (A, B, C, D)**
    - Dispersion is zero at 1300nm
    - **Larger effective area fibre (LEAF)** of 120mm^2
    - Cut off frequency is shifted
    - Minimised loss between 1500-1600nm
    - Reduced nonlinear effects
    - Designed for undersea links
- **Nonzero dispersion shifted fibre (NZ-DSF)**
  - **G.655**
    - This standard was created to reduce the effects of nonlinear effects found in DSF
    - The zero dispersion wavelength is outside the 1550 nm window
    - +ive and –ive dispersion fibre available
    - The CD is low in the 1550nm window
    - Addressed G.652 short comings
    - 1480nm cut off wavelength
- **Non-zero dispersion**
  - **G.656**
    - Lower dispersion between 1460-1625nm
    - Minimum dispersion of 2 ps/nm-km at 1460nm
    - Higher efficiency for RAMAN amplification
    - 1450nm cut off wavelength
- **Bend insensitive fibre**
  - **G.657 (.A1 .A2 .B2 .B3)**
    - Bend loss insensitive fibre for access networks
      - 10 – 5 mm bend radius
    - .A for access networks
    - .B for short distances at the end of access networks
    - Designed to be compatible with G.657.D fibre

Wavelength dependency of CD



Plastic Optical Fibre (POF)

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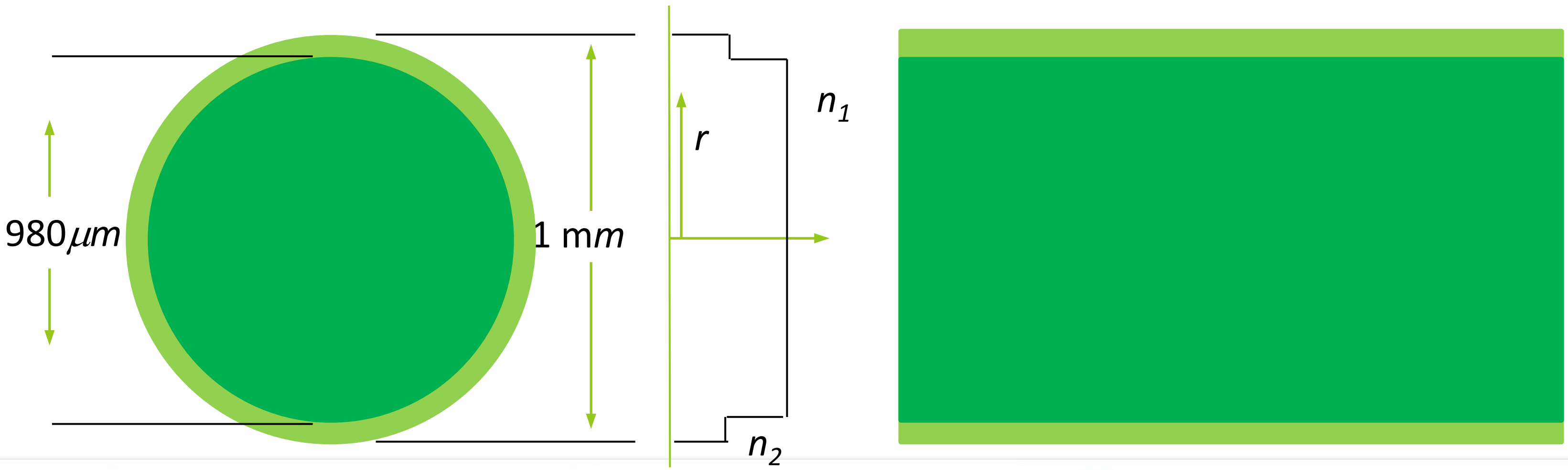
- Made out of a Polymer.
- Used for low speed and short distances (100m)
  - Core (diameter of 1mm) reflective index
    - PMMA 1.49
    - Polystyrene 1.59
  - Cladding
    - Silicon 1.46
- Attenuation loss 1dB/m @ 650nm
- Bandwidth 5MHz-km @ 650nm
- Applications
  - Home networks (Gigbit LAN)
  - Industrial
  - Car networks
  - Remote sensing
- Best for robustness under stretching and bending
- European Standard (EN)
  - **EN 60793-2-40-2011.**



Space Division Multiplexed (SDM)

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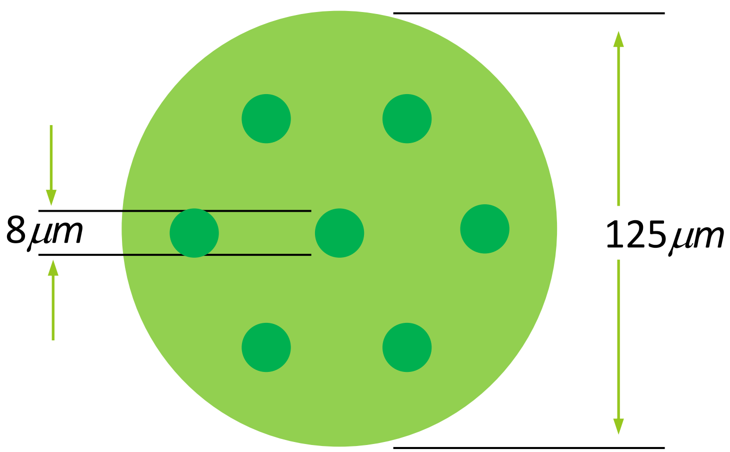
- Multi-core optical fibre within one cladding
- Increases bandwidth with one standard fibre diameter
- Advantages
  - Next step in capacity per fibre
  - Peta-bits per second capability
  - Higher density of transponders and amplifiers
  - Reduced cost-per-bit
  - Improved energy efficiency
- Dis-advantages
  - Management of waveband crosstalk
  - Does not overcome SMF loss and nonlinearity limitations
  - New tech is required to couple and uncouple into and out of the cores
- Just becoming commercially available
- Single mode fibre spectral capacity is limited to 7bits/sec/Hz
- Academics studies are predicting a capacity crunch in 2030
- SDM fibres are seen to be an answer to extending optical fibre capability to meet future bandwidth demands



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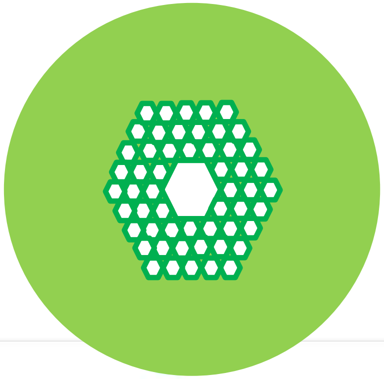
Hollow core

- Photonic-crystal fibre –
  - Photonic crystal fibre
    - Light is confined by band gap effects
  - Holly fibre
    - PCF's use holes, in the glass, in the cross section
  - Hole assisted fibre
    - Light is guided by conventional higher-index with the presence of air hole
  - Bragg fibre
    - Light is guided by concentric rings of multilayer film forming photonic-bandgap fibre
- Methods of construction is the same as other optical fibres



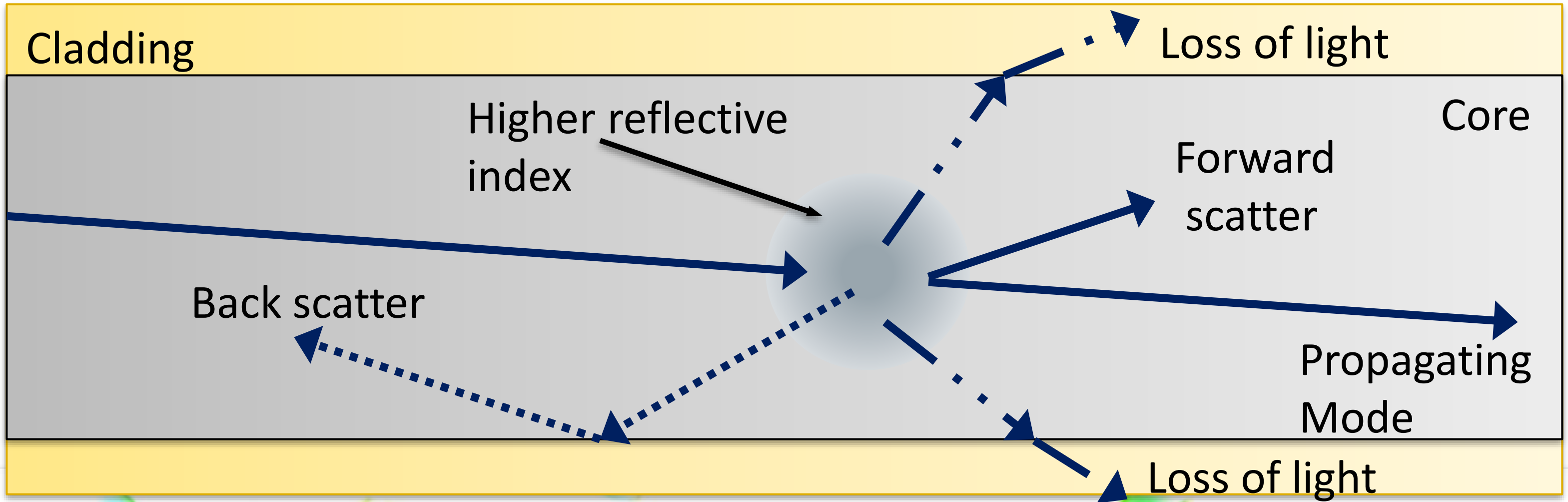
- This new technology provides the basis for high power delivery without nonlinear effects or material damage.
- Solid core
  - Operates with index fibre guiding principle
  - Higher average index than the micro-structured cladding
  - Higher effective – refractive index contrast at boundary points
  - Leading to stronger confinement
    - Nonlinear optical devices
    - Polarisation-maintaining fibre
- Hollow core
  - Operates by containing the light within the core by the photonic bandgap created by the micro-structured cladding
  - Light can be confined in a lower index material or air
  - circumvent limits imposed by available materials (attenuation limitations)

HEALTH WARNING!

NONLINEAR EFFECTS IN OPTICAL FIBRE – LIMITING TRANSMISSION DISTANCES

Rayleigh Scattering

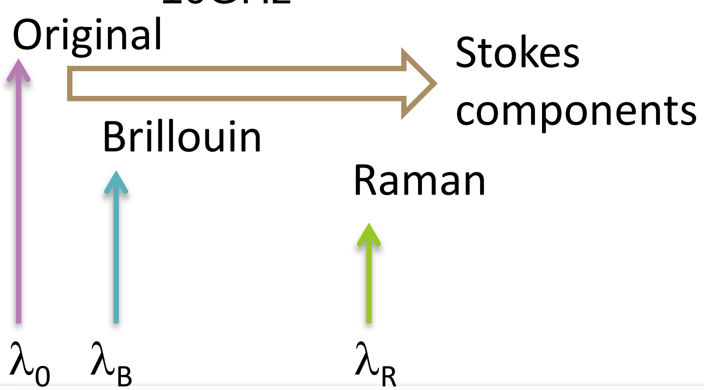
- Rayleigh scattering is the linear (elastic) scattering of light, in all directions off silica molecules.
- Elastic scattering (energy is conserved)
  - Scattered light frequency does not change
- Production of optical fibre inevitably results in a random density fluctuations of the silica,.
- Density fluctuations altering the reflective indexes, which alters the path of light propagating through the fibre
  - Created when silica cools from melting point
- Rayleigh scattering is responsible for the lower limit of the propagation loss in optical fibres.



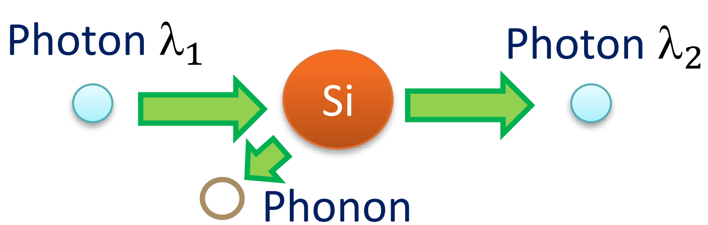
Simulated Brillouin Scattering (SBS)

Phibre

- At high optical powers the variations of the electrical field can **induce acoustic vibrations within the optical fibre**
- Acoustic vibrations causes scattering of the optical signal
- Generates very narrow linewidths and distorts the optical signal
  - 20-100 MHz at 1550nm (GHz spacing between channels)
  - Scattered light is shifted by 1 to 10GHz



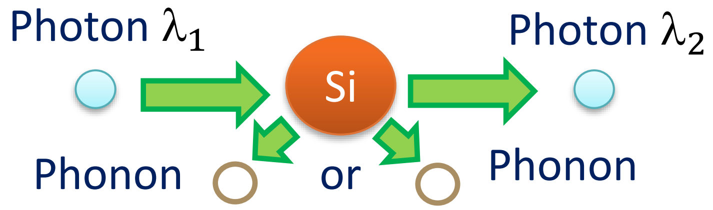
- No interactions between different wavelengths (in DWDM) – due to the narrow linewidths generated
- SBS can cause gain in the opposite direction to the signal propagation
  - i.e. back to the source
- SBS can generate a potentially strong signal back toward the transmitter, which affects the transmitter power and introduces power fluxuations.



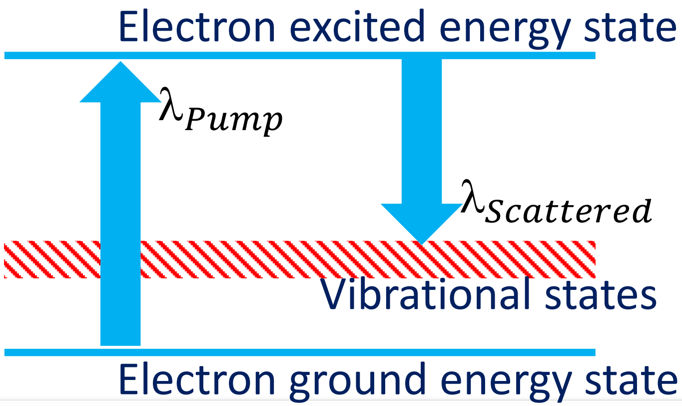
Simulated Raman Scattering (SRS)

Phibre

- As with SBS, photons interacts with silica atoms, creating photons, at lower energy (higher wavelength) as well as phonons (vibrations), which dissipate within the optical fibre
- Caused by vibrational and rotational transitions in the reactions between neighbouring silica atoms
  - Higher frequency phonons (vibrational not acoustic)
  - Scattering of a photon to a lower energy photons
  - Energy is conserved with the generation of a phonon



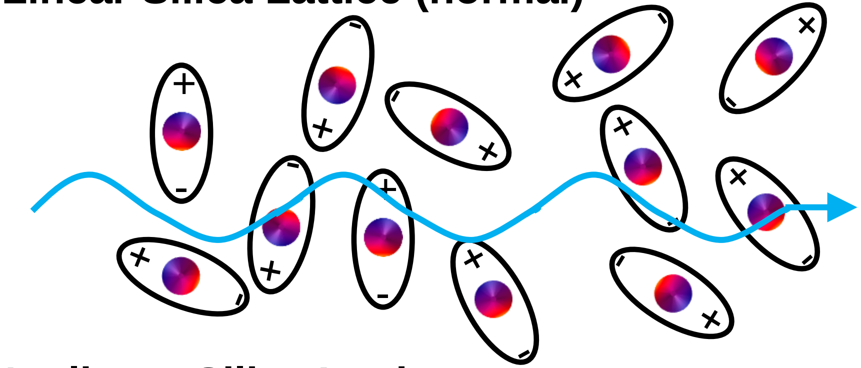
- SRS has the properties of:
  - Scattered light shifted by **13GHz**
  - SRS is a board band effect, compared with SBS
  - SRS is coupled in both forward or reverse directions
  - SRS can be used to provide amplification
    - Gain spectrum is **20-30 THz** wide



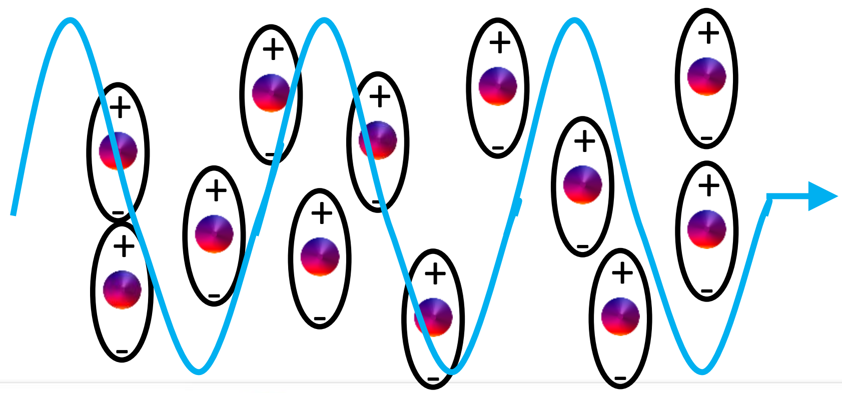
Nonlinear medium

- As Silicon is a **di-electric material**. As light traveling through a medium, at high electric field intensities, begins to interact with the dielectric polarisation of silica.
- At high power levels Silica atoms align to the polarisation of the electrical field.
- Scattering light increases exponentially once the incident power exceeds a threshold value
- Nonlinear phenomena cause
  - Simulated Raman Scattering (SRS)
  - Simulated Brillouin Scattering (SBS)
  - Self Phase modulation (SPM)
  - Cross Phase modulation (XPM)
  - Four Wave Mixing (FWM)
- Network engineers carefully design their networks to prevent nonlinear effects

Linear Silica Lattice (normal)



Nonlinear Silica Lattice



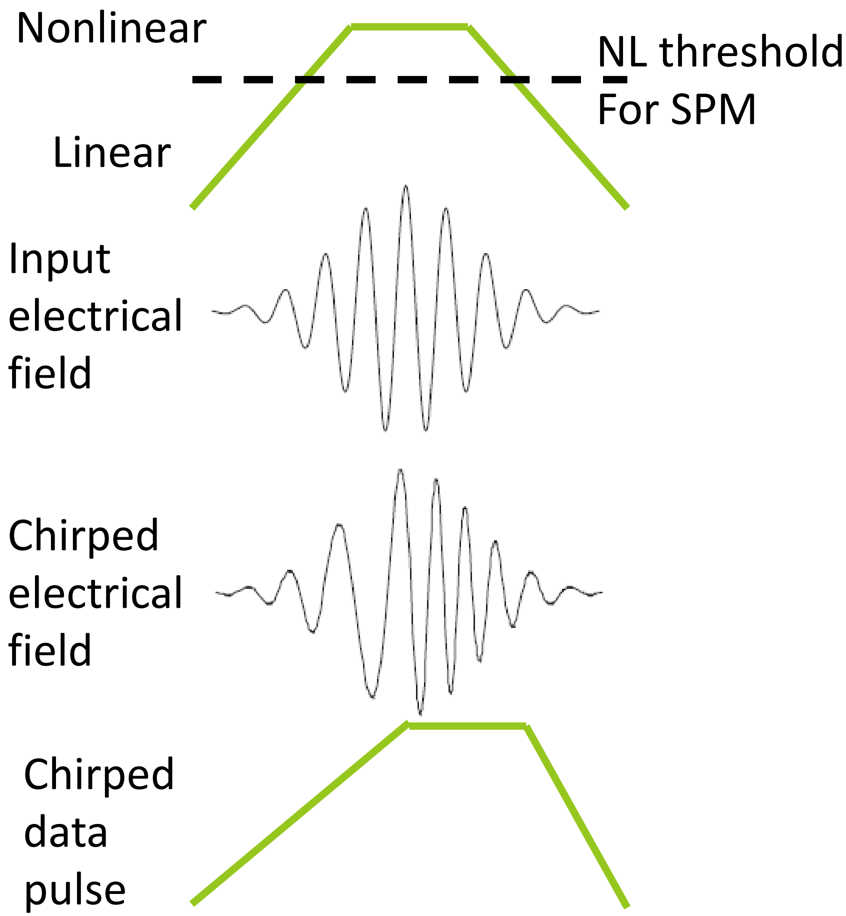
Nonlinear Phase Modulation

- The fibre reflective index is dependent on the intensity of the optical signal
- **Presence of high power within the core, changes the reflective index of the fibre**
- Nonlinear effect is dependent upon:
  - Power present in the fibre
    - Multiple wavelengths in DWDM systems results in higher power being present in the fibre
  - Cross sectional area of fibre
    - Smaller the fibre core, the greater concentration of power
    - Lead to the creation of large effective area fibres (LEAF) variants **G.654 (A,B,C,D)**

- Nonlinear propagation of data signal manifests itself as :
  - **Self Phase Modulation (SPM)**
  - **Cross Phase Modulation (XPM)**
  - **Four Wave Mixing (FWM)**
- All these effects are detrimental to a optical signal
- Communications service providers have to carefully design their networks to reduces these effects
- Fibre produces have designed a number of different types of fibres to reduce these NL effects
  - Non Zero-Dispersion fibre
  - Large effective area fibre (LEAF)
  - +ive and -ive dispersion fibres

Self Phase Modulation (SPM)

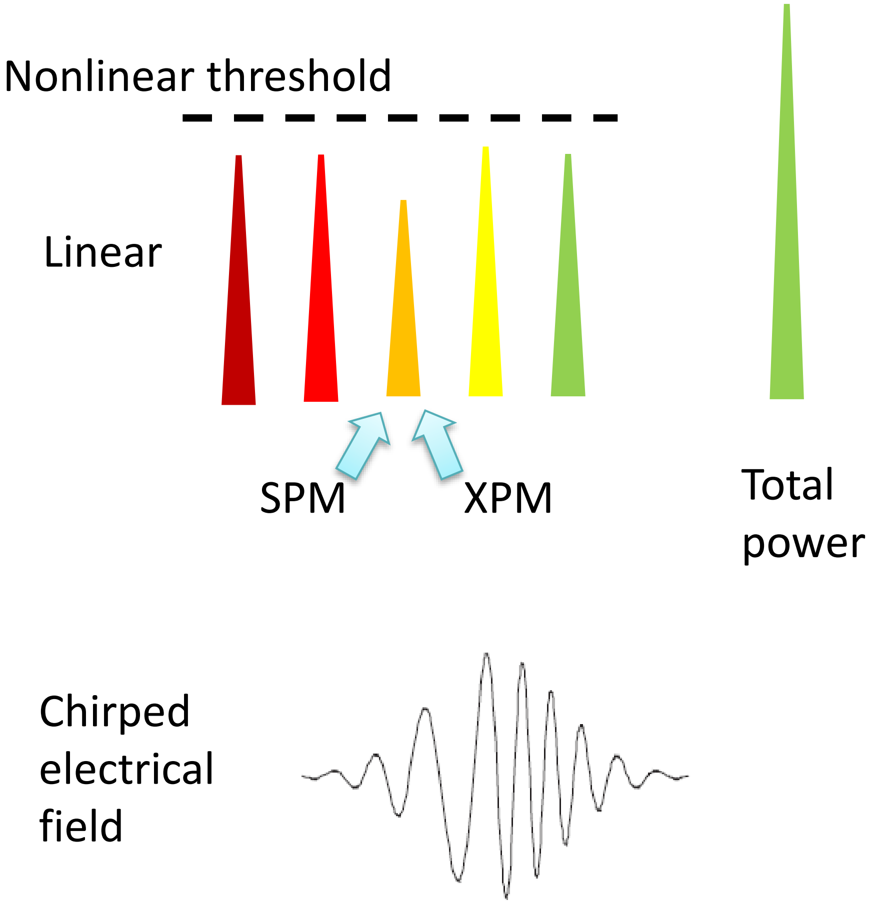
- Nonlinear reflective index causes a pulse of light to experience a phase shift
- Due to the optical pulse has differing power levels for the duration of the pulse
- SPM leads to development of an optical chirp which enhances broadening effects of chromatic dispersion (CD)
- Leading to greater Inter-symbol-interference (ISI)



Cross Phase Modulation (XPM)

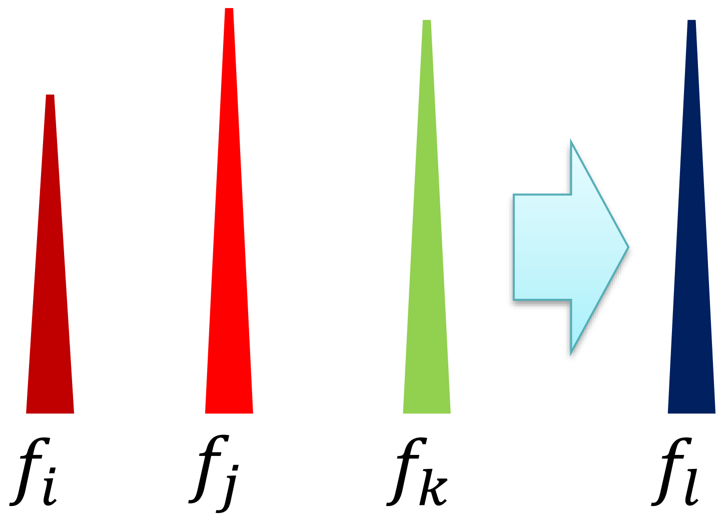
Phibre

- High number of wavelength channels in a WDM systems can lead to power exceeding NL threshold
- The presence of multiple channels causes phase shifts of adjacent wavelength channels
- The phase shift and chirping caused by SPM is further enhanced by the presence of adjacent channels



Four Wave Mixing (FWM)

- Intensity dependence of reflective index does not just induce phase shift, but gives rise to new signals
- New signals are at new frequencies
  - $f_l = 2f_i - f_j$
  - $f_l = f_i - f_j - f_k$
- Three waves combine to generate a fourth wave
- The effect is bit rate independent
- It is dependent upon channel power intensity and spacing
- New signals can interfere with already existing signals

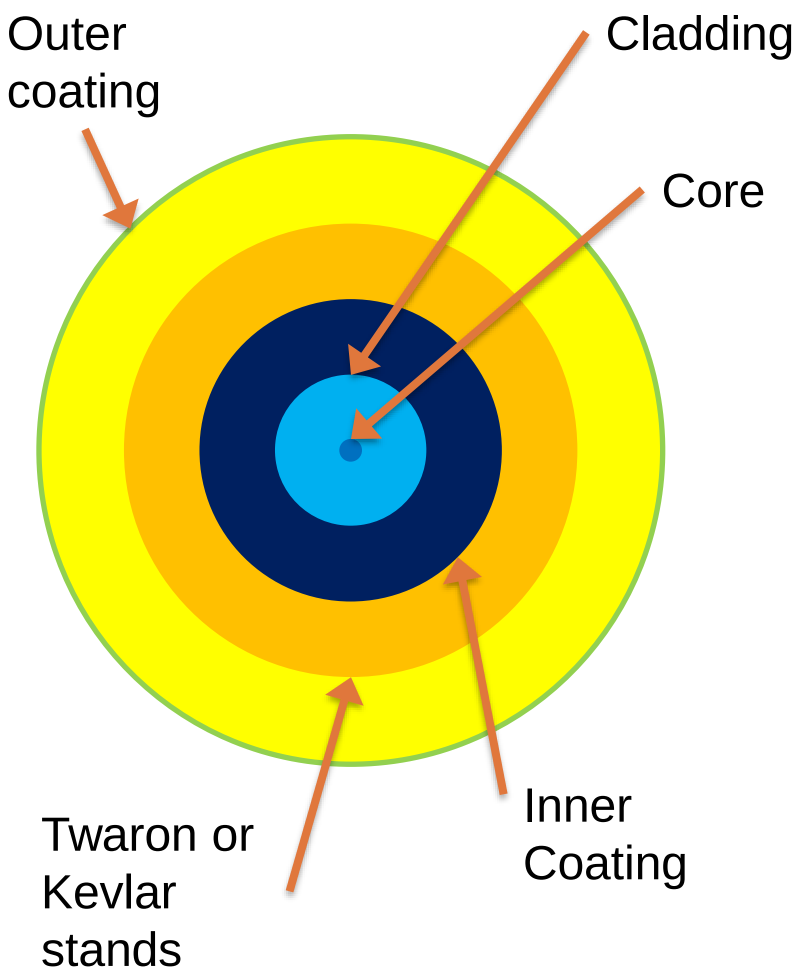


$$f_i = \frac{1}{\lambda_i}$$

CABLES

Fibre cables

- An inner primary cladding is a coating placed over the silica fibre an acts as buffer.
- It is designed to act as a shock absorber to protect it from moisture and physical damage and to minimize attenuation caused by micro-bending.
- Protects fibre from rigors of manufacturing
- To provide extra strength for the cable, Twaron or Kevlar stands are used between the inner and outer coatings
- An outer secondary polymer coating (PVC or polyurethane) protects against mechanical damage and acts as a barrier to lateral forces.
- Fiber optic waveguides are effected by environmental conditions: strength, attenuation and resistance to losses caused by micro-bending.



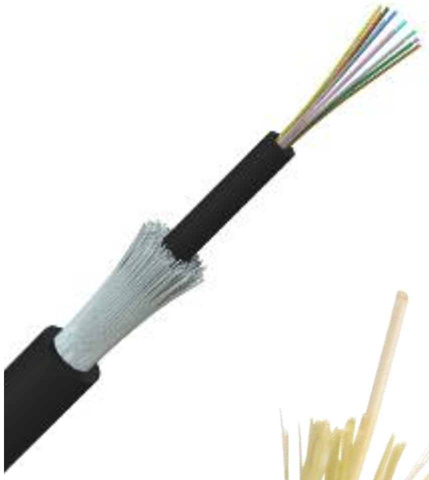
Fibre colour code

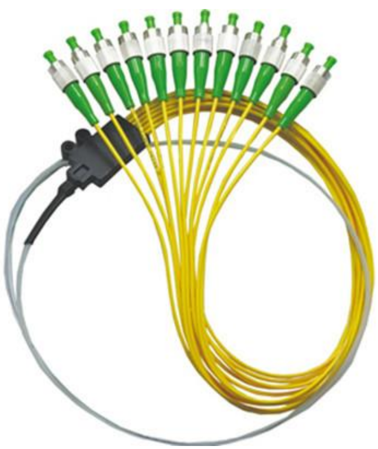
- To help identify fibres within a multi-fibre cables
- Colour code is TIA/EIA-598
  - Used by some cable manufactures
  - Other standards do exist
- The colour code is repeated with a black tracer to identify 13-24 fibres

Fibre number	Colour	Abbreviation
1	Blue	BL
2	Orange	OR
3	Green	GR
4	Brown	BR
5	Gray/Slate	SL
6	White	WH
7	Red	RD
8	Black	BK
9	Yellow	YL
10	Violet	VI
11	Rose/Pink	RS
12	Aqua	AQ

Internal cables

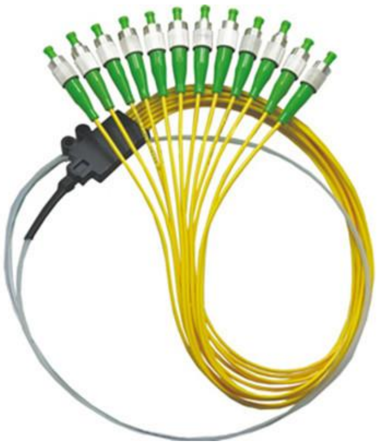
- These are typically tight-buffered cables and designed for internal environments
  - 250, 900μm buffer (colour coded)
  - loose tubes are also used
- Internal environments are mostly controlled, thus internal cables do not require as great environmental tolerance requirements
- More sensitive to tensile stress compared with external cables, with smaller bend radius's – leading to greater effects of micro–bending
- Made from material meet low smoke and halogen free requirements





Internal cables

- Types of internal cables.
  - Distribution cable
  - Breakout cable
  - Fibre optic jumper
  - Fibre pigtails



- Outer coating colouring

– SMF	– Yellow
– MMF	– Orange
– MMF, OM3/4	– Aqua
– MMF, OM4	– Violet
– Polarisation maintaining	– Blue

Exterior cables

- Outdoor cables are designed to handle a verity of environmental conditions
  - Temperature variation
  - Water submersion
  - Heavy winds
  - Sunlight radiation
  - Ground movement
  - Rodent attacks

- Built with
  - Polyethylene (one or more layers)
  - Steel armour (one or more layers)
  - Rubber (one or more layers)
  - Aramid yarn
  - Fibre tubes
  - Fillers
  - Central strength member (Steel or Kevlar)

Exterior cables

- The fibres are encase within a loose tube (2-3 mm in diameter) to reduce strain on fibres experienced during installation (mostly used for exterior cables)
- Multiple loose tubes can be found within one cable (colour coded for easily identification)
- Possible to obtain cables of up to 200 fibres

- Tubes can be hollow or filled with a water resistant gel, preventing moisture on the fibre and thus degrading the fibre performance
  – not suitable for vertical rises
- Outdoor cables are always black
- Typical diameter is 15 mm
- Cable stress and bend radius varies (always check manufactures specifications)

φ Phibre

Undersea

- Submarine cables experiences excessive stresses compared to other fibres
- Cables are laid on the sea bed and connects the worlds continents
- Cables are designed for greater:
  - Temperature variation
  - High pressure water submersion
  - Ground movement
  - Shark attacks
  - Trawler snagging

1 – Polyethylene
2 – Mylar tape
3 – Stranded steel wires
4 – Polyethylene
5– Mylar tape
6 – Stranded steel wires
7– Mylar tape
8 – Polycarbonate
9 – Copper or aluminium tube
10 – Stranded steel wires
11 – Petroleum jelly
12 – Optical fibers

Picture from http://www.kis-orca.eu/subsea-cables/design#.VzTlTb5X1js

Splicing and connectors

Connecting fibres strands

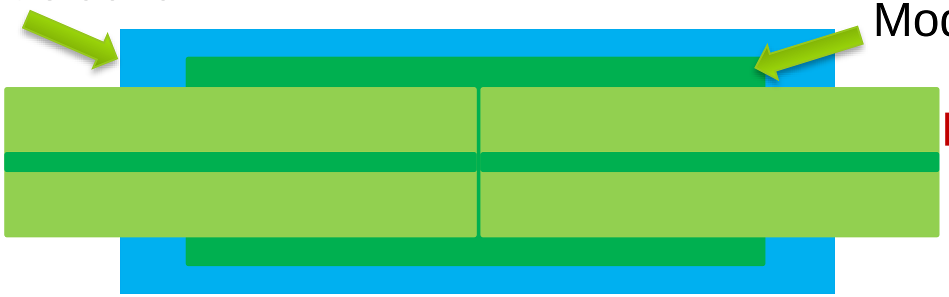
- Connecting fibres is more complicated than joining electrical fibres
- User is required to melt two ends of fibres and joint together
- Challenge is to increase fibre length while maintaining light inside to core
- Core must be highly accurately alighted
- Ensure the lowest power loss possible

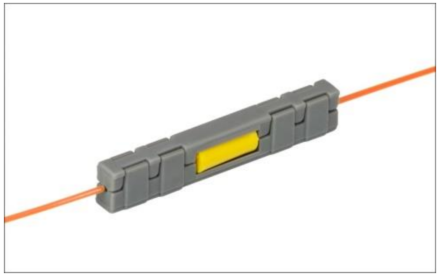
- **Types of connecting fibres**
- Mechanical (short term)
  - Holds fibres in place mechanically
  - Mode matching gel is used to reduce loss of the joint
  - Medium/long time term connection
- Connectors (medium term)
  - Fibre ends are butted up to each other
  - Variety of types
  - Short or semi permanent connections
  - Used for internal connections
- Fusion splicing (long term)
  - Uses electrical spark to heat silica to melting point to fuse fibre strands together
  - Lowest loss
  - Permanent connections

Mechanical splicing

- Alternative to fusion splicing
- Not a permanent joint
- Two fibre ends are precisely aligned and held in place by a mechanical means
- Mode matching gel is used to reduce joint losses (performance decreases over time)
- Greater loss and reflectance
- Self contained units

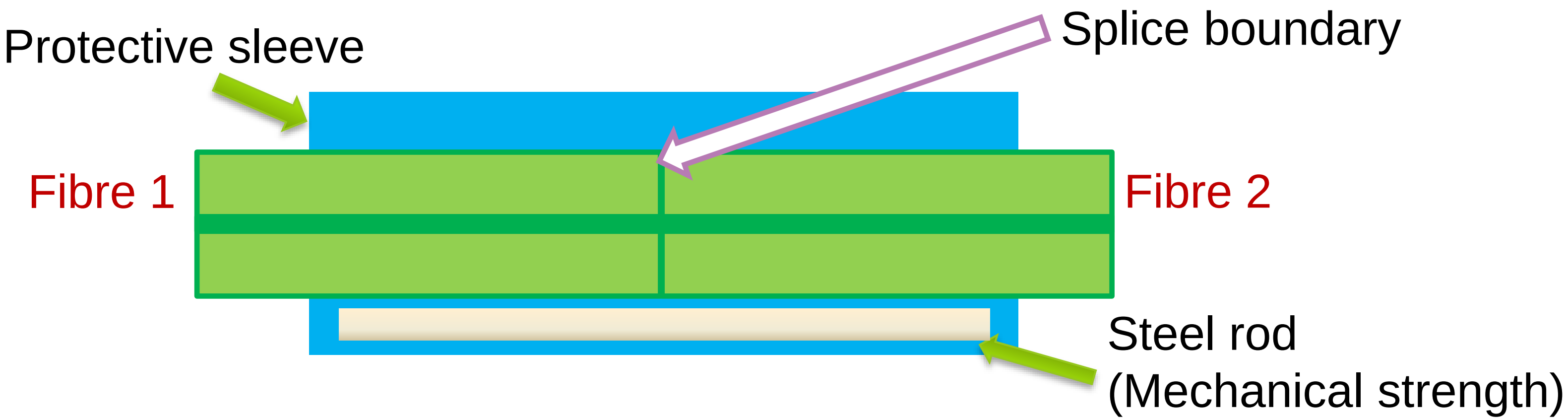
- Used for testing bare fibre with:
  - **Optical time domain reflectometers (OTDRs)**
  - **Optical loss test systems (OLTSs)**
- Simple to install
- Equipment cost is low (splicer is not needed)
- Splices are optimised by using a visual light source
- Fibre loss ranges from 0.1 – 0.8 dB in loss
- Temperature sensitive





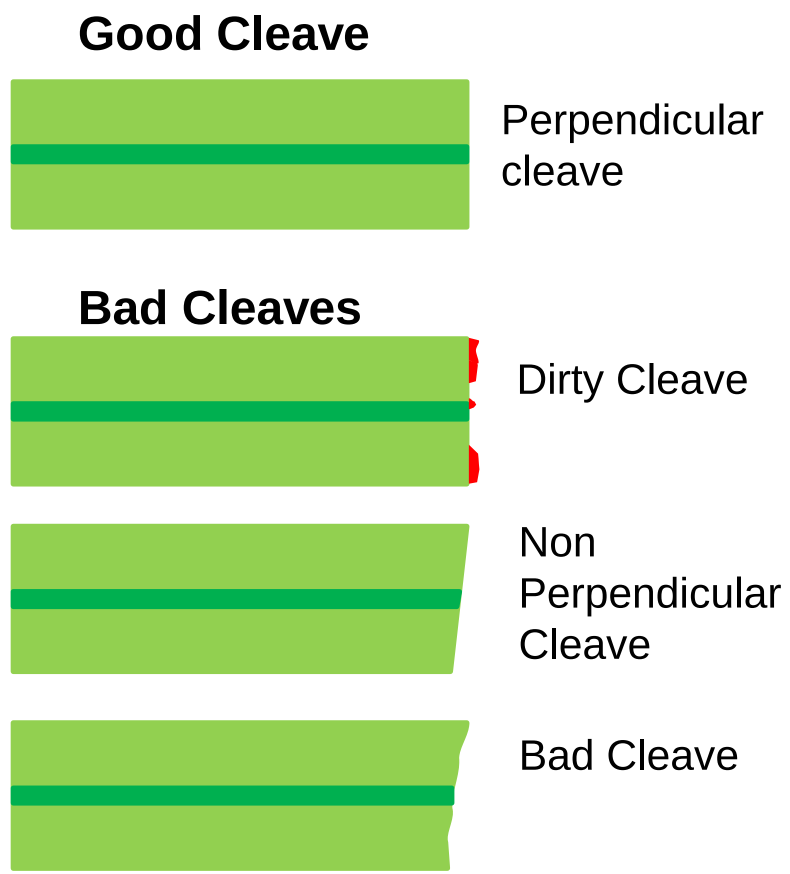
Fusion Splicing

- Permanently joining two optical fibres
- Achieved by melting the ends of two optical fibres to each other
- Lowest possible loss
- Typical splice loss is 0.1 dB (approx.) for SMF and MMF
- Requires expensive fusion fibre splicer
- Modern fusion splicers aligns and splices optical fibre automatically
- A small electrical arc is used to clean the fibre ends
- The splicer then generates larger electrical arc to heat the fibre ends, to fuses the ends together



Fusion Splicing preparation

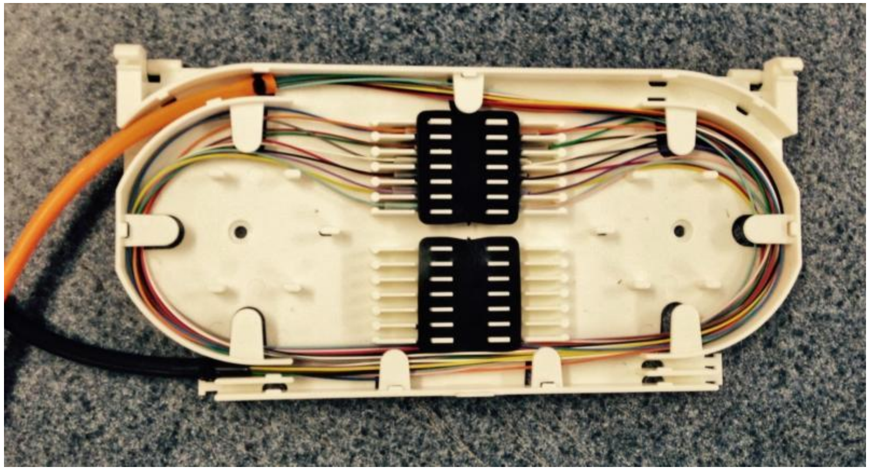
- Fibres cables are prepared by removing all protection and cladding layers
  - Strip jacket and Kevlar strands, which exposes the fibre tubes or individual fibres
  - The tube or tight buffer is stripped off
    - Any gel in the cable, must be removed carefully
  - Fibre cladding coating is removed (1cm in length) to expose the glass
  - The fibre is cleaned by Isopropyl alcohol (IPA) wipes to remove any dirt
  - Fibre ends are cleaved to achieve uniform and perpendicular face (very important)
  - Place the fibre into the guides in the fusion splicing machine and clamp it in place

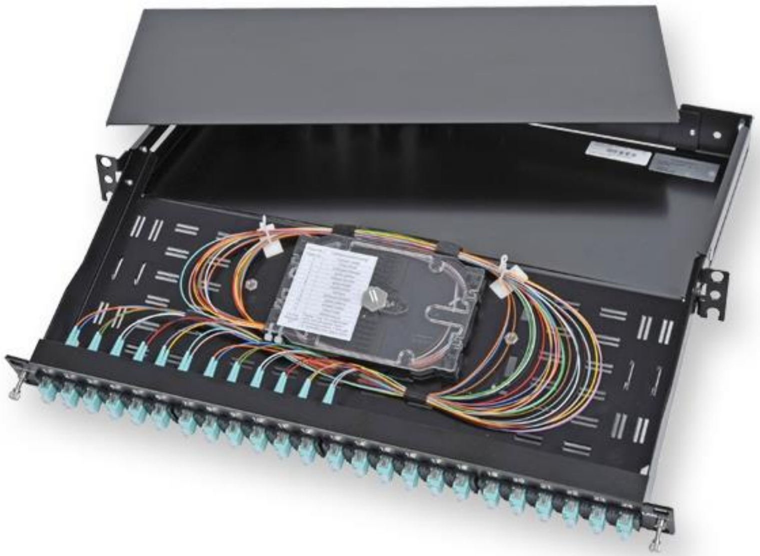


A good YouTube video can be found at: https://www.youtube.com/watch?v=TWPKV_JUVnU

Splice Trays and Patch Panels

- **Splice trays**
- Splice trays are used to hold and protect fibre splices (fusion or mechanical)
- Splice tray should match the splice protector you are using, as they can be different sizes
- Splice trays can hold 12 to 24 splice protectors
- These trays are designed to allow the installer to dress spare fibre around the holders
- **Patch panels**
- Patch panels are used to terminate a fibre cable
- Rack or wall mounted
- Ensure sufficient space for excess cabling



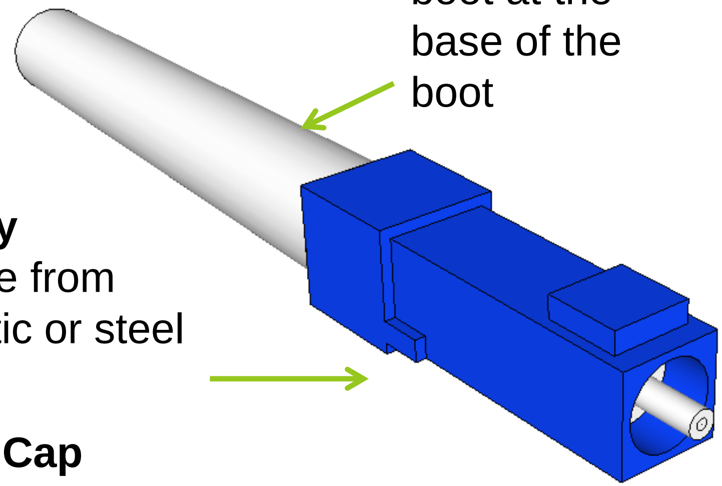


Connectors

Phibre

- Used for indoor connections
- There are many types of optical connectors used in telecom networks
- Manufacturers allows for many different connectors to maintain connector standards through their network
- Each type has different advantages to specific requirements
  - Space
  - Reliability
  - Interior
  - Exterior
  - Multi fibre connections

Boot
Strain relief boot at the base of the boot



Body
Made from plastic or steel

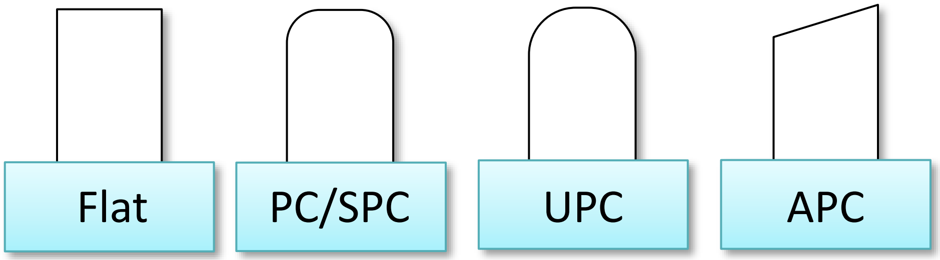
Cap
Used to protect fibre ends from dirt

Ferrule
Ceramic
  Lowest insertion loss
  Best repeatability
Steel
Plastic

- Fibres are placed in the ferrule, glued, cut and polished to reduce reflection and loss

Polished ferrules of connectors

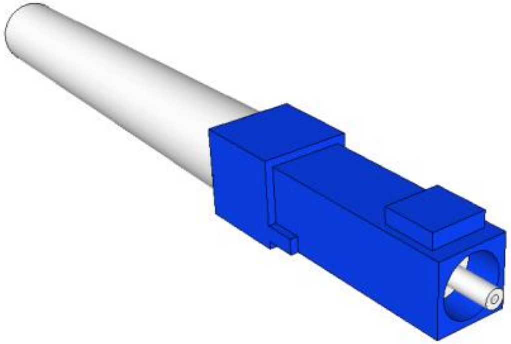
- Four types of polished ends are used in telecommunications
- Used with SMF and MMF
- A good polish reduces connection losses and signal reflection
  - Flat
  - Polished Connection (PC)
  - Super PC (SPC)
  - Ultra PC (UPC)
  - Angled PC (APC)



Connector polish	Connected return loss (dB)	Insertion loss (dB)
Flat	<-30	High
PC	<-35	Medium
SPC	<-40	Low
UPC	<-55	Low
APC	<-60	Medium

Phibre

Connector boot colours



Boot Colour	Ferrell connection	
Blue	Polished Connector (PC) , 0^0	SMF and polarization maintaining fibres
Black	Polished Connector (PC) , 0^0	
White	Physical Connector (PC), 0^0	
Green	Angled Polished Connector (APC) , 8^0	
Gray/Beige	Physical Connector (PC), 0^0	Multi Mode Fibres
Red		High optical power systems (RAMAN)

Types of connectors

- LC

- SC

- FC

- ST

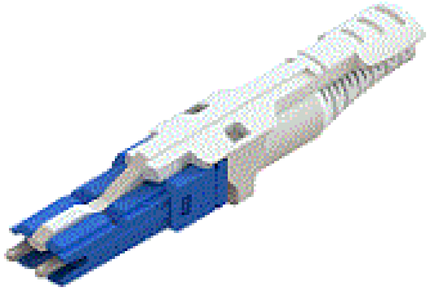
Types of connectors

- MPO/MTP

- MU

- E2000

- CS



OPTICAL FIBRE TESTING

Testing

- Scope of testing is to ensuring optical network is operating as designed
- Field testing is used for
  - **Installation**
    - Ensuring cables conform to stated specifications
  - **Maintenance**
    - Test for cable degradation
  - **Restoration**
    - Trouble shooting
    - Determining the cause of an outage or degradation
- **Single** and **dual** ended tests
  - Access to other side of link
  - Can be difficult over large distances
  - Add cost and time to measurements
  - Equipment need to be referenced and calibrated

- **Types of measurements**
  - Visual fault finding and damage inspection
  - Total optical link loss
  - Attenuation profile
    - Attenuation per unit length (dB/km)
  - Attenuation
    - Splices
    - Couplers
    - Connections
  - Fibre length to event
  - Optical return loss
  - Chromic dispersion
  - Polarization mode dispersion
  - Signal quality
    - OSNR
    - BER (Q-factor)

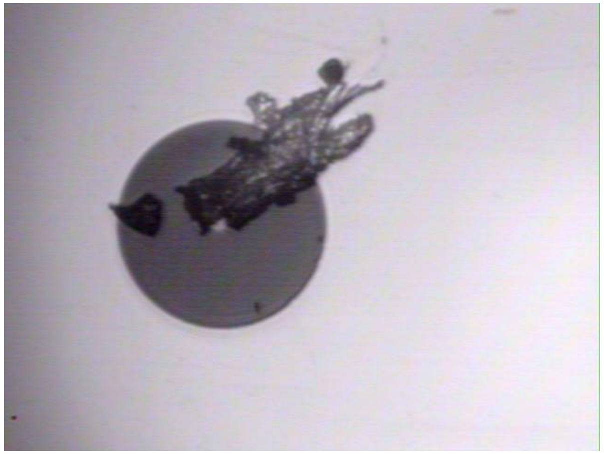
Visual light source

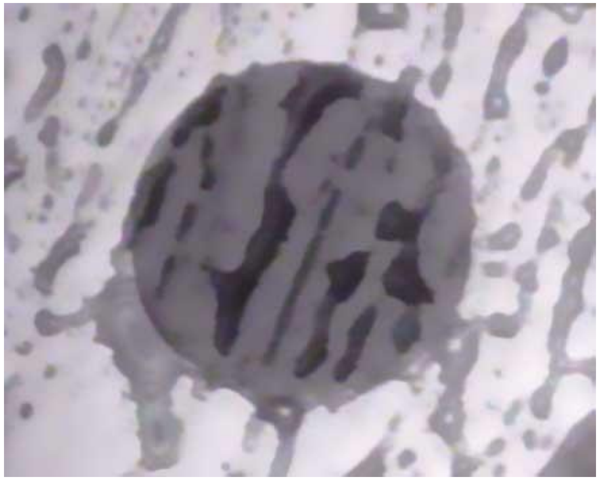
- Quick method to **check fibre connectivity**
- Testing
  - Locate
    - **Tight bends**
    - **Breaks**
    - **Continuity testing**
- Identify fibres through installation sites
- Stand alone or installed in higher grade equipment

Visual fibre end inspection

Phibre

- A visual tester allows the user to determine the degree of contamination or connector face damage.
- High loss can be explained by interface damage.
- This tool provides a video image of the quality of the connector face.
- **ALWAYS CLEAN YOUR CONNECTOR!!!**
- Dust contamination can significantly effect connector performance
  - Increasing **connection loss** and **return loss**
  - Cause scratches on connector surface can to lead to permanent damaged
- Cleaning equipment
  - Wet clean (95% Pure Isopropyl alcohol)
  - Dry clean
    - Lint free tissues
    - Push type cleaners

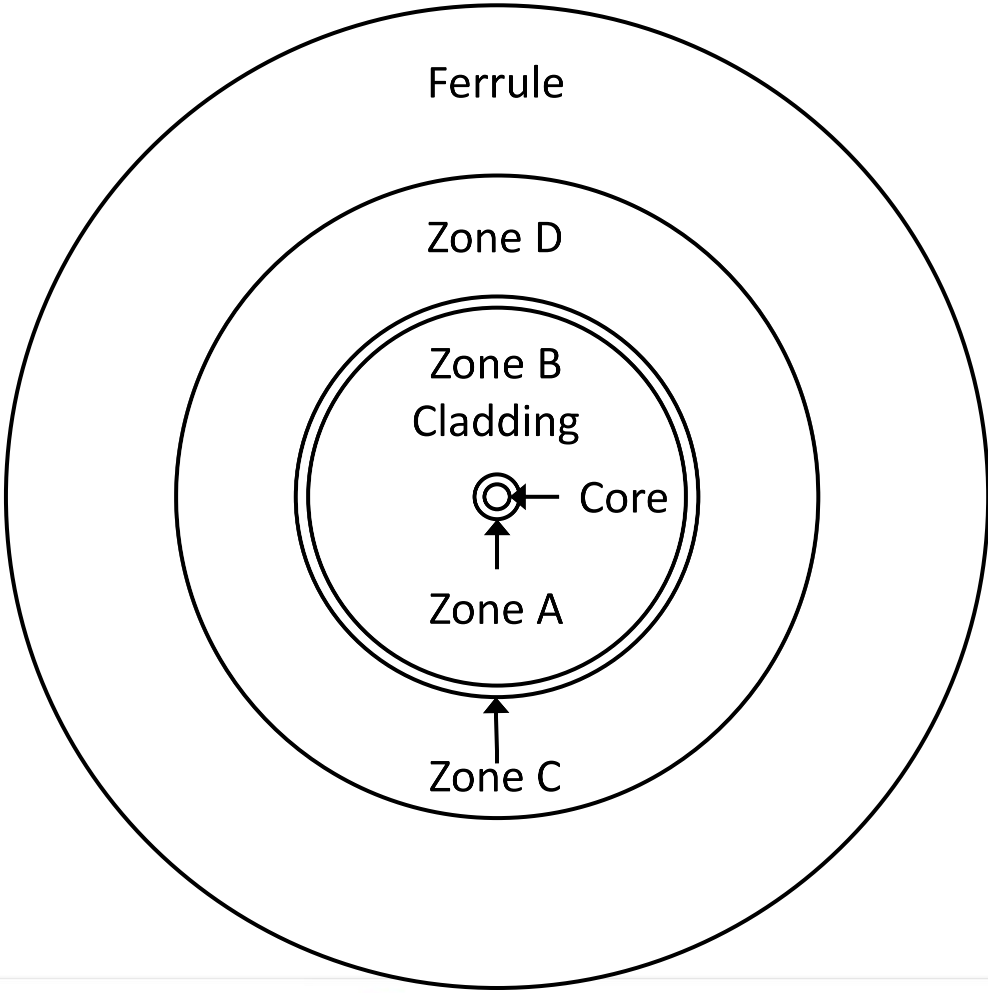




Visual fibre end inspection

Phibre

- Connector end face damage levels are specified in the International Electrotechnical Commission (IEC) standard **IEC 61300 Part 3-35**
  - Zone A – Core
  - Zone B – Cladding
  - Zone C – Adhesive
  - Zone D – Contact
- A visual scope allows the user to determine the degree of contamination or connector face automatically



Connector cleaning

- Methods of cleaning connector end faces
  - Compressed clean air
    - Use Static free nozzles
    - Best use safety glasses!
  - Clean, residue and lint free swabs
    - Swabs have a small head to fit inside connector adaptors
    - Adaptor cleaning device
  - Clean, lint free tissues
    - Cletops cleaners
    - Tissues
  - Cleaning solvent
    - Residue free
    - 95% pure isopropyl alcohol (IPA)
    - Distilled water

Power loss

Phibre

- Measures the **total loss of power over the fibre section** under test
- Simple measurement
- Requires a laser power source and receiver
  - Calibration between source and receiver is required
  - Can be performed with a:
    - Single patch cords
    - Two patch cords and one connector
    - Three patch cords and two connectors
- Applies to all types of fibre
- Power meters have wide spectral width and can be affected when passing through optical filters

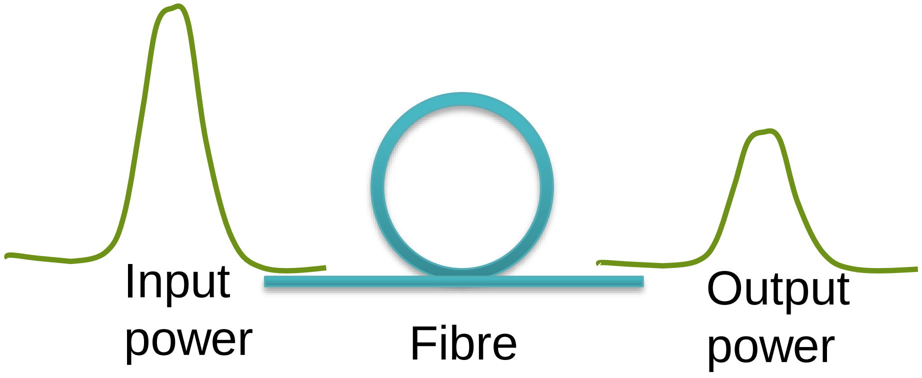
- Relative measurement (dB)

$$P_{loss}(dB) = 10 \times \log\left(\frac{Input\ power\ (W)}{Output\ power\ (W)}\right)$$

$$P_{loss}(dB) = P_{input}(dB) - P_{output}(dB)$$

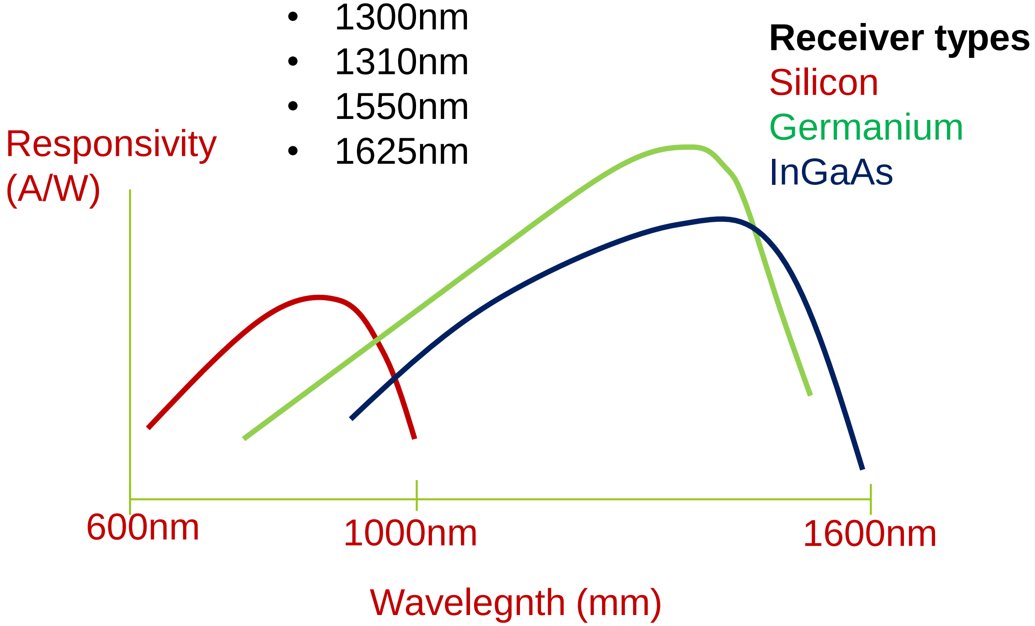
- Absolute measurements (dBm)

$$P_{loss}(dBm) = 10 \times \log\left(\frac{Power\ (mW)}{1(mW)}\right)$$



Measurement of power loss

- **Optical power sources**
  - LED (for MMF)
  - Laser source (for SMF)
  - – Provides a stable and continuous wave (CW)
    - 850nm
    - 1300nm
    - 1310nm
    - 1550nm
    - 1625nm

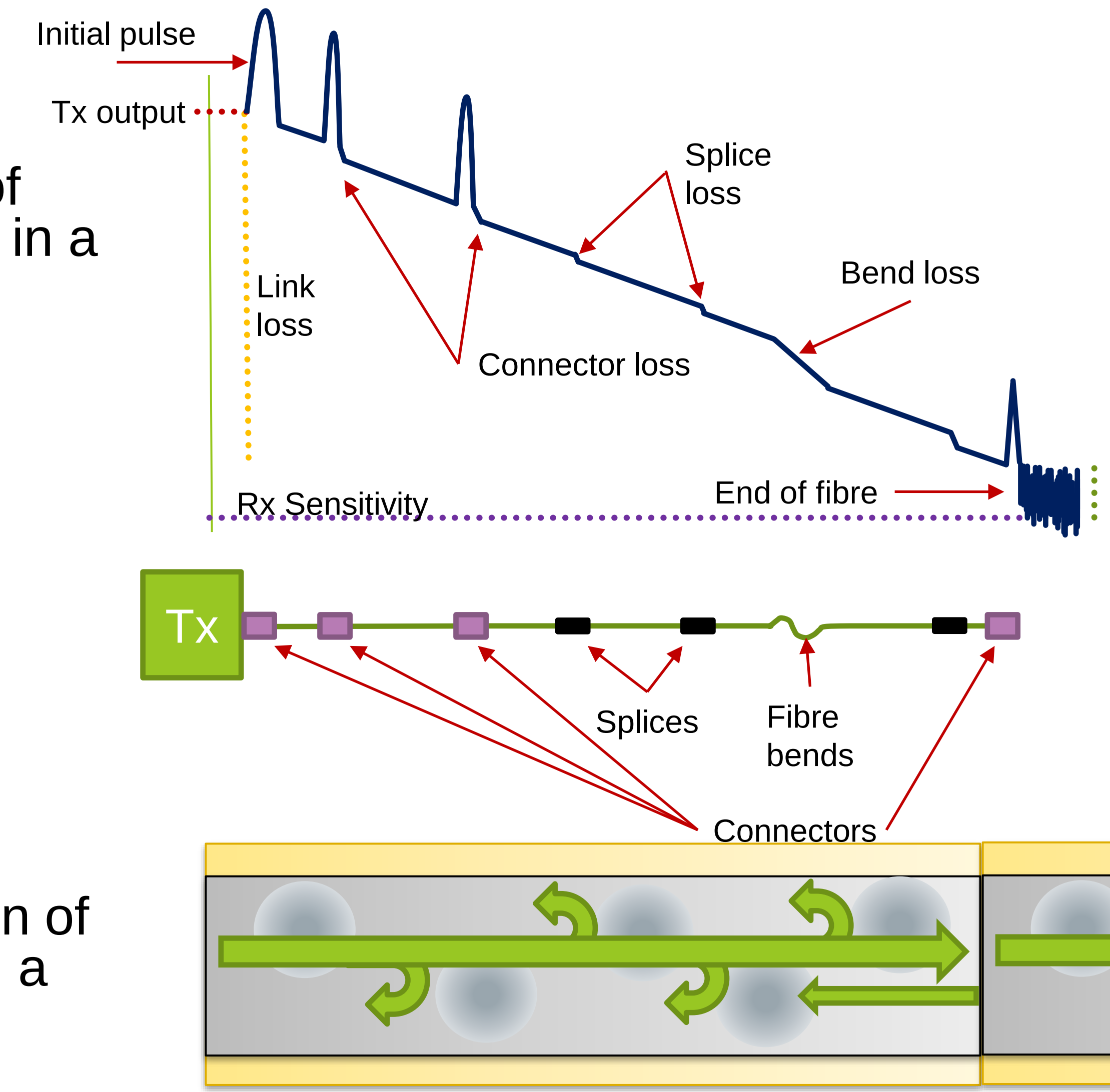


- Optical power meters
  - – Key piece of equipment for any engineers tool box
  - – Displays the incident power onto a photodiode
  - – Receiver range (850 – 1625nm)
    - Indium Gallium Arsenide (InGaAs)
    - Silicon
    - Germanium
  - – Wavelength selective
  - – Absolute and relative power measurements
    - Relative (dB)
    - Absolute (dBm)
    - Linear (W or mW)
  - – Measurements are limited by dynamic range of receiver
    - +20 to -60 dBm

Optical time domain reflectometry (OTDR)

Phibre

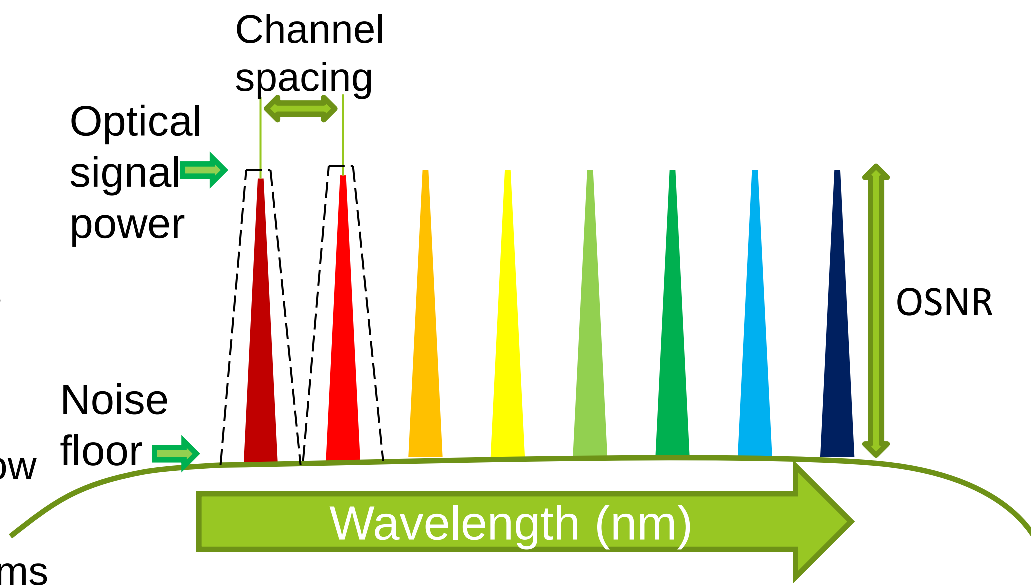
- Method to measure loss of power as unit of distance, in a graphical format
  - Attenuation of fibre
  - Bend loss
  - Splice loss
  - Connector loss
  - Reflectance
  - Optical return loss
  - Distance
- Locates fibre breaks and losses in a fibre path
- Can determine the location of excessive loss or break in a link



Optical spectral analyser (OSA)

- Equipment used to measure and **display the spectrum of light traveling in optical fibre**
  - Power (dBm or W) measurements per wavelength (nm or THz)
  - Optical power (dBm or mW)
  - Central wavelength (nm or THz)
    - Standardisation of optical channel
  - Spectral width (nm or THz)
    - Width of an optical channels
  - Channel spacing (GHz)
    - Distance between optical channels
  - Optical signal-to-noise ratio (dB)
    - Measured from peak to noise level
    - Noise is measured in 0.1nm window (typical value)
- Key tool to debug problems in a WDM systems

$$OSNR = 10log\left(\frac{P_{sig}}{P_{noise}}\right)$$

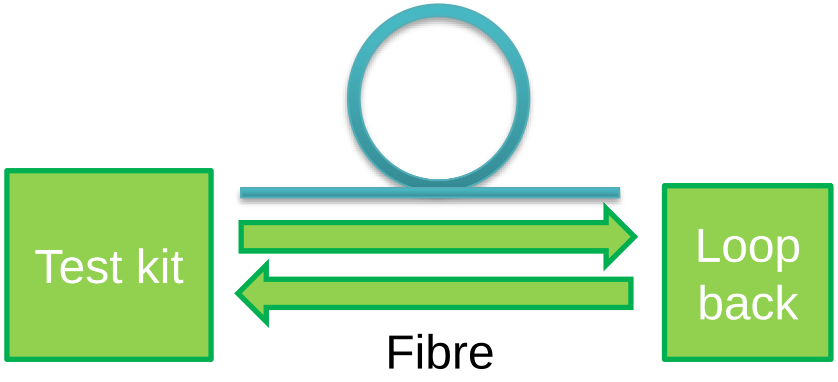


Chromatic dispersion (CD) testing

Phibre

- **Measure the CD for a fibre link**
- In most cases dispersion of an optical fibre path would not be known
- Measurement units (**ps/nm**)
  - Already installed fibre
  - Legacy of relaxed CD installation requirements
  - Long and ultra long links
  - Dispersion managed soliton systems
- Field testing measurement methods
  - Phase shift
  - Differential phase shift
- Measurement system scans transmission waveband and measured the relative group delay

- Chromatic dispersion is calculated from relative group delay
- User can obtain the following values of the fibre
  - Zero dispersion wavelength
  - Slope dispersion wavelength
  - Dispersion at specific wavelengths

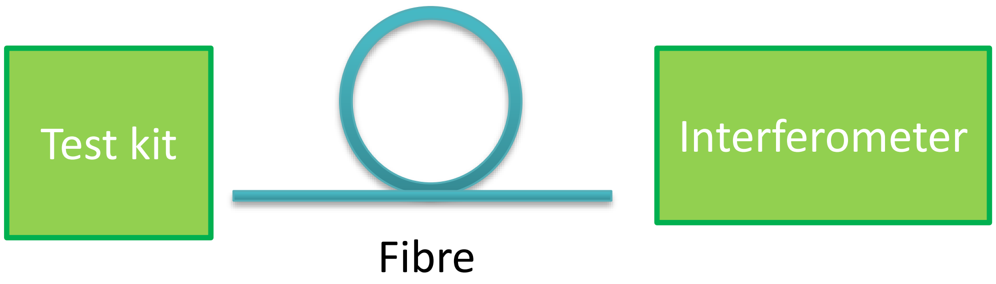


Polarisation Mode Dispersion (PMD) testing

Phibre

- PMD measurements are increasingly important in optical networks for >40G systems
- PMD measurements changes
  - Vibrations (sound)
  - Temperature
  - Fibre movement
  - Stress
- Field measurement of PMD can be made:
  - Michelson Interferometer (preferred solution)
    - Requires white light source
  - Wavelength scanning
  - Polarised OTDR (not yet available)

- Measures the delay between the two polarisations
- Total PMD is measured in units of **picoseconds (ps)**
  - Absolute measured in $\boldsymbol{ps/\sqrt{km}}$



Bit error rate (BER)

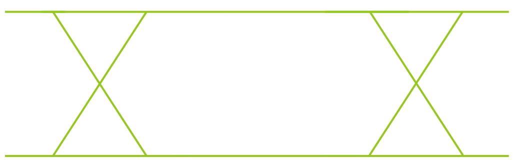
Phibre

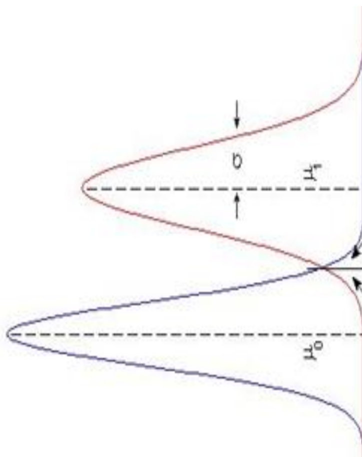
- Is the rate at which bit errors occur in the transmission of digital data per unit time
- These errors are caused by optical impairments (noise, distortion, dispersion, loss of signal, jitter)
- BER is proportional to signal distortion
- The performance degrades with increased signal distortion
- BER is determined:
  - Comparing transmitted and received bits, counting the errors of a known data packet
  - Measurement of signal power and variance to measure the probability of error occurring in the bit stream
- FEC codes are used to **increase transmission range** and performance with minimum equipment deployment

Transmitted: 1 0 1 0 0 1 0 1 1 1
Received: 1 0 0 1 0 1 0 0 1 1

Bit stream

Eye Diagram



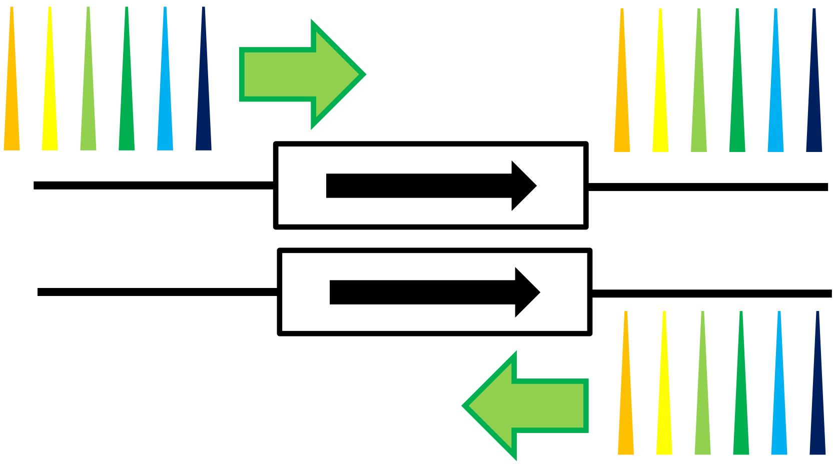


$$BER(D) = \frac{1}{2}\int_{-\infty}^{D} pdf_1(x)dx + \frac{1}{2}\int_{D}^{\infty} pdf_0(x)dx$$

PASSIVE OPTICAL COMPONENTS

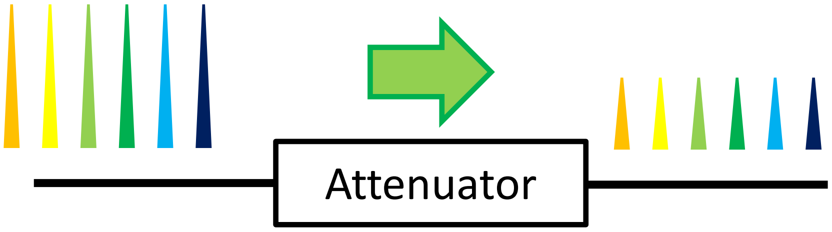
Optical Isolators

- Consider it an **optical diode**
  - Only allows light to travel in one direction through the device
- Prevents back scattered light (feedback) travelling back towards light source

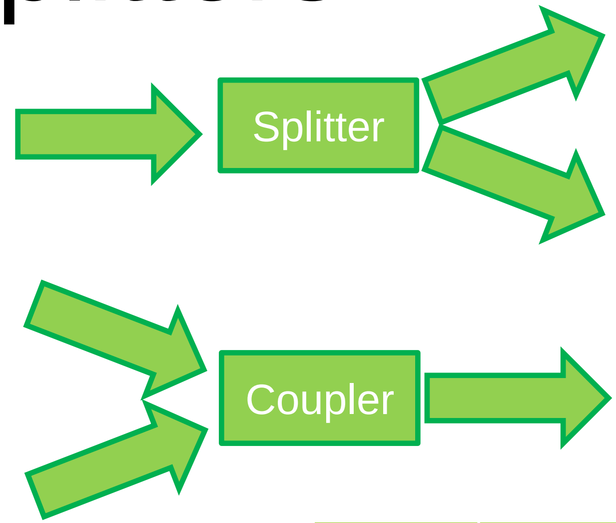


Optical Attenuators

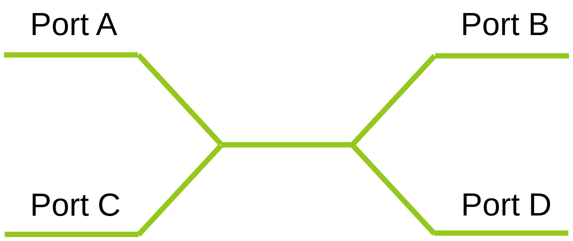
- Used to reduce the optical power of an optical signal
- Wavelength dependent
- Can be fixed or variable



Couplers and splitters



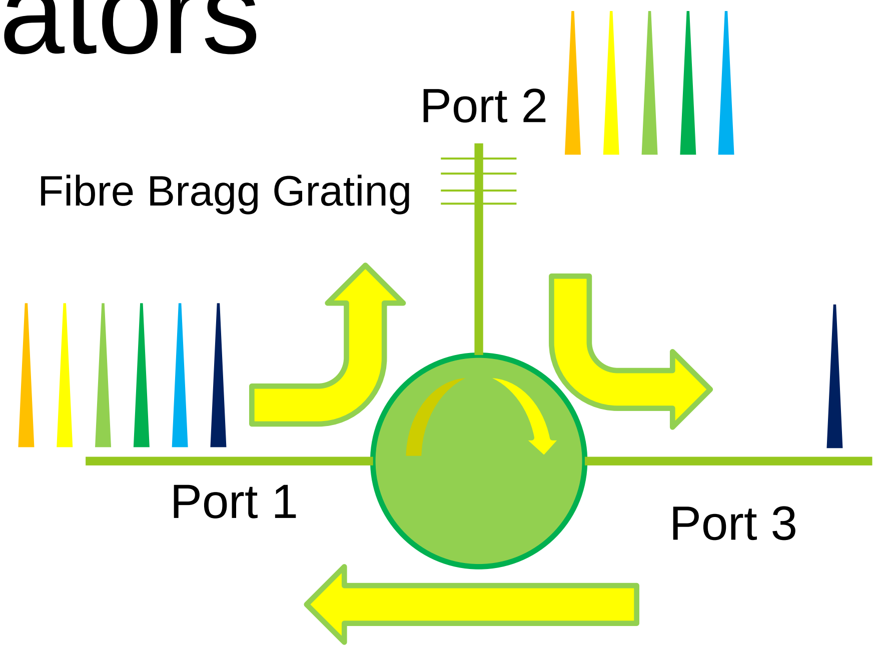
- Splits or combines light into separate fibres
- Created by fusing of two fibres together
- Polished couplers are also available
  - Expensive, only used for specific requirements
- Important considerations
  - Insertion loss
  - Operating waveband (850, 1310, 1550, 1625nm)
  - Fibre types



Coupling Ratio	dB loss per port (ideal + excess loss) (dB)
50/50	3.5/3.5
40/60	4.5/2.6
30/70	5.8/1.9
25/75	6.7/1.7
20/80	7.6/1.3
10/90	11.0/0.8
5/95	14.2/0.5

Circulators

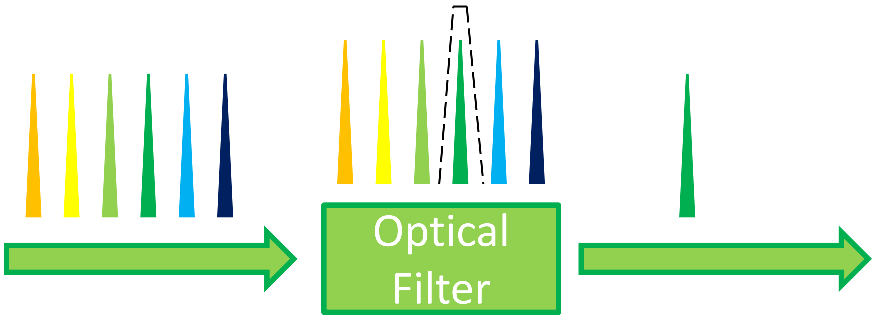
- Used to separate optical signals travelling in different directions in an optical fibre
- Light entering port one travels through the circulator and appears on port two.
- Some light is reflected back into the circulator by the presence of a Fibre Bragg grating (FBG) and appears on port 3 instead of port 1



- Devices are made from:
  - Faraday rotator
  - Fibre Bragg grating
- Direction of light
  - Port 1 to Port 2
  - Port 2 to Port 3
  - Port 3 to Port 1

Filters

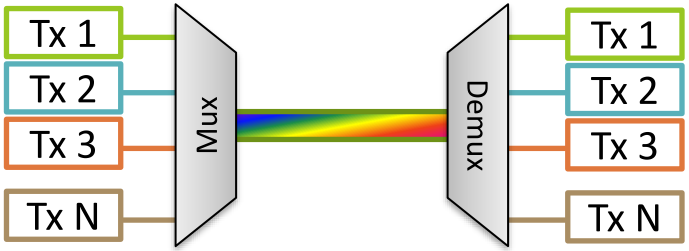
- Selection of a specific channel or waveband on an optical fibre
- Usage
  - Fibre to the X (FTTX)
  - Wavelength division multiplexing WDM
  - Local area network (LAN)
  - Cable television (CATV)
  - Sensing
  - Amplifiers
  - Transmitters
  - Medical Equipment



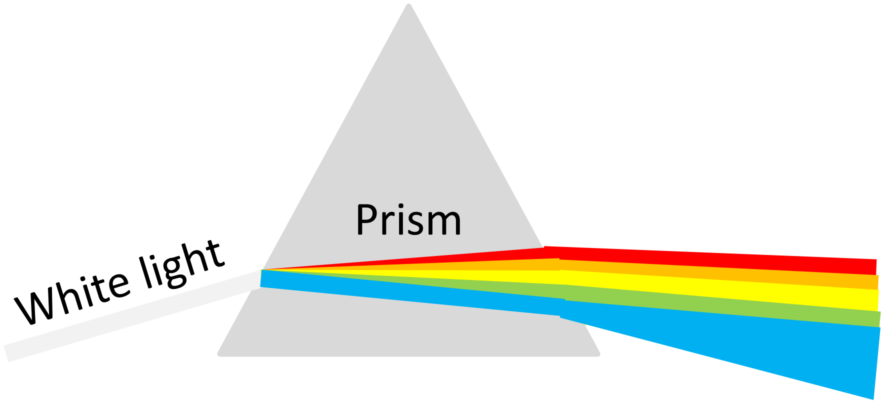
- Filters need to be
  - Low insertion loss
  - Polarisation independent
  - Insensitive to variation of ambient temperature
  - Filter to have flat passband
    - Reduce accumulated loss by cascading filters
  - Sharp passband tails
    - Reduce adjacent channel crosstalk

Channel Multiplexing

- Used for **Wavelength Division Multiplexing (WDM)** for increasing transmission capacity by transmitting multiple channels through one fibre
- Developed in 1980's
- It's a popular method to increase capacity
  - Due to the ability to combine channels of data of different wavelengths onto a single fibre without experiencing high loss
- Provides ability to add additional channels to an optical fibre without substantial loss



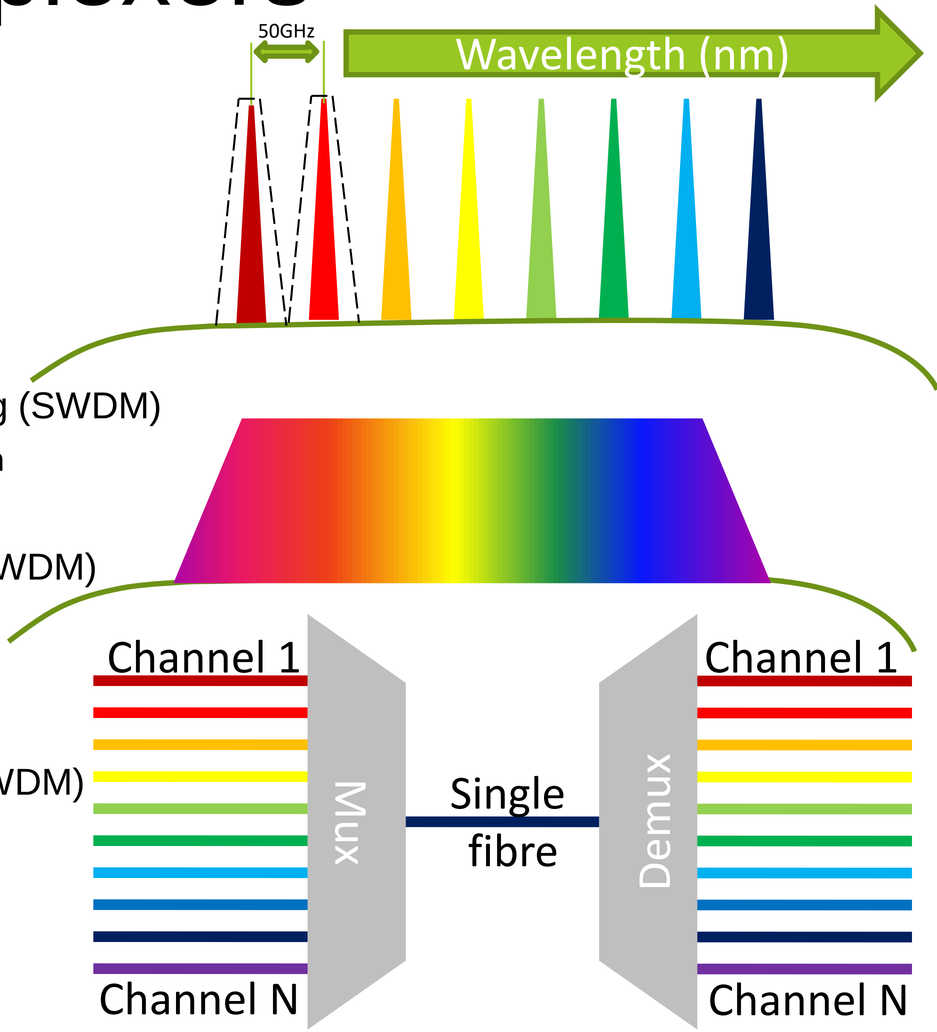
$$\Delta f = -\frac{c}{\lambda^2}\Delta\lambda \qquad \Delta\lambda = -\frac{c}{f^2}\Delta f$$



Multiplexers and Demultiplexers

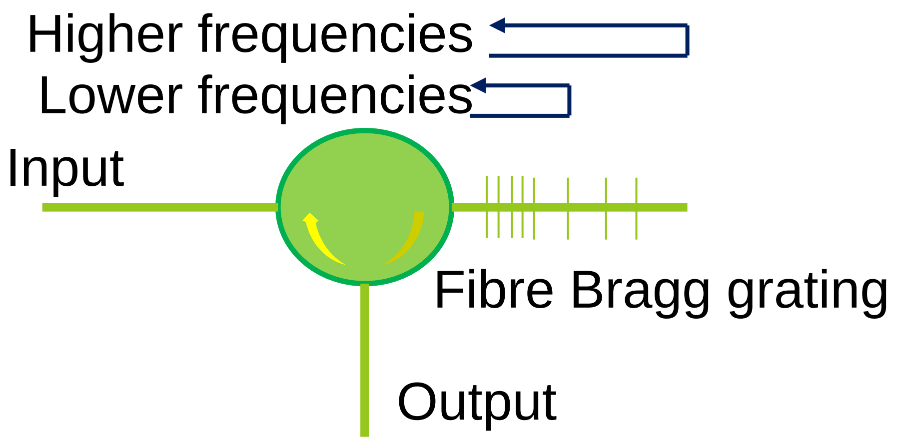
Phibre

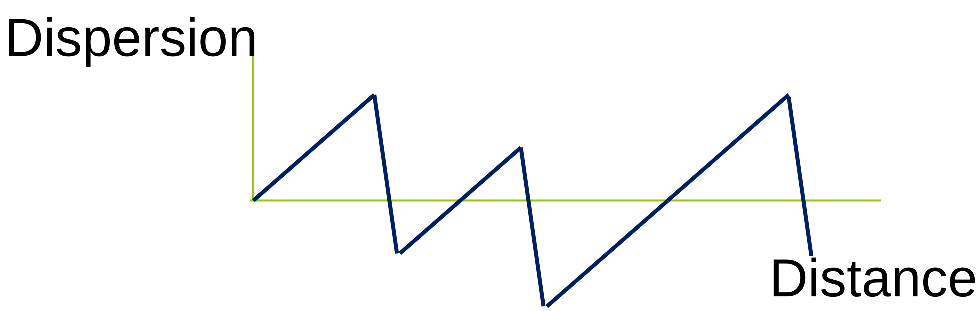
- Construction method
  - Thin film filter
  - Fused fibre coupler based
  - Arrayed waveguide grating (AWG)
  - Other types of available
- Standards
  - Short wave Wavelength Division Multiplexing (SWDM)
    - Four channels at 850, 880, 910 and 940nm
    - 30nm spacing
  - Coarse Wavelength Division Multiplexing (CWDM)
    - ITU-T G.694.2
    - 20nm spacing
    - 1271 to 1611 nm range
  - Dense Wavelength Division Multiplexing (DWDM)
    - ITU-T G.694.1
    - 100GHz (0.8 nm)
  - Gridless networks in the future
  - 50, 33 and 25G Mux's available



Dispersion compensation modules (DCM)

- DCMs is used to undo the dispersion experienced during transmission
- Used for On Off Keyed (OOK) signals
- Optical compensation
  - Strategically placed in the network
  - Types
    - Dispersion compensation fibres
    - Braggs gratings
- Electrical compensation
  - For Phase Shift keying signals
  - Digital signal processing (DSP) used power and phase information allows the DSP to use a input response filter to unwind the CD



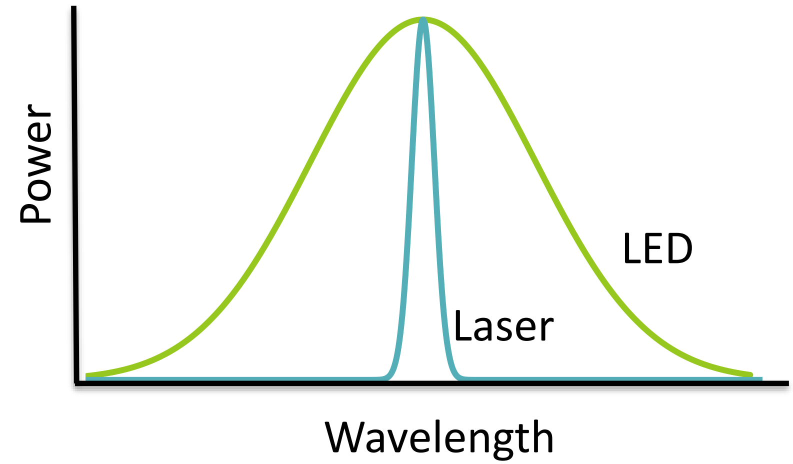


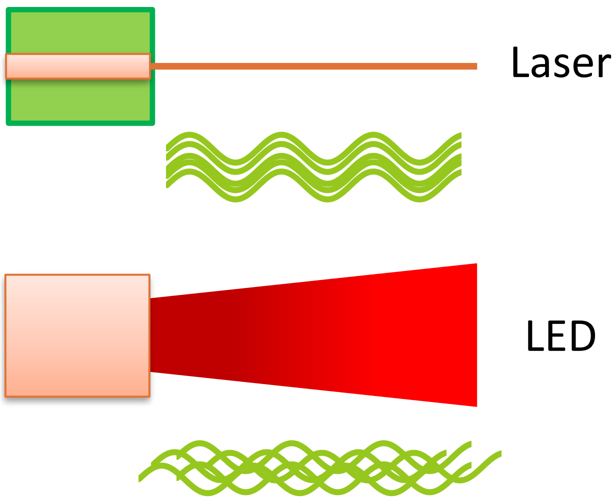
Dispersion map for and optical link

OPTICAL NETWORK ACTIVE COMPONENTS

Optical transmitters

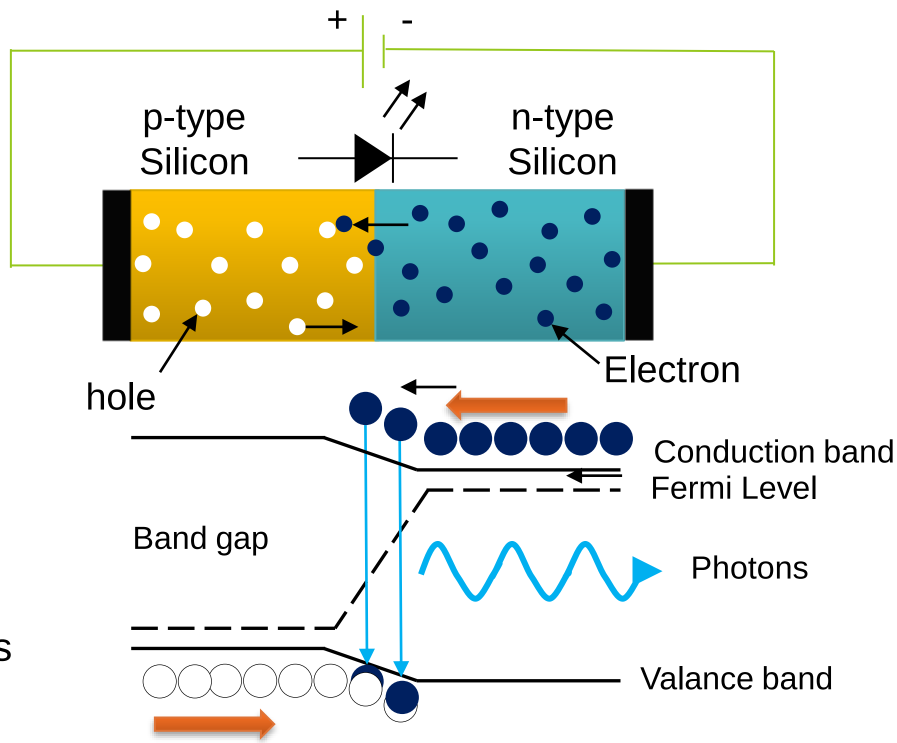
- Convert electrical signals into optical signals
- Transmitters (semiconductor devices)
  - Compact
  - Produce reasonably high power
  - Narrow spectral width
  - Efficient
  - Reliable
  - Stable wavelengths
- Optical transmitters are constructed from semiconductor materials
- Converts electrical signals into optical signals
  - LED (incoherent light)
  - Vertical-cavity surface-emitting laser (VCSEL)
  - Laser (coherent light)





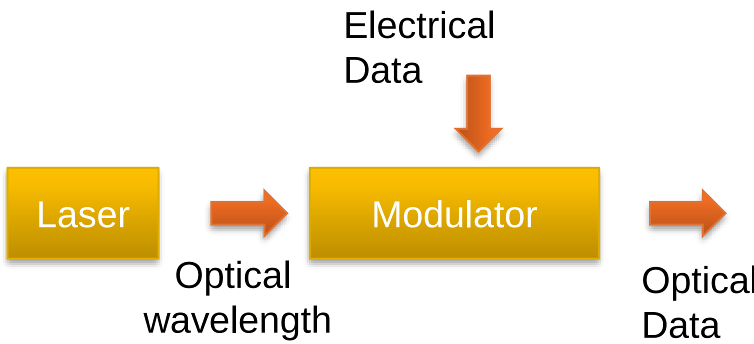
LEDs

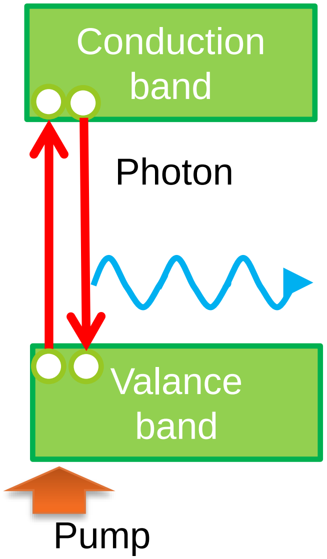
- Light emitting diodes (LED) is a semiconductor device
- *p-n* junction diode,
  - Two types of semiconductor material. One has an excess of electrons and the other has an excess of holes.
  - When a voltage is applied it promotes the electrons recombine with the holes, which produce photons of light (electroluminesence) .
- Advantages of LEDs
  - Mostly used in multimode telecom systems
  - Limited to <2km distances
  - Wide cone of irradiance of multiple wavelengths
  - Transmission power -15dBm to -20dBm
  - Low energy consumption
  - Slower speeds (100Mb/s)

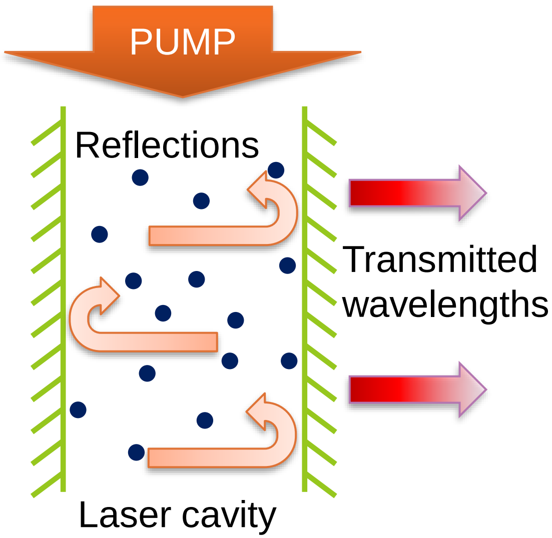


Lasers

- Laser refers to Light Amplification by Stimulated Emission of Radiation
- VCSELs are a type of laser
- The device can generate an beam of high intensity, coherent (narrow) monochromatic (wavelength) EM radiation (UV, Visible, IR bands)
- Used in single mode optical and multimode fibres
- Used for 1310 to 1550nm bands
- High risk to human eye and skin
  - Mostly used in single mode telecom systems
  - 80km distances (limited by loss in fibre)
  - Coherent light source
  - Small cone of irradiance
  - Transmission power -20dBm to +10dBm
  - Low energy consumption
  - High speeds (100's Gb/s)

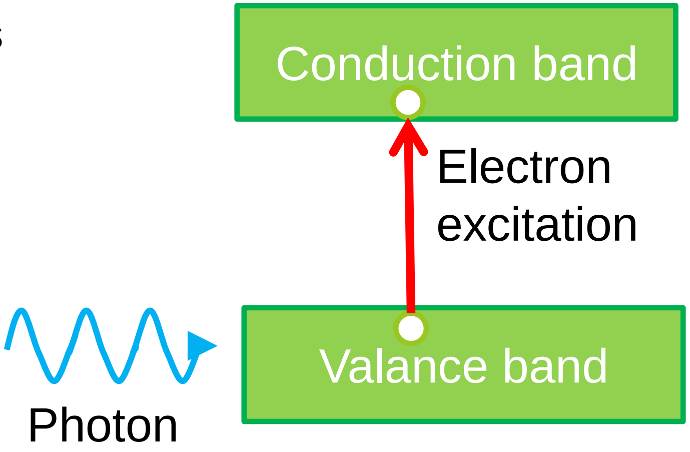


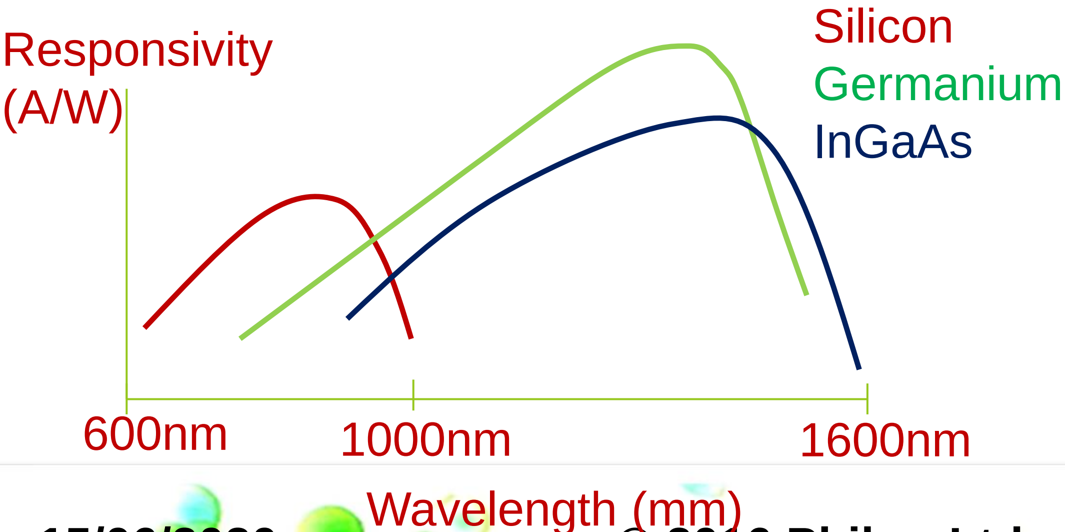




Optical receiver

- Converts optical field into electricity current signal by the photoelectric effect
  - Photocurrent is produced by the absorption of photons and in proportional to the optical signal
  - Front end amplifier increases power of the signal
  - Decision circuit determines the digital data from the analogue optical signal
    - Dependent on modulation scheme
- Photodetector is made from semiconductor materials
  - Each materials have different properties





Phibre

Transceivers form factors

- Contains transmitter and receiver optics and electronics
- Size and electrical interface is determined by the multi-source agreement (MSA)
- Allows for multi-vendor interoperability

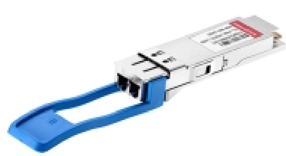
- Interfaces with
  - Transmission cards
  - Switches
  - Routers
  - Media convertors
- Hot-pluggable modules
- Reach
  - SR - 850 nm, 300 m (max)
  - LR - 1310 nm, 10 km (max)
  - ER - 1550 nm, 40 km (max)
  - ZR - 1550 nm, 80 km (max)
    - Manufacture induced standard
  - PSM4 – 1310nm. 500 m , MPO
    - 8 fibres at 28GE = 100GE

Transceivers form factors

- **Small form factor pluggable (SFP)**
  - SONET/SDH, 1 GE, OTU1
  - Fibre channel
- **Enhanced SFP (SFP+)**
  - Ethernet (10GE)
  - Fibre channel
  - OTU2, 2e

- **XFP**
  - Ethernet (10GE)
  - Fibre channel
  - OTU2, 2e

- **Quad SFP (QSFP)**
  - 1GE, 10GE
  - OTU2
- **QSFP +**
  - 40GE
  - OTU3



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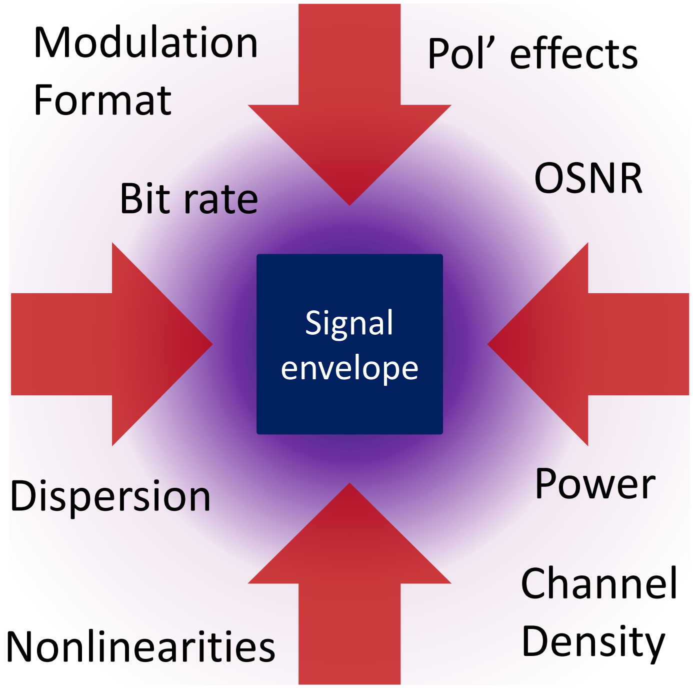
- **CFP, CFP2, CFP4,**
  - 10x10GE and 4x25GE
- **CXP**
  - 120G (12x10G)

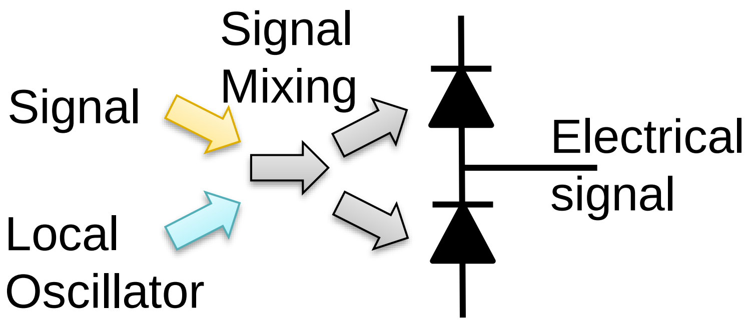
- **CFP8**
  - 400GE
- **QSFP28 and QSFP56**
  - 100GE
  - OTU4
- **Double Density QSDP (QSFP-DD)**
  - 8x 25G or 8x PAM4, 200GE, 400GE
- **Octal SFP (OSFP)**
  - 400GE
- **Consortium for On-Board Optics (COBO)**
  - 400GE

Coherent modulation

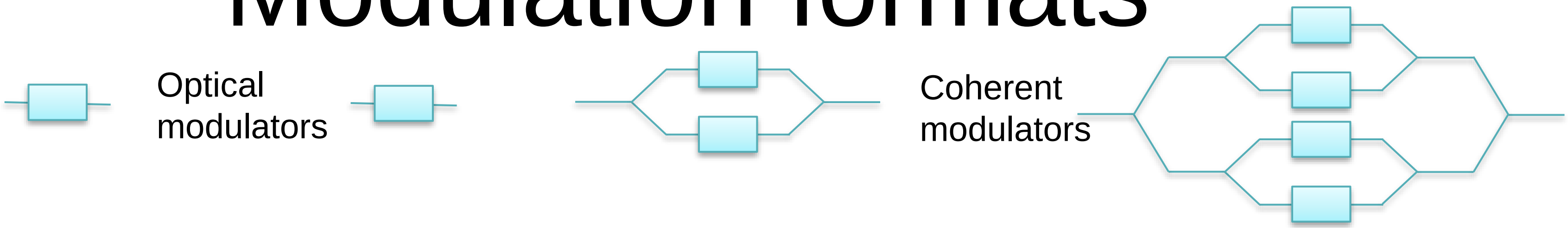
Phibre

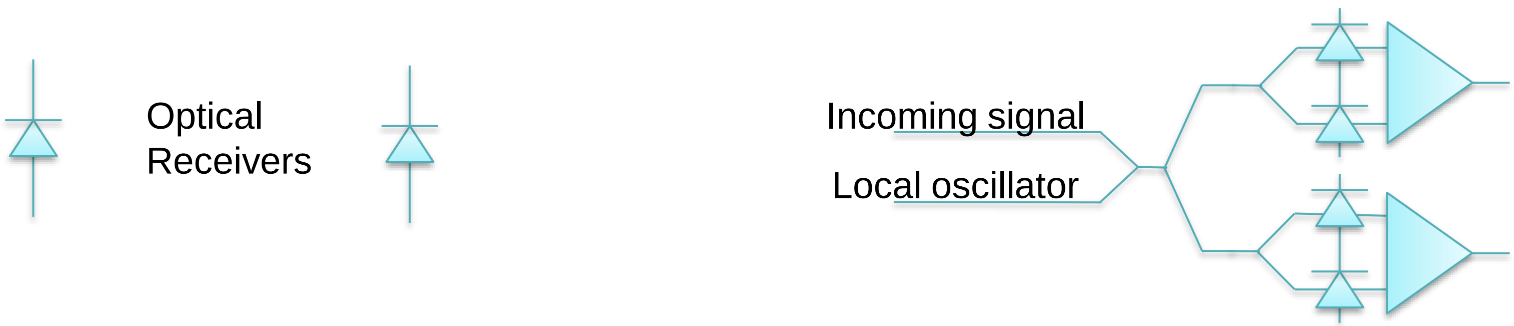
- Greater transmission speeds
  - Leads to higher signal degradation due to CD, PMD and Nonlinear effects
- Coherent transmission refers to the use of advanced modulation to transmit information
- Phase shift keying (PSK) modulation measures the phase between bits
  - More tolerant to detrimental effects in fibre
- Recovering **phase** and **power** of an optical signal is performed by the use of two balanced photodiodes.
- The balanced receiver or coherent receivers have allowed the 10x increase in transmission speeds
  - Used for transmission rates exceeding 40+ Gbps
  - Phase shift keying (PSK)
  - Quadrature amplitude modulation (QAM)
  - Single and dual polarisations are used

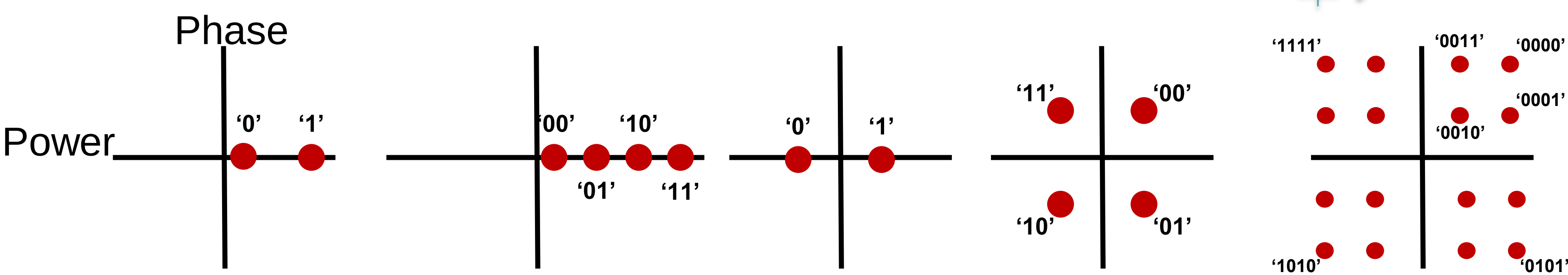




Modulation formats





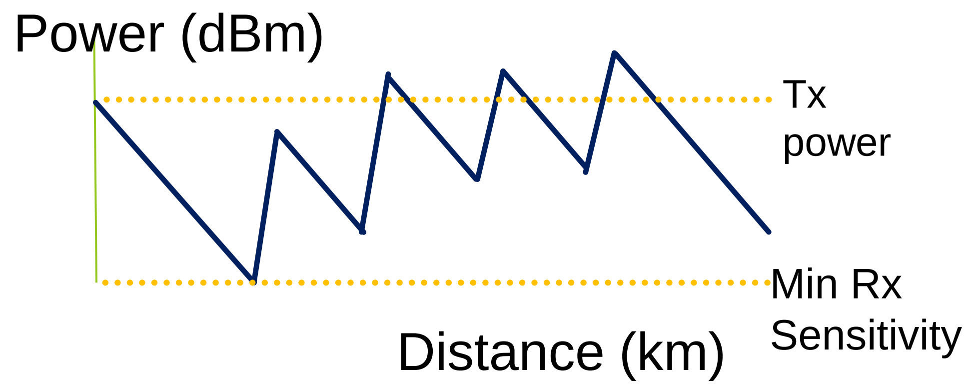


OOK	PAM4	BPSK	QPSK	16QAM
1 bit/symbol	2 bit/symbol	1 bit/symbol	2 bit/symbol	4 bit/symbol

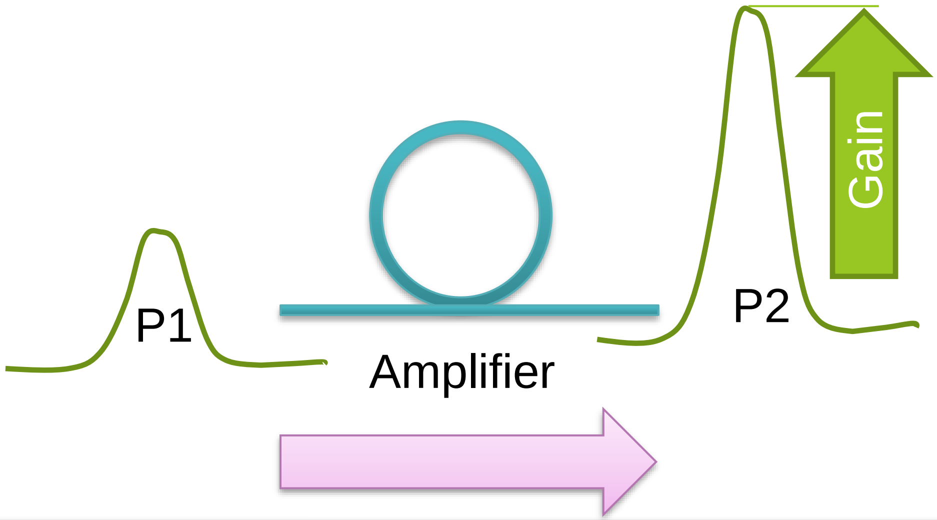
Dual polarisation systems are also used, which doubles the spectral efficiency

Amplifiers

Phibre

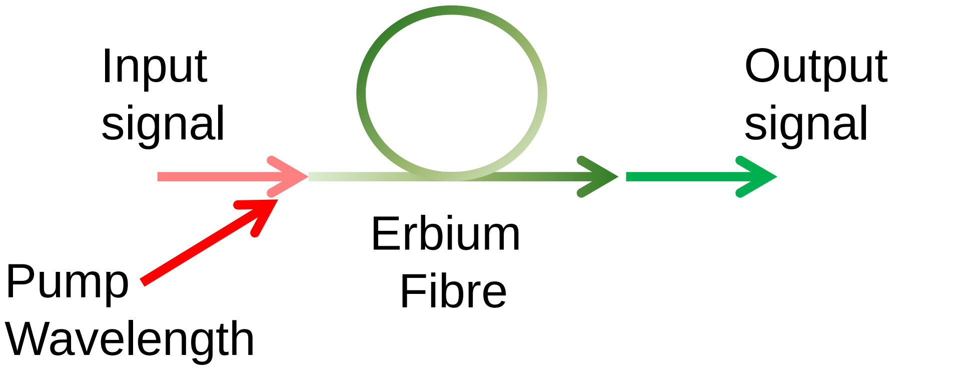


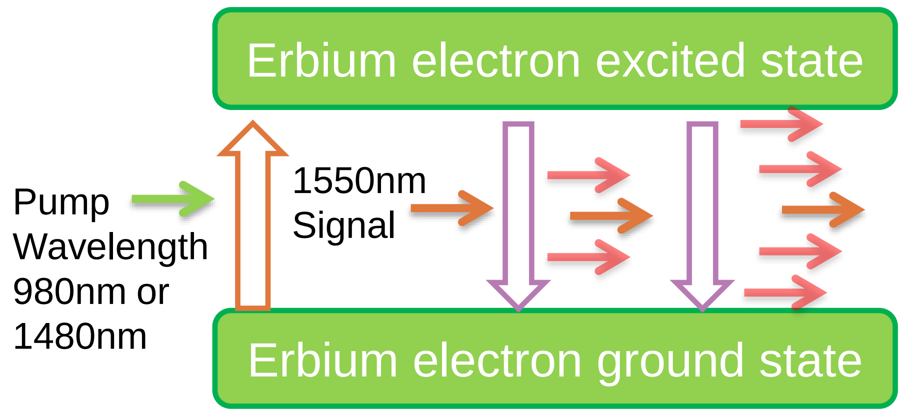
- Amplifiers are used to increase the power of an optical signal, In order to increase the transmission distance.
- Types of amplifiers
  - EDFA (Erbium Doped Fibre Amplifier)
  - RAMAN
  - SOA
  - RAMAN/EDFA hybrids
- As well as amplifying the signal, amplifiers also introduce noise into the system
  - Amplitude spontaneous noise (ASE)



EDFA Amplifiers

- EDFA (Erbium doped fibre amplifier)
  - Developed and commercially used in the 1990's
  - Excitation of electrons of Erbium doped atoms in the optical fibre provides the amplification
  - Based on amplitude spontaneous emission of electrons
  - C band operation (1525-1565nm)
  - Typically 20 dB of gain
  - Noise figure 5-7 dB
  - DWDM EDFA's amplifiers can be gain flattened (filters or fibres)
  - If fibre paths is less then approximately **80km**, then a EDFA are best suited.

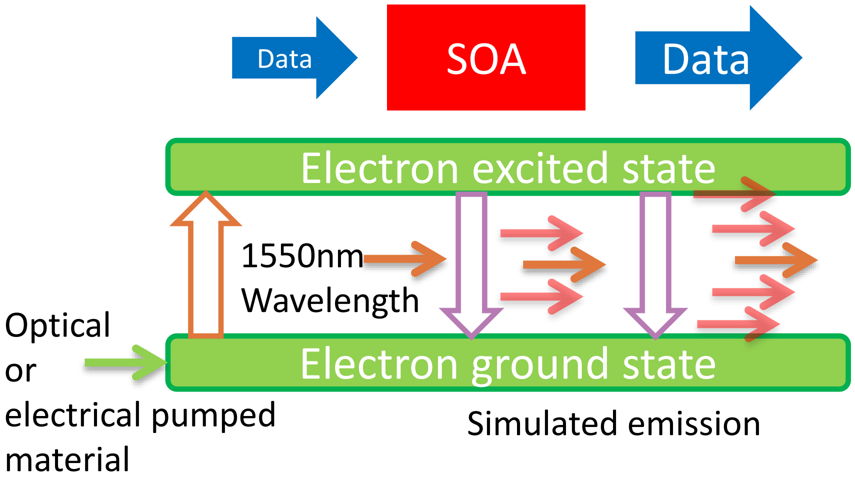




Simulated emission

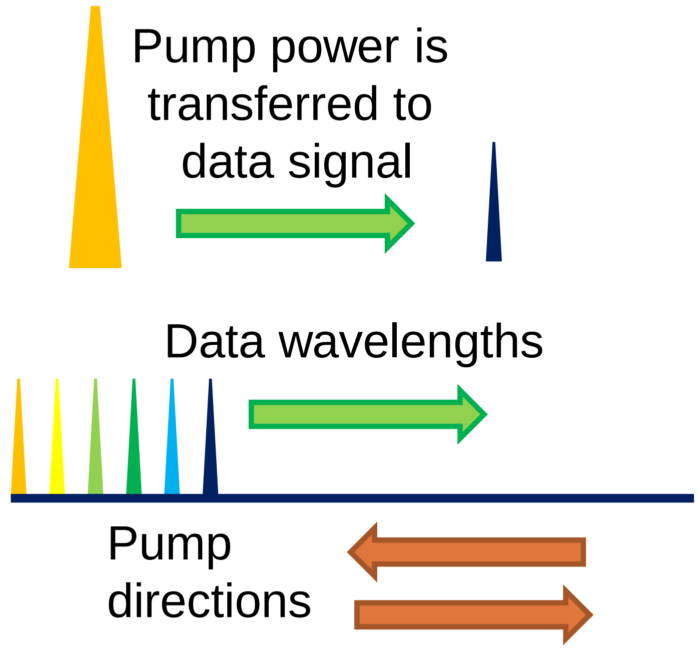
Semiconductor Optical Amplifier (SOA)

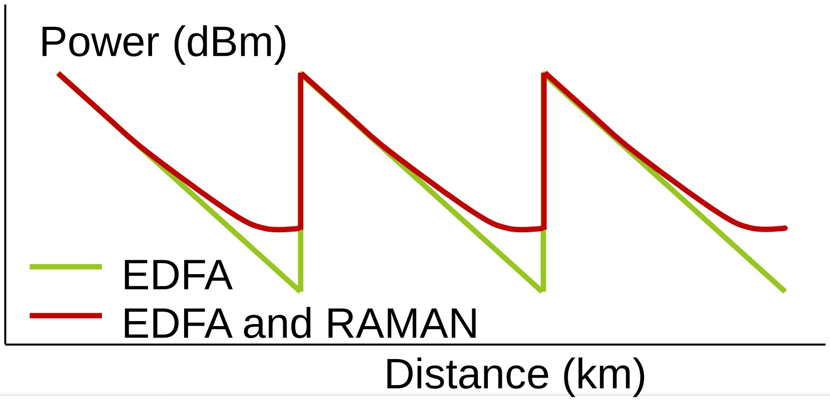
- A laser cavity with anti reflective coating
- Electrical or optical pumped
- Amplification is delivered by simulated emission
- Do not have the performance advantages of EDFAs:
- Advantages
  - Integrated with other devices
  - Cheaper to manufacture
  - Tuneable (1300 – 1600nm)
  - Operate in different wavelength regions
- Disadvantages
  - **Lower gain**
  - Higher **Noise Figure (NF)**
  - Polarization dependent
  - Distort signals at high powers
  - Signal bit rate limitation by carrier recovery lifetime,
  - Gain saturation
  - Higher coupling losses between fibres and devices.
- Used in **passive optical networks** (PON) and photonic integrated chips
- Typical gain of 10-20 dB
- Noise figure 5-9dB



Raman Amplifiers

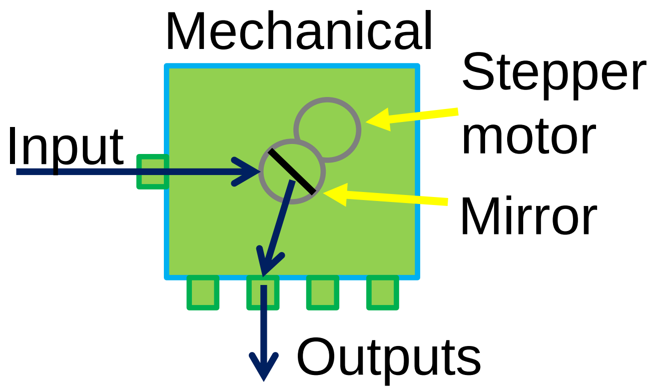
- Developed in the 2010’s
- High power pumps levels required
- Pump wavelength power is transferred to data wavelengths by the nonlinear method
- Operates over SMF fibre (>100km lengths)
- Distributed and discrete amplifiers are available
- Counter and Co pumps systems
- Typically 14 dB of gain (counter propagation)
- Low noise figure
- Amplifier range is **80km – 250km** (depending on pump power)

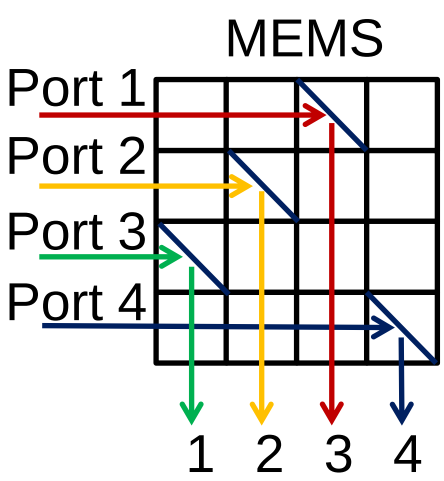




Optical switches

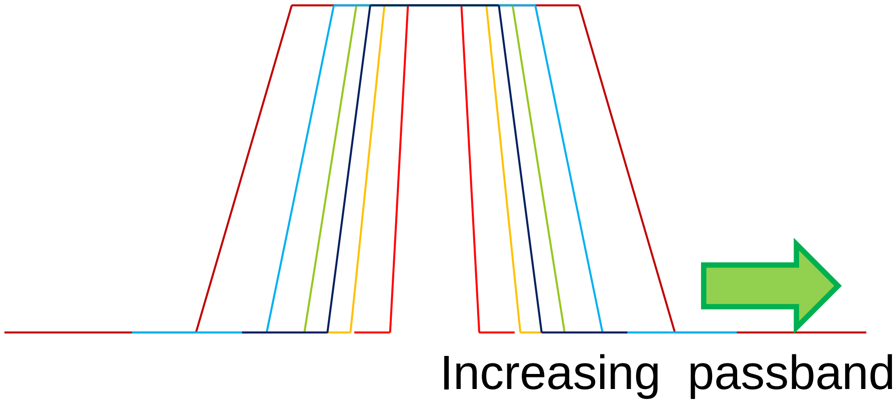
- Used to switch light signals from one fibre to another
  - Network redundancy/protection
  - Test system
  - **Reconfigurable Optical Add-Drop Multiplexers (ROADMs)**
- Types of optical switches
  - Bulk mechanical switches
  - Micro-electro-Mechanical system (MEMS)
  - Liquid crystal switches
  - Thermal-optic
  - Semiconductor optical amplifier (SOA) switches
  - Piezo electric beam steering
  - Nonlinear

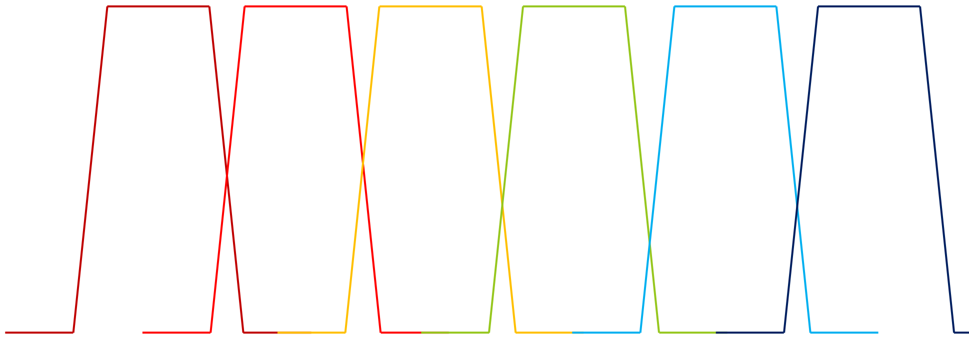




Tuneable Filter

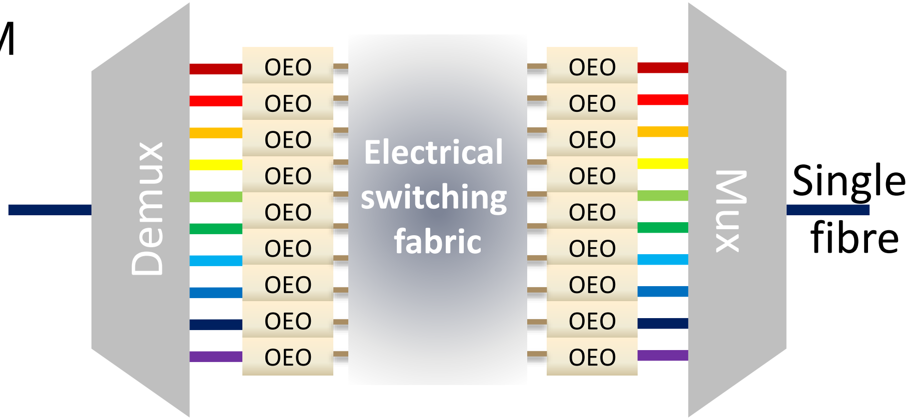
- Tuneable filters over a wide range of wavelengths
- Types of technologies
  - Acoustic optic tuneable filter
  - Linear variable filter
  - Angle tuned thin film
  - Liquid-crystal filter
- Used in **Wave Selective Switches (WSS)**
- Required properties
  - High pass band
  - Steep spectral edges
  - Adjustable bandwidth
  - Fast tuning speed
  - Polarisation insensitive
  - High laser damage threshold
  - High environmental durability
  - Low power consumption

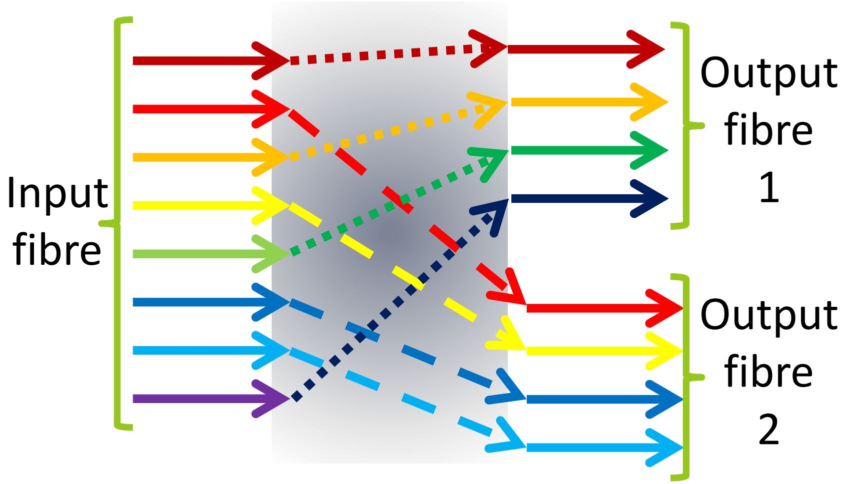




Wave Selective Switch (WSS)

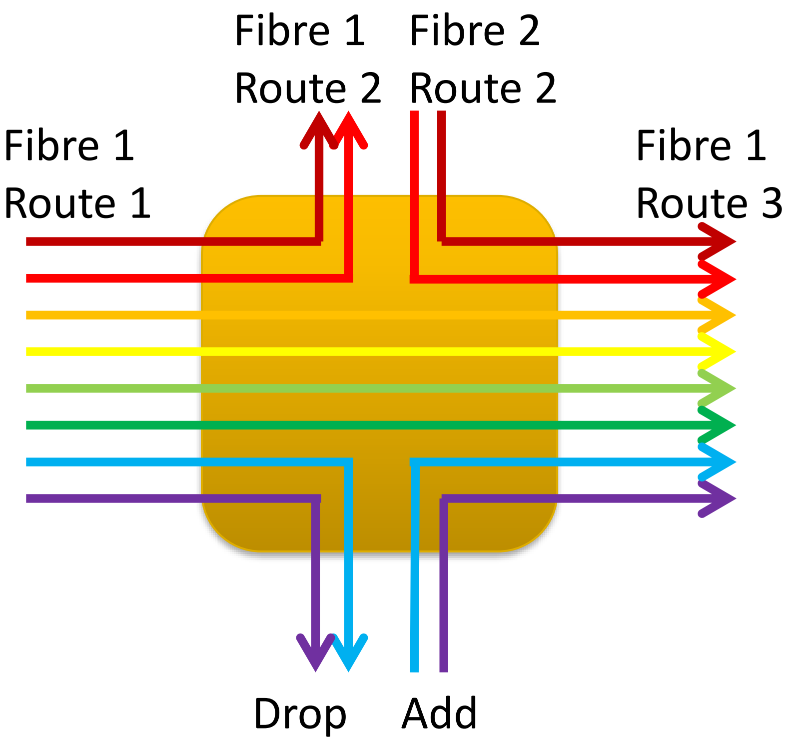
- The routing of wavelengths in a DWDM system between optical fibres
- Simplification signal routing
- Wavelength blocking was a problem
- Electric switching fabrics were large
- 80 channel non-blocking square system would result in 6400 switches
- **Optical-Electrical-Optical (OEO)** conversion is an expensive option
- WSS selects channels to pass to output fibres
- A number of technical solutions used
- Built in amplifier to level signal powers





ROADM

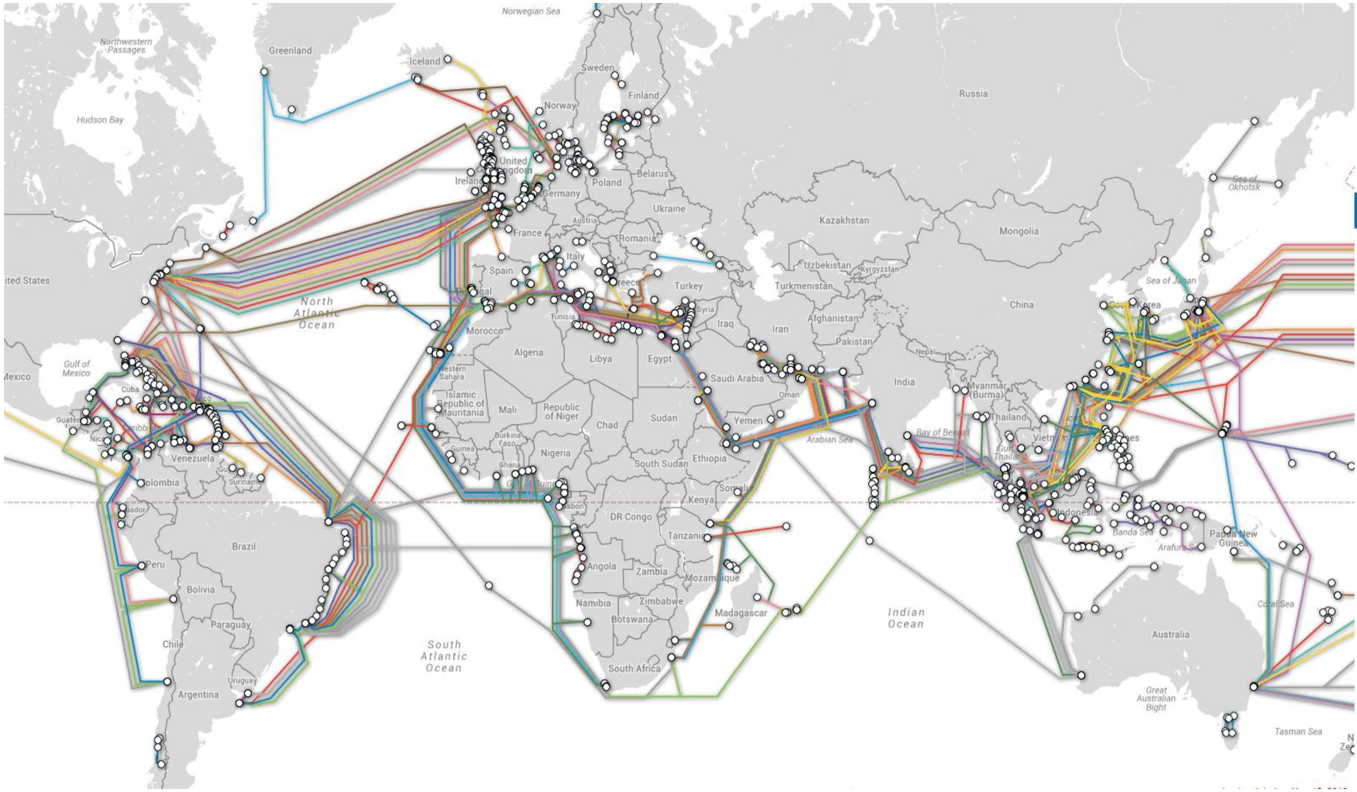
- A **reconfigurable optical add-drop multiplexer (ROADM)** can:
  - Add, block, pass or redirect optical signals of various wavelengths into optic fibres.
- Developed from optical cross connects
  - Static networks
  - Manual changes
  - Expensive to alter
- Advantages of ROADMS is the redirect optical channels without the need for optical regeneration (OR)
- Remotely reconfigurable
- Affords adaptable architecture
- Enables resiliency at the optical layer in case the fibre break



OPTICAL NETWORK

Network sizes

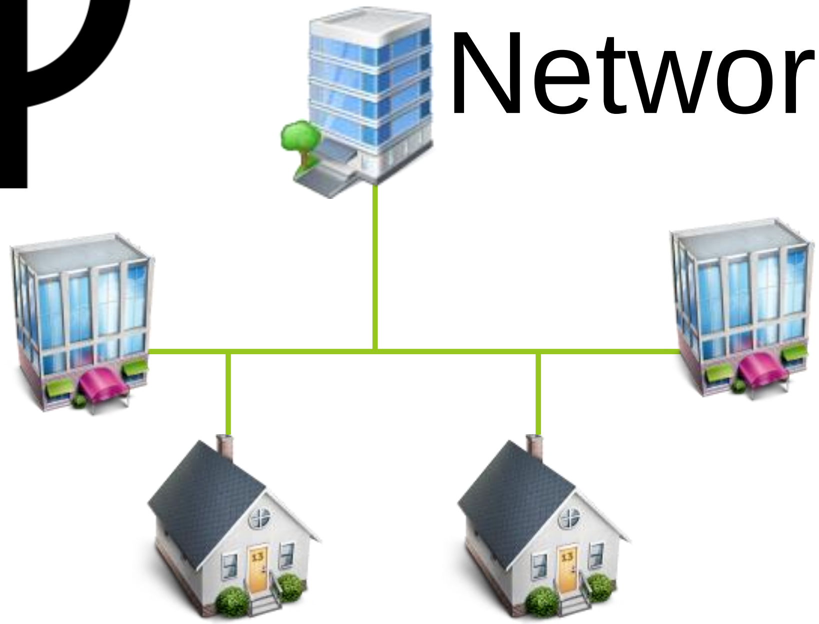
- Ultra Long Haul
  - Inter continental links
  - > 1000 km
- Long Haul
  - Regions
  - 600-1000km
- Regional
  - Between cities
  - 250-600km
- Metro
  - Internal city network
  - 10-250km
- Access network
  - Central office to home or business networks
  - Passive optical network (PON)
  - 1-10km

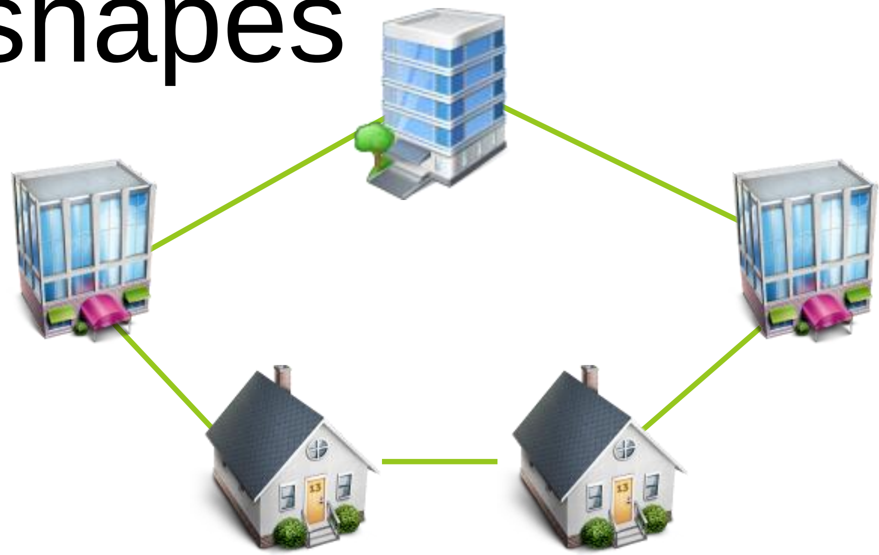


http://www.submarinecablemap.com/

Phibre

Network shapes

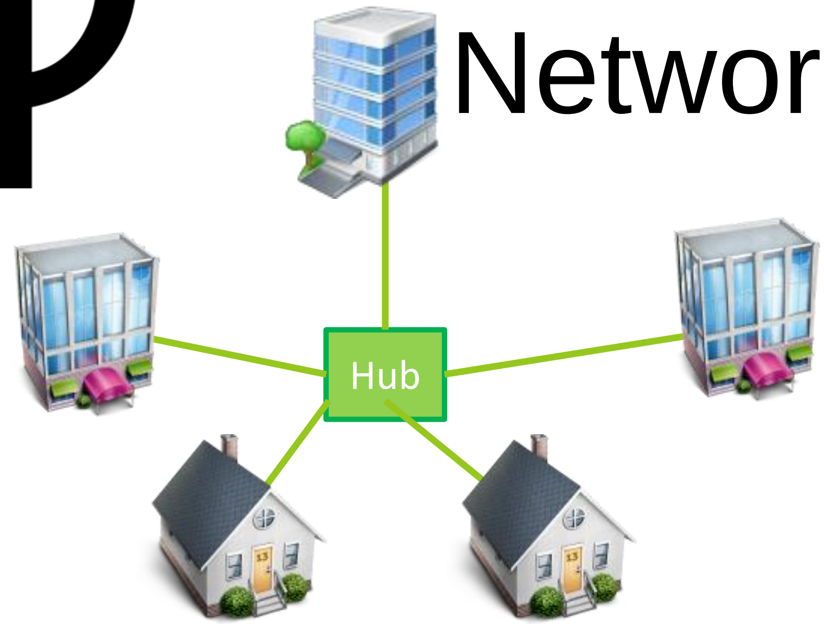


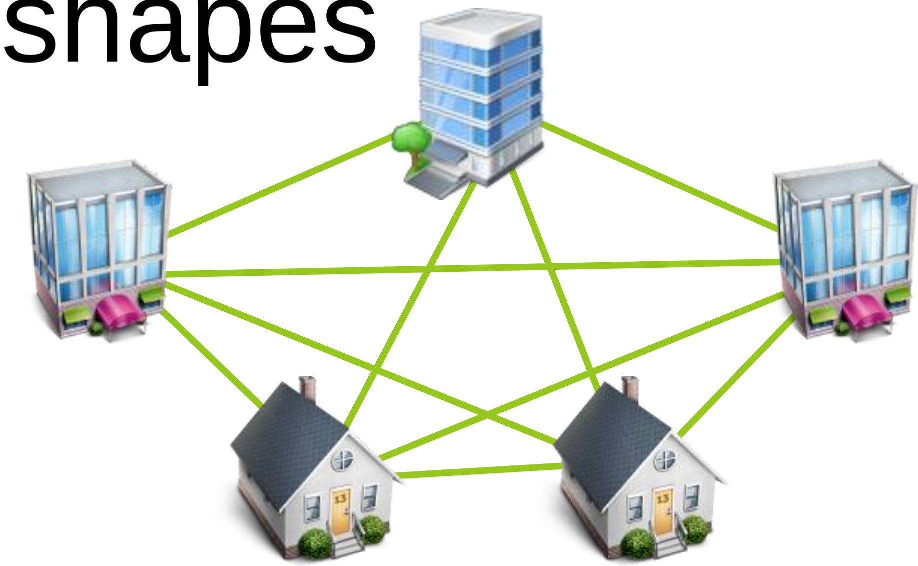


- **BUS**
  - Single direction transmission
  - All devices are connected on one cable
- Advantages:
  - Simple, reliable and cost effective
  - Small networks
- Disadvantages:
  - Network fails if the cable is damaged
  - High network demand reduces performance
  - Transmission length is limited to cable length

- **RING**
  - Cost effective
  - Unidirectional traffic (2 fibres)
- Advantages:
  - Not effected by high traffic
  - Only nodes with tokens can transmit data
- Disadvantages:
  - Troubleshooting is difficult
  - Adding and deleting nodes disturbs network operation
  - Node failure disturbs the whole network

Network shapes

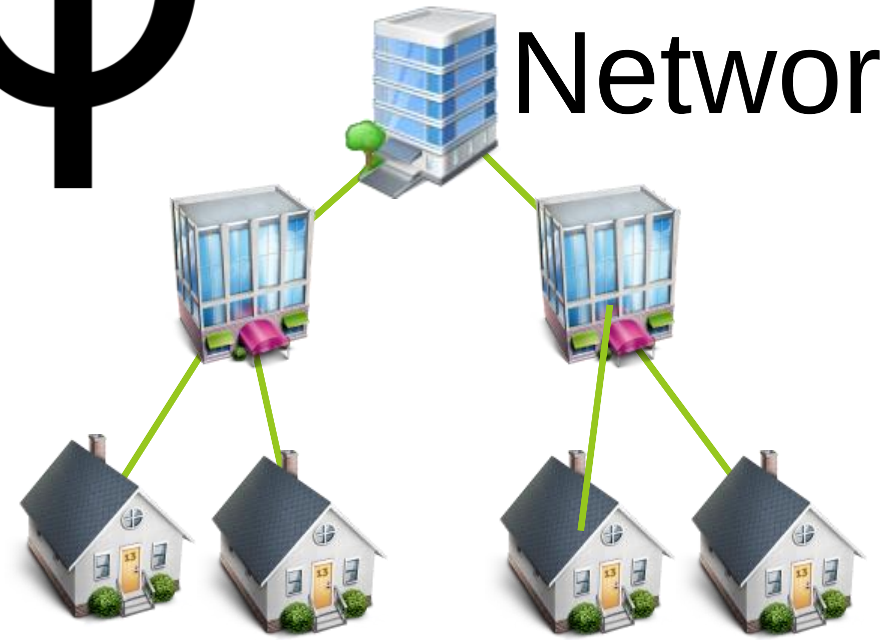




- **Star**
  - A hub repeats data flow to required site
- Advantages:
  - High performance with low nodes and network traffic
  - Easy to upgrade, troubleshoot, setup and modify
- Disadvantages:
  - Installation cost is high
  - Expensive to operate
  - Hub failure effect whole network

- **Mesh**
  - Point-to point connection (flooding or Routing)
- Advantages:
  - Each connection carry own data load
  - Robust
  - Faults are easily diagnosed
  - Secure and private
- Disadvantages:
  - Installation and configuration is difficult
  - Increase network connection costs
  - Large amount of cabling

Network shapes

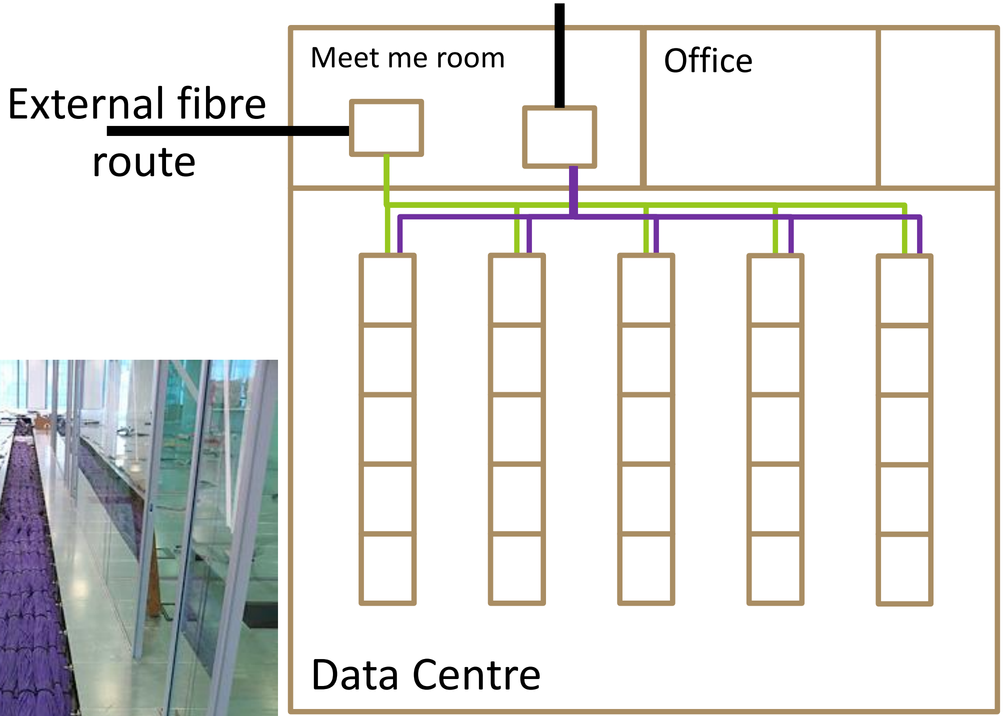


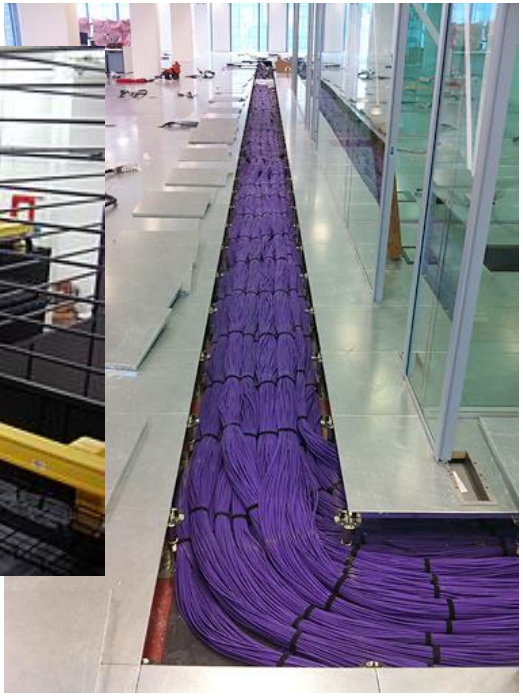
- **Tree**
  - Used in Passive optical networks (PON)
- Advantages:
  - Extension of bus and star topologies
  - Easy to maintain, manage and expand network
  - Network errors are easily found
- Disadvantages:
  - Upstream fails will effect all downstream node
  - Increase network connection costs
  - Large amount of cabling

CREATING A NETWORK

Building fibre routing

- External cables are terminated and presented in one location at a site
- Distributed integral rooms through overhead or unfloor routes





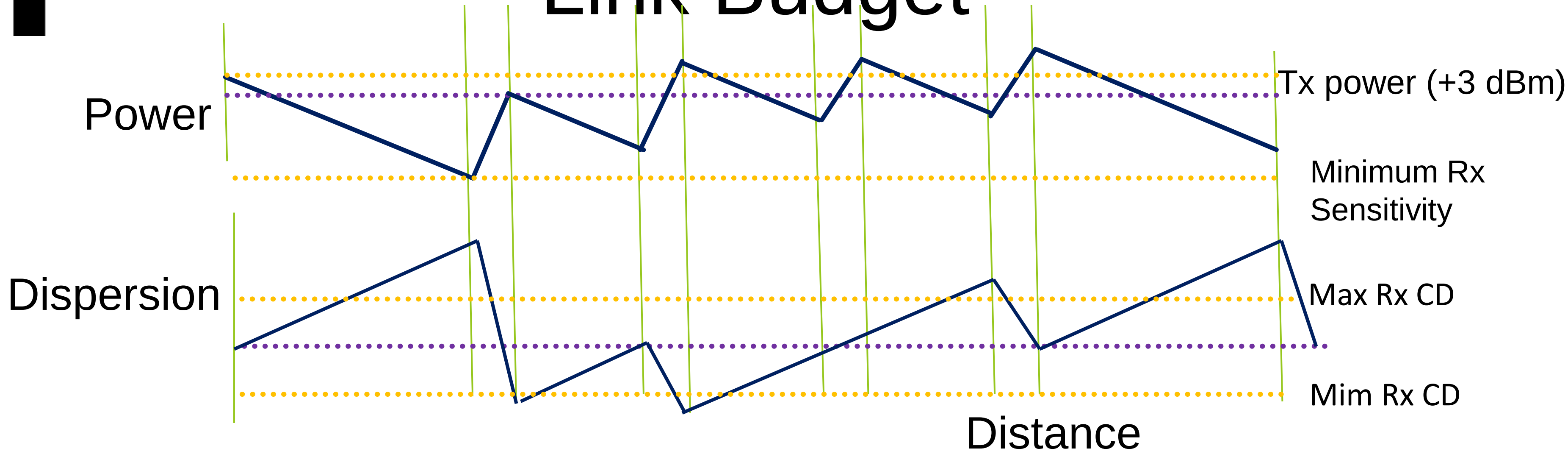
External fibre routing

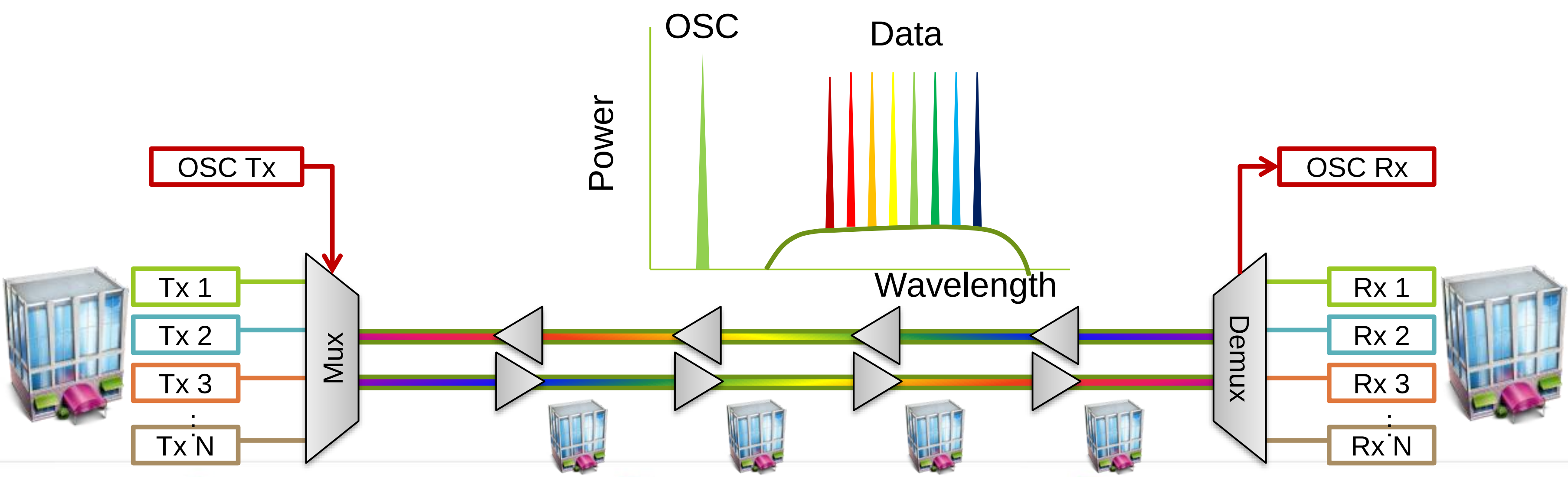
- Buried installations

- Aerial installations

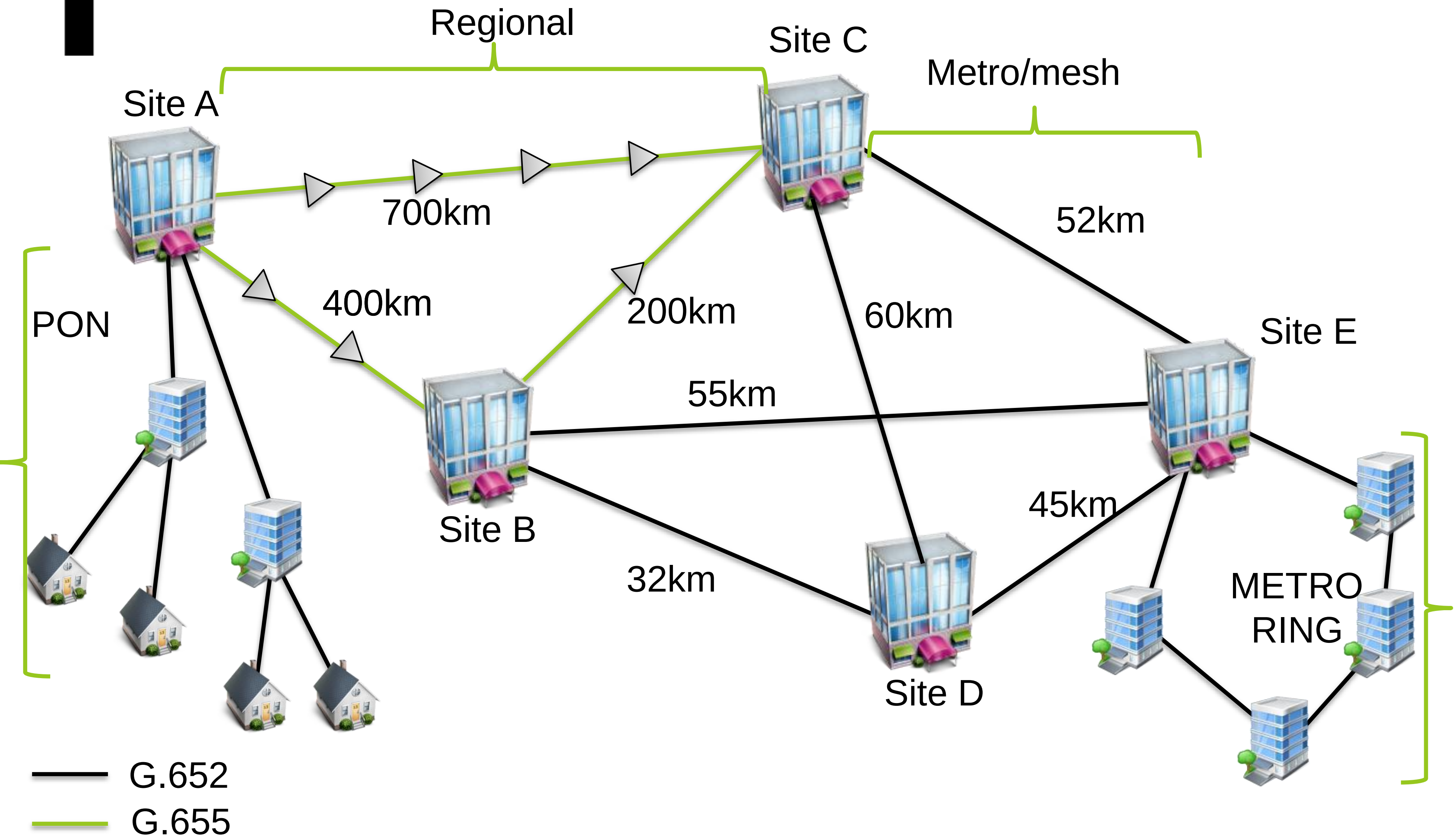
Site locations

Power and Dispersion Link Budget





Fibre connections



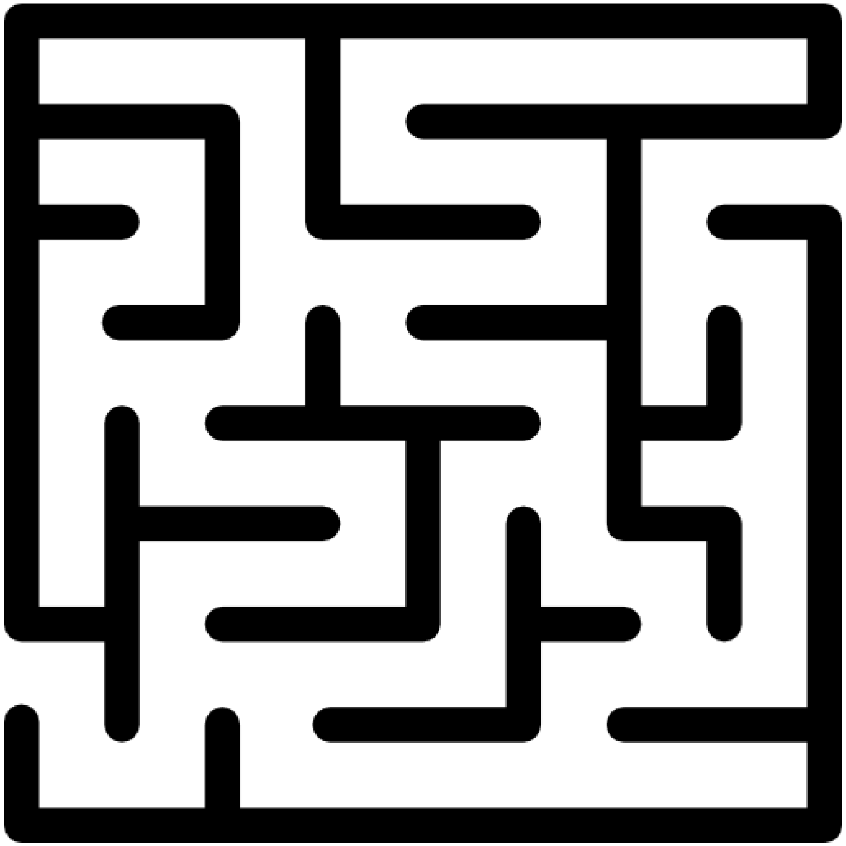
DIGITAL PAYLOADS

Delivering data

- Once the infrastructure is in place
- How do you successfully deliver data across large multi-domain network?
  - A robust protocol is the best approach
    - Setting up communication link
    - Determine source and destination address
    - Order packets for transmission
    - Determine data packet size and rate of transmission
    - Check success delivery of data
    - Routing paths
    - Switching
    - Grooming (Multiplex) and (De-multiplex) packets into larger packets
- We shall discuss protocols which have developed to address all aspects of data delivery
- Several protocols operate at multiple layers to ensure successful data delivery to required destinations

Delivering information

- Consider the postal services
  - Data packets take the form of parcels
  - IP address is your post code
  - How often you send a parcel is considered the transmission rate
  - Protocol can be considered to be the delivery company (you might use multiple companies)
  - Delivery van is your transport protocol
  - Roads represent wires, fibre or wireless transmission links



Communications protocols

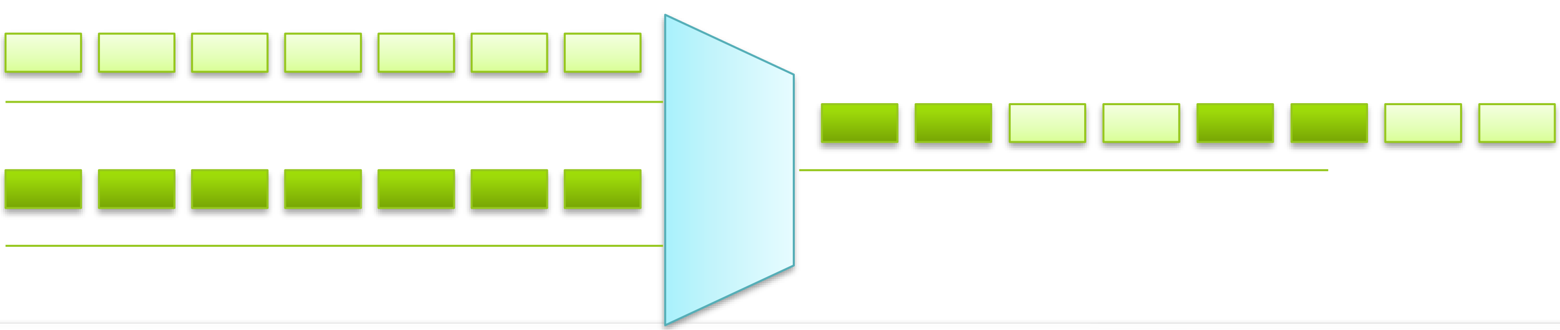
- Types of communications protocols
  - Plesiochronous digital hierarchy (PDH)
  - Synchronous Optical Networks (SONET)
  - Synchronous Digital Hierarchy (SDH)
  - Optical transport networking (OTN)
  - Ethernet
    - Wide area network (WAN)
    - Local area network (LAN)
  - Fibre channel
  - Internet protocol (IP)
  - Asynchronous transfer mode (ATM)

Which box do you use?

Icon designed by Freepik

Circuit switching

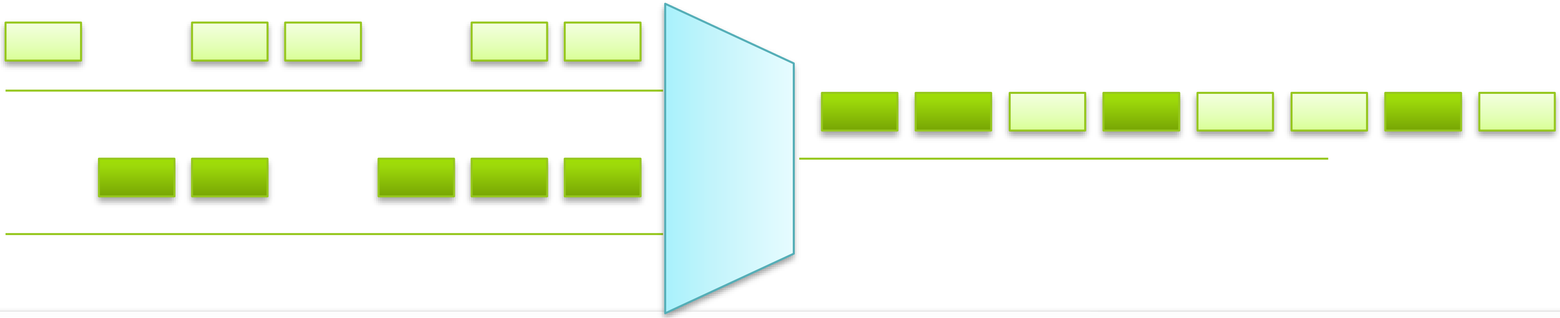
  - Connection-oriented services (point to point connections)
  - Connection between two or more parties across an underlying network
  - Allocated Bandwidth for circuit
- Circuit
  - A guaranteed amount of bandwidth is allocated to each connection
- Total amount of connections has to less than the available link bandwidth
- Leased by the carrier to customers
- Once set up the circuit remains nailed down for a long time
  - Months to years
- Variable rates
- Not effective at handling burst data traffic
- Use for voice traffic



Phibre

Packet switching

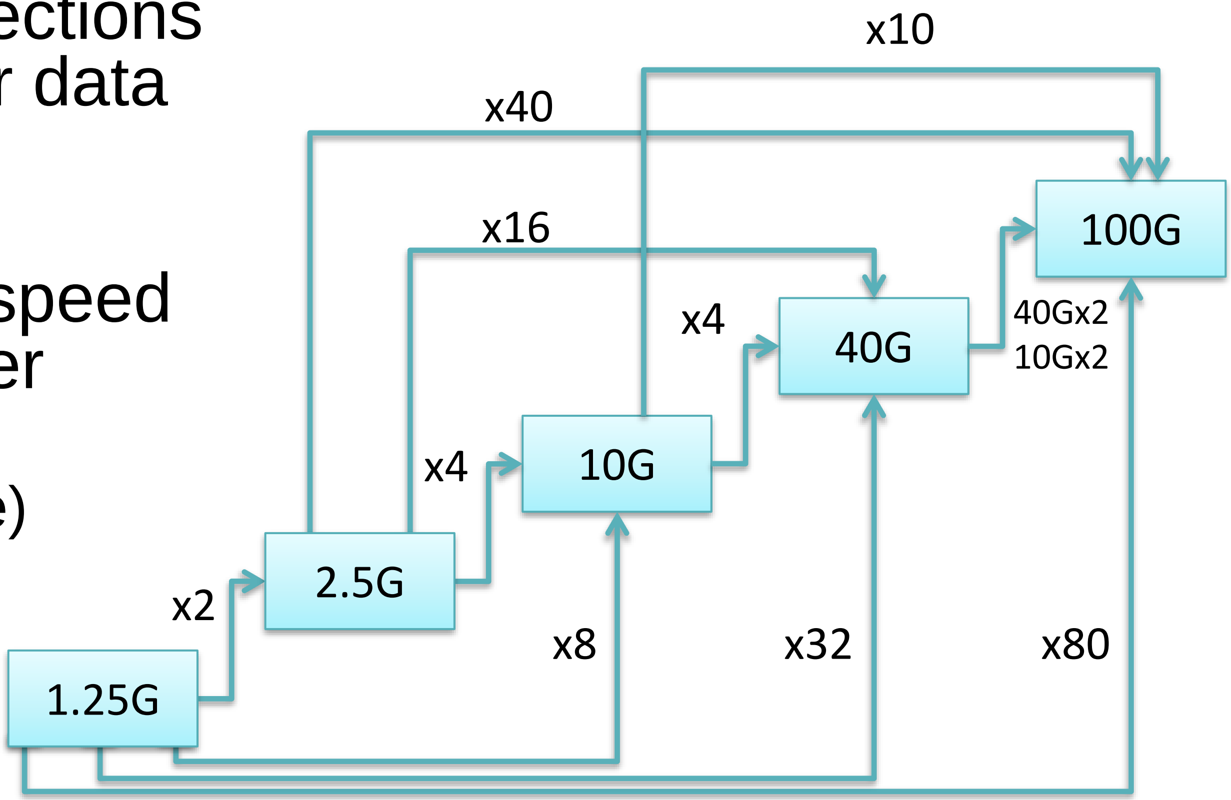
- Packet switched network were created to deal with transporting bursty traffic efficiency
- Data is broken into packets of data
- Packets are multiplexed from multiple data streams
- Packets are switched at the electrical layer, based on the destination
- Intermediate nodes read the header information and pass on the packet towards the destination
  - IP is an example of packet switched network
- Statistical multiplexed
- Improves bandwidth ulterization
- Large traffic demand can cause packets to be queued and buffered until network becomes free again.
- Sometimes packets are dropped



Phibre

Time Multiplexing

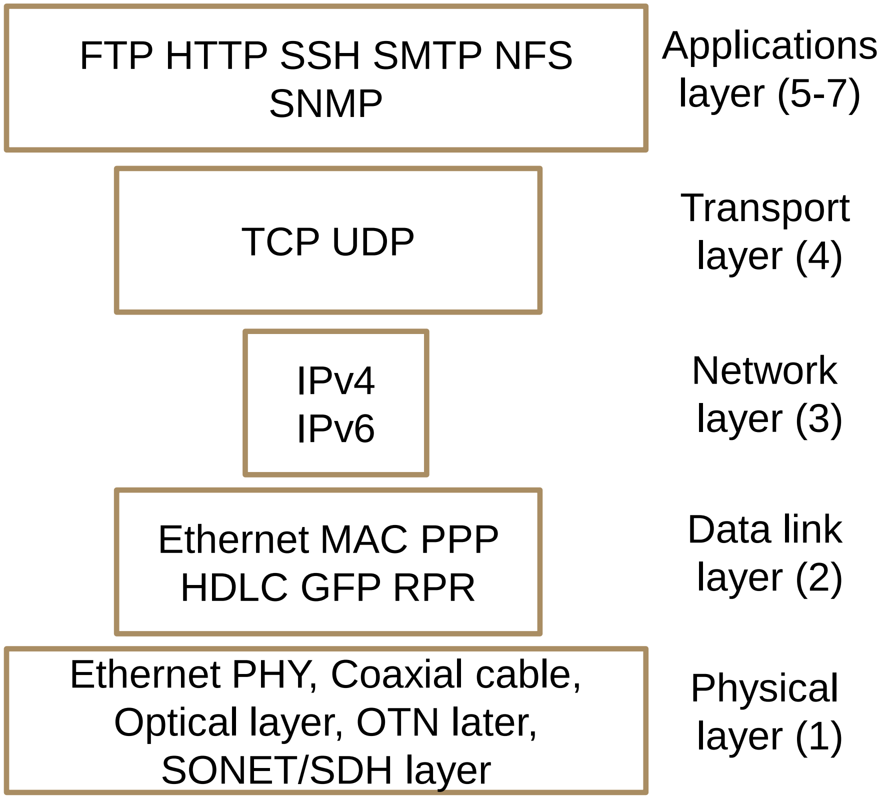
- Effective use of available bandwidth
- Dedicated connections for each voice or data connection is unmanageable
- Multiplex lower-speed signals into larger packet payloads
  - Fixed line (voice)
  - Mobile phone
  - Data



Phibre

Telecoms stack (OSI model)

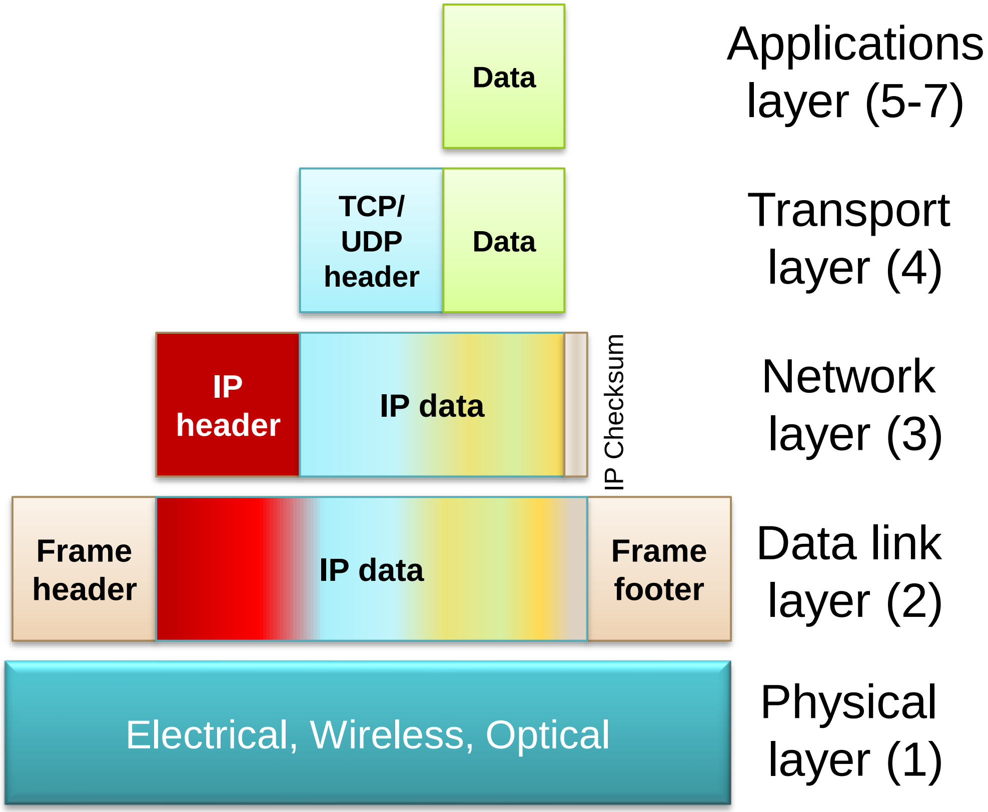
- 7) Application:
  - Supports transfer of files or network functions
- 6) Presentation:
  - Comms services that masks the differences in dissimilar systems' data formats
- 5) Session:
  - Manages dialog and how data flows are handled
- 4) Transport:
  - Defines how information is exchanged.
- 3) Network:
  - Controls data transfer between computers (routing packets)
- 2) Data link:
  - Checks protocols and procedures for operating communication channels
- 1) Physical:
  - Ensures functional control of data paths



Packet frame layout

Phibre

- Frame header
  - Source port
  - Destination port
  - Sequence number
  - Communication channel
  - Management
  - Alarms
  - Payload Frame alignment
  - Path monitoring
  - Communication channel
- Payload
  - Higher level data packet
- Frame footer
  - Forward Error Correction



Plesiochronous digital hierarchy (PDH)

- Created in the mid 1960's
- Referred to Asynchronous digital hierarchy (ADH) in North America
- Designed for multiplexing digital voice circuits
  - Voice can be sampled at **8 KHz**
  - Represented as **8 bits per sample**
  - **64 kb/s** total sample size for voice calls
- Became an accepted standard and is still seen today

- Dis-advantages
  - Complex multiplexing schemes
  - Poor network management
  - Difficult different vender interoperability
  - Slow restoration time
  - Difficult to extract packets from large payloads
  - Bit stuffing is required

Level	North American (Mb/s)	Level	Europe (Mb/s)
D0	0.064	E0	0.064
D1	1.544	**E1**	**2.048**
D2	6.312	E2	8.448
D3	44.736	E3	34.368
D4	139.264	E4	139.264

Synchronous Optical Networks (SONET)/ Synchronous Digital Hierarchy (SDH)

- Can be considered the first generation of optical networks
- Designed from lessons learned from PDH
  - Rates persist from PDH into SDH
- Simultaneously developed
  - SONET adopted by North America
  - SDH adopted by Europe and Japan
- Advantages
  - Multiplexing simplification
    - Equipment synchronised to single clock
    - No bits stuffing required
  - Management
    - Performance monitoring
    - Connectivity and traffic type
    - Identification and reporting of failures
    - Data channel for management information

SONET	SDH	Bit Rate (Mb/s)
STS – 1		51.84
STS – 3	STM - 1	155.52
STS – 12	STM – 4	622.52
STS – 24		1,244.16
STS – 48	**STM – 16**	**2,488.32**
STS – 192	**STM – 64**	**9,953.28**
STS – 768	STM - 256	39,814.32

Synchronous Optical Networks (SONET)/ Synchronous Digital Hierarchy (SDH)

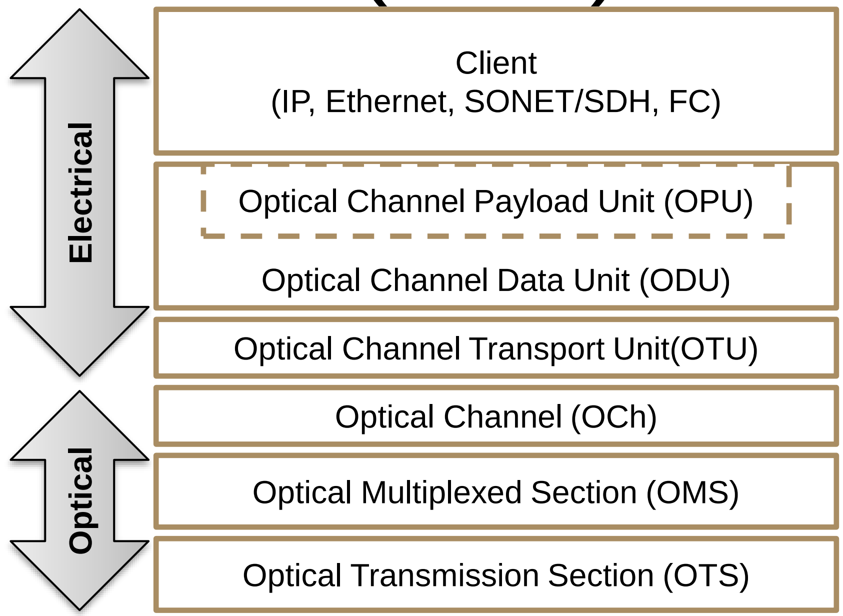
- Interoperability
  - Defined standard optical interface
- Network Availability
  - Standards incorporated network topologies and restoration
  - **50ms** response time

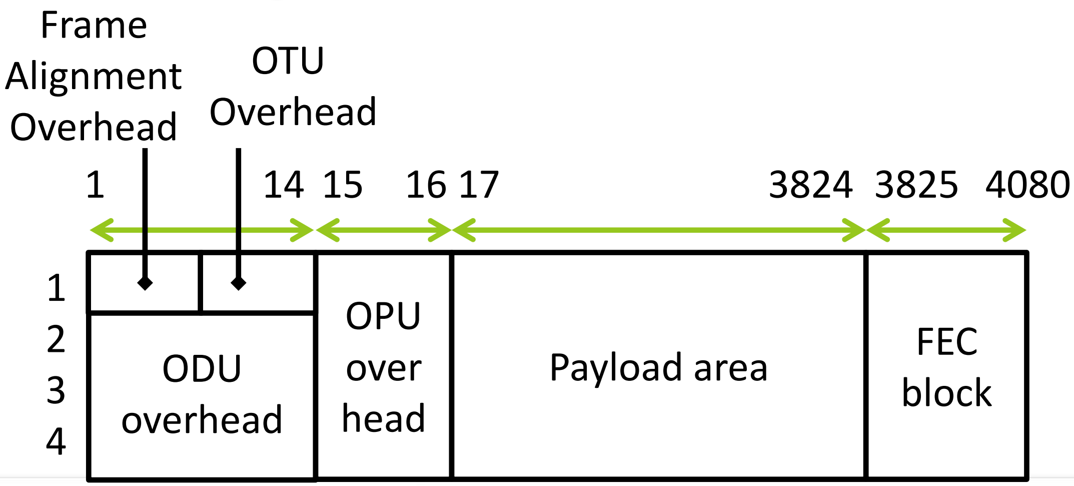
- Good for supporting constant data rates
- Multiplex signals to a higher rate
- Designed for low speed voice and data connections of up to 51 Mbps constant bit rate

SONET	SDH	Bit Rate (Mb/s)
STS – 1		51.84
STS – 3	STM - 1	155.52
STS – 12	STM – 4	622.52
STS – 24		1,244.16
STS – 48	**STM – 16**	**2,488.32**
STS – 192	**STM – 64**	**9,953.28**
STS – 768	STM - 256	39,814.32

Optical transport network (OTN)

- Builds on the concepts of SDH/SONET to carry all types of traffic
  - Defined in **ITU-T G.709**
  - Interfaces for Optical Transport Network
  - Transport of Voice and Data
  - 1.25G to 100G transport rates capability
  - Mux and demux lower rate signals
  - Packet structure has
    - 4 rows with 4080 columns
    - Regardless of transmission rate
  - Flexible rate and management features





Phibre

Optical transport network (OTN)

- **Forward Error Correction**
  - OTN has a FEC code incorporated in the standard
  - FEC enhances transmission distances and overcome noise degradation
  - FEC overhead is added to the end of the payload data
  - Reed-Solomon is the default FEC code used
- **Management**
  - Supports management of section, line and path levels.
  - Monitoring method across end to end connections through multiple network providers.
    - Signal identification
    - BER measurement
    - Alarm information
    - Communication channel
- **Protocol transparency**
  - The protocol operations
    - Administration
    - Operation
    - Management
  - Is transparent to client signals
  - OTN frames can contain entire SONET/SDH or Ethernet frames without modification
- **Asynchronous timing**
  - OTN payload floats within the frame
  - Accounts for mismatching between clocks of the OTN and clients signals
  - Reduces implementation and costs

OTN Multiplexing

Phibre

Client signal	OTN Line rate definition (G.709)	OTUk Line rate (Gbps)
Gig-E, STM-1, STM-4	ODU0	1.244
STM-16	OTU1	2.666
STM-64, 10GE (using GFP-F)	OTU2	10.709
10 GE LAN (direct mapping over OTN)	OTU1e (without stuffing bits)	11.049
10 GE LAN (direct mapping over OTN)	OTU2e (with stuffing bits)	11.095
10G Fibre Channel	OTU1f (without stuffing bits)	11.270
10G Fibre Channel	OTU2f (with stuffing bits)	11.300
STM-64, 40GE	OTU3	43.018
4x ODU2e (2.5G tributary slots)	OTU3e1	44.570
4x ODU2e (1.25G tributary slots)	OTU3e2	44.580
100GE	OTU4	111.810

Phibre

Ethernet

- Originally designed for communicating over a shared medium (BUS networks)
- Determines rules for when a packet is:
  - Computer identification
  - In-transit data format
  - Final destination data processing
  - Lost or damaged transmission handling
- Application has extended to fibre, wireless as well as twisted pair cable
- Wide range of data rates: 10 Mb/s, 100 Mb/s, 1GE, 10GE, 40GE, 100GE, 400GE
- Designed for local area networks (LAN)
- Simple to implement, install, maintain manage and low cost

- Institute of Electrical and Electronic Engineers standard association (IEEE-SA) develops the Ethernet standard **IEEE 802.3**
- Ethernet packets are made up of:
  - Preamble (PRE)
  - State-of-frame delimiter (SFD)
  - Destination address (DA)
  - Source address (SA)
  - Length/type
  - Payload
  - Frame check sequence (FCS)

Ethernet frame

Pre	SFD	DA	SA	Length type	Payload	FCS

Asynchronous transfer mode (ATM)

- Defined by ANSI and ITU
- Developed to intergrate voice and data networks In the 1980s
- ATM is used over the SONET/SDH
  - Public switched telephone network (PSTN)
  - Integrated Services Digital Network (ISDN)
- Popular with telephone companies
- Use has reduced in recent years in favour of IP
  - Lower price for deployment
  - Better performance
- Packets are fixed sized cells
  - 5 bytes for overhead
  - 48 bytes for payload
  - A compromise between voice and data demands
- Circuit based connection method
  - Path is constructed before data is transmitted
  - Data only travels a long that path
- Able to provide quality of service guarantees
- Low jitter network

Phibre

Fibre channel

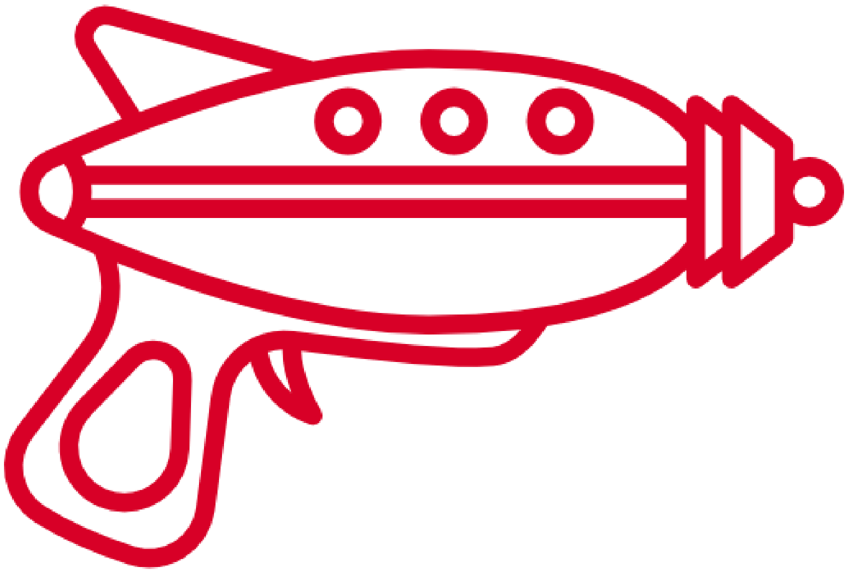
- Supports upper level protocols
- Similar to TCP as used in IP networks
- High reliability and throughput
- Development for computer data storage to servers
- Highly efficient for transferring high amounts of data
- Otherwise known as fabric – operates in unison as one big switch

Name	Data rate (Gb/s)	Transmission rate (Gb/s)
1GFC	1	1.0625
2GFC	2	2.125
4GFC	4	4.25
8GFC	8	8.50
10GFC	10	10.519
16GFC	16	14.025
32GFC	32	28.05
128GFC	128	4x28.05

Internet protocol (IP)

- Predominant packet transport technology for many applications
- IP role is to deliver packets from a source host to the destination host, by using IP addresses, contained in the packet headers.
- IP encapsulate data with a packet structure for delivery
  - Defines the addressing method
- The current dominate protocol is IPv4, however, number of addresses is running out, which has driving the uptake of IPv6
- Internet protocol is responsible for:
  - Addressing hosts
  - Routing packets from source to destination
  - Defines format of packets and address system

- IP packet
  - Header
    - Source address
    - Destination address
    - Network hops
    - Type of service
    - Packet size
    - Flags and fragmentation
    - Check sum
    - Type of packet protocol
  - Payload
- IPv4 address
- Dotted-decimal notation
- **192.168.0.10**
- IPv6 address
- Hexadecimal number
- **2001:0DB8:AF09:0000:0000:0000:0000**



HEALTH AND SAFETY IN TELECOMMUNICATIONS NETWORKS

H&S

- This section will only cover health and safety issues for telecommunications networks
- Dangers are explained in this section
- Highlight possible harm to eye and skin
- International standards for laser safety
- How to reduce risk of injury
- Responsibility for staff and management
- This is only an intro, further training is needed to gain a greater understanding all the damage caused by lasers

Laser Hazard Classifications

- All types of laser radiation exposure limits have been set by British Standards
- Determines the level of exposure a person can be exposed to without suffering adverse effects
- Exposed levels are determined by wavelength, intensity and duration of exposure
- Exposure can arise when service interruption or when being serviced

Laser Safety Standards

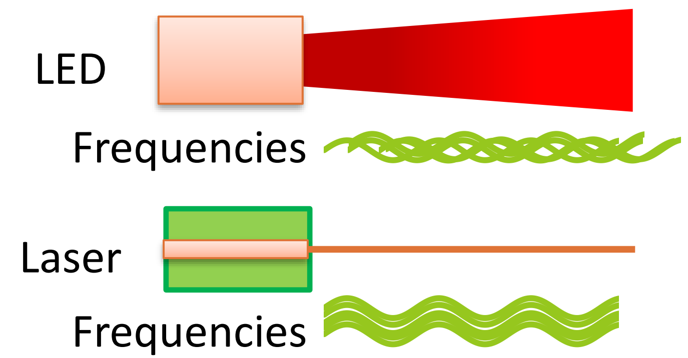
- Two international standards
  - International Electro Technical commission **(IEC) 60825**
    - Adopted in the UK as BS EN 60825-1:1994 “Safety of Laser Products. Part 1. Equipment classification, requirements and user’s guide
      - General
      - Manufacturing Requirements
      - User Guide
  - American National Standards Institute **(ANSI) Z136**
- Both standards agree on a classification system for power output, wavelength and the duration of a pulse
- Standards are designed to:
  - Ensure sufficient warning are placed on the hazards
  - Protect people from damage of laser radiation and other hazards
  - Reduce possibility of injury
  - Define requirements for manufacture and user to establish using procedures

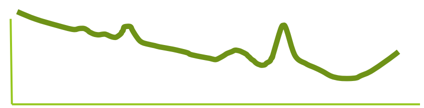
Typical risks and hazards

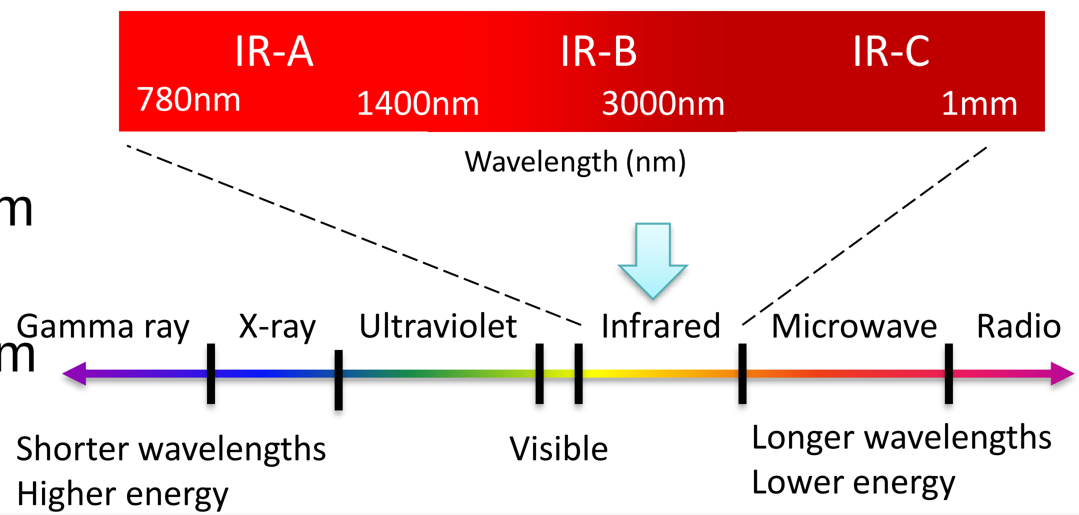
- Types of hazards seen in optical networks
  - EM hazards (blindness and burns)
  - Optical hazards (non Laser)
  - Fire (burns, inhalation)
  - Electrical (shock)
  - Manual handling (Physical injury)
  - Chemicals (fumes or burns)
  - Fumes (inhalation)
  - Sharps (cuts)
  - Trip hazards (trailing cables)
  - Working at:
    - Height
    - Holes

Infra-red light

- IR wavelengths are invisible to the human eye but can be felt to us as heat
- IR band is split into three groups
  - Infra-red A 780-1400nm
    - Near infra-red
  - Infra-red B 1400-3000nm
    - Mid Infra-red
  - Infra-red C 3000nm-1mm
    - Far Infra-red

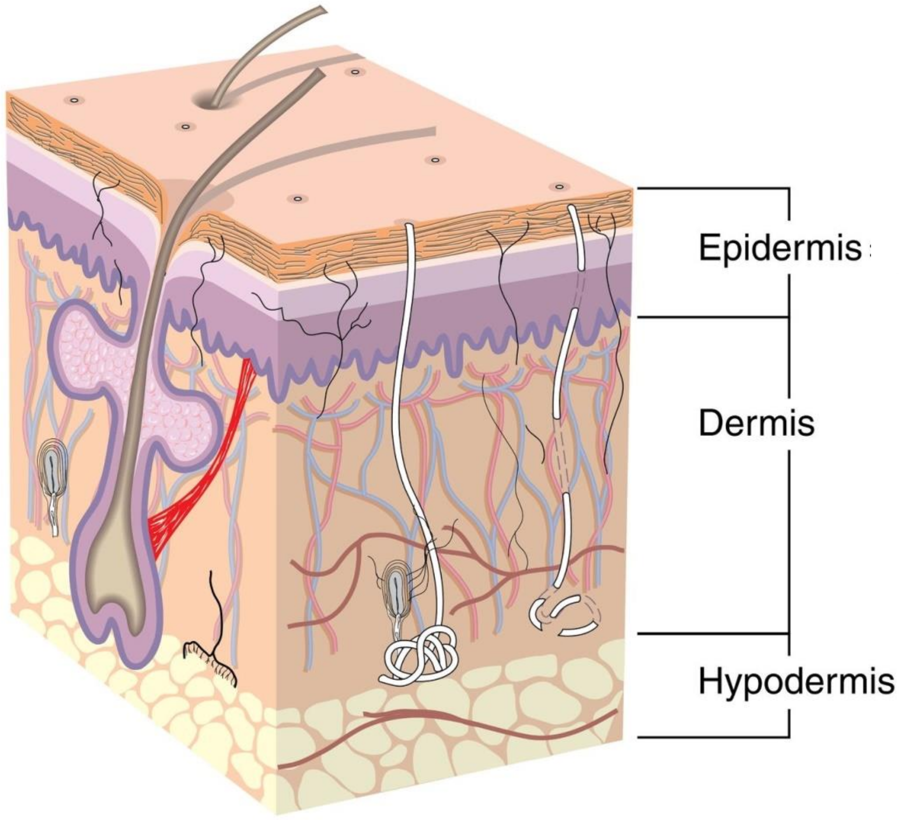






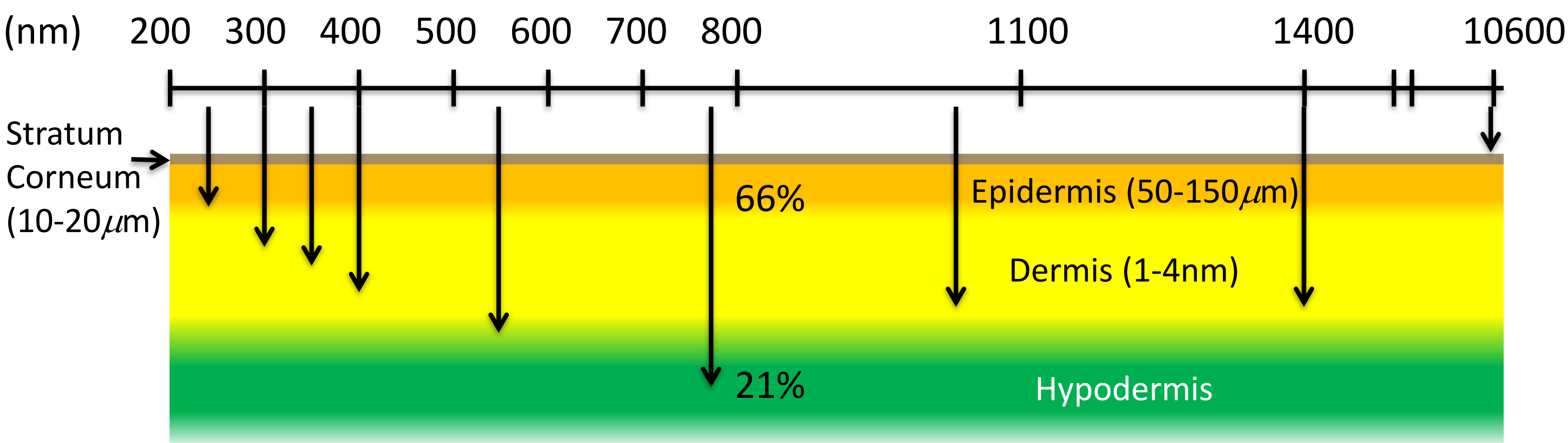
The Human Skin

- Human skin is the largest organ of the body and protects muscles, bones and inner organs from damage, loss of water and abrasion.
- Skin plays an key and first immunity role in protecting human body from pathogens (bacteria and viruses) and excessive water loss.
- It also provides other functions of insulation, temperature, regulation, sensation, synthesis of vitamin D and the protection of vitamin B.
- And is made up from multiple layers



Skin damage

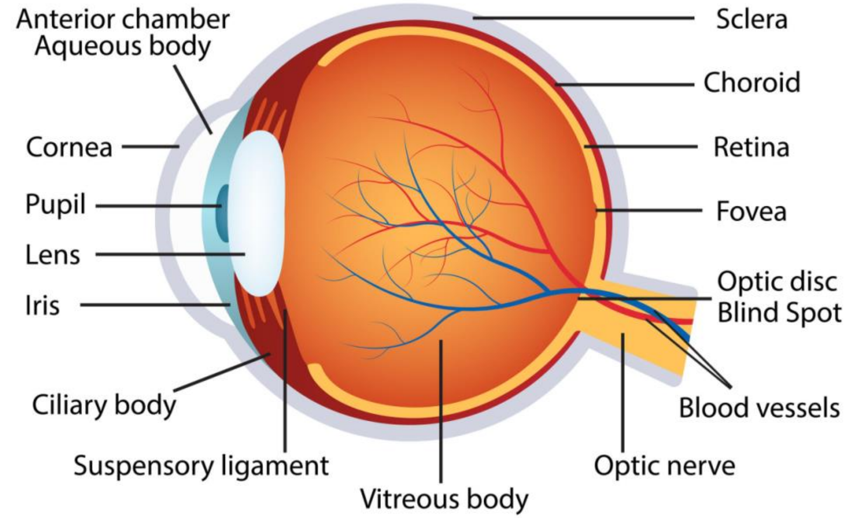
Wavelength	Range	Effect
UV(A, B, C)	200-400 nm	Sunburn, Skin Cancer Accelerated skin aging
Visible	400-700 nm	Pigment darkening, Skin burn
Near IR	700-1400 nm	Skin burn
Mid IR	1400-3000 nm	Skin burn
Far IR	3-100 mm	Skin burn

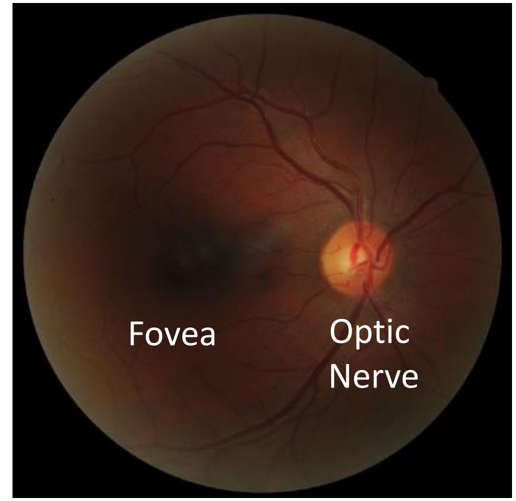


The Human Eye

Phibre

- Is an organ which is sensitive to the visible region of the EM spectrum. The retina allows the perception of light, vision and depth perception.
- The human eye can distinguish around 10 Million colours, with the sensitivity to detect down to a single photon of light
- Light passes through the pupil and is focused onto the retina
- Light illuminating the rod and cones cell contained on the retina provide the mechanism to perceive light

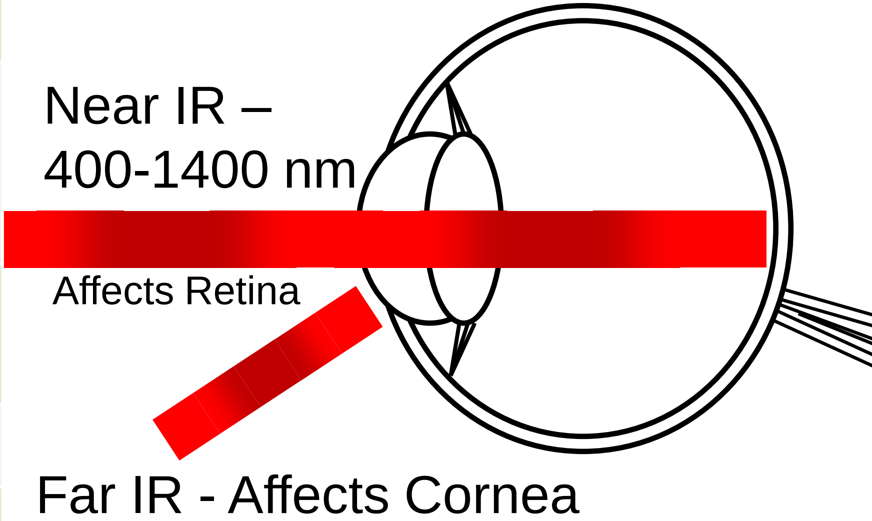




Eye damage

Phibre

Wavelength	Range	Effect
UV(A, B, C)	200-400nm	Photokeratitis
Visible	400-700nm	Photochemical Cataract and retinal burn
Near IR	700-1400nm	Cataract and retinal burn
Mid IR	1400-3000nm	Corneal burn
Far IR	3-100mm	Corneal burn



Laser classifications
4 main classification for safety

Class	Types of lasers	Danger
Class 1	Safe laser system	Completely harmless during normal use.
Class 1C	Medical applications	Completely harmless during normal use.
Class 1M	Safe unless using magnifying optics	Harmless if you don't look at it in a microscope.
Class 2	Applies to visible light lasers	Only harmful if you intentionally stare into beam, blink reflex protects the eye
Class 2M	Applies to visible light lasers	Should not be viewed through magnifying optics,
Class 2C	Medical lasers	Should not be viewed directly
Class 3R	Low power lasers	Skin and eye damage
Class 3B	Medium power lasers	Skin and eye damage
Class 4	High power lasers	Burns, melts, starts fires

-21.6dBm   0dBm   7 dBm   27dBm   @1550nm

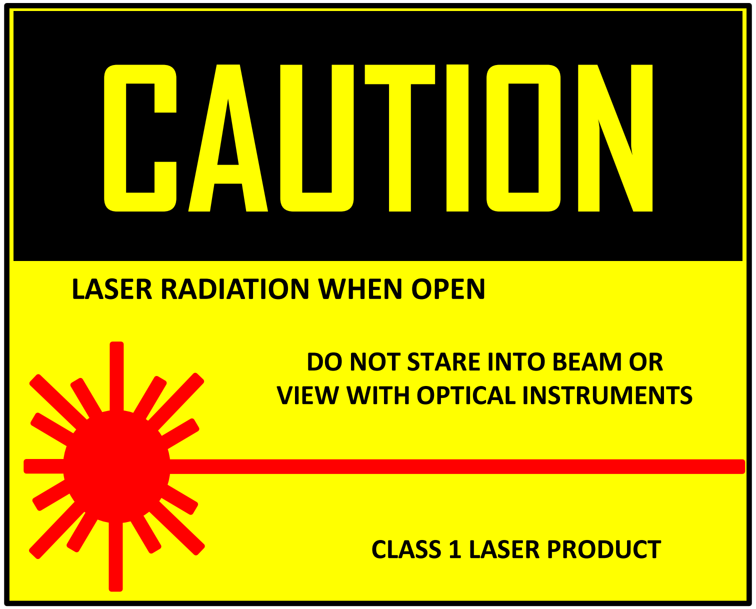
CLASS 1/1M   CLASS 2/2M   CLASS 3R   CLASS 3B   CLASS 4

Warning signs

CLASS 1
LASER PRODUCT

LASER RADIATION
DO NOT STARE INTO BEAM OR VIEW
DIRECTLY WITH OPTICAL INSTRUMENTS
CLASS 2M LASER PRODUCT

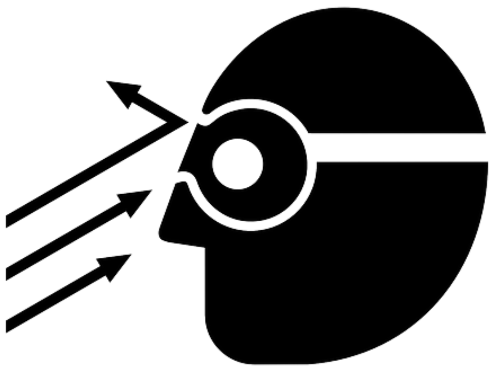
LASER RADIATION
AVOID EYE OR SKIN EXPOSURE TO
DIRECT OR SCATTERED RADIATION
CLASS 4 LASER PRODUCT



Laser Safety Officer

- Responsibility:
  - Monitors departmental arrangements and assists staff to improve standards:
  - Providing expert advice
  - Reviewing company protocols
  - Maintaining central registers:
    - Designated laser areas
    - Qualified users
    - Laser equipment
  - Providing training
  - Investigating accidents

Protective clothing



- Eyewear should be based on:
  - wavelength(s) being used
  - radiant exposure
  - maximum permissible exposure (MPE)
  - optical density of eyewear
  - visible light transmission requirements
  - adequate peripheral vision
  - prescription lenses
  - comfort
- Skin protection
  - Reduce exposed skin
  - Wear appropriate clothes for the level of laser classification

THE END

WELL DONE