Introduction to Optical Networking

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Introduction

- Work for Packet Clearing House
- Previously Senior Network Engineer at FX Networks, New Zealand
  - Built a national fibre network over the past two years
    - DWDM/CWDM/MPLS based
- Earlier worked for CityLink, large metro fibre provider in Wellington and Auckland
- Not specifically an optical engineer, however having to do everything is the kiwi way :)

What we’re going to cover

- Intro to fibre and light
- Outside plant
- Ethernet over fibre
- Muxes
- CWDM
- DWDM
- Network architectures

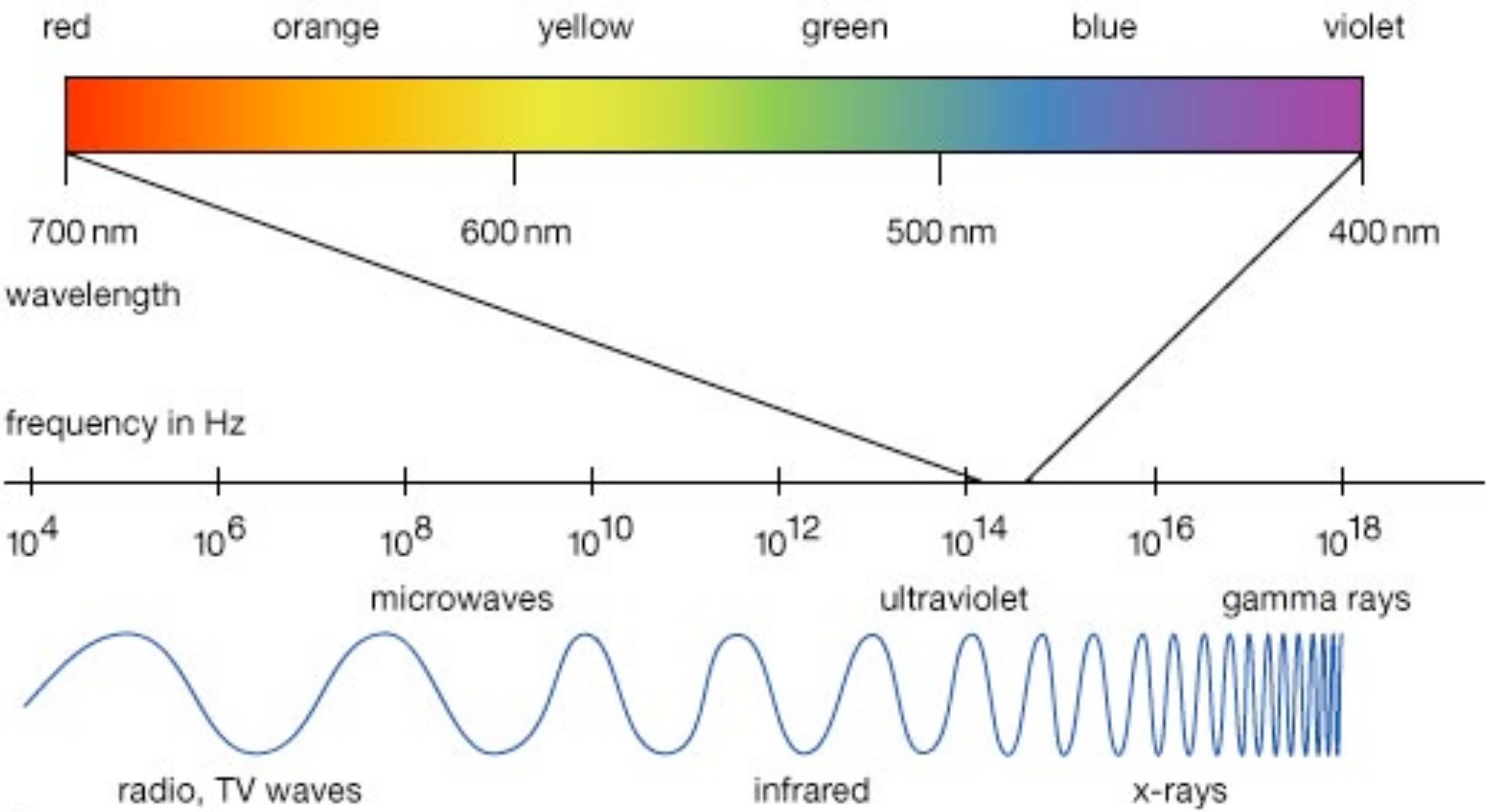
What is light?

- Electromagnetic radiation
  - Requires no medium through which to transport it’s energy
  - Covers a large spectrum all the way from subsonic - audible - RF - visible - x-ray and gamma rays
- Sometimes behaves like a wave, sometimes like a particle
- Waves have a wavelength and corresponding frequency

$$\text{frequency} = \frac{c}{\lambda}$$

$$\lambda = \frac{c}{\text{frequency}}$$

Electromagnetic Spectrum



What is light?

- ‘Low’ frequency signals referred to by their frequency in Hertz.
    - Hz (cycles per second)
- ‘High’ frequency signals referred to by their wavelength in metres.
    - Visible light and above
    - Nanometre nm (10e-9 metre - one millionth of a millimeter
    - Red light ~700nm
    - Purple light ~400nm

A little bit of maths...

- Decibels - logarithmic measurement scale
  - A ratio between two values, NOT an absolute measurement
- Light strength measured in dBm
  - Ratio with a reference level of 1mw

$$L_{\mathrm{dB}} = 10\log_{10}\left(\frac{P_1}{P_0}\right)$$

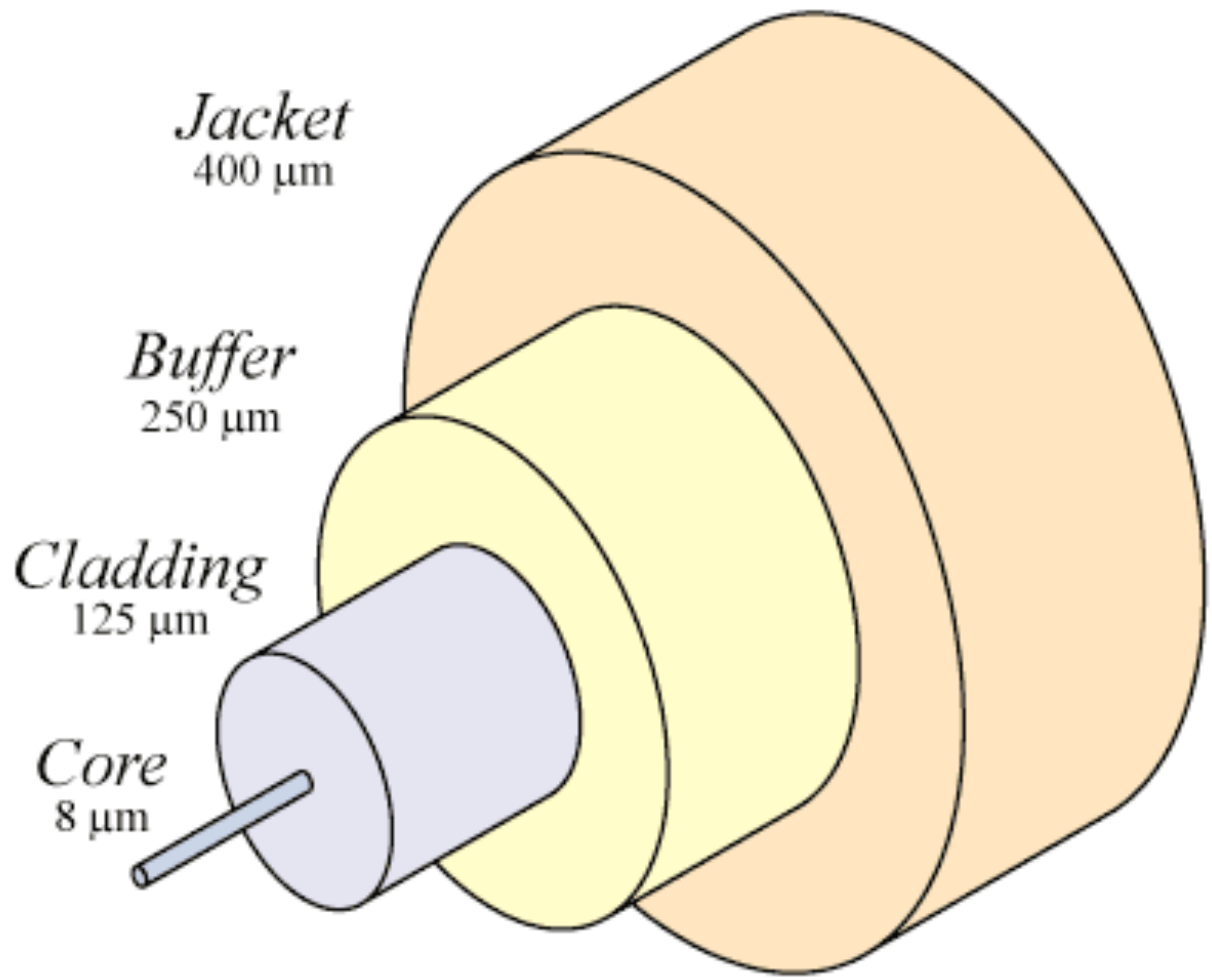
- Makes calculations easy
  - For light we can add and subtract dB loss from dBm values
    - 20dBm - 10dB = +10dBm
    - The loss (or gain if +ve) is simply a ratio, thus has no specific unit

A little bit of maths...

- Light amplifiers provide a +ve dB change
- Anything impeding or **attenuating** a light signal causes a -ve dB change
- This forms the basis of calculating optical budgets

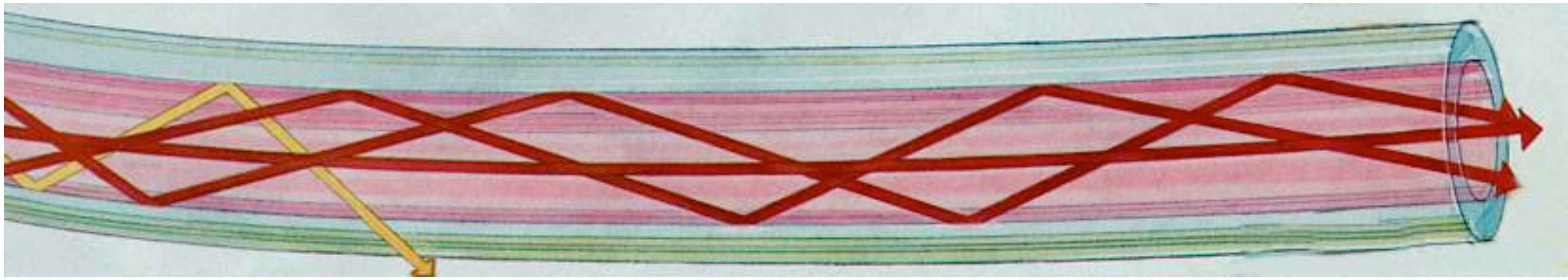
Fibre optic cable

- A glass core of fibre with a cladding around the outside with a **lower index of refraction**.
- This causes **total internal reflection**



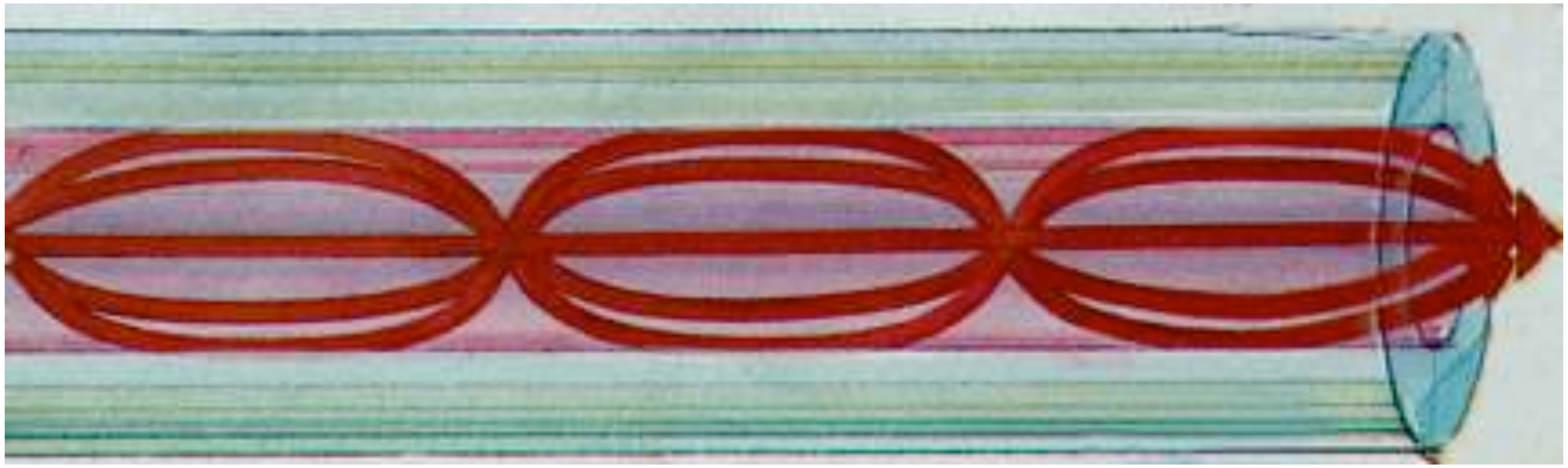
Total internal reflection

- Confines light within the fibre
- Light rays reflect back into the core if the hit the cladding at a shallow angle
- Any rays exceeding a critical angle escape from the fibre



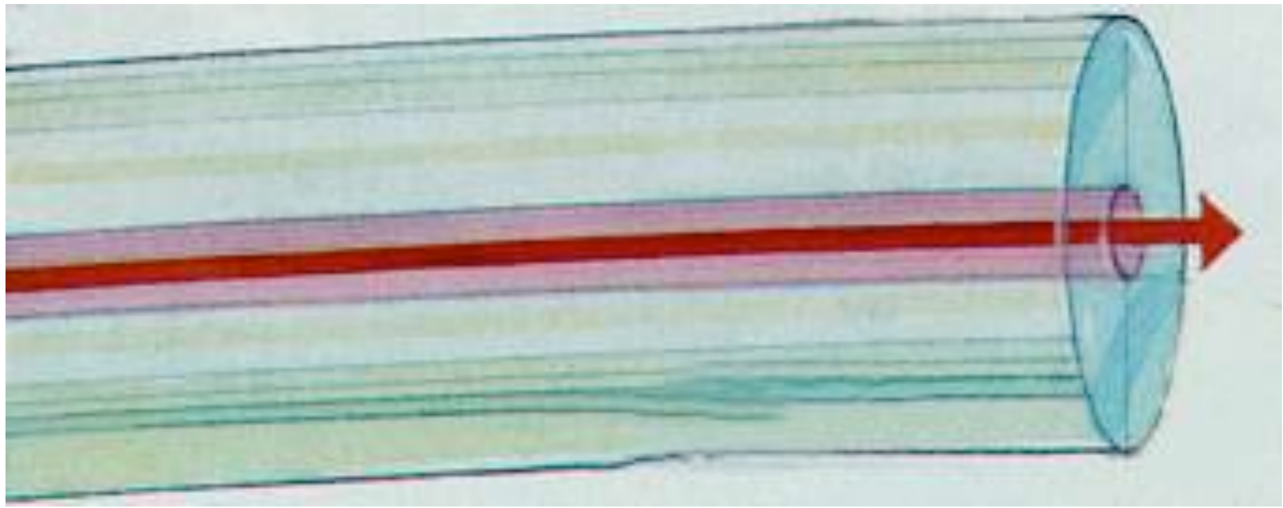
Multimode fibre

- Core diameter of 50 - 100 microns
    - typical values of 50, 62.5, 100 microns
- Generally used for runs <2Km
    - Gig and 10Gig require runs < 200m
- Light takes multiple paths through fibre resulting in signal degradation



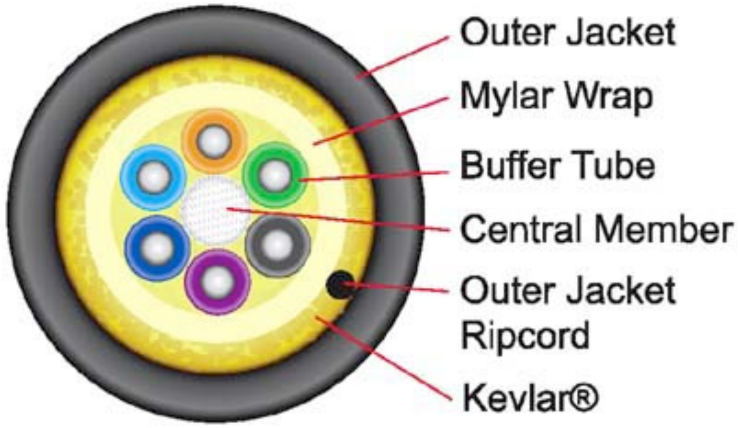
Singlemode fibre

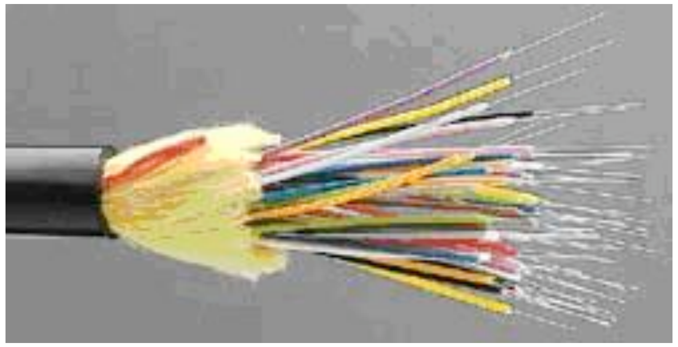
- Narrow core of around 8 microns
- Smaller change in refractive index between core and cladding
- Light travels mostly parallel to the axis of the fibre
  - Little pulse dispersion
  - Less attenuation

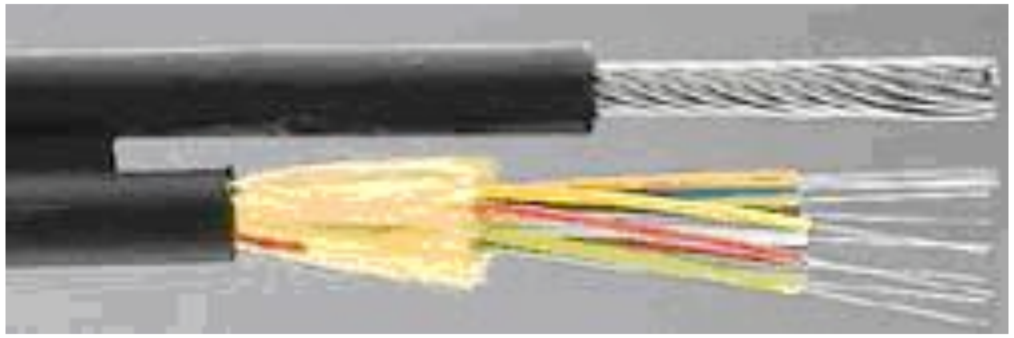


Fibre cable types

- Loose tube
    - Typically used for outside runs
- Tight Buffer
    - Typically used for indoor runs
- Armoured, aerial, composite cables also available

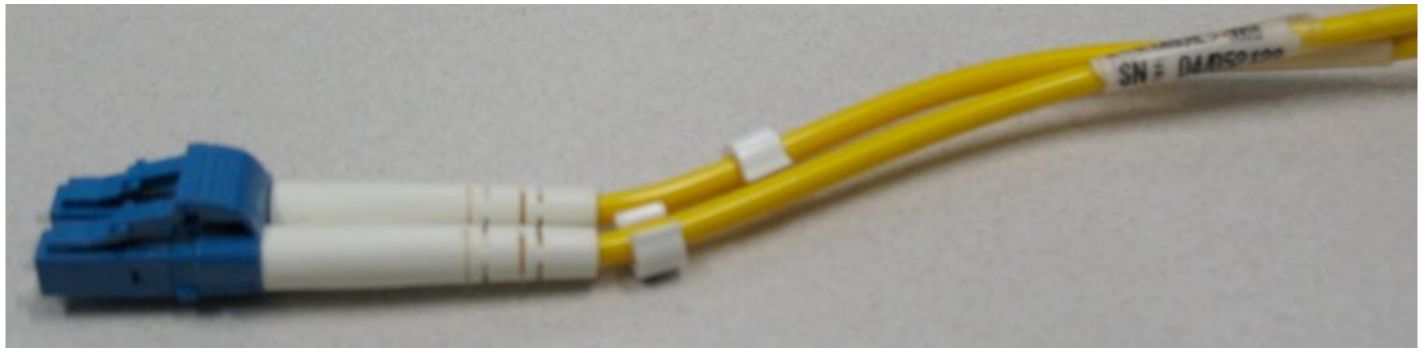
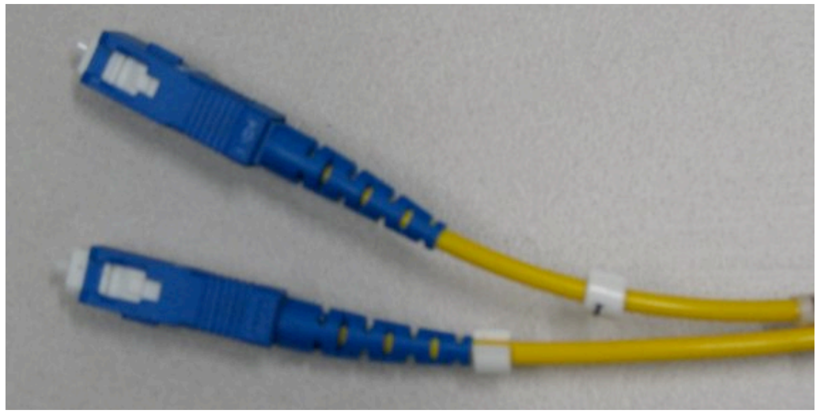
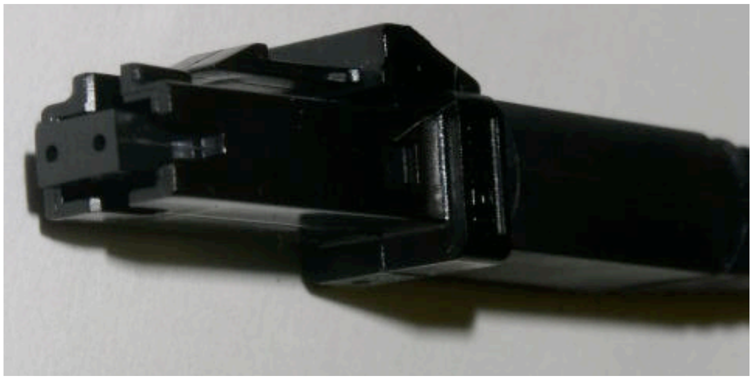






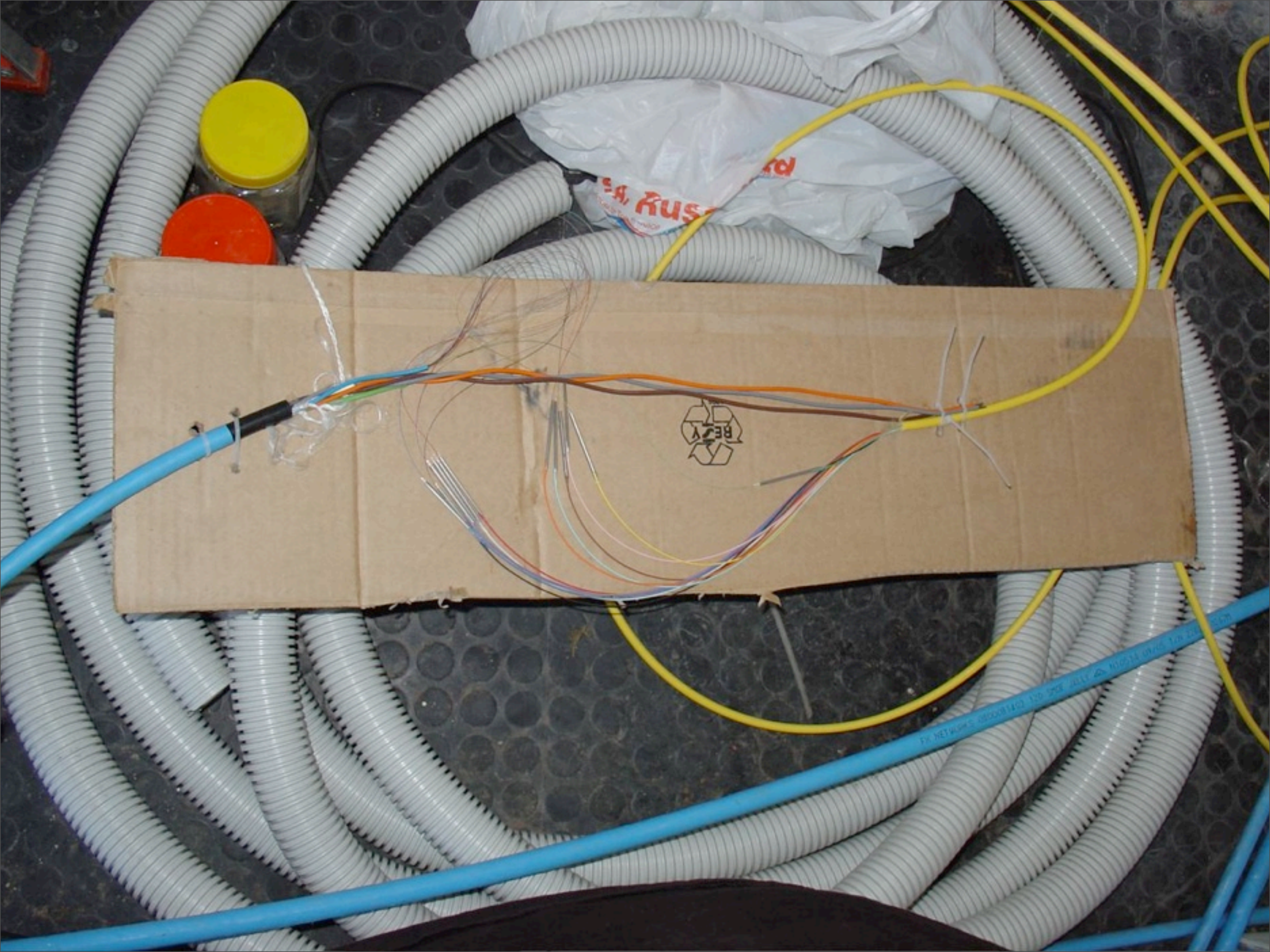
Common connectors

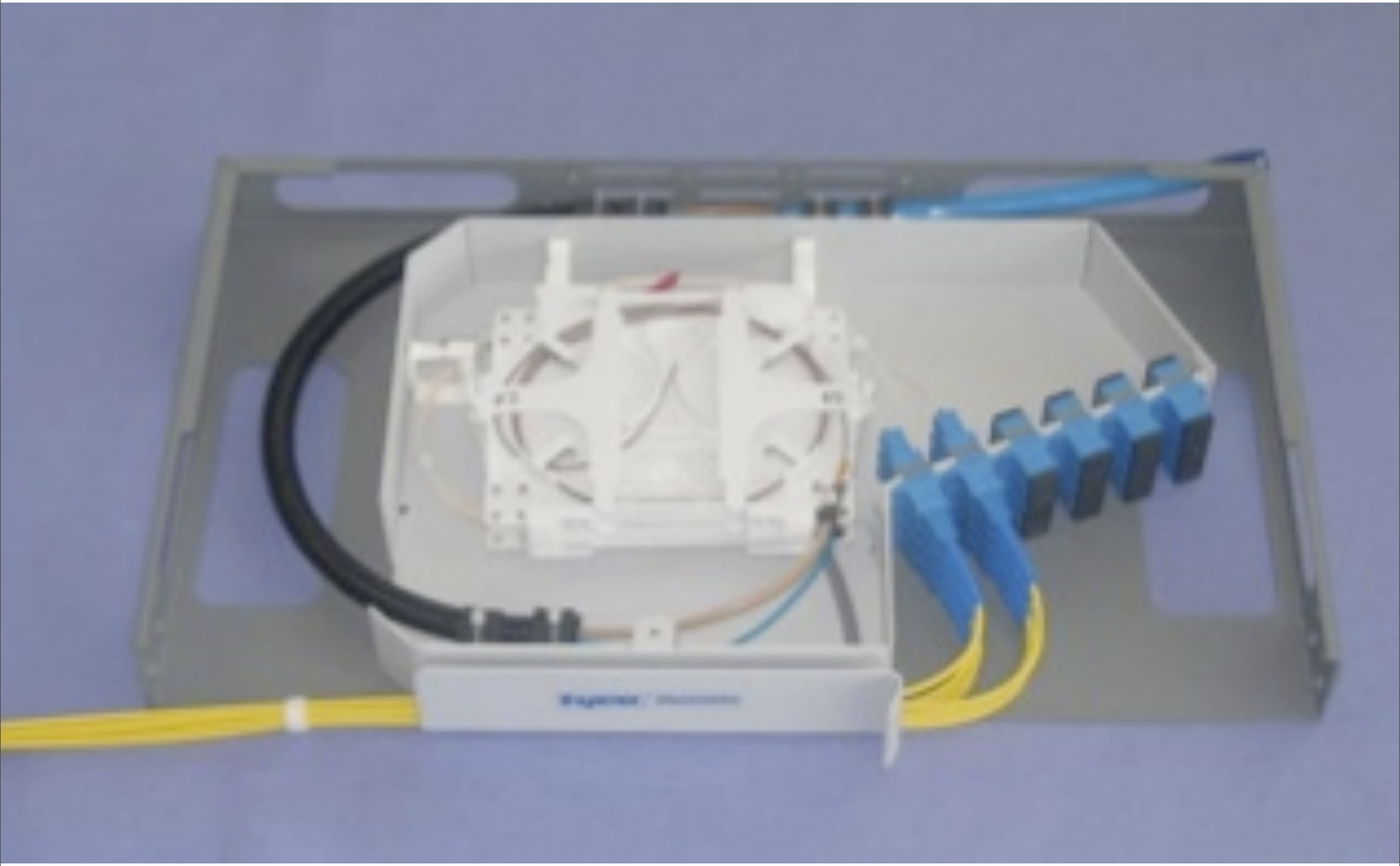
- LC
- SC
- MT-RJ
- ST
- Many available with an angled ferrule
    - Less reflections at patch points

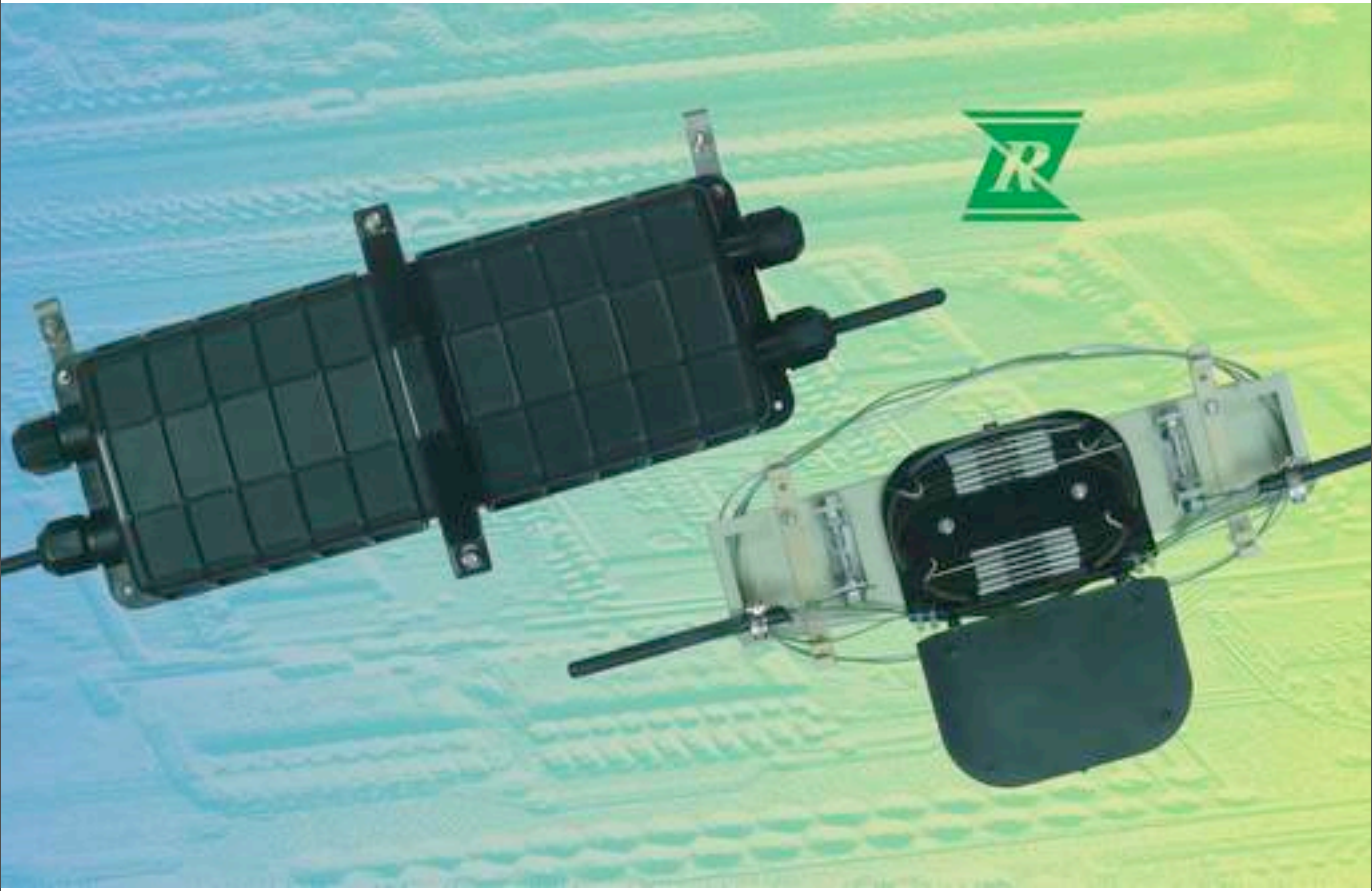





Building a fibre circuit

- Run the cable
- Splice the cable
    - Joint closures contain splices
- Attach / joint connectors onto the end of a circuit
- For long haul links, ideally splice fibres end to end
- Metro fibre networks tend to use a lot more patching for flexibility







Test tools

- Optical Time Domain Reflectometer (OTDR)
  - Sends pulses down a fibre, measures the reflections coming back
  - Can measure ‘quality’, attenuation, and location of bad splices / connectors / patches
  - Single ended test
- Light source and power meter
  - Sends a light signal of known wavelength and power
  - Power meter measures signal at far end. Dual ended test.

Optics

- Very common and very cheap these days
  - Ethernet, SDH, Fibrechannel, many more
- Typically runs at:
  - Multimode - 850nm
  - Singlemode Short haul - 1310nm
  - Singlemode Long haul - 1550nm

Optical budget

- Transmit power
  - The light power transmitted by an optic.
  - Can be anywhere from -10dBm to +6dBm
  - DWDM / CWDM amplifiers even more
- Receive sensitivity
  - The minimum power required for the receiver to operate error correcetly
  - Can be anywhere from -10dBm to -28dBm

Optical budget

- The path between the transmitter and receiver will attenuate the signal
- Singlemode fibre ~ 0.2dB / km
- Good splice ~ 0.1dB
- Connector ~ 0.5dB
- Tight bend in fibre - lots
- Tx power - [path loss] must be > Rx sensitivity
- Typically want 3dB headroom on the link to cater for changes
  - Tx power - [path loss] -3 must be > Rx sensitivity

Ethernet optics

- 10/100 Mbit/s still common in access networks
- 1Gbit/s - very common and cheap
- 10Gbit/s - quite common, still quite expensive
- Singlemode and Multimode optics available with varying reaches
    - LX - 10km -4dBm / -10dBm (Tx power / Rx sens.)
    - ER - 40km +0dBm / 16dBm
    - ZX - 80km +4dBm / 20dBm
    - UX - 120km +4dBm / -27dBm

10Gbit/s Ethernet

- Runs at *about* 10Gbit/s
- Two main types:
  - LAN PHY, line rate of 10.3125Gbit/s
    - 10GBASE-E**R**
  - WAN PHY, line rate of 9.353Gbit/s
    - Fits nicely into STM-64 / OC-192 containers
    - 10GBASE-E**W**
- Three different types of ‘module’

Xenpak module

- The original module
- Comparatively big
- Longer optic reaches first appear here
- Fibre and copper
- Uses SC fibre connectors
- Cisco's early 'standard'
- www.xenpak.org

XFP Module

- Smallest form factor 10Gbit/s module
- Optical only, no copper at this stage
- ‘High’ technology due to size, typically behind Xenpak in development terms
- Seems to be the standard going forward
- Uses LC fibre connectors
- Cisco’s standard in expensive kit

X2

- Cisco's answer to providing a higher density module than the Xenpak
- Which is weird, because it is only marginally smaller than the Xenpak, and a whole lot bigger, and a whole lot different to XFPs!
  - Means I have to hold multiple different module types :(
- Newer than Xenpak, so not all optic variants have made it here yet
  - Means I have to hold multiple different switches to suit optics :(
- Fibre and copper
- SC fibre connectors

Optics

- 10GBase-SR - Short Range multi-mode, 26 to 82m. 850nm.
- 10GBase-LR - Long Range single-mode, 10km. 1310nm.
- 10GBase-ER - Extended Range single-mode, 40km. 1550nm.
- 10GBase-ZR - Ze best Range single-mode, 80km. 1550nm.
- 10GBase-LX4 - 240 to 360m over multi-mode fibre! 10km over single-mode
  - Achieved through CWDM using four separate lasers in the vicinity of 1310nm. 3.125Gbit/s per lambda.
- WAN PHYs: -LW, -EW, -ZW

Copper 10Gbit/s

- CX4 - provides 10Gbit/s over Infiniband style connectors
- Up to 15m
- Serial signals running at 2.5Gbit/s in each direction through multi-pair cable
- Minimum bend radius ~50mm

10Gbit/s Considerations

- Fibre - clean clean clean!
  - 10/100/1000Mbit/s is reasonably immune to dirty fibre connectors
  - 10Gbit/s less tolerant - starts doing really odd things
  - CRC input errors normally show up

10Gbit/s Considerations

- Watch out for microbends
- Dispersion in the fibre becomes a problem > 80km
  - Even though optical budget on longer links which would suggest
- Copper CX4 cables
  - Watch bending radius
  - Cable assembly is somewhat delicate
  - Well twisted pairs and lots of shielding
- How to test 10gig networks?

>10Gbit/s

- How do you transport it?
- Most DWDM systems based on 10G wavelengths
- 40Gbit/s interfaces typically 4x10G wavelengths
- CRS-1 40Gbit/s interface is cool
  - DWDM Transponder that slots straight in your router
  - 7600 DWDM transponder card coming soon
- Huge step investment moving past 10Gbit/s

Optical Multiplexers

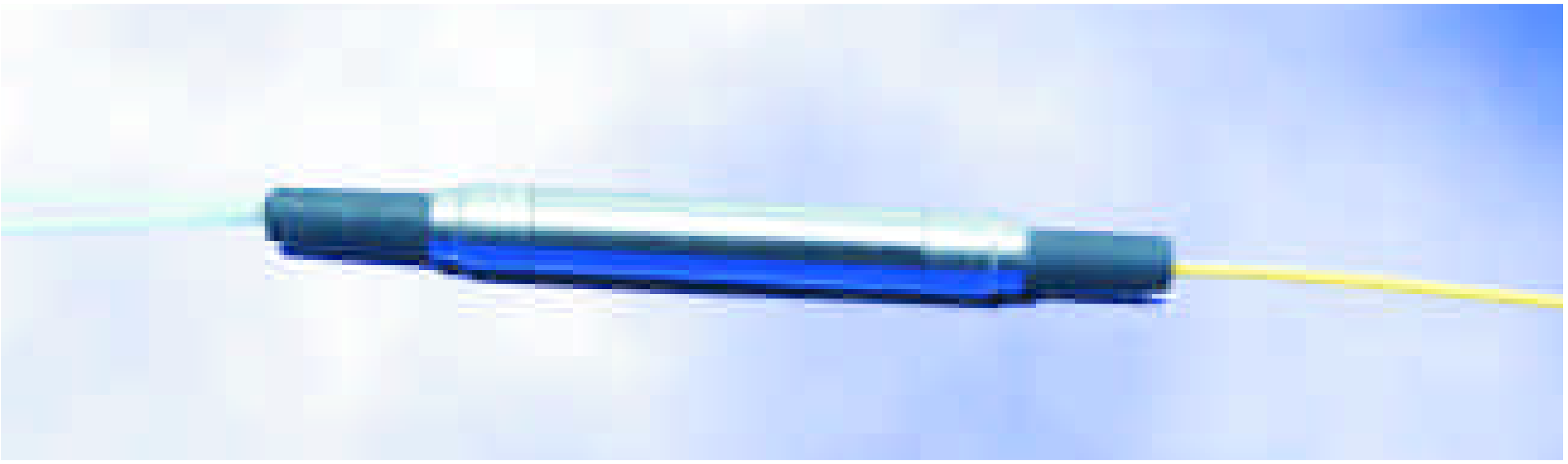
- Fibre optic cables can carry a very large bandwidth
- Mux techniques
  - Directional - i.e. Rx and Tx on the same fibre
  - Wavelength Division Multiplexing (WDM) - multiple different frequencies on the same fibre
  - Coarse WDM (CWDM) provides up to 8 channels with simple optics
  - Dense WDM (DWDM) provides up to 128 channels with advanced optics

Fibre coupler

- One fibre on line side, two fibres on equipment side
- One fibre melded into two fibres. Incoming light exits on both fibres
- Simple and cheap
- High Loss
- High reflections
- Normally a 50/50 split between the two equipment side fibres
    - 90/10 split often used for passive fibre tap

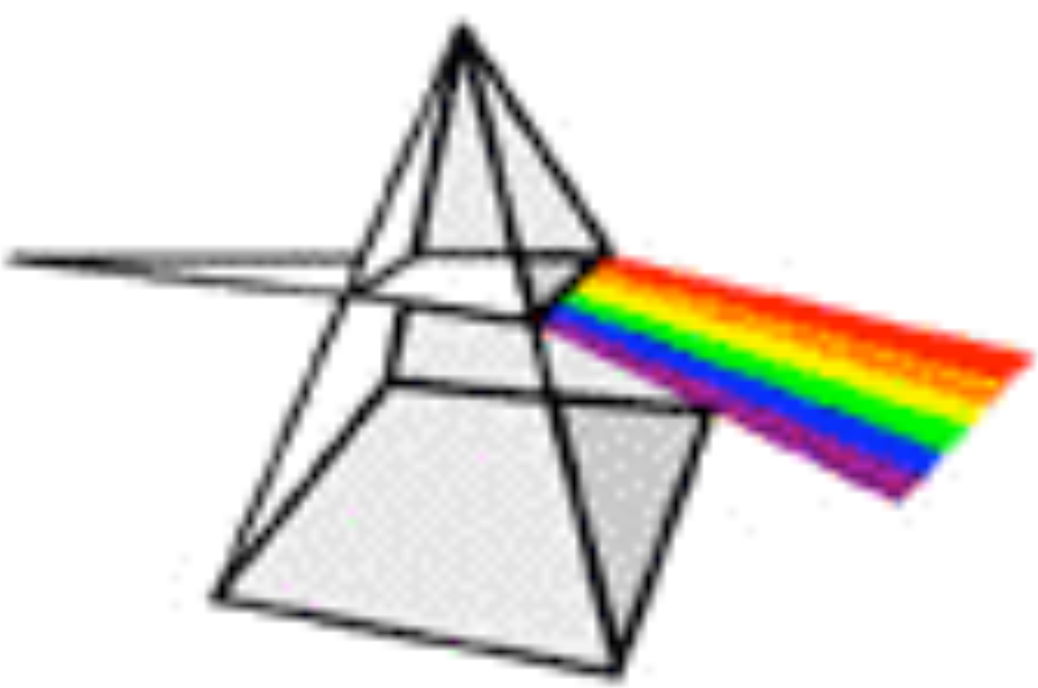
Circulator

- Can be 1x2, or 2x2
- Splits a signal using optical components to route light from an input fibre to an output fibre, and return light to a different fibre
- Low reflections, high isolation
- Low insertion loss, but generally work only for specific frequency bands
    - trade off between insertion loss and bandwidth



WDM mux

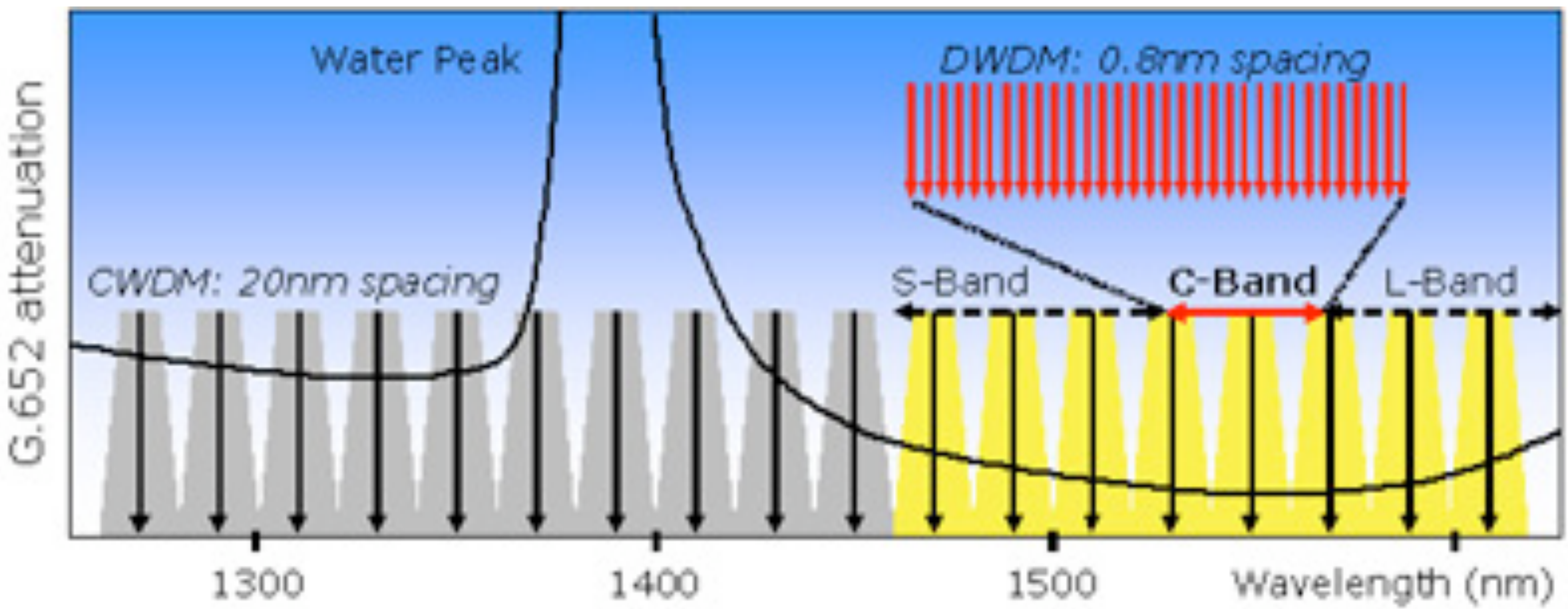
- Uses prisms to mux and demux multiple wavelengths onto one fibre
- Heart of CWDM and DWDM systems



CWDM

- Basic WDM mux, completely passive
- May have monitor ports for checking power levels
- Uses ‘coloured’ optics which must be plugged into the corresponding ‘colour’ on the WDM mux or demux
- Manual physical configuration
- May require attenuators to reduce signal levels
- Wide (20nm) spacing between adjacent channels

Channel spacing



DIY CWDM

- All you need:
- A CWDM mux and demux
- Coloured Optics
  - 1gig optics readily avilable
  - 10gig optics available but still expensive

DWDM

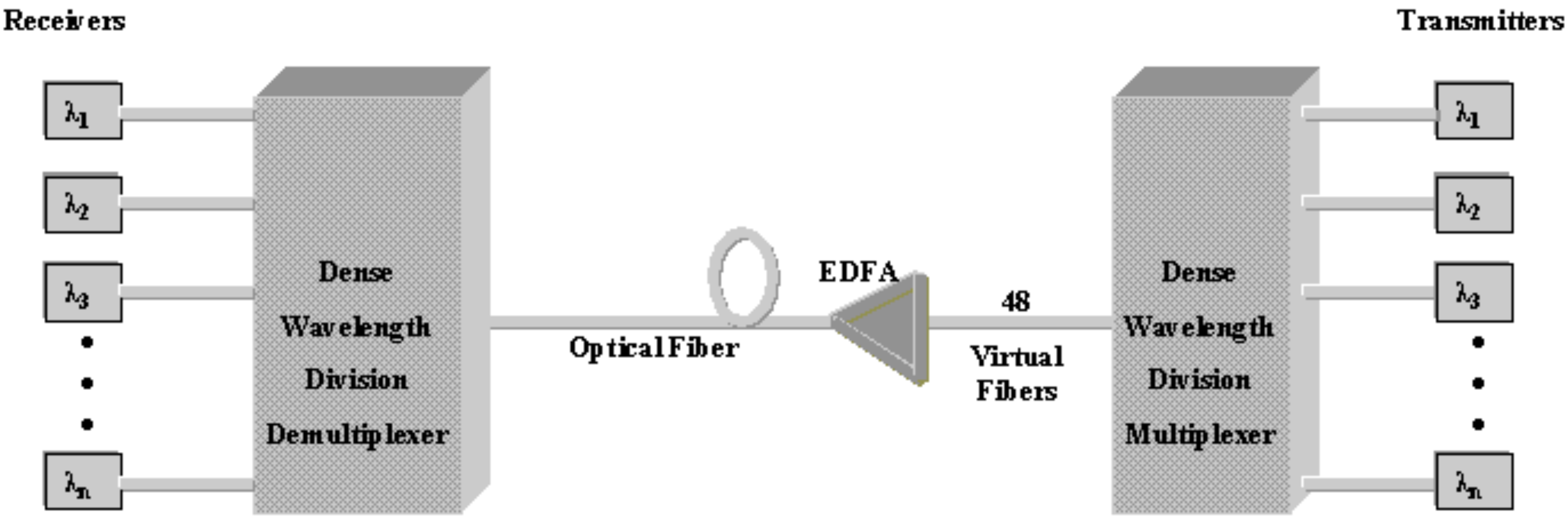
- Same principle as CWDM
- Typically start at 32 channels, smaller channel spacing (0.8 - 1.6nm)
- Easily up to 128 channels with current technology
- Channels generally 10Gbit/s on modern equipment
  - 1Gbit/s and 2.5Gbit/s common

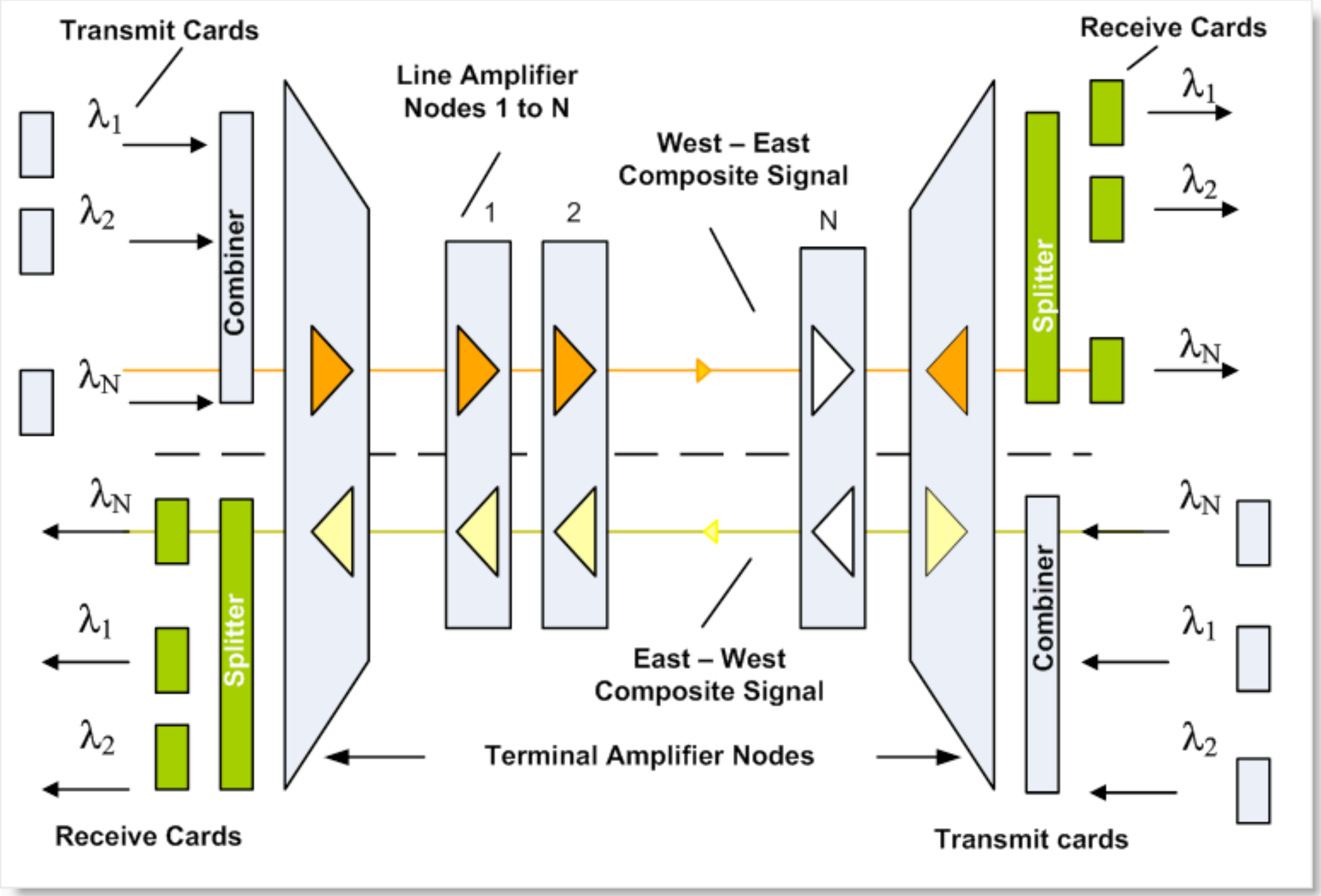
DWDM components - input from line

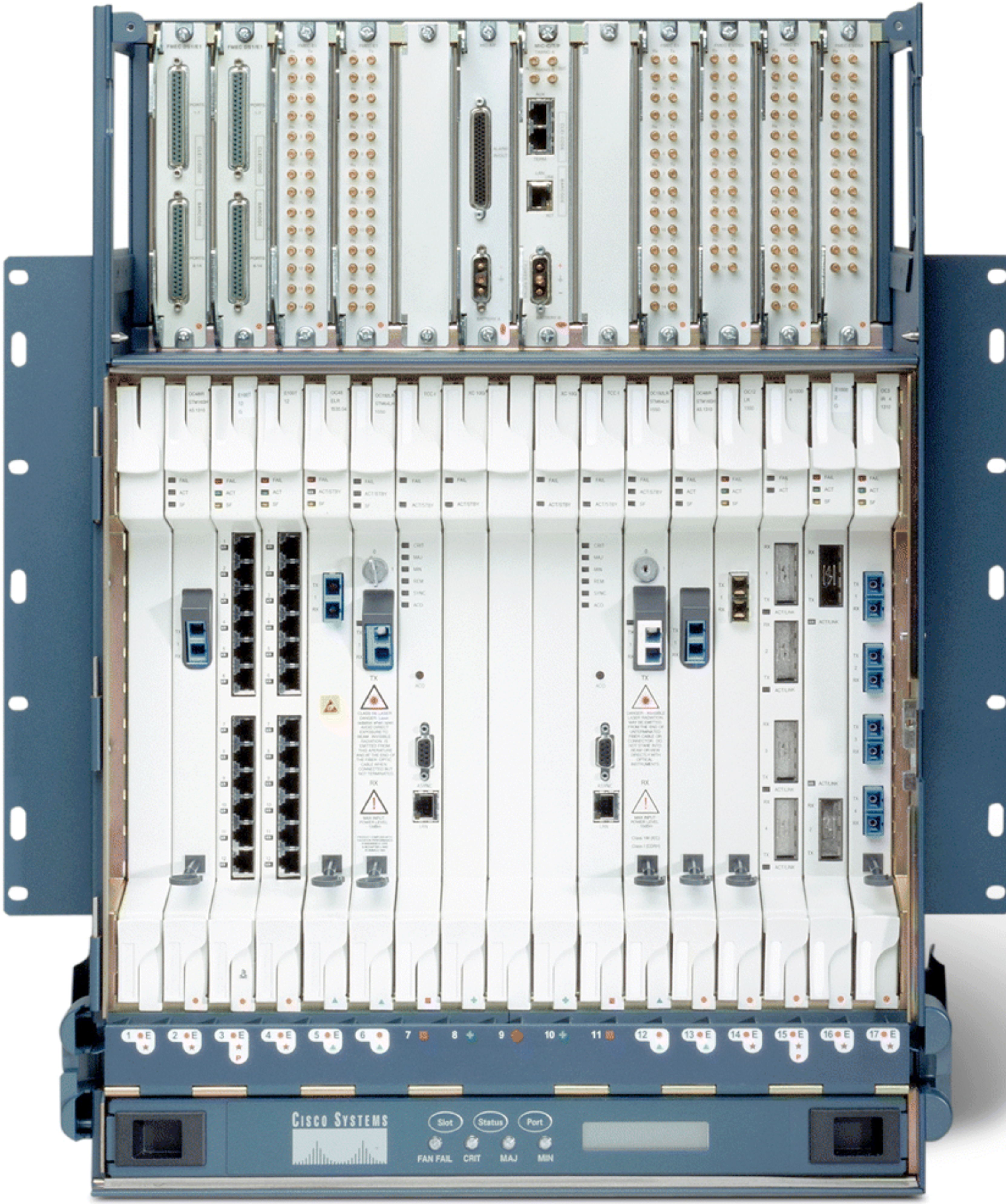
- Pre-amp
- Dispersion Compensation Unit (DCU)
- MUX
- Channel attenuation
- Channel transponders
- Client optics

DWDM Components - input from client

- Client optics
- Transponder
- Channel attenuation
- Mux
- DCU
- Power amp


Receivers
Transmitters
λ_1
λ_2
λ_3
λ_n
Dense
Wavelength
Division
Demultiplexer
Optical Fiber
EDFA
48
Virtual
Fibers
Dense
Wavelength
Division
Multiplexer
λ_1
λ_2
λ_3
λ_n


Transmit Cards
λ1
λ2
λN
Combiner
Line Amplifier
Nodes 1 to N
1
2
N
West – East
Composite Signal
Receive Cards
λ1
λ2
λN
Splitter
λN
λ1
λ2
Splitter
Receive Cards
East – West
Composite Signal
Terminal Amplifier Nodes
λN
λ1
λ2
Combiner
Transmit cards



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Architectures

- An optical network to deliver optical services
  - Optical network provides intelligence
  - Engineered to provide resiliency / redundancy
- Optical technologies as point to point solutions
  - Work around capacity/cost constraints
  - Higher layers (IP, MPLS, Ethernet) provide network intelligence
  - May provide resiliency, or it may be left to the higher layers

Architectures - CWDM

- Metro rings
  - CWDM - add/drop mux at each client site
  - CWDM optics straight in DWDM for long haul transport
- Point to point
  - Multiple optical services between two sites

Architectures - DWDM

- Line
  - no redundancy
  - trunk side redundancy
- Ring
  - Redundancy around ring trunk-side
  - Client-side redundancy with Y-cables
- Multi-degree ROADM