30/09/2024

COURSE

Optical Fibre networks 1/4
Optical Fibre : characteristics

PAUL JOLIVET

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 organisation

PROGRAMME

Course : 4 sessions (3h each) on Sept 30, Oct 7 and Dec 2 & 16
Project : 2 sessions with support on Oct 14 & Nov 18
Project Defence : Jan 13
Exam (no information on the schedule)

TWO TYPE OF SESSION WITH ME

Course
Application on a project
- A teamwork with contributions from all members
- Practical use of the knowledge share in the courses
- Search work on the internet
- Support from teacher
- Defence in English with slideshow and share of the speech between team members

Optical Fibre Networks : Course 1/4 programme

1. OPTICAL FIBRE PHYSICS AND PRINCIPLES
The medium
Principle of communication using light
Types of fiber optics

2. OPTICAL FIBRE CABLES
Cable types, evolution, active systems
Cables with tubes, ribbons

3. OPTICAL FIBRE ACCESSORIES
Connectors and splicing optical fibre
Jumpers between equipments
Connecting with optical fibre

4. INSTALLING OPTICAL FIBRE
Urban zones, other
Street cabinets, manholes and ducts
Aerial installation
Inter-continental cables, submarine

A bit of history

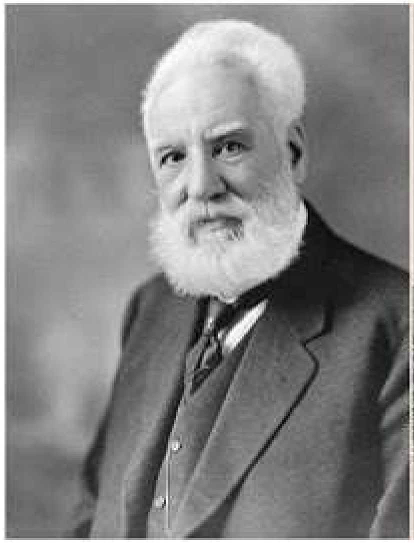
End of 19th century

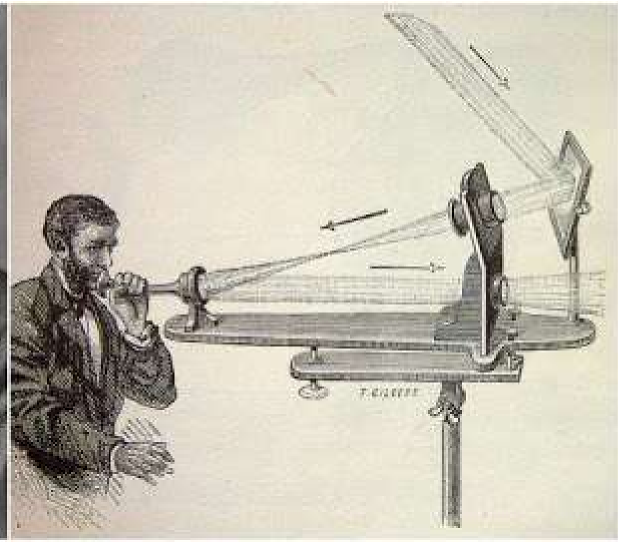
- Using mirrors to direct light
- Conducting light in a water jet

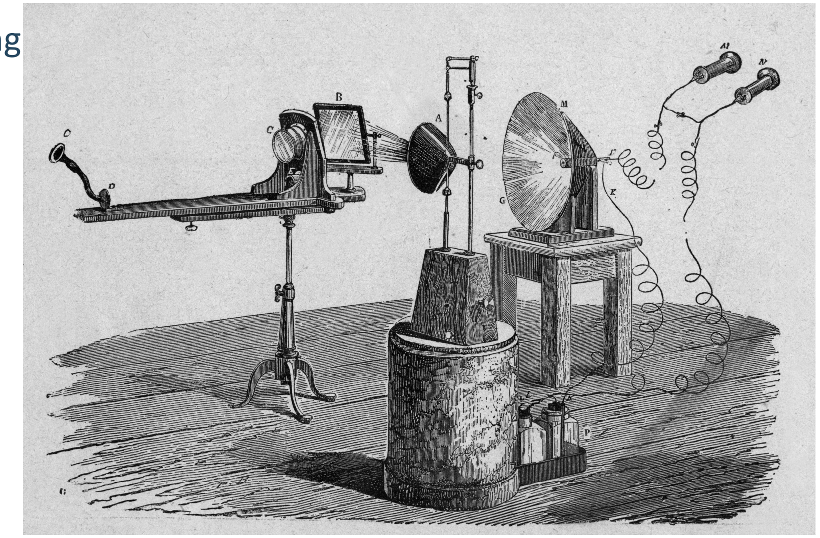
Optical fibre created in the second half of 20th century

- 1961 Elias Snitzer and the theory for single mode fiber
- 1973 Bell Laboratories created the first fibre
- 1975 first telecommunication network on fibre optics
- 1980 Sprint uses the first full fibre optic network
- 1991 Desurvire et Payne demonstrate optic amplification, opening the field to long haul communication and internet

Source







Optical Fibre
A bit of physics
Medium characteristics

COURSE

Optical Fibre, basic principles

LIGHT TRANSMISSION

Transmission components

- Coding the message into electric input
- Transcoding the electric input into light signal

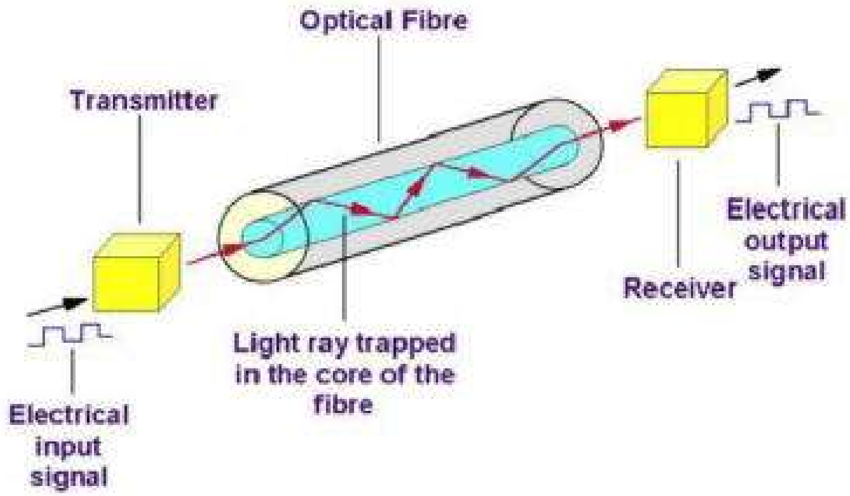
… and the reverse operation

PRINCIPLE OF A WAVE GUIDE

Fibres are behaving like a guide for the signal

Optical physics applies, including

- Reflections
- Refraction
- Attenuation due to the material

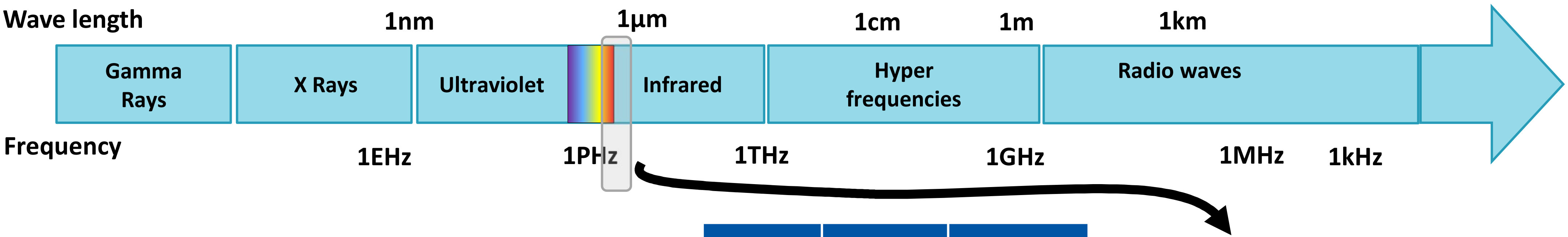


OPTICAL FIBRE AND LASER ARE COMBINED AND OPTIMISE SIGNAL TRANSMISSION

Electromagnetism and transmission

ELECTROMAGNETIC SPECTRUM

Large use of the electromagnetic spectrum for technology



USED SPECTRUM FOR FIBER OPTIC

Using wavelength close to infrared
… above visible light

Wavelength @ 0,85µm + 6 bands
(see table)

Color	From…	…to
Red	0,62 -	0,70 µm
Orange	0,59 -	0,62 µm
Yellow	0,57 -	0,59 µm
Green	0,50 -	0,57 µm
Blue	0,44 -	0,50 µm
Violet	0,40 -	0,44 µm

	From…	…to
O	1,26 -	1,36 µm
E	1,36 -	1,46 µm
S	1,46 -	1,53 µm
C	1,53 -	1,565 µm
L	1,565 -	1,625 µm
U	1,625 -	1,675 µm

Typically used wavelength

RANGE OF WAVELENGTH FOR OPTICAL FIBRE

From 800nm to 1600nm (visible spectrum is from 400 to 700 nm)

Commonly used wavelength is

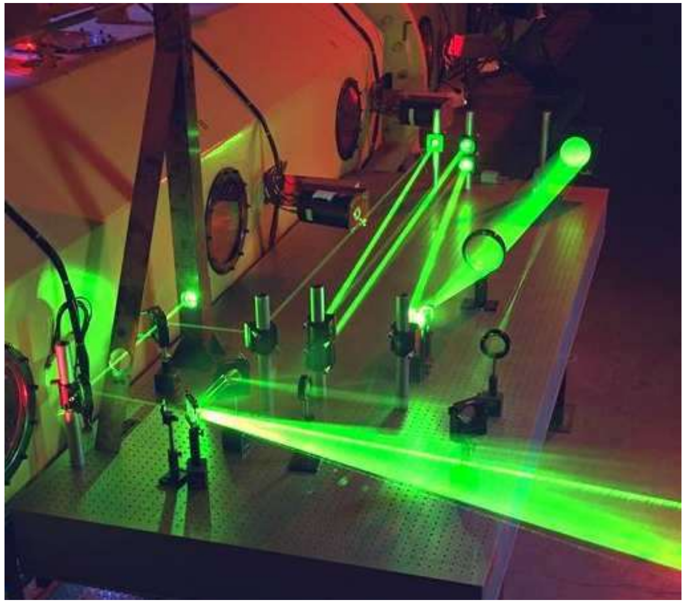
- 850 nm and 1300 nm for multi-mode fibres
- 1310 nm
- 1550 nm

Highly depends on the fibre index in one hand and the availability of laser on the other hand
These wavelength are optimising transmission properties of the fibre

LASER technology

WHAT IS LASER?

Light
Amplification by
Stimulated
Emission of
Radiation

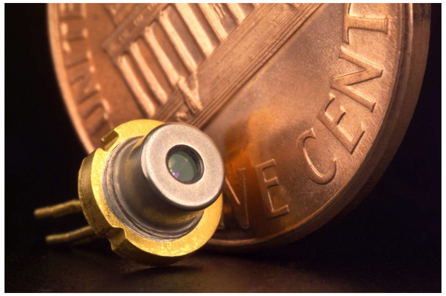


PRINCIPLE AND ADVANTAGE

Coherent light
- Constant wavelength

Spatial coherence that can be focused
- Cutting application
- Focused energy for long distance emission

- Temporal coherence
- Very narrow spectrum (single light color)
- Possibility to emit ultrashort pulses



Using light for transmission : celerity

$$\boxed{v = \frac{c_i}{\lambda_i}}$$

WAVE PHYSICS… BASICS ABOUT CELERITY

Wave characteristics in the fiber defined by its

- λ_i Wave length (m)
- v Frequency (Hz)
- c_i celerity (m/s)
- $c_0 = 299\ 792\ 458\ m/s$

MEDIUM CHARACTERISTICS

« i » defines the medium
Depending on its characteristics,
celerity and wavelength vary

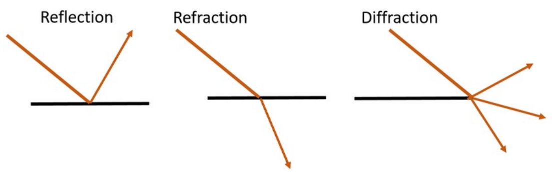
SMALL APPLICATION

c_0~$300\ 000\ km/s$

$\lambda_{laser\ telecom} = 1{,}5\mu\text{m}$

Propagation between Paris and New-York (~5000 km)

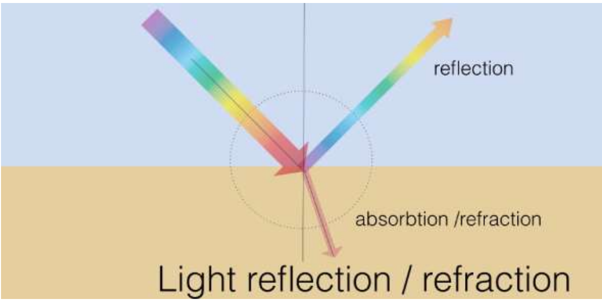
Using light for transmission : refraction



<u>Refraction</u>
Variation of direction of a wave propagating from one particular medium to another

<u>Reflection</u>
Brutal change of direction of a wave striking a surface

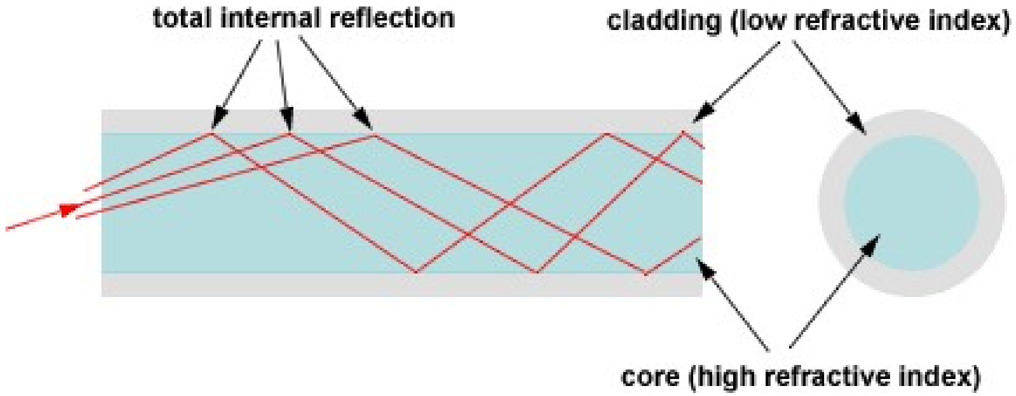
<u>Absorption</u>
Transfer of energy while a wave propagated through a medium



WHEN DO THESE PHENOMENON APPLY WITH OPTICAL FIBRE ?

Refraction
- light entering in a fibre
- Light moving from one fibre to another through a connector

Reflection
- light reaching the border of the fibre while propagating
- light striking mirror in splitter equipments



Using light for transmission : refraction

$$n_i = \frac{c_0}{c_i}$$

WAVE PHYSICS… BASICS ABOUT REFRACTION

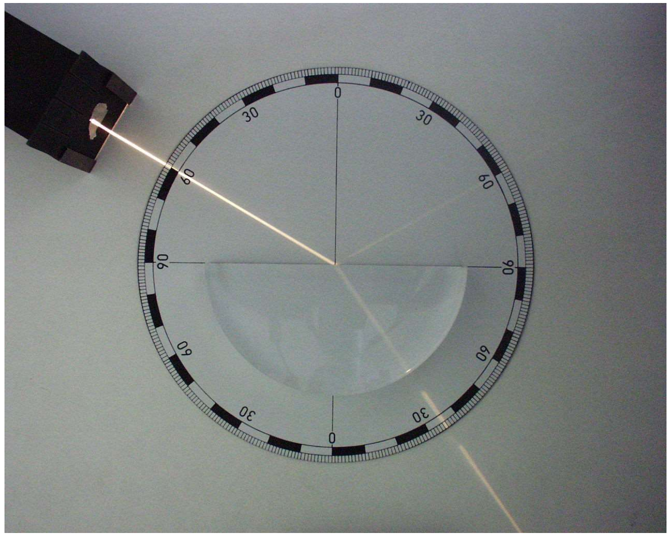
Refraction is the ratio between propagation in vacuum conditions and in a specific medium

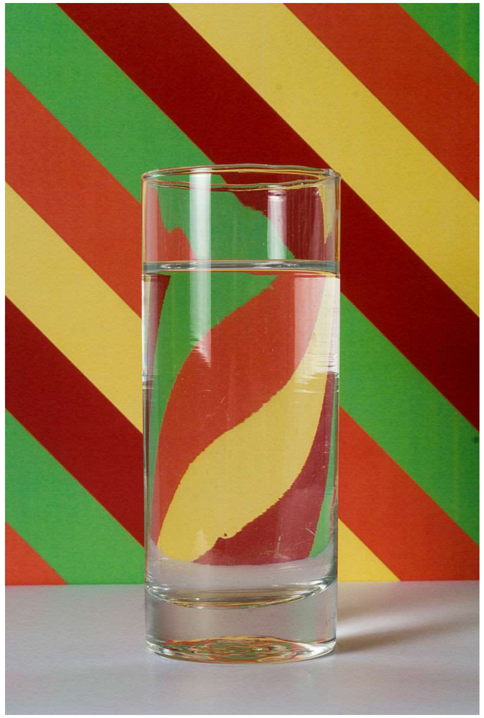
- n_i refraction value
  by definition refraction in vaccum or in the air is $n_0 = 1$
- c_i celerity (m/s)

SMALL APPLICATION

$c_{water} \approx 2{,}25\ 10^8\ m/s$

$n_{silicium} \approx 1{,}457$





Fibre characteristics

ATTENUATION

Related to how the signal is getting weaker

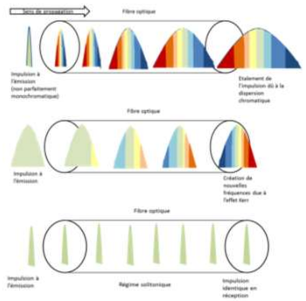
Linear attenuation corresponds to reduction of signal power based on distance
Related to the wavelength (due to Rayleigh diffusion on the shorter waves)

Attenuation can be compensate by amplification systems

CHROMATIC DISPERSION

Related to signal spreading : signal is getting larger as signal propagation celerity depends on wavelength

This effect can be compensated by fibre with index profile



CELERITY

Approximately the same than for copper, i.e. 75% of light celerity
Can be even more in laboratories
Repeaters on long haul fibres are reducing average speed of the signal

Paris – Noumea
20 000 km
theory 90 ms
in practise 280 ms

TRANSMISSION RATE

The highest rate communication was made by NEC @ 1Pbps (1M Gbps)

1 Pbps

Creating optical fibre

MATERIAL

Silicium (SiO_2) is the most used material for optical fibre
Other raw material can be used depending on expected wavelength (longer in IR)

- fluorozirconate, fluoroaluminate, and chalcogenide glasses
- crystalline materials like sapphire

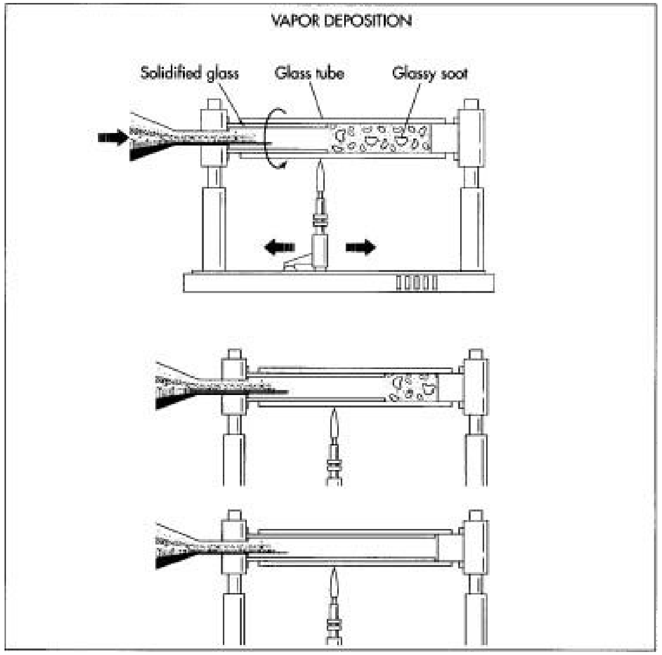
MANUFACTURING PROCESS

Silicium is melt from some piece in a vapored environment with various chemical vapors, including silicon tetrachloride ($SiCl_4$), germanium tetrachloride ($GeCl_4$), and phosphorous oxychloride ($POC1_3$)

A cylinder of pure silicium is created (10cm long)
The cylinder is strechted to form the final core fibre.

This fibre is rounded by a coating made of a different silicium (with a different refraction index including for instance phosphore or germanium).

The fibre is finally polished to prevent incorrect reflections.

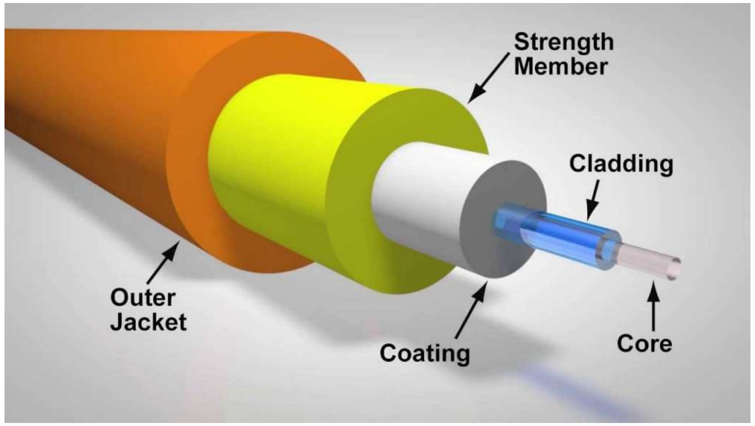


Optical fibre typical values

THE FIBRE ITSELF

Core : ~10 µm

Coating : ~100-150 µm



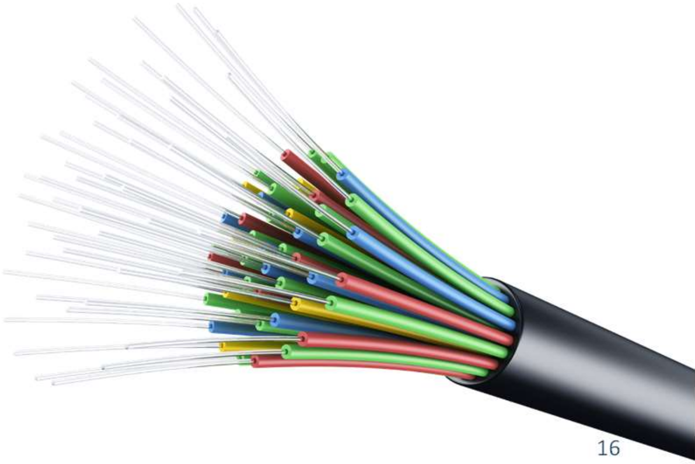
CABLE

Typical number of fibres in a cable varies depending on the use

- Few fibres for local use in an office or home
- Dozen to few dozen of fibres for collecting trafic or submarine cables
- Hundreed of fibres for backbone / agregation cables
- … some cases of thousands of fibres for datacenter connection (quite often preference is given to multiplying cables rather than concentrating fibres on a single cable)

Typical cable section : from less than a mm to few cm

… with a strong impact on the capability to get into existing ducts in dense areas



Optical Fibre
Different types of fibre / cables

COURSE

Application of refraction to optical fibre

PRINCIPLE OF WAVE PROPAGATION IN OPTICAL FIBRE

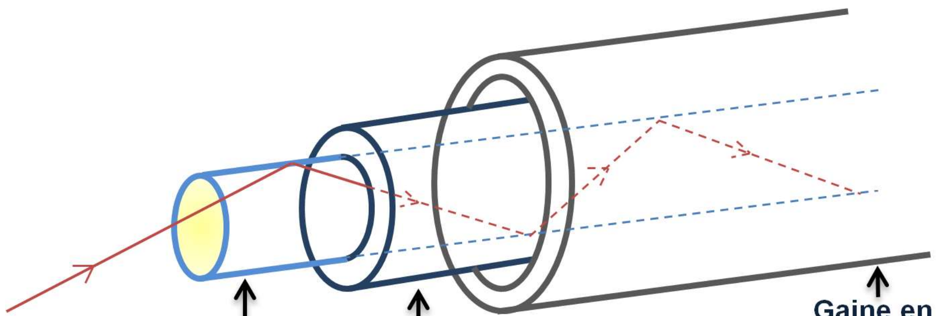
Reflexion and refraction are used to guide the signal in the fiber.
The principle is:

- To cancel any refracted ray
- To maximise the reflexion and therefore to maximise the transmitted signal energy

To reach that objective, a fiber is made of multiple layers:

- A core made of silicium with a fixed refraction index
- A coating with a lower refraction index
- A jacket to protect the fiber from the outside

The coating aims at containing the signal within the core of the fiber



Optical fibre, technology evolution

OPTICAL FIBRE: SINGLE/MONOMODE

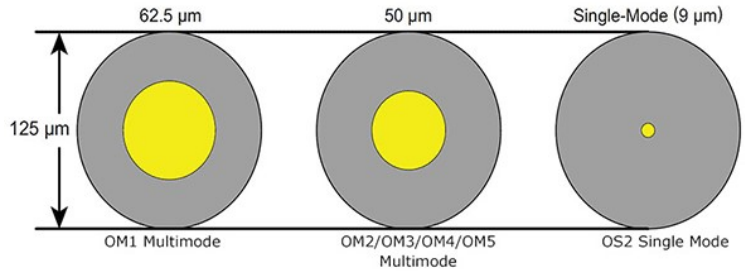
Reduced size core allowing signal propagation straight in the fibre
One only wavelength at a time, therefore no interference
Optimized for long haul and capacity

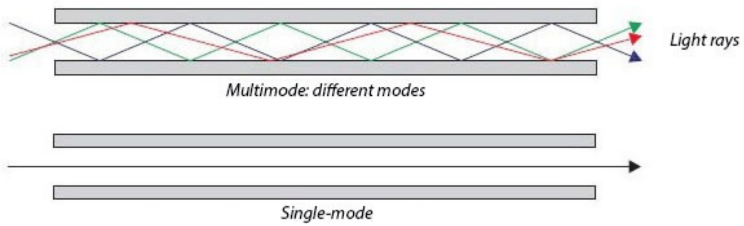
OPTICAL FIBRE : MULTIMODE

Multiple waves can coexist
Attenuation has to be managed over long distances

THE OTHER EVOLUTION TO HIGH RATES : MULTIPLEXING AND DIGITAL SIGNAL MANAGEMENT

EDFA, WDM
Coherent detection
Digital Signal processing

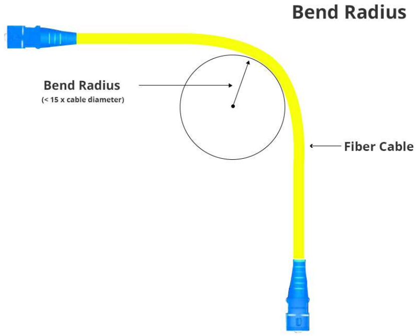




Optical fibre in telecommunication is massively single mode fibre

Limits of refraction for optical fibre

PRINCIPLE OF WAVE PROPAGATION IN OPTICAL FIBRE



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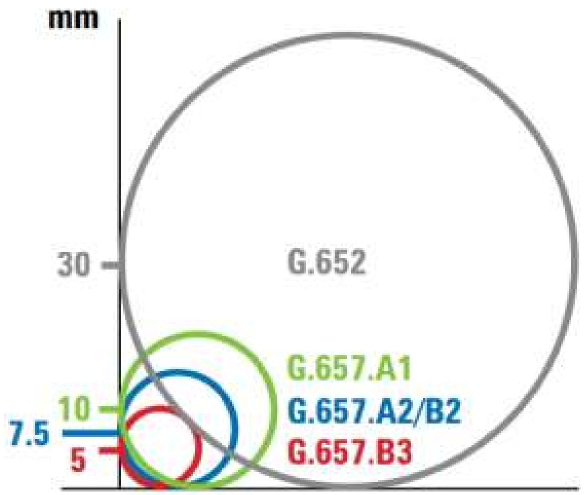


Typology of optical fibre

FIBRE TYPES AND REASONS

G654 was designed for submarine cables
G655 an optimisation while WDM was not existing
G657, **G652**
The latter is the evolution of the first, both largely used for terrestrial networks

NOTES

G652 and G657 are very close and can be mixed with some conditions

G655 was designed originally to maximise rate while multiplexing was not existing

	G652	G654	G655	G657
Mode	Single mode			
Band	Optimal for 1300 nm		0 dispersion @ 1500nm	D, E, S, C, L5
Loss		Ultra low loss		
Bending	+			+++
Typical use	Great for long haul links	Submarine cables		Largely used now while applicable for almost any type of use

OPTICAL FIBER LIFETIME

Not damaged by light
The most important risk is environmental conditions (animals, heat/cold, bending…)
With regards to micro failures (heat/cold).

Cables to embed and protect fibres

TYPICAL CABLE VALUES

Number of fibres embedded

- 1 (of few) fibres for jumper cables
- 24-48 fo for
  - collecting traffic in networks
  - Submarine cables
- 72/96 for transportation
- 144/288 for long haul terrestrial networks / Core networks
- 1152++ for specific requirements (for instance between datacenters)

ENVIRONMENTAL CONSTRAINTS

Cables can also embed specific requirements

- LSOH to reduce gaz emission in case of fire
- Increased protection to torsion/bending (however brings a constraint to deployment)
- Specific resistance to animals for instance rats in sewers

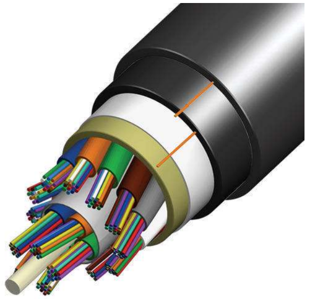
Cables are challenged in datacenters and other sites as people are walking on them…

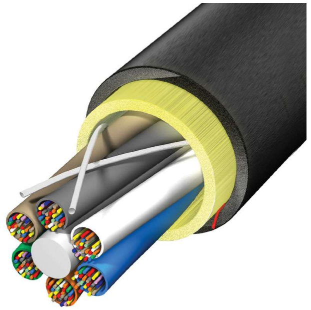
Optical fibre, cable technology

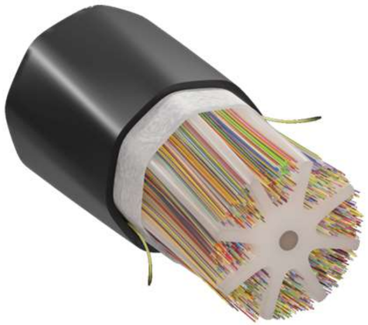
CABLE WITH TUBES

Fibres are gathered in tubes

- Loose tubes
- Micro tubes

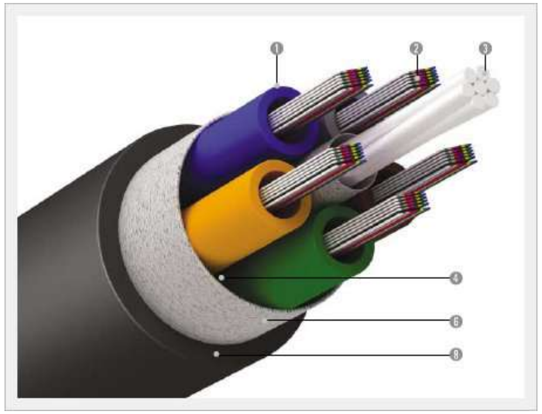






CABLES WITH RIBBONS

A technology aiming at making easy the connexion of high number of fibres in the same cable



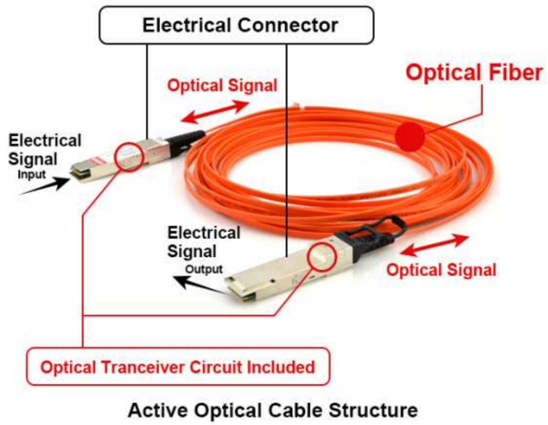
Cables that brings power

ACTIVE CABLES … SPECIAL NEEDS

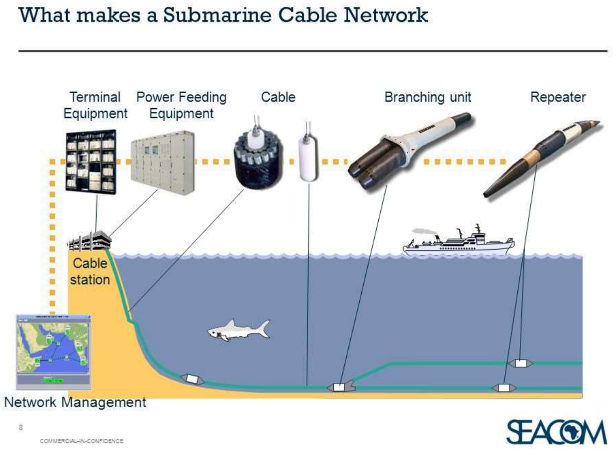
To address the need for bringing at the same time communication and power, a typical need for

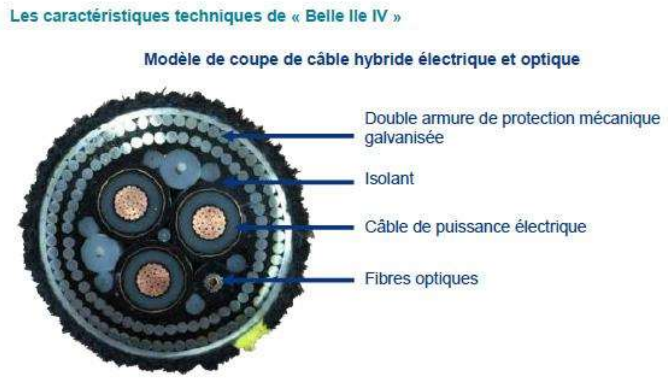
- Very long haul connection (intercontinental)
- Submarine cables

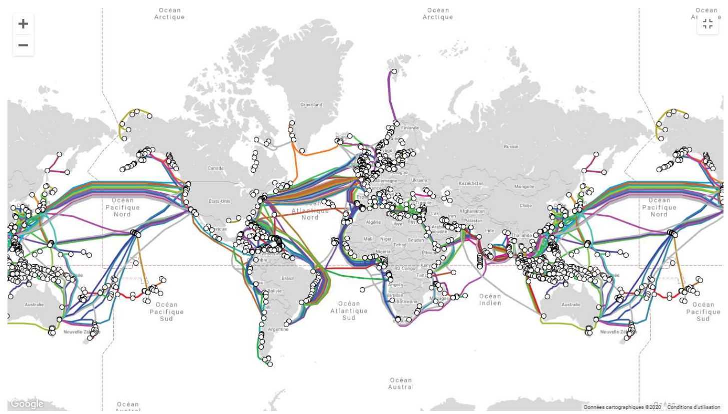
Some application also for office building to bring power and telecom facility everywhere in the same cable. Low constraint with electromagnetic fields compared to coaxial cable.



Active Optical Cable Structure







Optical Fibre Accessories around

Connectors

WHY A (PHYSICAL) CONNECTOR ?

Aligning or coupling fibre
- High precision for the light to get through completely
- Reduce as much as possible loss of energy

Easy connection/deconnection in an equipement

CHARACTERISTICS

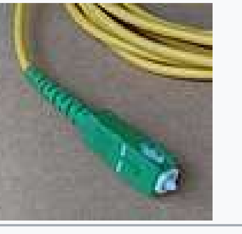
Minimum loss (usually around 0,4 dB)
Reliability and resistance to environmental conditions
Easy manipulation for connecting devices/equipments

The most widely used connectors in the area:
- SC (Subscriber Connector), very common
- LC (Lucent Connector), smaller that SC
- FC (Ferrule Connector), used for monomode jumpers, currently replaced by SC connectors
- ST (Straight Tip), used for multimode jumpers, highly résistent to too strong tightening

Connector history (1/4)

	Nom long	Norme	Type	Remarque	Illustration
DIN LSA		CEI 61754-3		Obsolète	
EC	European Connector	CEI 1754-8		Telecom	
FC	Fiber-Ferrule Connector	CEI 61754-13		Telecom	
ESCON				Mainframe IBM et compatible	
ST	Straight Tip	CEI 61754-2	Baïonnette	Développé par AT&T	

Connector history (2/4)

	Nom long	Norme	Type	Remarque	Illustration
LX5		CEI 61754-23		Rarement utilisé	
LC	Lucent Connector[3]	CEI 61754-20	Snap		
MIC	Media Interface Connector (FDDI)				
MU		CEI 61754-6		Utilisé au Japon	
OptoClip 2		IEC(86B)CFO 10	Push-pull		
SC	Switching Connector	CEI 61754-4		Standard/Subscriber/Square Connector (Très utilisé)	
MTRJ	Media Termination - Recommended Jack[3]	CEI 61754-18			

Connector history (3/4)

	Nom long	Norme	Type	Remarque	Illustration
SMA 905				Lasers industriels	
TOSLINK				Audio numérique	
E-2000		CEI 61754-15	Snap	Telecom	
MPO	Multi-fibre Push-On/Push Off	IEC-61754-7; EIA/TIA-604-5 (FOCIS 5)	Snap (couplage multiple push-pull)	Intègre 12 (version la plus courante) ou 24 brins optiques.	
VFO	Verranne Fibre Optique		Vissé	Maximum 2.5GBits/s.	
Souriau	Souriau 8016 10A 003		Vissé	Multimode. Obsolète. Date des premiers réseaux optiques en France pour la transmission PDH (TNLO 34MBit/s).	

Connector history (4/4)

	Nom long	Norme	Type	Remarque	Illustration
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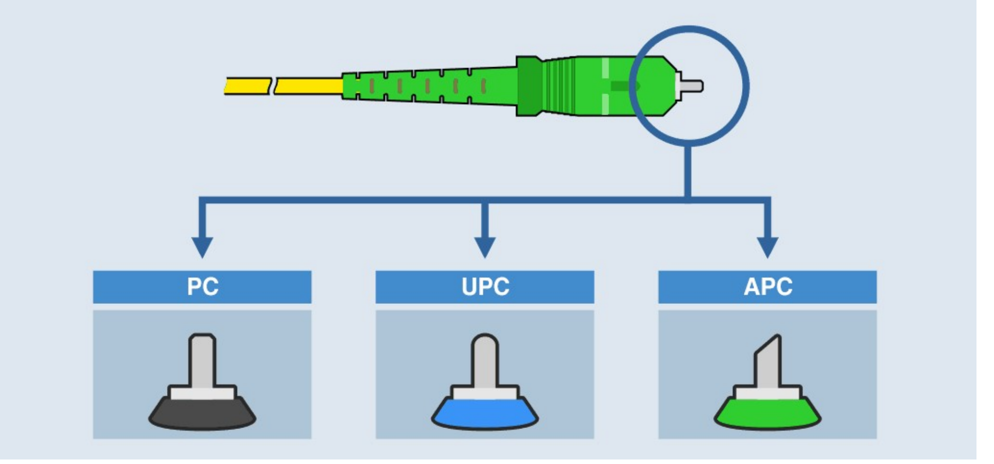
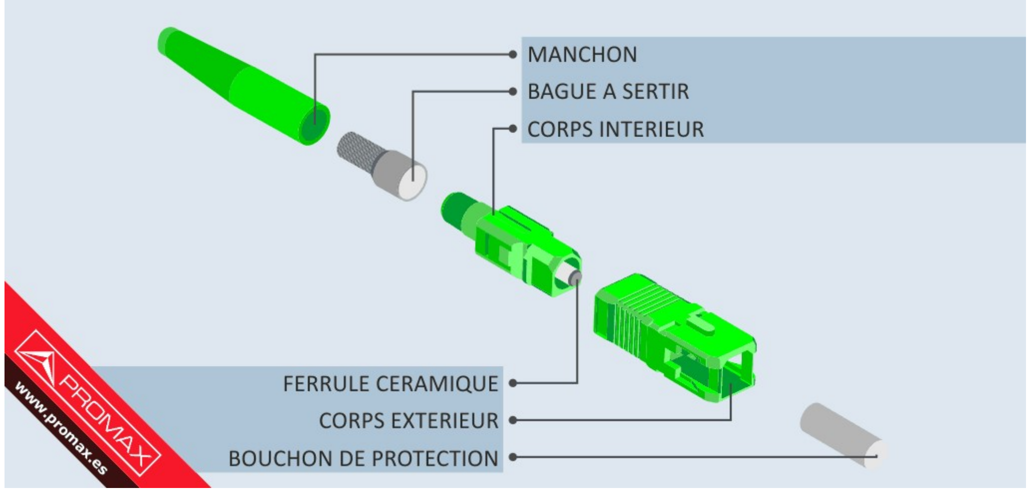
Connector structure

FIBRE CUT

PC – Physical Contact (allow a very low return loss)
UPC – Ultra PC (even lower return loss)
APC – Angle PC (the lowest return loss solution, up to 60 dB)

Depending on the need, conectors can either be mono-fibre or bififibre.





SFP

SMALL FORM-FACTOR PLUGGABLE

This is the optical module that

- Emits the signal on the fibre
- Receives the signal on the other end

- Adapts electric signal to light signal, specific to wavelength
- Includes LED/Laser beam

DIFFERENT TYPES OF SFP ACCORDING TO USE

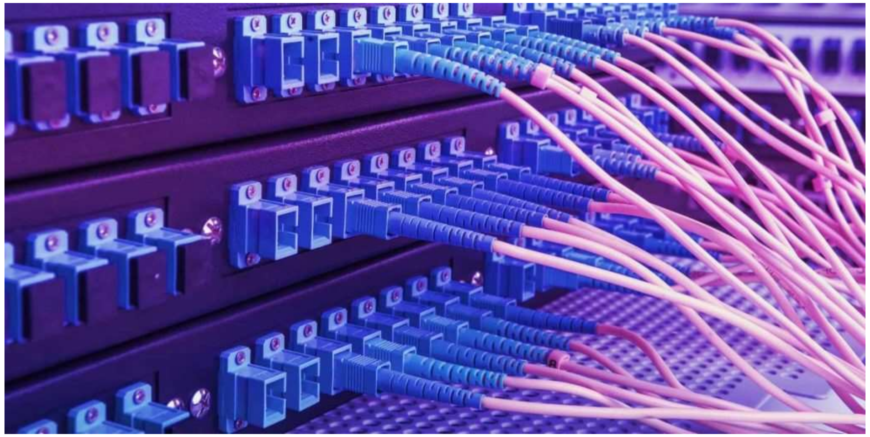
SFP / SFP+ for various rates (up to 25 Gbps currently)
Single or bi-fibre adapteur

Jumpers

SINGLE FIBRE CABLES (OCCASIONNALY BI-FIBRE)

Used for connection between equipement in a rack
(also used at home between wall adapter and internet box)

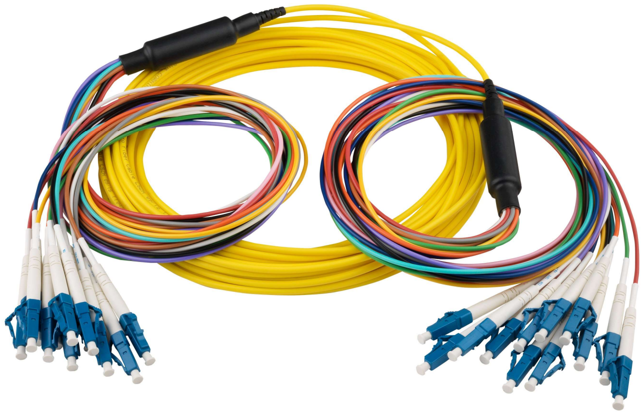
Allow to (re)map easily connections in datacenters for instance



SC connector

LC connector

Breakouts and half breakouts

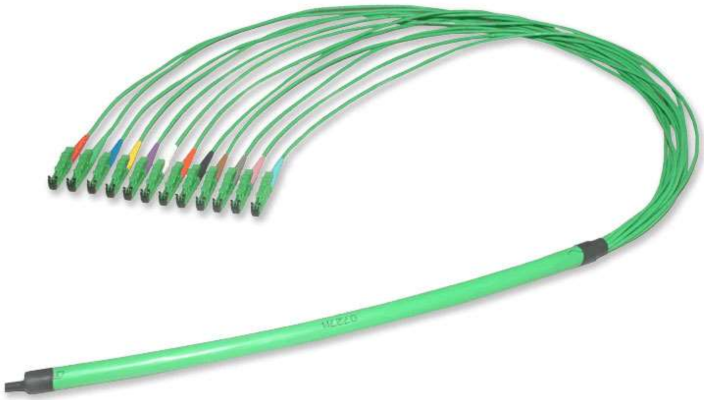


VARIATION ON JUMPERS

Allow connection between equipment requiring a set of fibres (typically radio site with multiple sectors)

Preventing a mess of jumpers between equipments, especially with equipements are not close the one to the others

Embed connectors, thus imply loss



Installing optical fibre

Manholes

DEVELOPED INFRASTRUCTURE

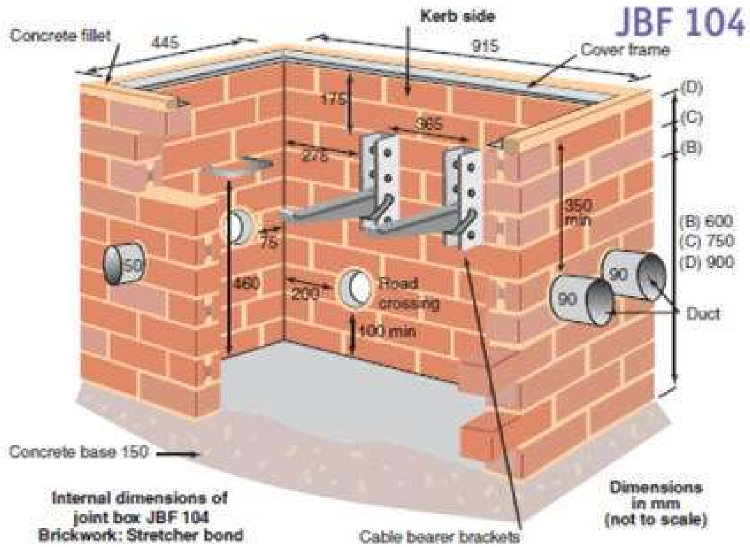
Typically in France GCBLO infra
but also other existing partners (Axione…)

A contract with rules to access the infra
- Number of equipments
- Number of cables
- Access and maintenance

Some rules for developping infra, especially
in dense area depending on cities

MULTIPLE FORMAT/SIZE

L1T/L2T/L3T
Characteristics, mainly the size and access to ducts
Interconnection between infra



Splicing optical fibre

A KEY FOR NETWORK EXTENSION AND CONNECTIONS

Soldering to fibres to offer continuity

TOUCHY OPERATION

Aligning the core to avoid refraction/reflection
Case of G657 and G652

A SENSITIVE OPERATION

An operator usually made outside

- Sensitivity to dust
- Sensitivity to humity

…that can lead to signal attenuation
Targeted attenuation is less that 0,1 dB (usually a challenge)

Street cabinet

CAPABILITY OF SUCH CABINETS

Possibility to share space between operators
Easy access to mapping capability
Risks of easy access

- Multiple actors from various companies
  Sometime keys are used… and broken
  Real difficulty to trace accesses
- Malicious operations,
  however not that much

TYPICAL USE

FTTH
Other networks special cases

Ducts for telecom cables

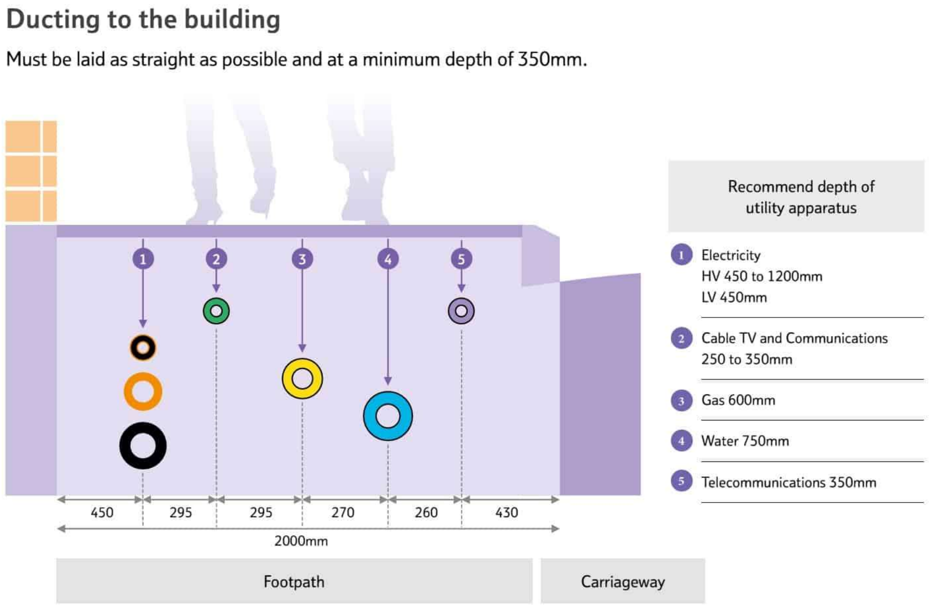
EXISTING NETWORKS

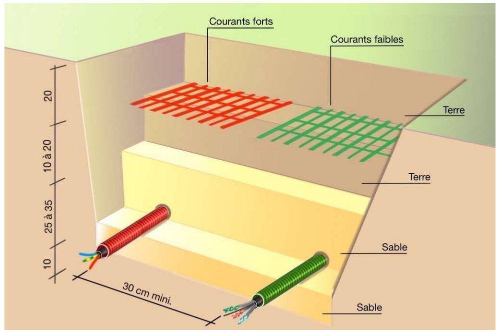
Several operators have a duct infrastructure

Orange has to provide access

Other existing offers (Axione, Covage, …)

- Constraints in some areas from regulation





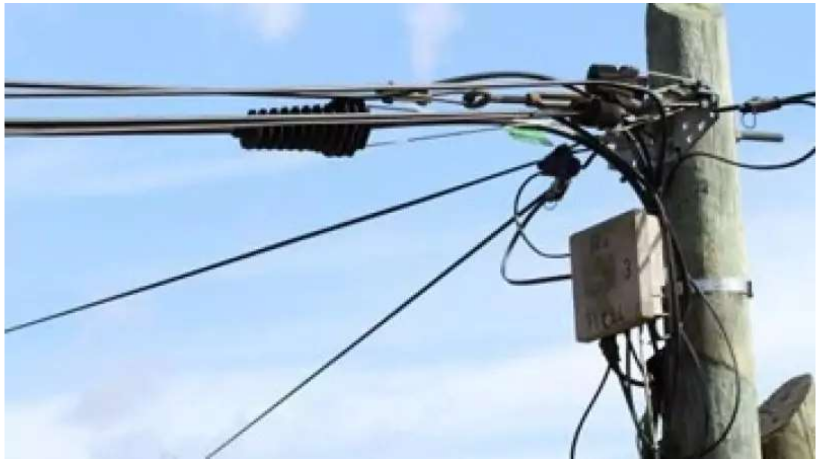
Digging for optical fibre networks

URBAN AREAS
Existing networks present and prefered when not saturated see previous slides

SUBURBAN AND COUNTRYSIDE
Long haul trenches, micro trench made by machines

RULES
Depth
Size/Number for ducts normalized
Soil to fill holes
Access to manholes and equipment

Alternative to ducts : aerial net (1)



ALREADY DEVELOPED NETWORK

Existing networks available for development, for instance in France

- Orange
- Enedis

CONSTRAINTS

Type of fibre cables due to resistance between poles
Some perturbation with vibrations due to wind
Limitation (weigth and cable capacity) to usually less than 72fo

RISK OF THE INFRASTRUCTURE

Weather condition (storms…)
Malicious acts

… but much cheaper than digging for ducts, especially

Alternative to ducts : aerial net (2)

NETWORK FROM POWER PROVIDERS

Existing networks over high voltage lines

Available for long haul

Constraints on the places to get in/out the line

- Limited to pole places
- Usually tied to the power provider network

TECHNOLOGIES

Usually along with a structure cable

In some case, embeded in the power cable (not usual)

Due to the structure of the poles, this network is considered as secure as ducts

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bouygues
TELECOM

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