

Coarse wave-division multiplexing

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Not an ethernet switch



Multiplexing, sharing link bandwidth

Combining multiple connections to share one link:

- Ethernet uses *statistical multiplexing*, with data placed in frames which then queued for transmission onto the link.
- The phone system traditionally works on *time-division multiplexing*, with each call being allocated a time slot.
- AM radio works on *wavelength-division multiplexing*, with each channel allocated a frequency.

Can also do wavelength-division multiplexing using optical fibre links.

CWDM

Coarse means wide spacing between channels

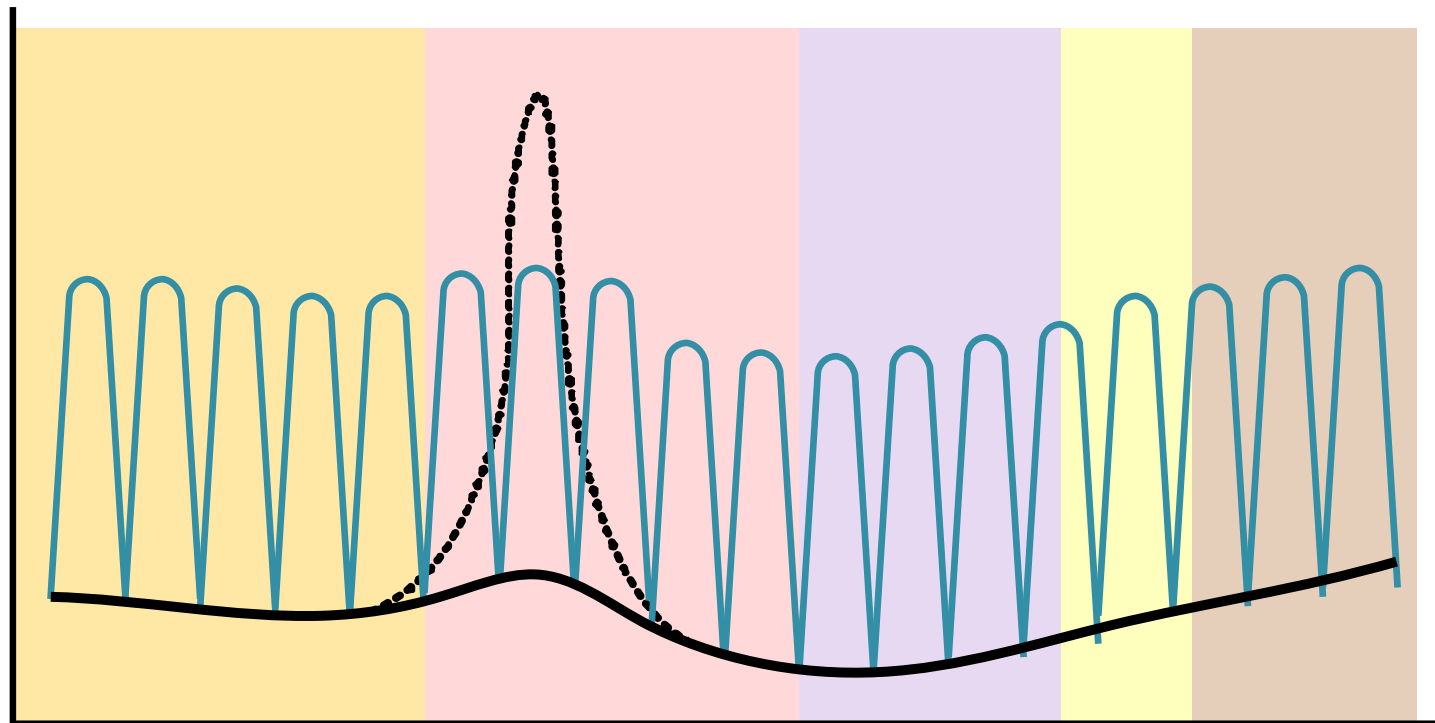
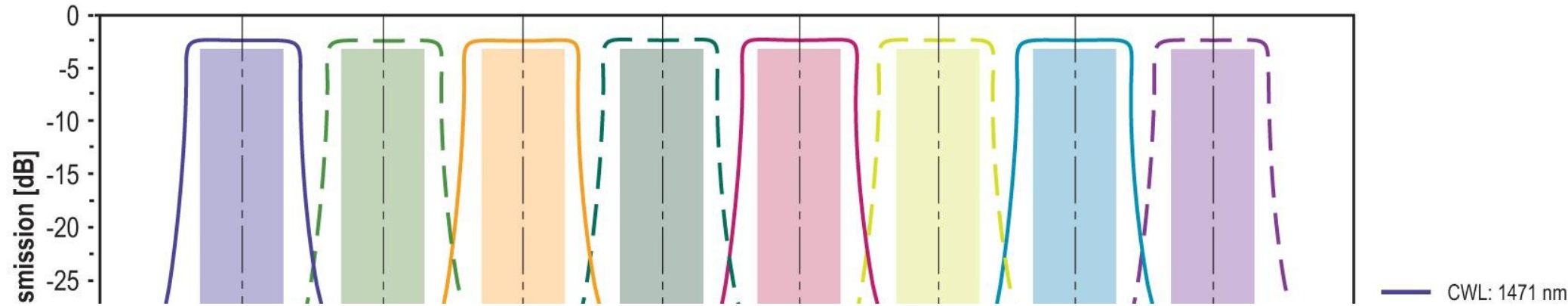
- Less expensive equipment than “dense”, but a smaller number of channels.
- Price is competitive with ethernet switching

Wavelength division multiplexing

- Each signal is assigned a *frequency*.
- At the transmitter these signals are *mixed* together.
- At the receiver the mixed signal is *filtered* into its constituent signals.

Very much a analog technology

CWDM spectral view



SFPs - assigning a frequency

SFPs use a wavelength.

- 1000Base-LX uses 1310nm.
- 1000Base-ZX uses 1550nm.



CWDM SFPs use wavelengths to fit the CWDM system being used, a different SFP per wavelength

- a 8 channel CWDM system will use 1470, 1490, 1510, 1530, 1550, 1570, 1590, 1610.
- to prevent error, SFPs and CWDM mux ports are colour-coded

SFPs - driving the distance

With no amplification we need power

- 1000Base-LX SFP 8dB budget, 5Km
 - Average launch power: -3dB to -11dB
 - Receiver saturation: -3dB, sensitivity: -19dB
- 1000Base-X CWDM SFP 25dB budget, 80Km
 - Average launch power: 0dB to +5dB
 - Receiver saturation: -3dB, sensitivity: -25dB
 - Note that connecting this SFP with a loopback cable will overdrive it by 3 to 8dB
- The “channel isolation” specification of any of the CWDM muxes must be greater than the output power of any SFP.

SFPs - bastardry

SFPs have a EEPROM to provide information about the unit.

We could checksum that EEPROM and have our switch reject SFPs with checksums it doesn't know about.

Locking purchasers of our switch into buying our SFPs, at monopoly prices.

SFPs - anti-bastardry

But EEPROMs are programmable, so let's reverse-engineer the checksum and program them.

We could then provide SFP types that the switch manufacturer does (CWDM, single fibre, etc)



SFPs - bastardry still hurts

But even so, we still had to fake the parameters in the EEPROM.

So we can't do things like pulling the receiver sensitivity from EEPROM, pulling the received dB from the DOM, and alerting if using the last few dB.

Combiners and splitters

Combining light is easy, fuse the fibres together.

- with few reflections is harder, but only slightly.

Splitting is easy, once you observe that bending a fibre causes some light leaks out.

Amplification, not in practice

Optical amplifiers work on the same principle as a field effect transistor

- A small signal at the gate leads to a cascade of photons from the pump
- This is done by adding elements to the fibre, much as a semiconductor is also “doped”.
- Optical amplifiers might cover one or two bands, and some bands can be amplified at all.

The lack of amplification becomes the practical difference between CWDM and DWDM systems.

If we can't amplify, we must use powerful transmitters, sensitive receivers and highly-isolating filters in the CWDM system.

Changing frequency, not at all

This can easily be done in electronics; it's the basis of FM radios.

There is no non-lab device to change the frequency of light.

So considerable thought is given to allocation of wavelengths.

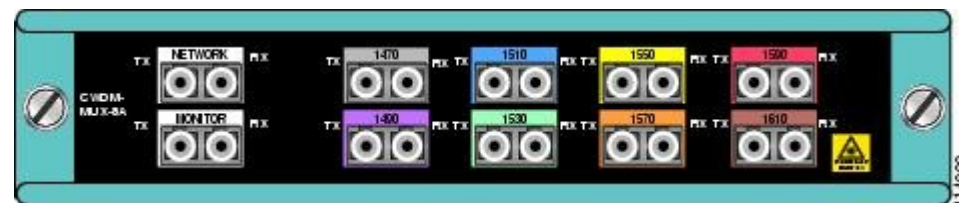
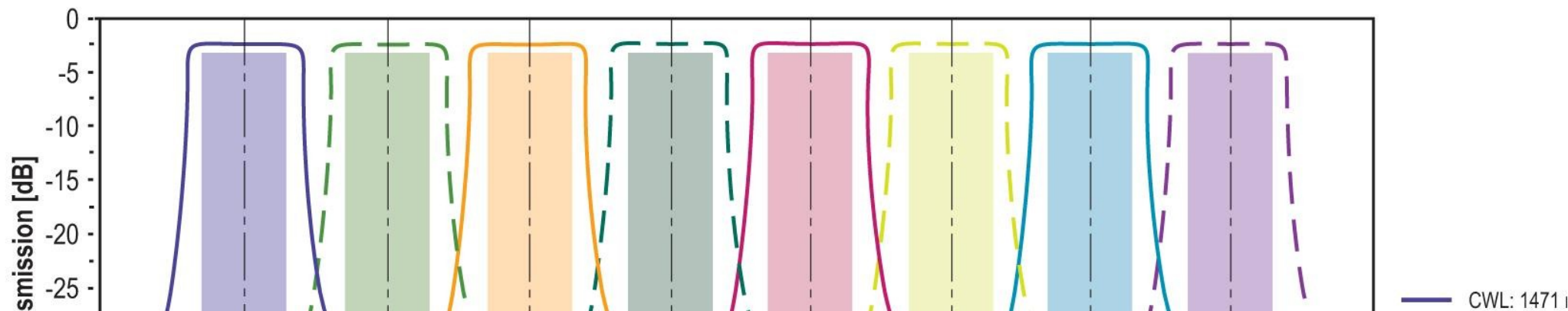
A multiplexor

Transmit

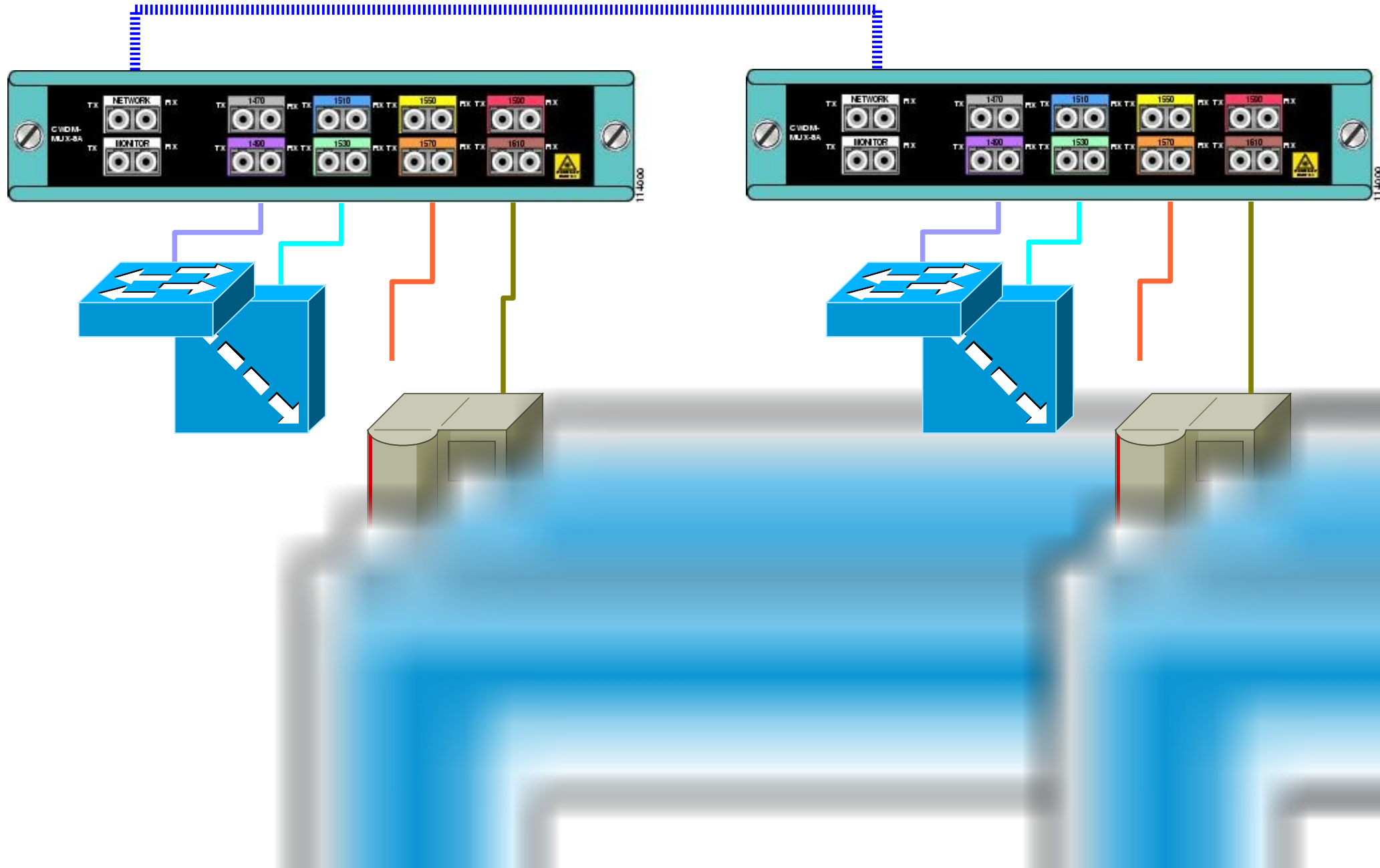
- filter and combine signals

Receive

- split and filter signals



Simple shared link network



Why?

Each user gets full bandwidth

- No inter-service QoS
- No inter-service denial of service

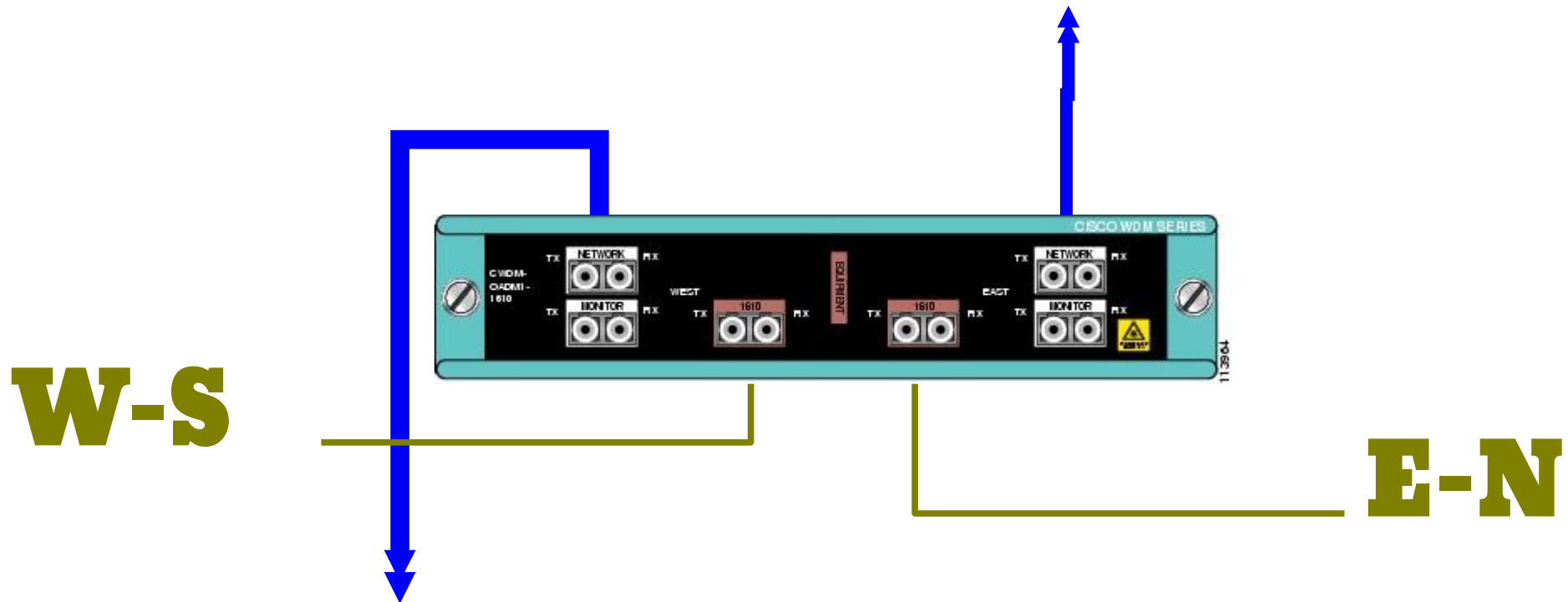
Can use differing protocols on differing channels

- ethernet, fibre channel, TV, ISDN

Add-drop multiplexor

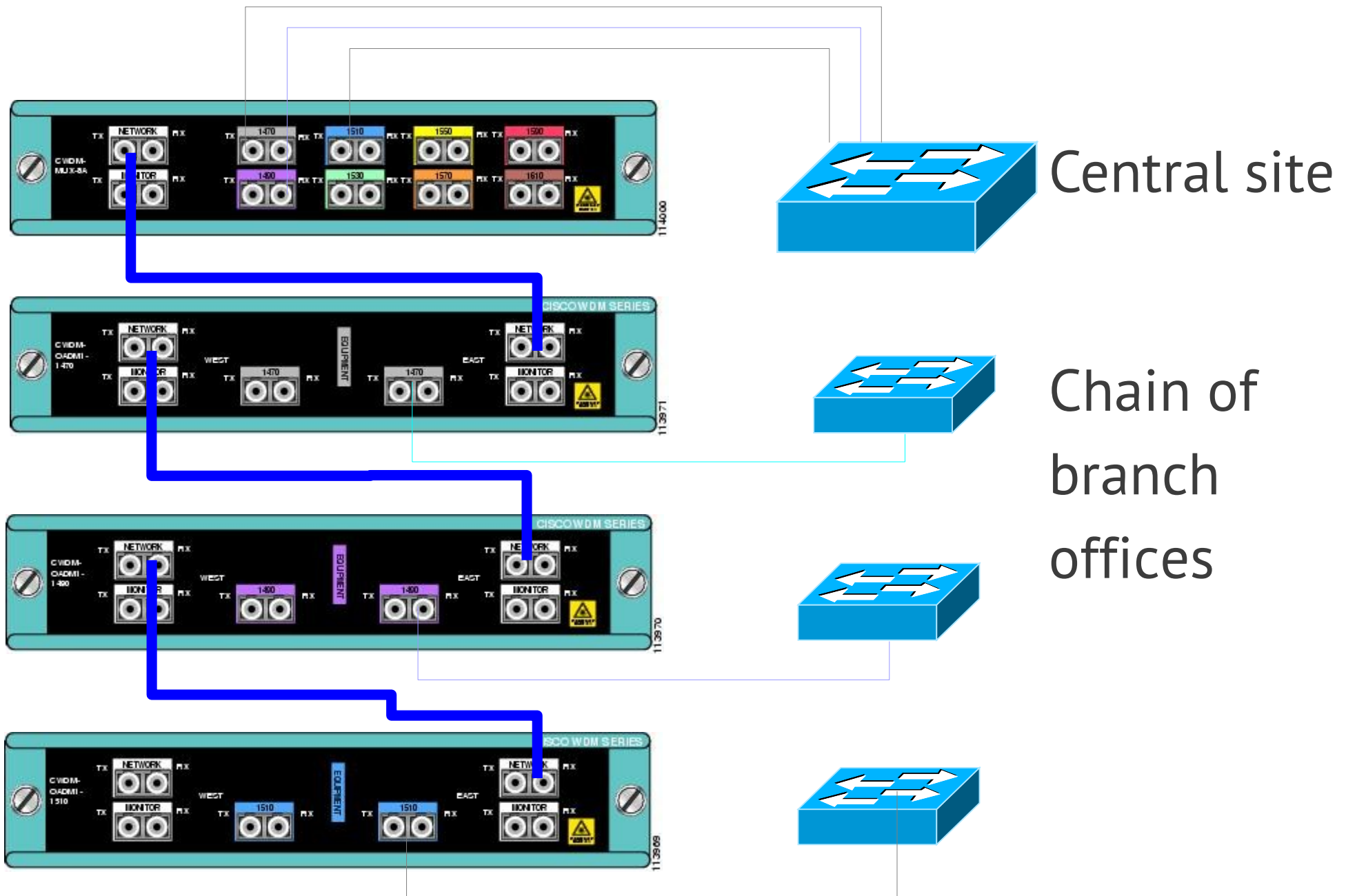
Add/drop west wavelength, sending it south.

Add/drop east wavelength, sending it north.



If you want to hurt your brain, consider the individual fibres, rather than the pairs.

Simple chain network



Why?

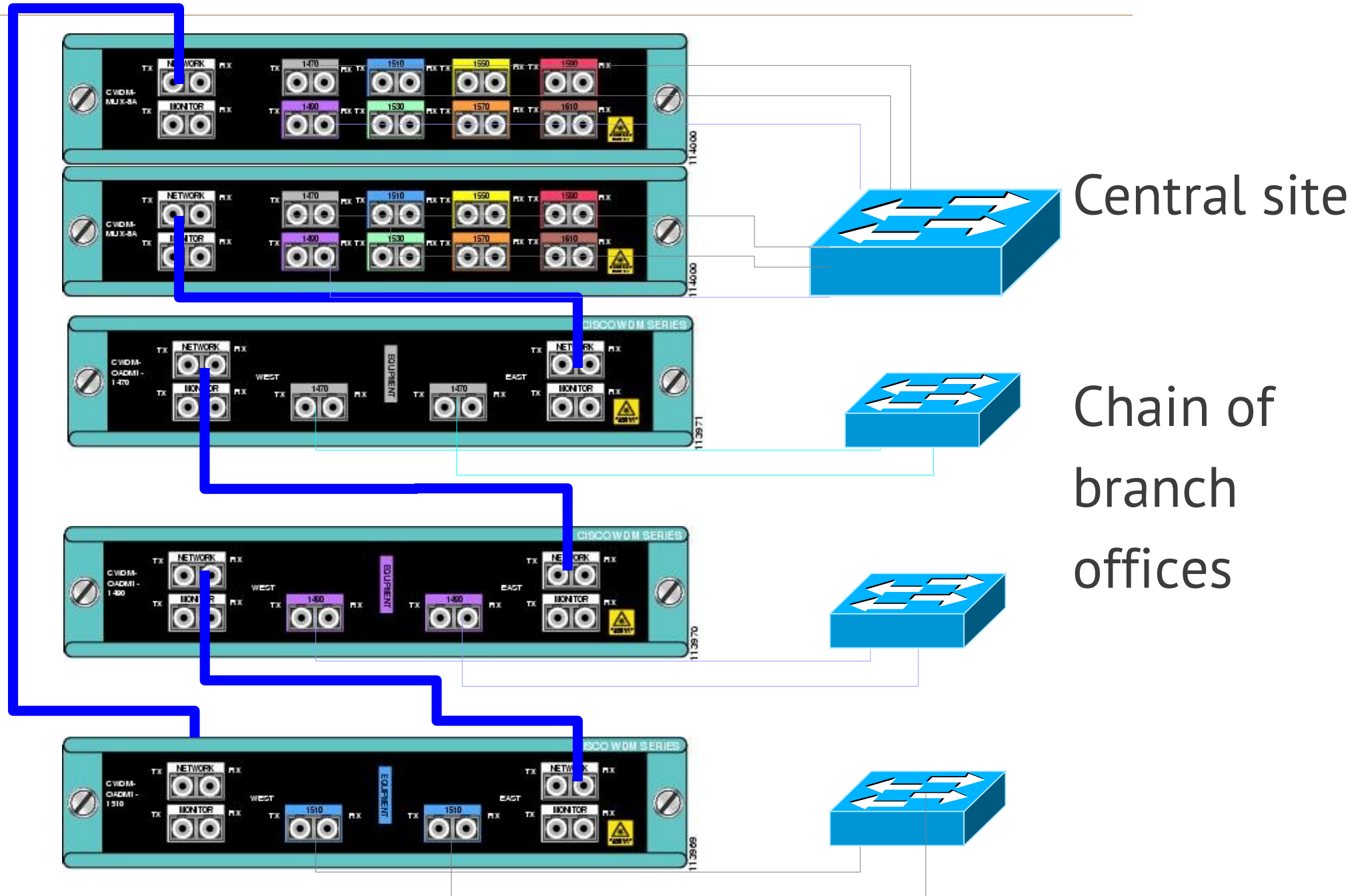
Efficient use of metro fiber

- in our example: 2 cores, not 6 cores

Could chain ethernet switches, but

- Further sites vulnerable to power outages at closer sites.
- In-pit muxing can keep shared failure modes out of the site altogether. Useful for schools – they can only access stuff which can cause an outage to themselves.

Redundant chain network



Why

If we can make a loop of fibre then we get a fully redundant network.

Note that the movement of traffic from the main to the backup link still requires routing (a switch's spanning tree or MPLS/IP OSPF/BGP).

- This is the cheap optical technology, the expensive one will automatically re-route.
- For switches put this network in its own Multiple Spanning Tree.

Optical fibre

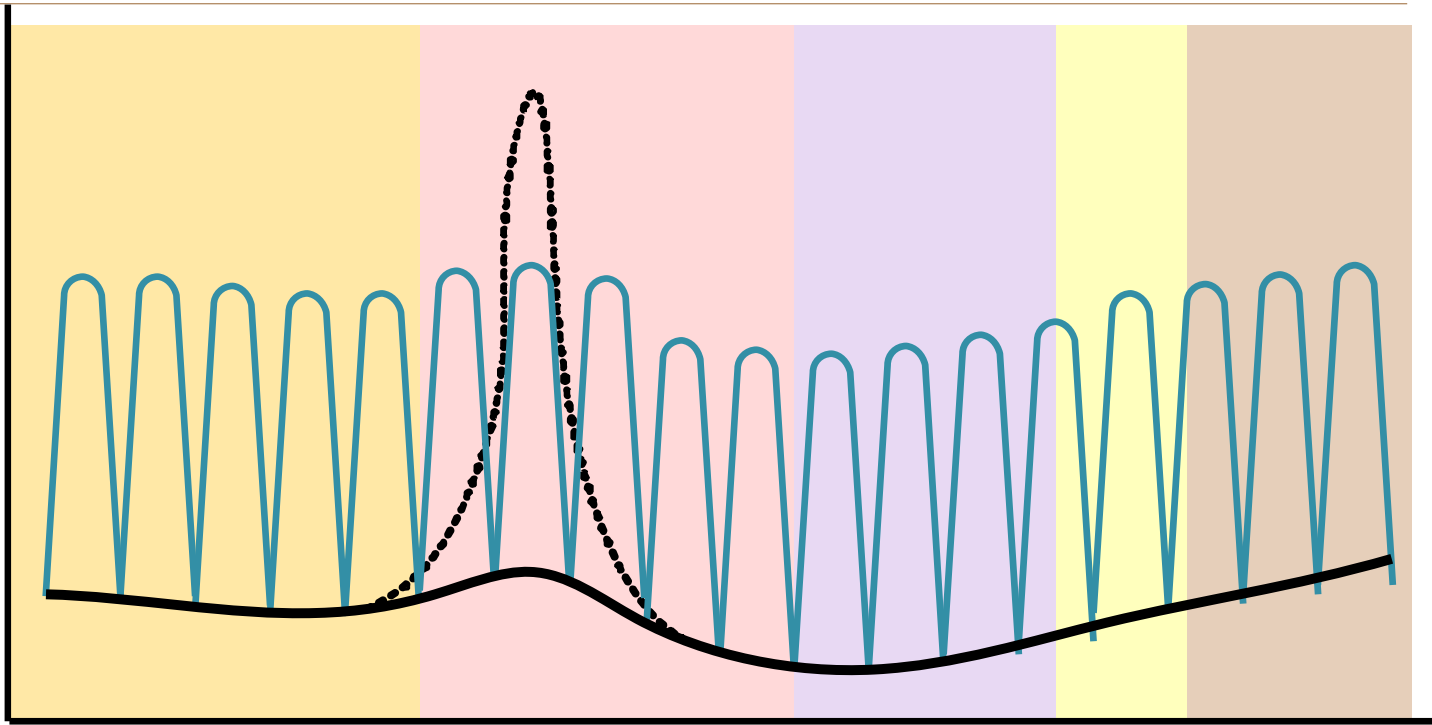
Fibre optic cable has linear loss and dispersion in only some frequency ranges. These usable frequency ranges are called *windows*.

- When specifying fibre we select models with wide windows and low loss

Optical fibre windows

800 to 900nm	Obsolete 1 st window High loss, so not used
1260 to 1490nm	Combined Original and Extended bands No dispersion E may contain water peak
1460 to 1530nm	Short wavelength band Low loss, some dispersion
1530 to 1565nm	Conventional band Low loss, some dispersion EDFA amplification
1565 to 1625nm	Long wavelength band Low loss, more dispersion EDFA amplification
1625 to 1675nm	Ultralong wavelength band

CWDM channels and the water peak



Older fibre has high attenuation at the “water peak” of 1390nm in the E band.

You want to specify “ITU-T G.655” zero water peak, non-zero dispersion-shifted fibre.

CWDM channel plan

To allow interoperability systems should use the same frequencies for channels.

The ITU-T G.694.2 band plan:

- Lowest channel centred on 1271nm.
- Channels every 20nm.
- Highest channel centred on 1611nm, giving 18 channels.

Not all channels are usable, due to fibre characteristics.

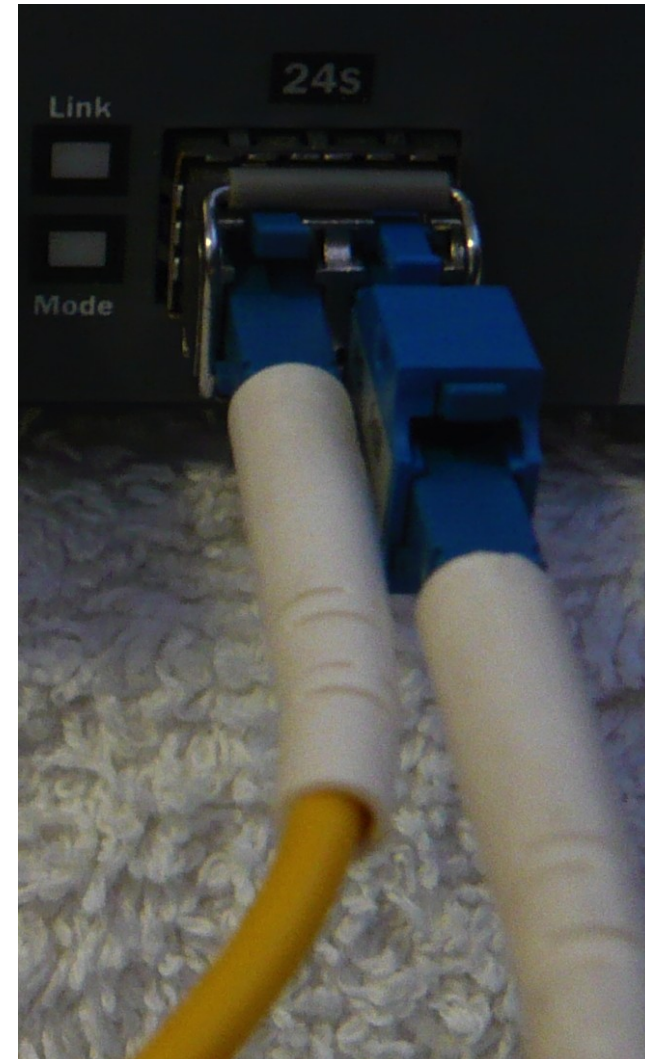
Not all channels can be used by the one system, due to device characteristics.

Only a few channels can be amplified

Power budget

WDM is an analogue system, and can be under- or over-driven

- If under-driven, then amplify, but this typically isn't economic for CWDM
- If over-driven then attenuate.
- Attenuators come in 5dB multiples and work on all wavelengths
- Install attenuation at receiver



Power budget calculation

You want the data sheet for the SFP, the data sheet for the fibre, and the fibre installation test results

From the data sheet for the SFP

- Transmitter
 - Centre wavelength
 - (Minimum, typical, maximum) average launch power
- Receiver
 - (Minimum, centre, maximum) wavelength.
 - Sensitivity at a bit error rate of 10^{-12}
 - Saturation
 - Dispersion penalty, typically over 100Km

Power budget calculation, cond

- From the data sheet for the fibre
 - Nominal loss per Km at centre wavelength (0.35dB/Km)
- From the installation tests
 - Actual loss (typically less than nominal loss, above)
- What is the best case power seen by the receiver?
 - Maximum transmitter launch power – actual loss
- What is the worst case power seen by the receiver?
 - Minimum transmitter launch power – nominal loss
- Is the best case power less than the receiver's saturation?
- Is the worst case power greater than the receiver's sensitivity?

Eye safety

CWDM systems use high power, they can scorch a retina or kill rods.

- No un-capped fibres.
- Assume all fibre ports are live, never point fibres at people.
- Stand in a failsafe place, move after each patch.
- Discourage onlookers.

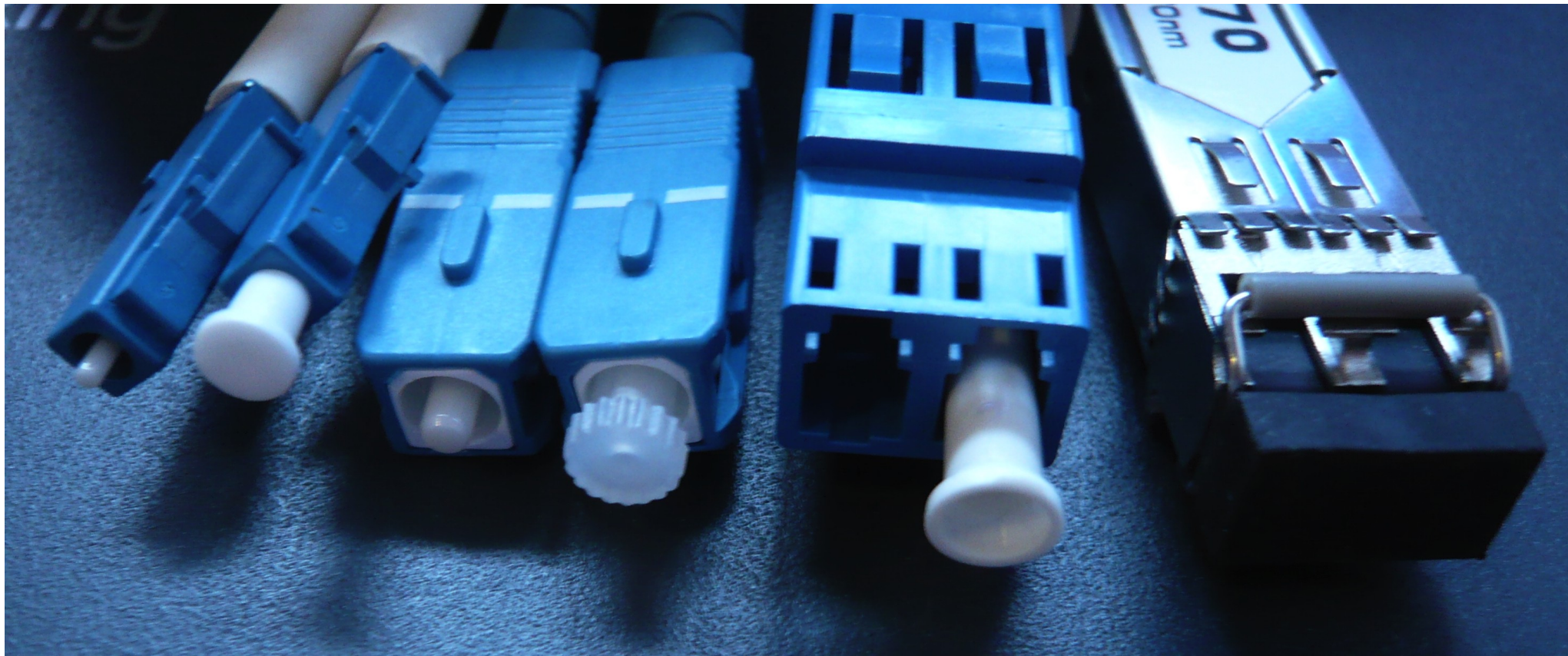


Do not look into laser
with remaining eye

Fibre caps

Remove cap last, restore cap first.

Keep a ziplock bag in each rack for caps.



Installation

A high standard of optical practice is required

- system design
- record keeping
- unit testing
- fibre end inspection and cleaning
- patch lead turn radius

This is quite different to practices with site optical ethernet, where huge headroom in the power budget allows some level of poor practice.

Installation – visual fault indicator

A visible laser (650nm)

- Discovery of cabling error.
- Use during patching to avoid cabling error.
- 1mW laser visible to ~4Km
- A “weapon” (lawful excuse to carry, must be secured, AVOs)

\$100

- Cheap ones are fine.



Installation – light meter

Meter is calibrated for particular wavelengths.

\$450 - \$800, for what you are doing, cheap ones are fine



Installation – light source

Laser with stable frequency and calibrated output.

\$850 - \$2,500

For sources and meters look for

- The wavelengths you want, at least 1310nm, 1550nm
- Battery and plugpack operation
- Large range of connector adapters (SC, LC, FC, ...)
- Australian re-calibration service



Installation – Cletops cleaner

For cleaning fiber optic plugs.

- SC and LC spacings

\$110



Installation – OneClick cleaner

For cleaning fibre optical sockets and ferrules.

- SC (round ferrule) and LC (square ferrule) variants

\$90



Fault finding

Optical systems are analogue systems at heart.

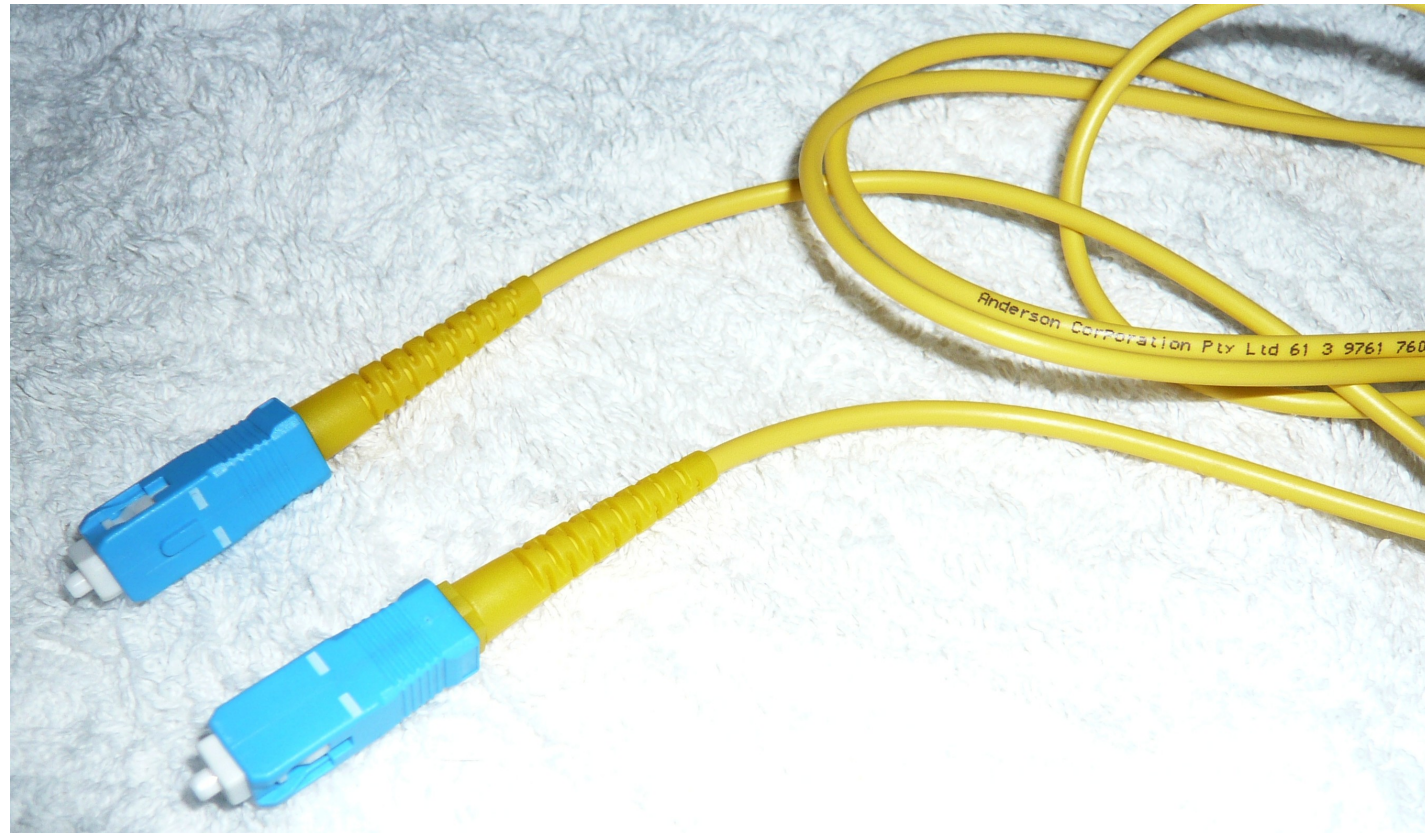
The style of fault-finding is more like electronics than program debugging:

- Attach a meter to a test point.
- Compare that with calculated nominal values and the values recorded during installation.
- Deduce the failure from the observations; or failing that determine which further measurements will discover the hypothesised failures.

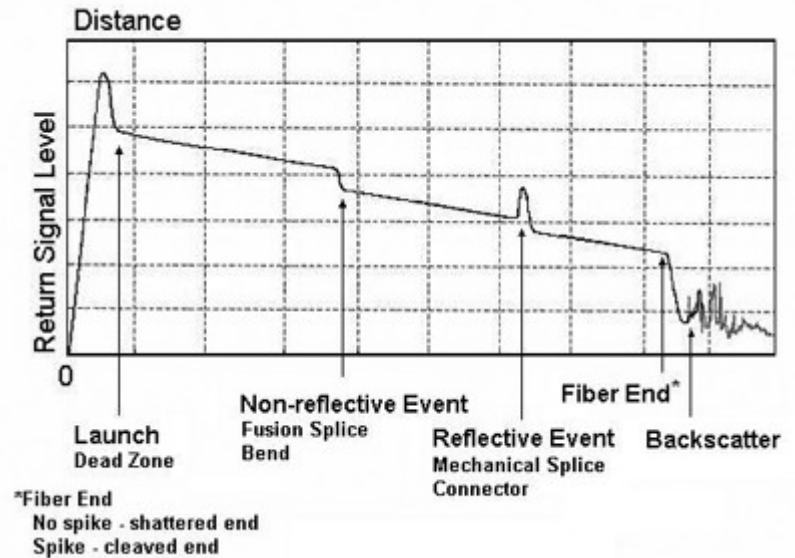
Fault finding – loopback cables

Put on during installation, then you aren't always driving to the far end.

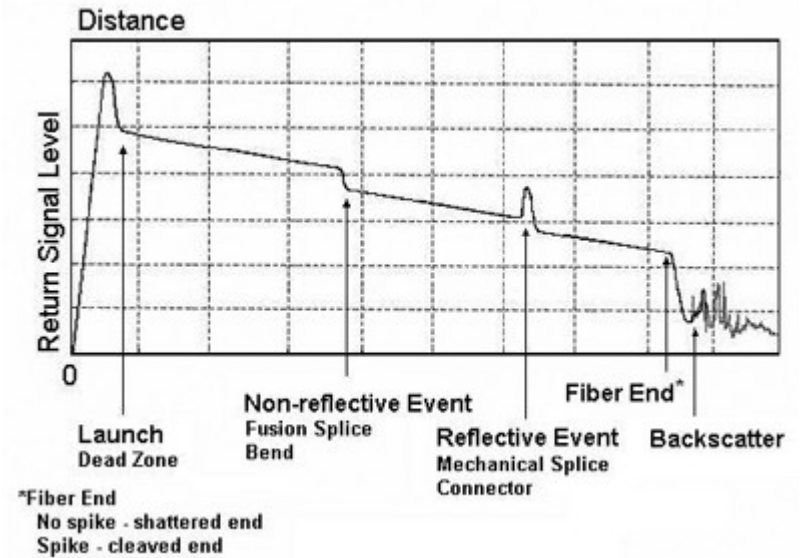
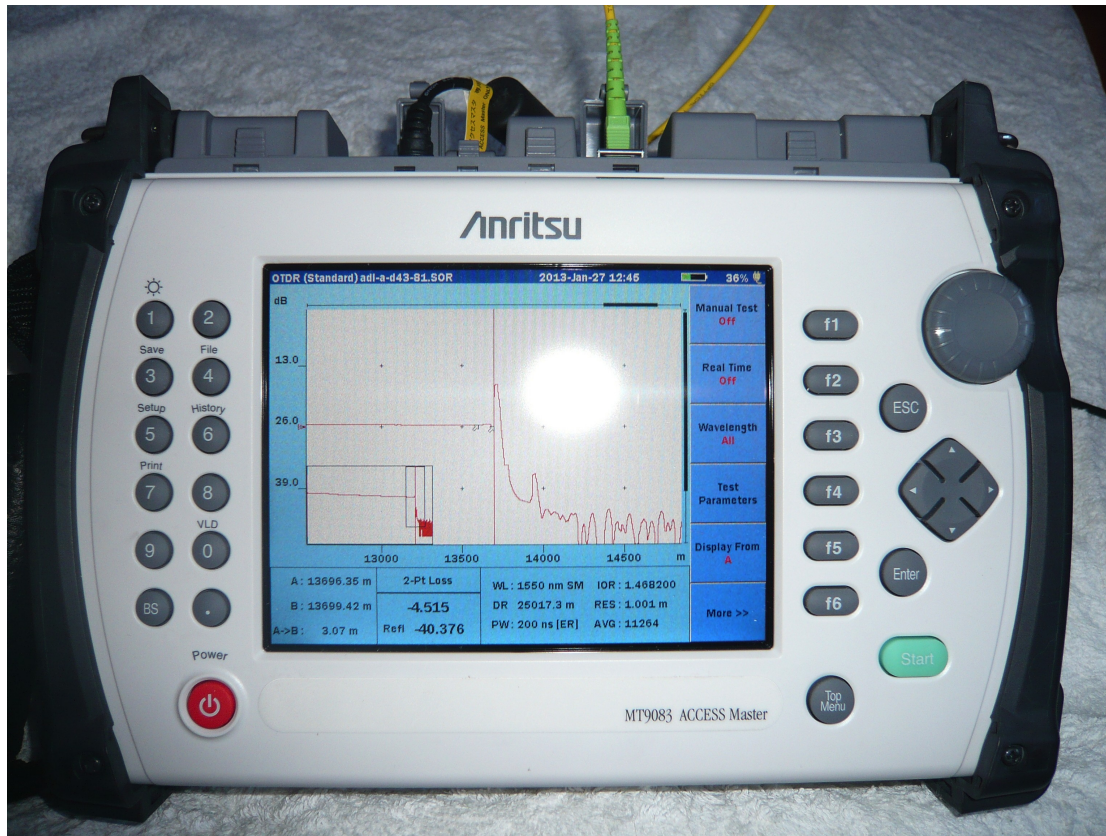
Easy way to exclude transmitters and segments from being faulty.



Fault finding - OTDR



Fault finding - OTDR

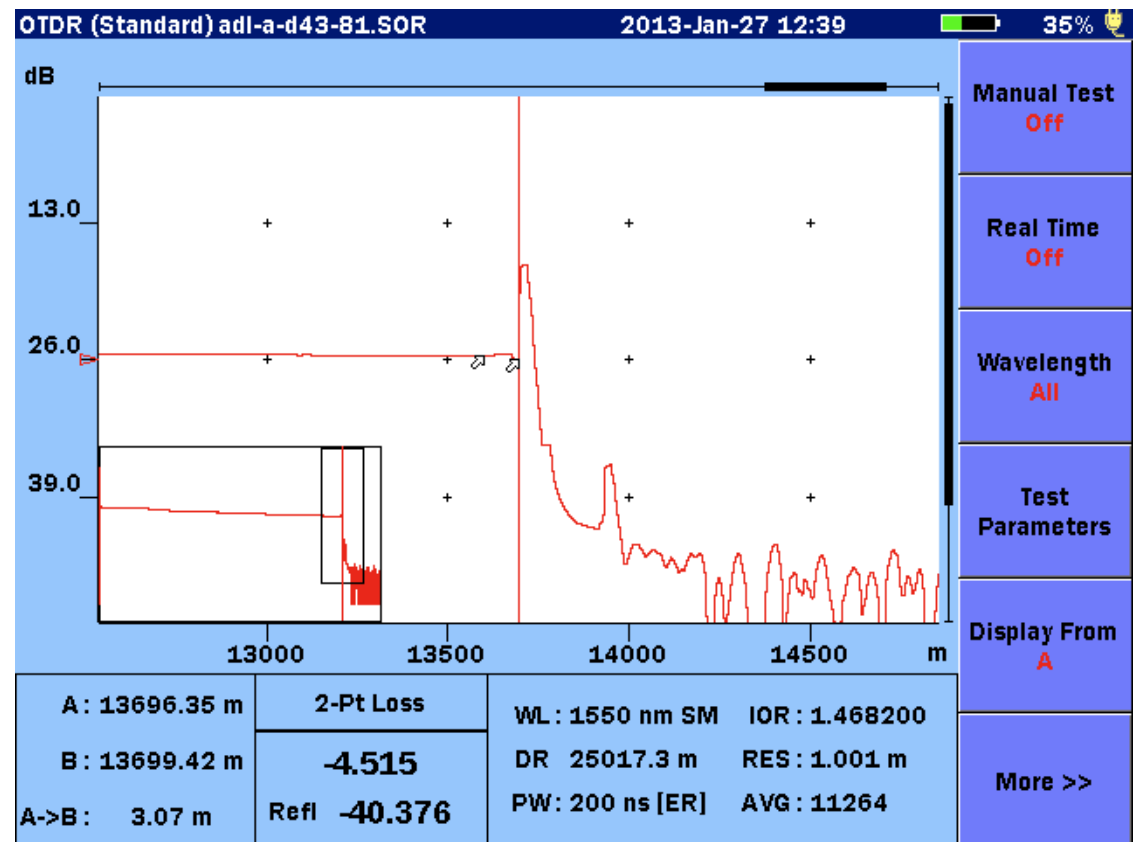


Fault finding - OTDR continued

You should request OTDR results for major fibre builds.

The .SOR file format is a BellCore specification, which is not free.

This is a 12Km fibre ending in a CWDM add-drop mux. You can see the launch cable, splices, and the reflection from the mux.



Fault finding - DOM

SFPs can measure received light

- inaccurate, but good enough to verify power budget
- under the hood uses PHY registers (ref SFF-8472)
 - these are read and set using a I2C bus
 - `ethtool -D eth0`
- can plot using SNMP and thus be alerted to changes

So what are the downsides?

Requires dark fibre.

Operational visibility = 0.

Knowledge required is well removed from knowledge of packet networks.

Topology is insufficient

- point-to-point links are not as useful as multipoint switched networks
- In many ways the movement is to connecting hosts to a set of multipoint networks.

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but you can use it like one

eg: to share a link between sites

