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COURSE

Optical Fibre networks 2/4
Multiplexing, coupling, amplifying

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Optical Fibre Networks : Course general objective

GET A PANORAMA OF OPTICAL FIBRE AND NETWORKS

Optical Fibre characteristics and advantages
Technologies around Optical Fibre
Other components of optical fibre networks

UNDERSTAND HOW TO DESIGN HIGH RATES OPTICAL FIBRE NETWORKS

Existing architecture of Optical Fibre networks (FTTH, FTTA, FTTO…)
Designing a network
Deployment constraints

UNDERSTAND HIGH-RATE NETWORKS TRENDS TO FUTURE

Optical Fibre Networks : Course 2/4 programme

1. COUPLING ON OPTICAL FIBRE

Use cases : typically collecting FTTH
Principle and Technical solutions

2. SPLITTING ON OPTICAL FIBRE

Use cases : typically securing signal
Principle and Technical solutions

4. OTHER PASSIVE OPERATIONS

Modulator
Attenuation
Filtering
Polarisation splitting
Isolation

4. AMPLIFYING SIGNAL

Use cases : typically long haul transmission
Principle
Technical solutions and constraints

5. MULTIPLEXING (WDM)

Use cases : typically optimizing fibre
Principle
Various types of WDM, technologies
Technical solutions and constraints

Passive and active components

TWO TYPES OF COMPONENTS ON OPTICAL FIBRE NETWORKS

ACTIVE COMPONENTS

Equipment embedding a component that emit light (including laser or LED)

Typically
- Amplifiers
- Routers

Active components always require to be powered

PASSIVE COMPONENTS

Equipment that interfere with the light going through them (propagation, polarisation…)

Typically
- Splitters
- Couplers

Passive component do not mandatorily require power supply; however this could be necessary if there is a need for
- monitoring
- configuration

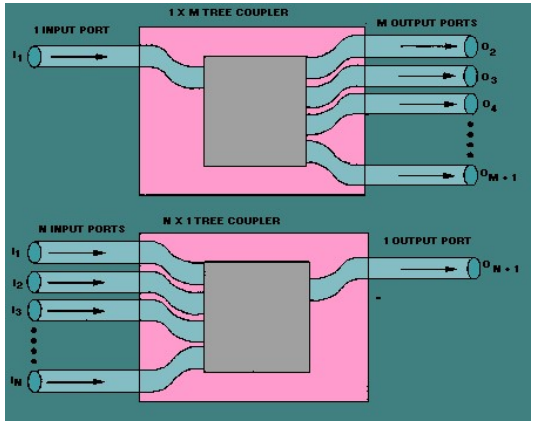
Coupling signals on optical fibre

Optical fibre couplers : principles

COUPLER TERMINOLOGY CAN BE USED TO DEFINE TWO SIMILAR TECHNICAL SOLUTIONS

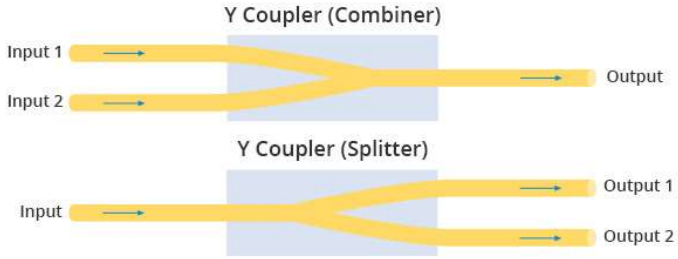
Multiplication of the input/output fibres with the same signal

- Allows to emit a single signal from one place to multiple other places
- In some cases multiple signals coming from multiple fibres to one only point



Optimizing the fibre capacity by using the free space

- Several signals can physically share the fibre capacity
- Principle is here to combine two inputs in a single fibre



The opposite operation is called splitting. Splitter is used for securing signals, it will be defined afterwards in this course

Optical fibre couplers : use cases

OPTIMIZING RESOURCE

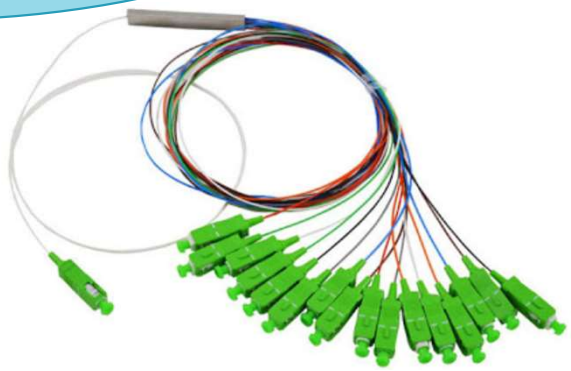
Several users can share the same resource that they do not need fully
Typical for FTTH infrastructures

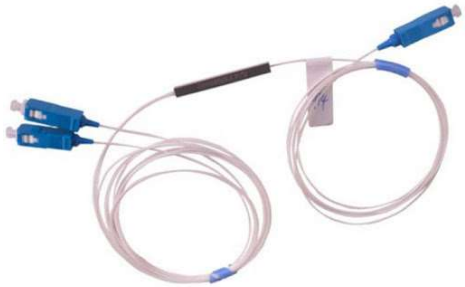
BROADCASTING SIGNAL

For systems requiring the same information to be share in multiple equipments (datacenters for instance)

SECURING SIGNAL

Making it circulating by multiple ways
Preventing risk of broken cable
Doubles the required resource





DRAWBACKS

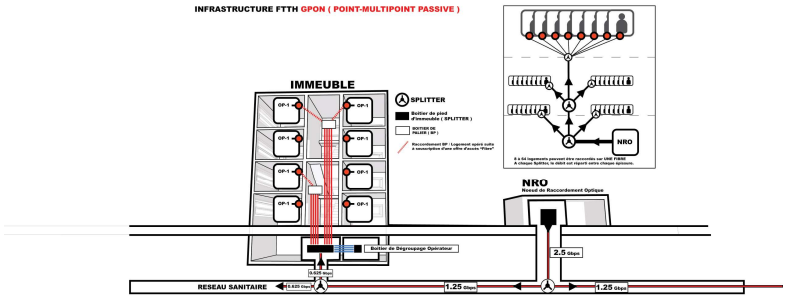
Sharing resource (limiting for the single user)
Loss of energy while splitting signal
Attenuation by equipments / connectors

Coupling optical fibre

THE PRINCIPLES

Sharing the input power between multiple inputs

- Power splitting
- Depending on the used technology, the balance of the power can be adjusted



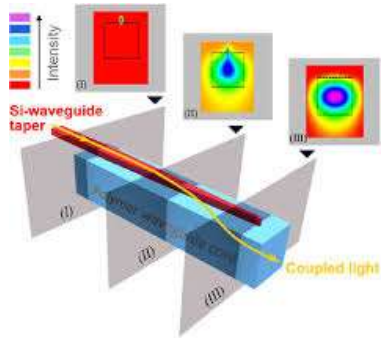
TECHNICAL CONSTRAINTS

The quality of coupling is related to

- Distance between waveguides
- Length of coupling portion
- Quality of the fibre and connection

THE TECHNICAL IMPLEMENTATIONS

Transfer by proximity of the waveguides



Transfer by fusion

- Robust solution
- No component addition
- Require expertise
- Adapted for limited number of coupled fibres

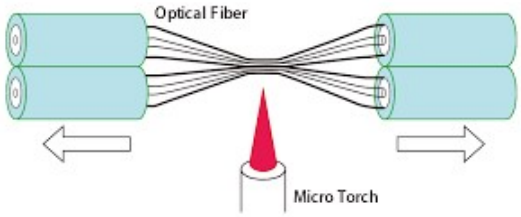


Figure 1 - Fusion Technology

Transfer in dedicated connectors (limit of the loss)

Optical couplers : equipment

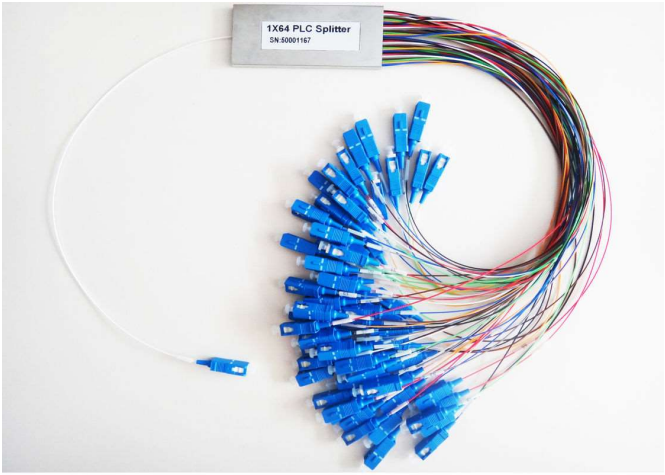
THIS CAN BE THE STORY OF CONNECTORS

See the picture on the side
For coupling a limited number of fibres, usually

With a warning : connectors are adding
attenuation to the signal

TYPICAL USE : FTTH NETWORKS

On a GPON architecture, up to 128 users' trafic
can be coupled on a single fibre
Coupling can be made in several steps in the distribution network

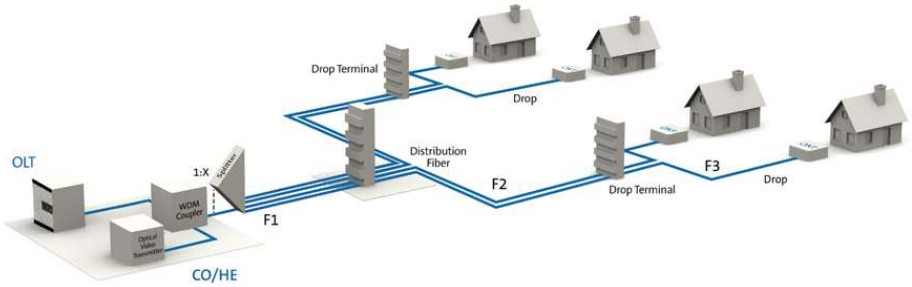


1 Central Office
- Centrix Platform
- Eclipse Hardware

2 Local Convergence Point
- SCF Closure
- Optical Cross-Connect

3 Network Access Point
- MultiPort Terminal
- MultiPort Flex Terminal
- FlexNAP Distribution System
- SCA Terminal

4 ONT
- OptiTap Drop Cable Assembly
- OptiSnap Connector

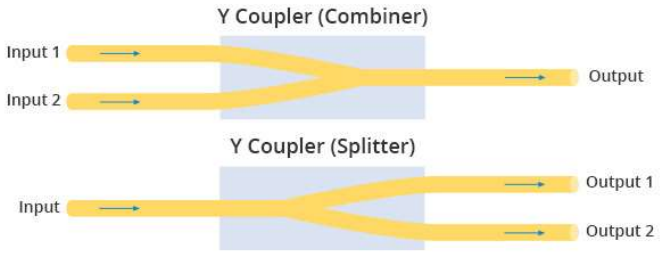


Splitting signal on optical fibre

Optical fibre splitters : use cases

BROADCASTING SIGNAL

Such functionality can be used for instance in datacenters where multiple equipment a redundant to ensure security and shall get the exact same information to duplicate it



MONITORING ACTIVITY

Extracting part of the signal (low) to follow-up what is happening on the fibre

SECURING SIGNAL BY MAKING IT CIRCULATING BY MULTIPLE WAYS

Typically used for FTTA networks based on loops

An equipment is connected by to ways to the same collection centre (or alternatively by different ways to different collection points). In case one way is damaged, the other is used.

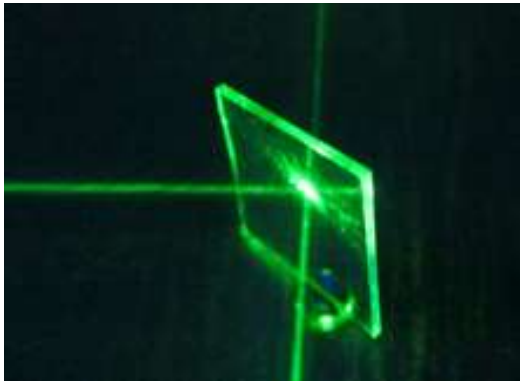
In the case of one collection point with two identical inputs, a physical switch is used

Optical fibre splitters : principles

BASIC PRINCIPLE

Use of a material prism/mirror

- Part of the light goes straight
- Part of the light is reflected



CONSTRAINTS

The output signals also split energy with an unbalanced ratio (could be as much as 70/30)

An existing loss of energy in the operation for passive splitters

- Either the loss of energy is acceptable for the transmission
- Either it is not, in such cases, amplification shall be combined

Other passive functions on optical fibre

Modulator

PRINCIPLE

Modulating the light signal in the fibre
Aiming at generating pulses for coding information

Modulation can be either done

- By modulating the signal prior the laser diod (out of the scope here)
- By modulating light after the laser diod (external modulation)

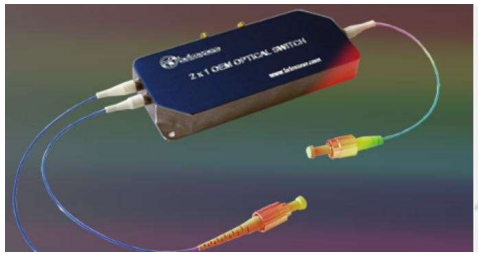
External modulation is done by

- interfering with the light (some acoustic systems)
- playing on the refraction on the fibre

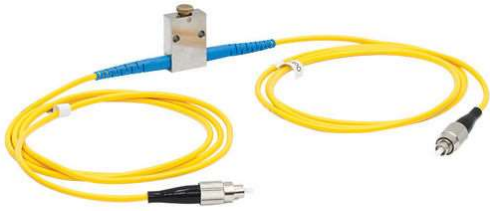
CONSTRAINTS

Loss of insertion with several dB

Some of the modulator still require energy to contain the loss of power to its minimum



Attenuation



PRINCIPLE

Reducing signal intensity on the fibre
Objective is to prevent glare on reception (for short range)
Could also compensate drift being the result of used components

Attenuation can be made

- On a fixed value (typically the connector shown aside)
- With a variable value (usually an active component in that case)
  Variable Optical Attenuator

TECHNOLOGY

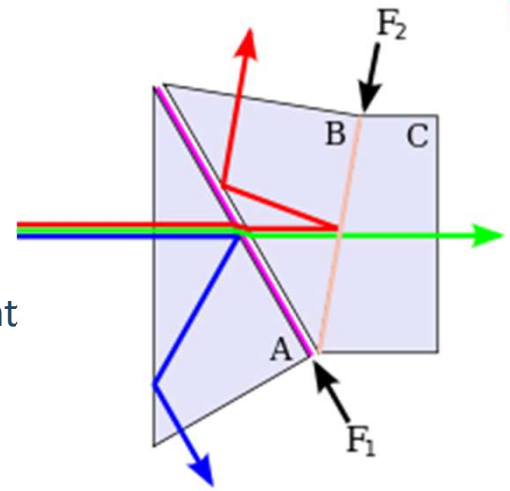
Thermo optic
Material filtering / Liquid cristal

Filtering

PRINCIPLE

Filtering incident signal
Prevent “noise” created by distance, unwanted coupling or active component combined with these reasons
Focus the light signal

Also used for passive WDM solutions to extract a wavelength



TECHNOLOGY

Bragg net
Chromatic filtering
Polar filtering by use of a set of cristals/prism

Polarisation splitting

PRINCIPLE

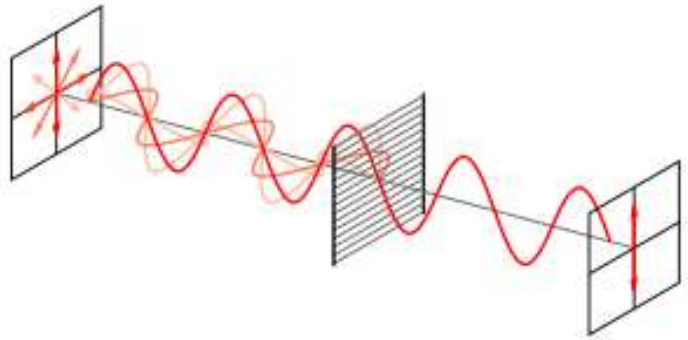
A specific type of filter used for separating signals with different polarisation or to compensate the polarisation drift

TECHNOLOGY

Based on cube prisms

Use of calcit properties

The main point is to get parallel propagation direction after the application of the polarisation filter

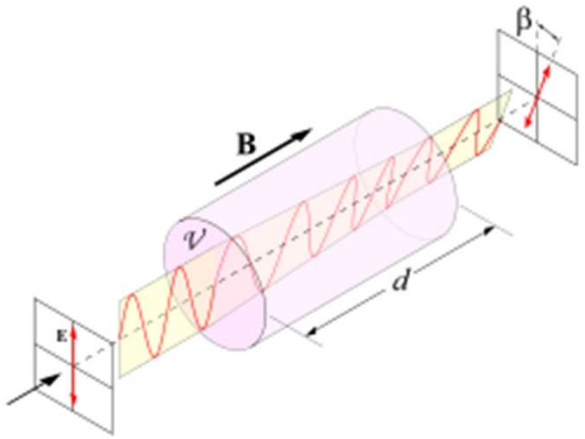


Optical isolator

PRINCIPLE

A specific type of filter used for allowing only one propagation direction in the fibre

The main aim is to eliminate parasite reflexions of the signal within the optical fibre



TECHNOLOGY

Usually based on a Faraday rotator that

- polarize the signal
- optical fibre properties that looses orthogonal propagation
- strongly attenuate the parasite propagations

The Faraday rotator is based on cristal. Each cristal has a Verdet constant that characterize an absorption to a certain wavelength
Typically for telecom optical fibre: *Yttrium Iron Garnet*

$Y_3Fe_2(FeO_4)_3$

Optical circulator

PRINCIPLE

A component that allows to have several light signal in a single fibre, typically to separate opposite sides propagation
A solution for bidirectional communication

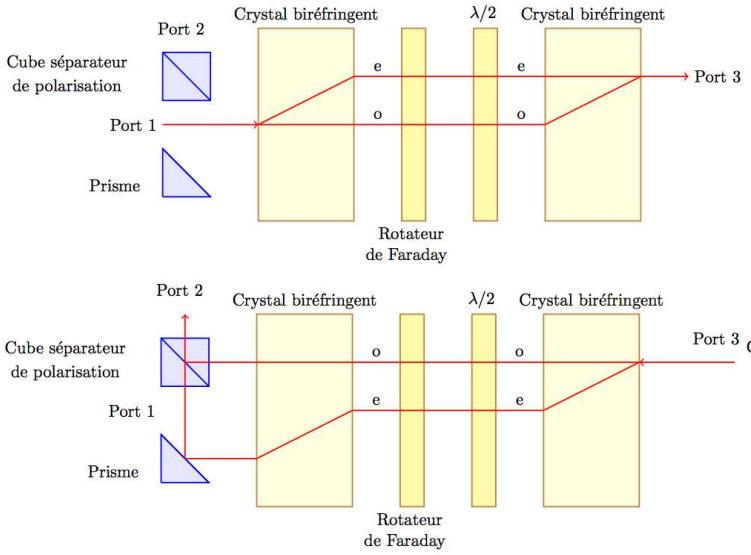
TECHNOLOGY

A 3-port approach using

- A Faraday rotator for the signal polarization
- Cristal, used as prisms/mirror

To reduce interferences in this operation, orthogonal polarization is used commonly in this circulator

The Faraday rotator is based on cristal. Each cristal has a Verdet constant that characterize an absorption to a certain wavelength
Typically for telecom optical fibre: *Yttrium Iron Garnet*



Amplifying signal on optical fibre

Amplifier and regenerator

ONE OBJECTIVE

Long distance communication implies attenuation and has limits
Signal has to be maintained in order to connect distant points (over oceans for instance)

TWO PRINCIPLES

Amplifier

- Signal amplification

Regenerator

- Signal amplification
- Reshape the signal to prevent distorsions
- Synchronize the signal

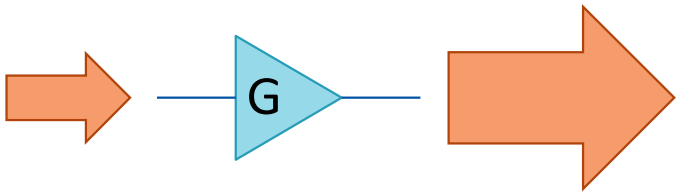
Both components are active as requiring to boost signal energy as a minimum
The regenerator is a component that is completely adapted to the rate and protocol as getting as deep as reshaping/synchronizing it. It works as a receiver/emitter

Optical amplifier characteristics

PRINCIPLE

Amplification without conversion (i.e. no work on the content itself). It is usually stimulated by a gain medium and doping ions in this structure.

In some cases additional light is generated to dope the signal. In those cases some parameters can apply to focus amplification



TECHNICAL SOLUTIONS

Various solutions applicable to optical fibre:

- EDFA
- Semi-conductor optical amplifier
- Raman amplifier
- Optical parametric amplifier

Semi conductor amplification (SOA)

PRINCIPLE AND CHARACTERISTICS

The gain medium is embedded in a semiconductor
The pump is powered by electricity

Semiconductor characteristics

- Anti-reflection coating with a result of less than 0,001%
- Usual semiconductors can operate in the band of 850 and 1600 nm
- Gains can be up to 30dB

PROS AND CONS OF THE TECHNOLOGY

Much less expensive than other technical solutions
Higher noise
Lower gain
Risk of non-linearity on the signal

Raman amplifier

PRINCIPLE AND CHARACTERISTICS

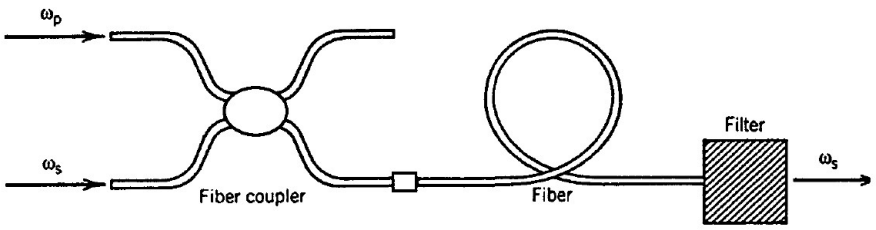
The basic principle is to create the amplification by a non-linear interaction with the fibre (used as the gain medium) and multiplexing:

- the signal
- a pump laser

The coupling can be directional, contra-directional or in some cases a combination of the two.
This also implies filters to compensate the coupling effects on the line

PROS AND CONS OF THE TECHNOLOGY

Higher power requirement compared to EDFA
Can be adjusted in terms of wavelength to the exact need
Amplification is reasonably flat over the wavelength
(note that this could be a serious drawback as this implies amplifying noise as well)



Schematic of a fiber-based Raman amplifier.

EDFA amplification

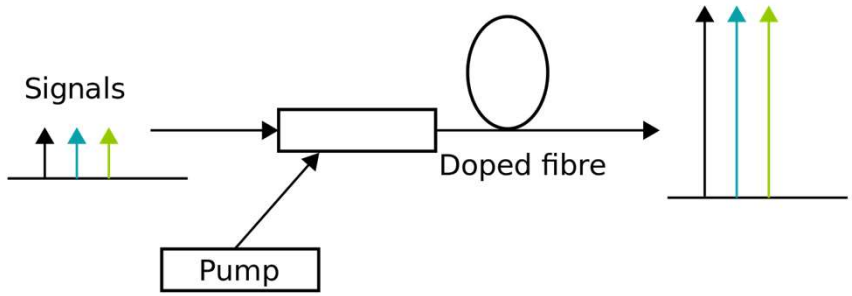
DFA PRINCIPLE

The principle is to force the signal through a doped fibre
The medium is powered by a pump that excites ions in the section of the doped fibre.
The interaction between those ions and the signal creates the amplification

CHARACTERISTICS

Amplification window

- Range of wavelengths
- Spectroscopic properties of the dopant ions
- Structure of the glass matrix of the doped fibre



EDWA (*ERBIUM-DOPED WAVEGUIDE AMPLIFIER)*

DFA amplifier including a waveguide to boost
Erbium ions are used in the doped fibre (corresponds to the used wavelength between 980 and 1480 nm)

Multiplexing on optical fibre

Multiplexing problematic

OPTIMIZATION OF THE RESSOURCE

Fibre optic capacity is huge
The limitation is still on the emitting/receiving equipments

REALITY IS

The total demand in terms of capacity is currently doubling every year
Multiplicity of emitters and receivers
The expected capacity of each transmission is reasonnably significant

- FTTH sold capacity is about 1-2 Gbps per user, maximum rate
- 5G radio site target maximum rate is about 10-25 Gbps

The largest customers are point to point

THE EQUATION IS:

Deploying future proof infrastructures (not adding cables on regular basis)
Not making bicycles running on motorways, reducing capacity

Multiplexing technical solutions

FREQUENCY DIVISION (WAVELENGTH)

The frequency band is split into sub-bands, allocated each to a user
The challenge is to make the best compromise between

- the correct size for the sub-band (vs rate)
- the space between bands to master interferences

TIME DIVISION

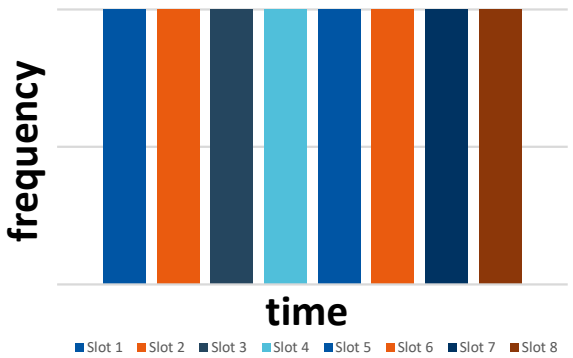
Time slots are allocated to each users
Allows to combine multiple low rate messages into a high rate signal
The limit is the compromise between available rate and real time combination

CODE DIVISION

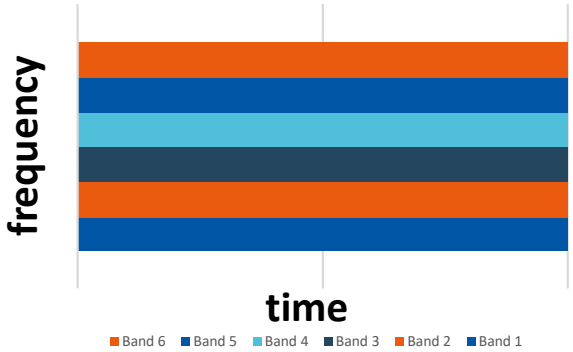
The principle is to share the whole bandwith and to identify the users by a code signature
Used a lot in the radiofrequency systems, some trials in the optical world

COMBINATION OF SOLUTIONS

FDM/WDM



TDM

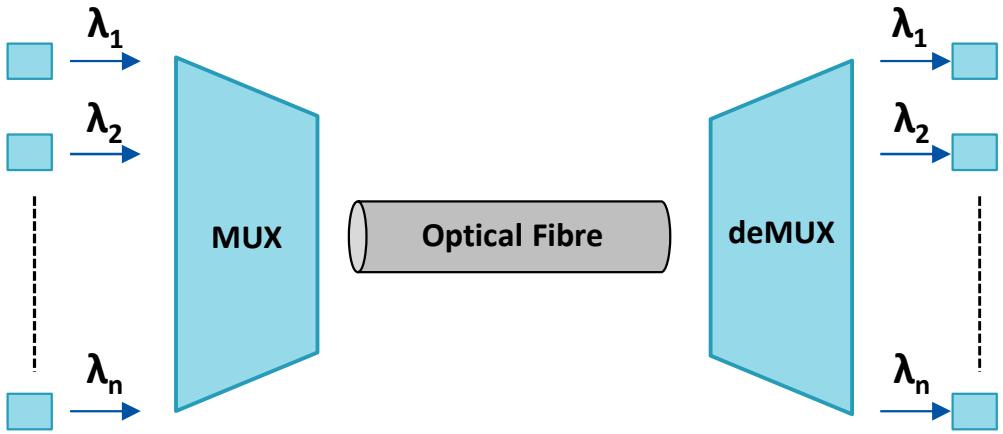


Multiplexing light principle

WAVELENGTH DIVISION MULTIPLEXING (WDM)

The optical fibre bandwidth it split into n carrier bands
Each band allows communication for a modulated signal
Some constraints:
- Space between bands to avoid interferences
- Total bandwidth (limitations of equipments)

Note that this is similar to FDD, however, in WDM case, the delta between band is large compared to the wavelength (here approximately 1nm)



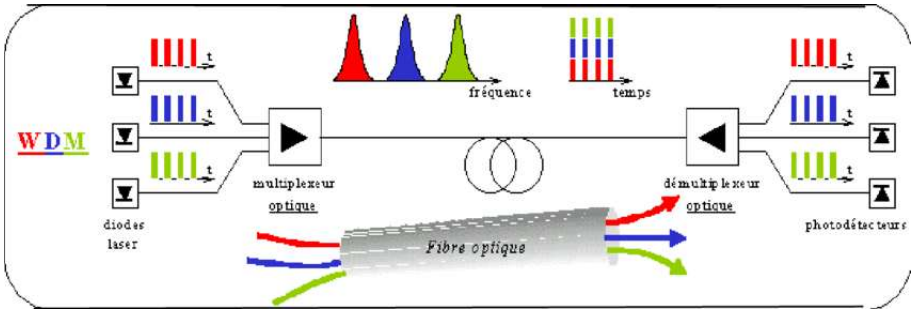
FURTHER MULTIPLEXING

In addition to WDM, Time Division Multiplex can apply to each of the emitter/receivers

Wavelength and multiplexing

MULTIPLEXING SOURCES

The system used at that time allows up to 64 bands on a fibre which allows typically up to 640 Gbps (with the assumption of the typical 10Gbps channels… to be enhanced)



TECHNICAL REQUIREMENT

Need for transceivers to adjust the signal to
Allocation of carrier wave

WDM technologies : DWDM

DENSE WAVELENGTH DIVISION MULTIPLEXING

Principle is that technology is called dense as soon as the space between bands is lower than approximately 1nm

Up to 160 wavelength on the same fibre
Space between wavelength is typically:

- either 0,2nm (corresponds to 25GHz), i.e. 160 bands
- or 0,4nm (corresponds to 50GHz), i.e. 80 bands

Implies electronics to regulate laser temperature

TYPICAL USE

A costly technology compared to other WDM implementations
Preferably used for long haul connections (typically submarine cables)
Dedicated to point to point connections

A VARIATION OF DWDM : U-DWDM (ULTRA DENSE)

Bands space at 0,08nm, up to 400 channels available

WDM technologies : CWDM

COARSE WAVELENGTH DIVISION MULTIPLEXING

Wavelength are spaced by a guard of 20nm

Allows up to 18 channels on the same fibre

TYPICAL USE

Cheaper than DWDM but optimizing less the resource
Used a lot for terrestrial communication

- Local
- Metropolitan

Applicable to

A VARIATION OF DWDM : WWDM (WIDE)

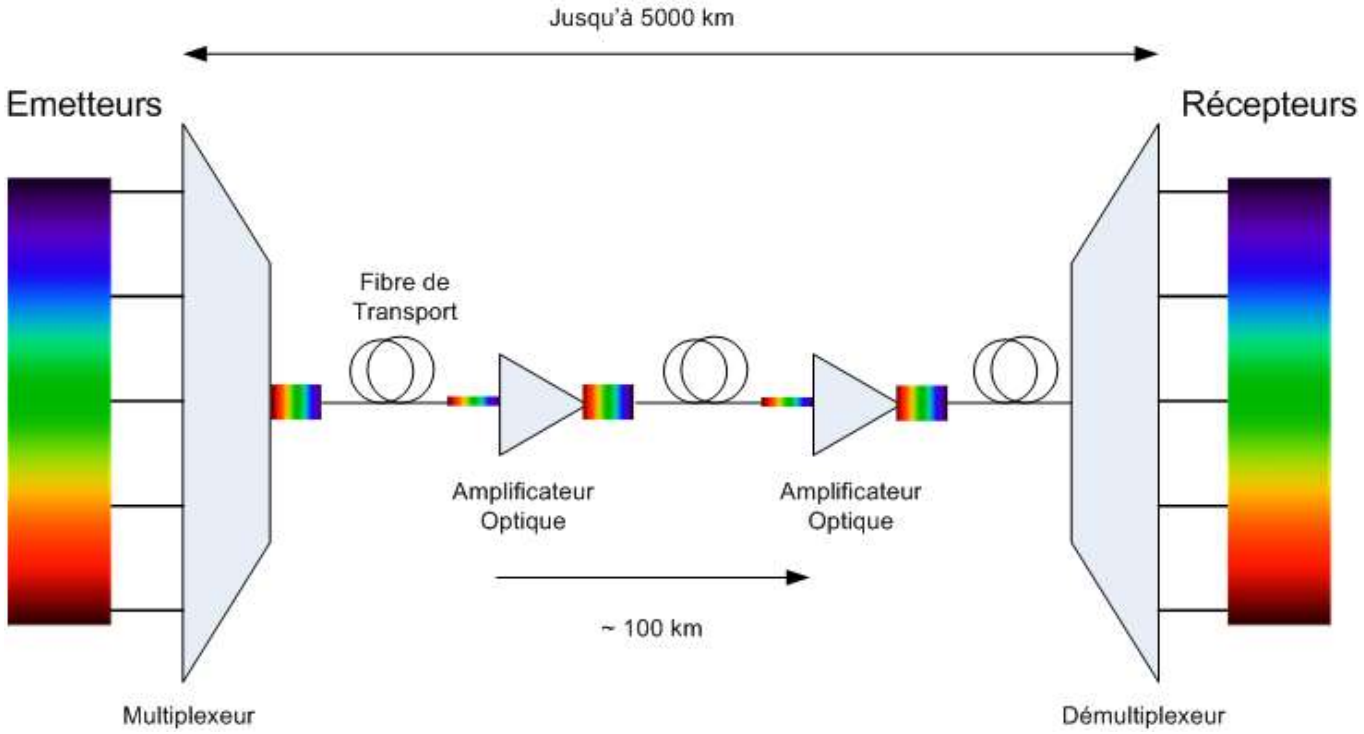
Only 4 channels are allowed

WDM Fibre optic networks topology

COARSE WAVELENGTH DIVISION MULTIPLEXING

Wavelength are spaced by a guard of 20nm

Allows up to 18 channels on the same fibre




on est fait pour
être ensemble
bouygues
TELECOM
COURSE