"Jules Verne and the 20.000 Leagues of **Subsea Cables**:
A true tale about submarine cables"

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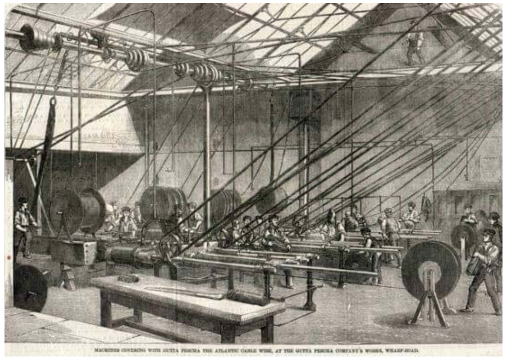
- The Heritage
- Network, Wet Plant & Dry Plant
- Topology
- Cable Capacity
- Business Background
- Permitting
- Submarine Cable Network Secutiy
- Trend and Challenges

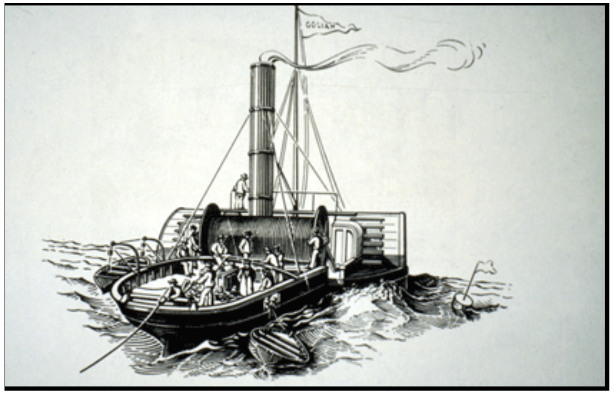
The Heritage

A Brief History – Part I

Pallaquium Gutta
Source: Google



Compagnie du Gutta-Percha
Source: Reynald Leconte, Subsea OFC



Goliath: lays 1st International Cable, UK – France, 1850-1851
Source: Reynald Leconte, Subsea OFC

- **1840: Telegraph cables start to be laid across rivers and harbours, but initially had a limited life**
- **1843-1845: Gutta-percha (a type of gum found in a Malaysian tree) was brought to Britain and starts to replace other materials that were used for electrical insulation, thus extending the life of the cable**
- **1850: 1st international telegraph cable laid between UK and France, followed by a stronger cable in 1851**
- **1858: 1st transatlantic cable laid between Ireland and Newfoundland by *Great Eastern*. This failed after 26 days and another was laid in 1866**

A Brief History – Part II

- 1884: 1st underwater telephone cable - San Francisco to Oakland
- 1920s: Short-wave radio superseded cables for voice and telex traffic, but capacity limited and affected by atmosphere
- 1956: Invention of repeaters (1940s) and their use in TAT-1, the first transatlantic telephone cable, began an era of rapid and reliable transoceanic communications
- 1961: Beginning of a high quality global network
- 1986: 1st international fibre-optic cable connects Belgium to the UK
- 1988: TAT-8, the 1st transoceanic fibre-optic cable system, connects the USA to the UK and France

How Submarine Cables Work

- **Fibre-optic submarine cables rely on a property of pure glass fibres whereby light is guided by internal reflection**
- **Because the light signal loses strength en route, repeaters are required at regular intervals to restore it**
- **Repeaters are now based on optical amplifying technology, which requires short lengths of erbium-doped optical fibre to be spliced into the cable system. These are then energized by lasers that cause them to 'lase', thus boosting the incoming light signal**

Network, Wet Plant & Dry Plant

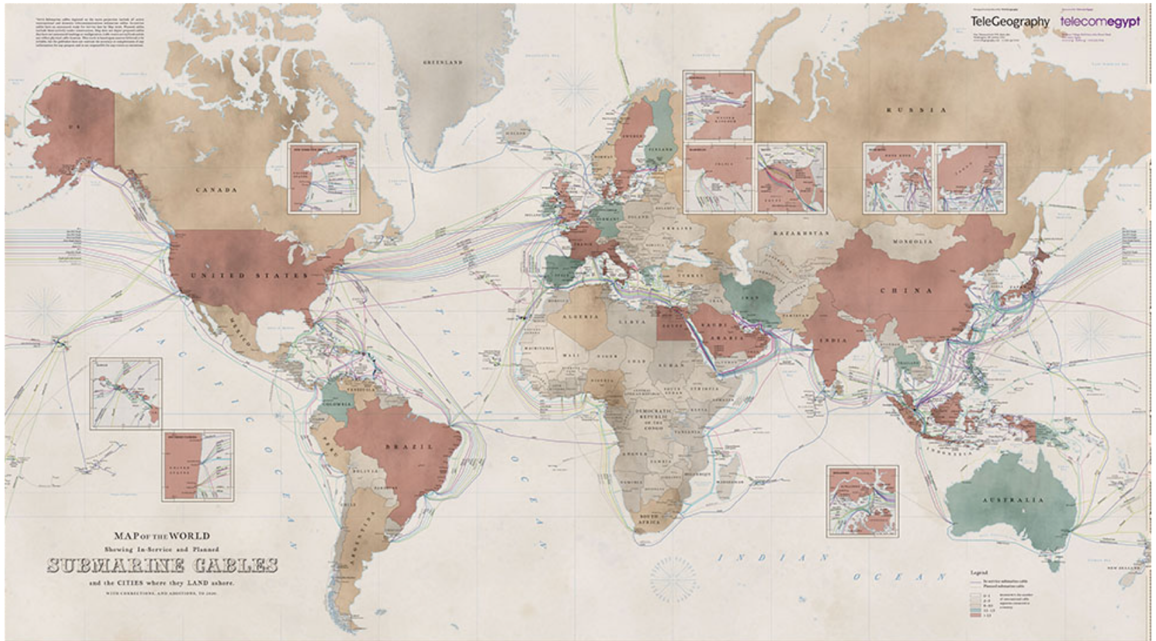
Submarine Cable - Network

- **Subsea cables play important roles as global infrastructure nowadays**

- 1995 → Subsea Cable : Satellite = 50:50
- 2020 → Subsea Cable : Satellite = 99:1

~406 Cable systems
~100.000km of new cables per year

https://submarine-cable-map-2020.telegeography.com/



Submarine Cable Map 2020
Source: TeleGeography

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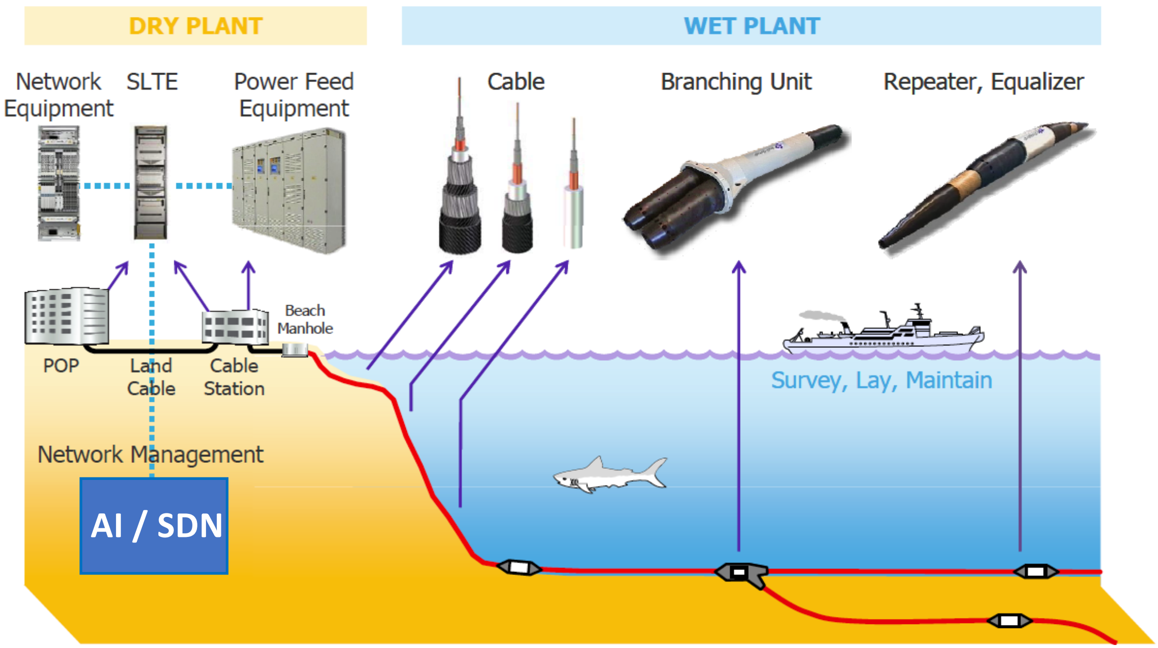
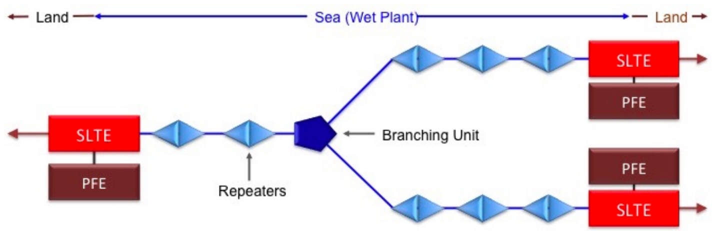
Typical Submarine Cable System



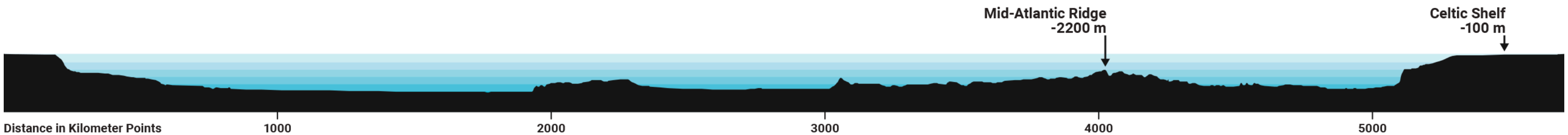
Traditional model of architecture and connection of subsea cable

Source: ICPC



Subsea cable high level design

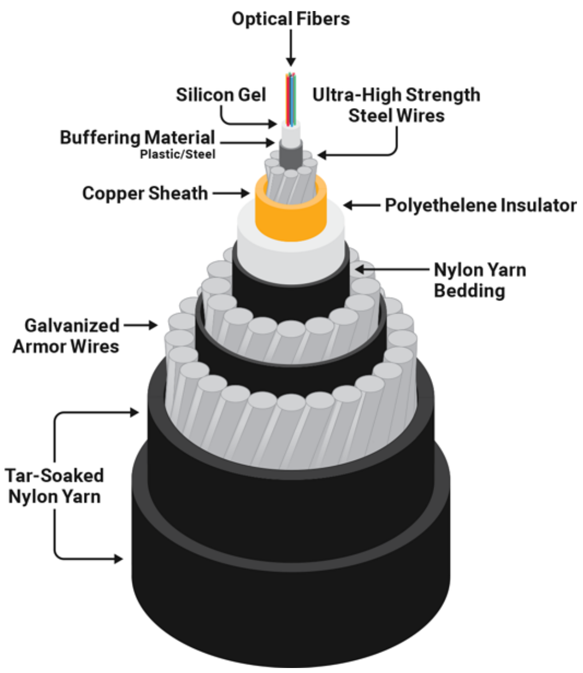
Source: Ciena



Example Trans-Atlantic cable route seabed profile

Source: TeleGeography

Submarine Cable
Wet Plant



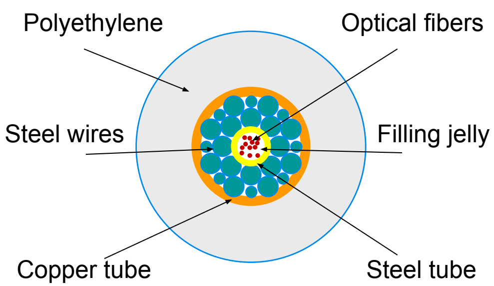
2020 **1858**

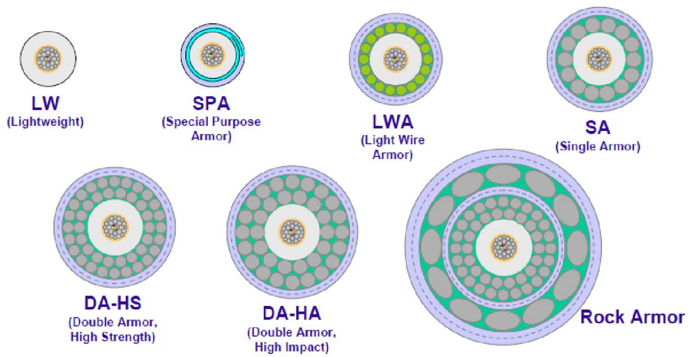
Traditional model of architecture and connection of subsea cable

Source: Michael Francois, Subsea OFC

Submarine Cable
Wet Plant

- **Function**
  - Protect the optical fiber
  - Power repeaters
- **Properties**
  - Optical
  - Mechanical strength
  - Pressure
  - Abrasion
  - Voltage
  - Design life 25 years





Cables type and structure

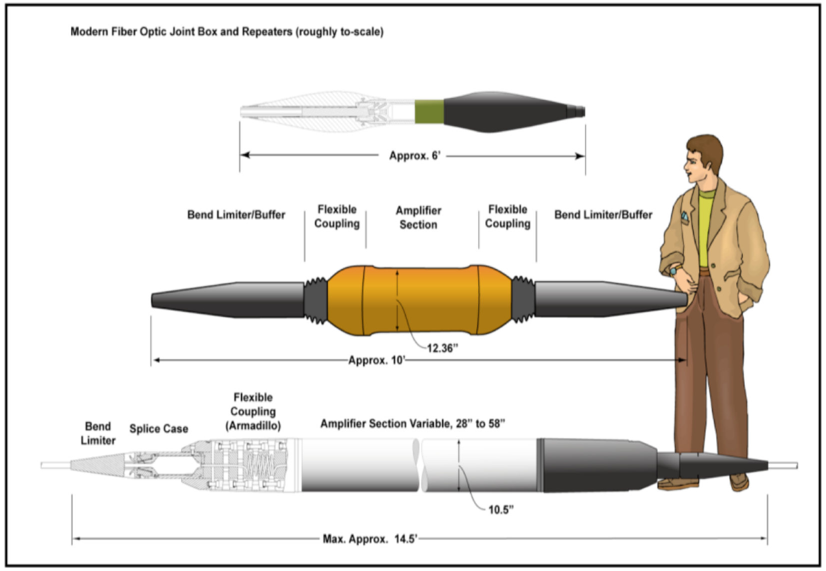
Source: Google

Submarine Cable: Key Elements – Repeater
Wet Plant

- **Function**
  - Amplify optical signal
  - After attenuation through fiber
- **Properties**
  - Optical
  - Mechanical
  - Pressure
  - Voltage
  - Water ingress with difficulty of mobile fiber penetrators
- **Active equipment**
  - Semicondutor Optical pump lasers
  - Specific qualification for 25 years design life

Repeater

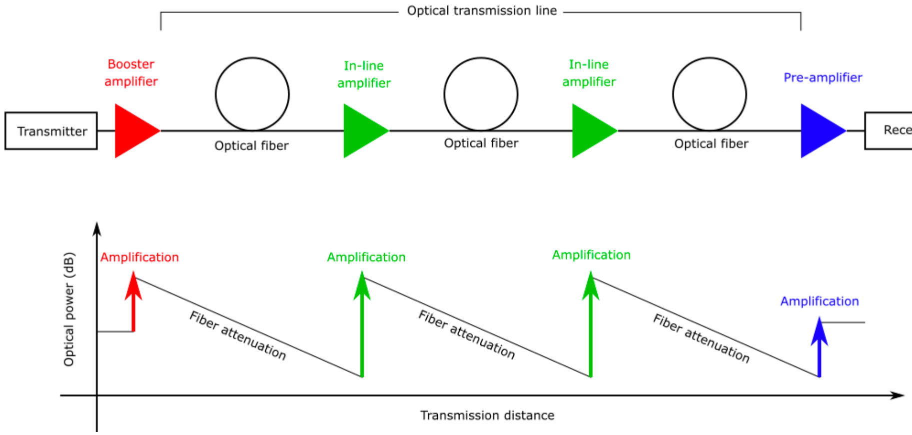
Source: Suboptic.org



Submarine Cable: Key Elements – Repeater (EDFA)
Wet Plant

- **EDFA introduced in 1994**
- **Few change since**
  - Transparent
  - Enabling WDM
  - Reliable
- **Continuous evolution**
  - Higher power
  - Pump <framing>
  - C + L band (?)
  - Raman (?)
  - SOA (?)

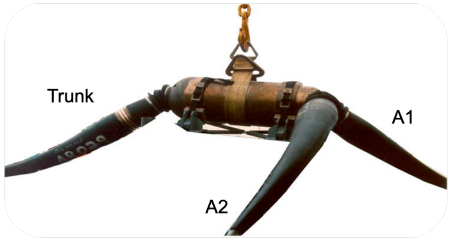
EDFA (Erbium Doped Fiber Amplifier)

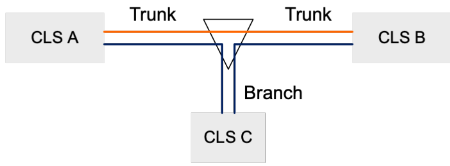


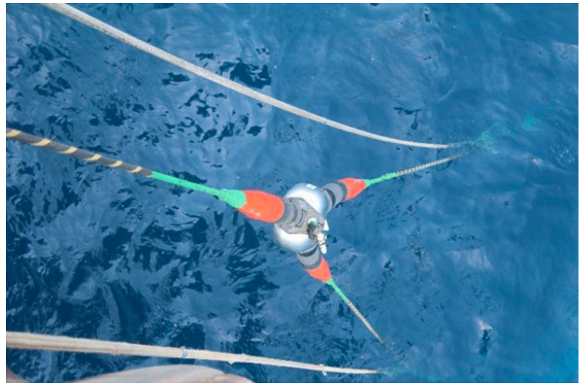
Repeater (EDFA)
Source: Fiber Labs

Submarine Cable: Key Elements – Branching Unit (BU)
Wet Plant

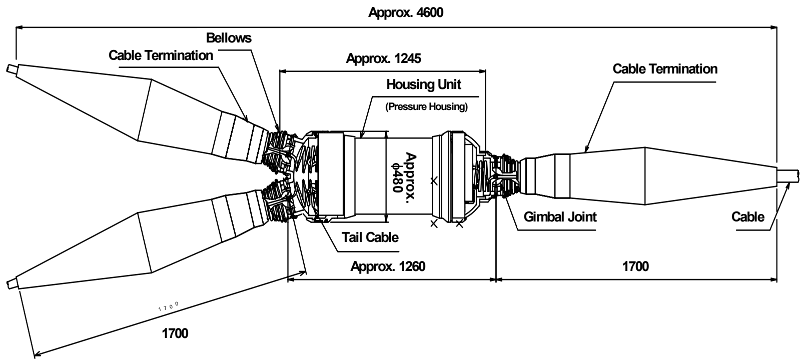
- **Function**
  - Split fiber path between 3 directions







- **Properties**
  - Optical
  - Mechanical
  - Pressure
  - Voltage
  - Water ingress with difficulty of mobile fiber penetrators

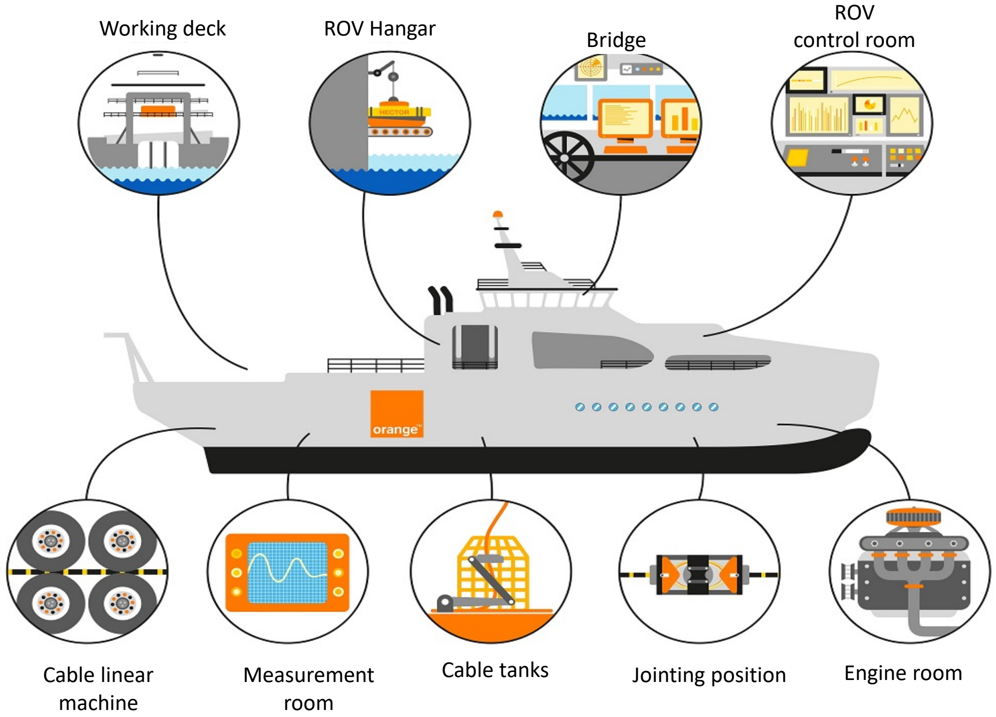


- **Active equipment**
  - Modern BU switch wavelengths and fibers
  - The more complex wet plan equipment

Submarine Cable: Key Elements – Cable Ship
Wet Plant

Modern Cable Ship

- Multi-function cable lay vessel
- World wide operations
- Range: 25,000nm or 60 day endurance
- Berthing for 80 personnel
- Overall length: 140m
- Molded beam: 21m
- Deep draft: 8.4m
- Install, bury, repair and maintain cables



Cable ship
Source: Orange Marine

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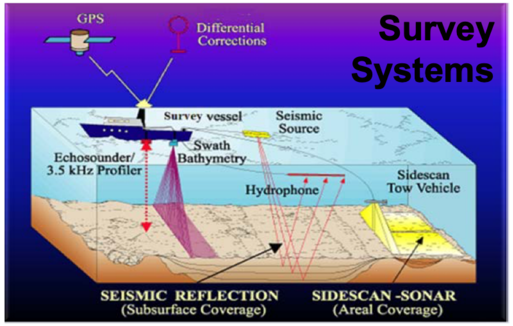
Submarine Cable: Key Elements – Survey
Wet Plant

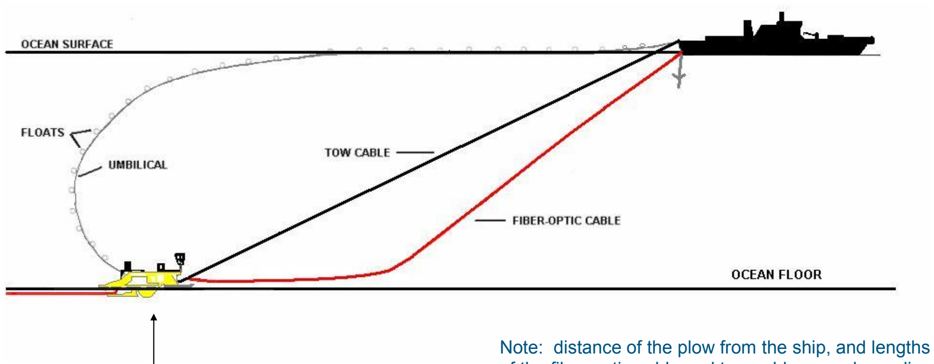
- **Marine Operations: Survey**

- Data collection, bathymetry, geotechnical, sub-bottom, and side scan data to support route engineering, cable selection, installation and burial
- Analysis of results like, revised RPL & SLD, cable armouring & protection, burial conditions, recommendations for installation procedures



Submarine Cable: Key Elements – Cable Burial Systems (ROVs & PLOWs)
Wet Plant

- **Marine Operations: ROVs and PLOWs**
  - Cable burial remains the most effective and economical method of protection
  - Towed cable plows remain the industry standard for cable burial (1m to 3m typical)

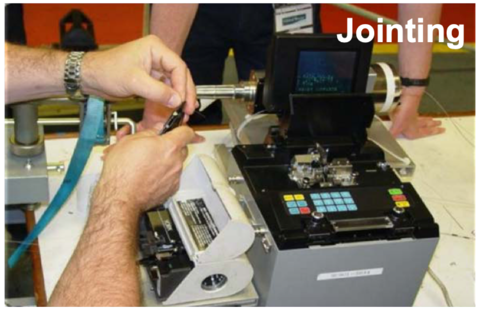


Note: distance of the plow from the ship, and lengths of the fiber-optic cable and tow cable, vary depending principally on sea-floor depth.

Submarine Cable: Key Elements – Maintenance
Wet Plant

- **Marine Operations: Maintenance**
  - Cable maintenance, recovery and operation

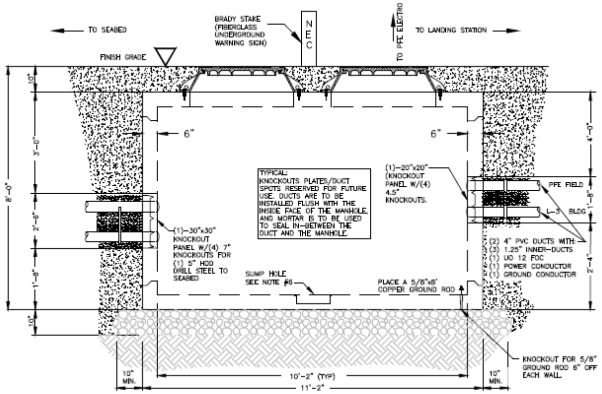
WACS Cable (shunt fault – 2020) in Africa



Submarine Cable: Key Elements – Beach Manhole (BMH)
Dry Plant

- **BMH**

- Traditionally the point where the transition between the subsea cable and terrestrial cable occurs.
- A chamber is constructed near the landing point and the beach joint ins constructed inside.
- The cable is often also anchored at the BMH.



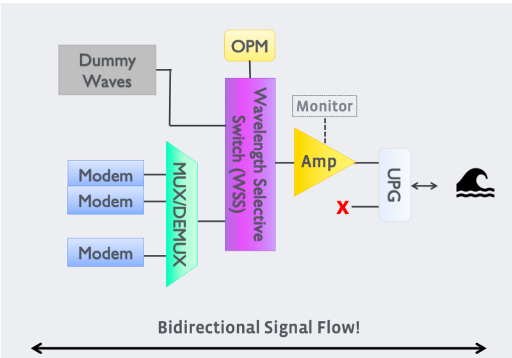
Submarine Cable: Key Elements – Cable Landing Station (CLS)
Dry Plant

- **Cable Landing Station (CLS)**
  - Terminates an subsea cable
  - Provides powering for the subsea cable
  - Provides a location for the Submarine Line Terminating Equipment (SLTE)
  - Provides a location for domestic and/or international interconnection

Submarine Cable: Key Elements – Submarine Line Terminating Equipment (SLTE)
Dry Plant

- **Submarine Line Terminating Equipment (CLS)**

- Transponders and power management for cable
- Use latest technology to get the most out of the cable
- Cycle SLTE every ~5 years as technology advances (cable has 25 year lifetime)
- Cycle multiple SLTE over life of cable



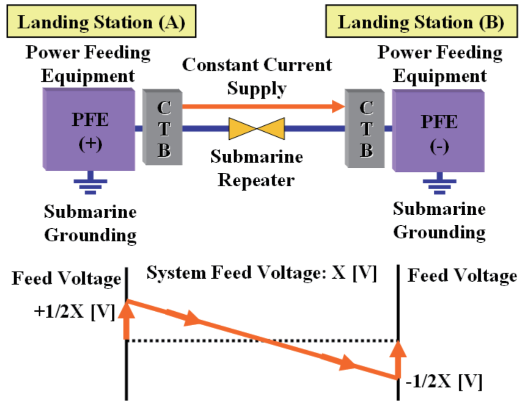
	1st Gen Coherent	2nd Gen Coherent	3rd Gen Coherent	4th Gen Coherent
Year	2010	2012-2015	2016-2019	2020+
Data Rate	40G	50G / 100G / 150G / 200G	100G – 400G	200G – 800G
Baud Rate	~11 Gbaud	~28-35 Gbaud	~40-60 Gbaud	~62-95 Gbaud
Highest Order Modulation	QPSK (& BPSK)	16QAM (&BPSK, QPSK, 8QAM)	32QAM (& below)	64QAM (& below)
Key New Technologies	Coherent CD & PMD Comp	1st Gen Features plus: SD-FEC Tx CD pre-dispersion	2nd Gen Features plus: 4D/8D mod formats, custom modulations, Nyquist shaping Improved FEC NCG	3rd Gen Features plus: Const. Shaping (PCS) improved FEC NCG, variable baud rates, Nonlinear comp (NLC), more…
Silicon Process	90nm	28-64nm	16-28nm	7nm

Submarine Cable: Key Elements – Power Feeding Equipment (PFE)

Dry Plant

- ❑ **PFE**

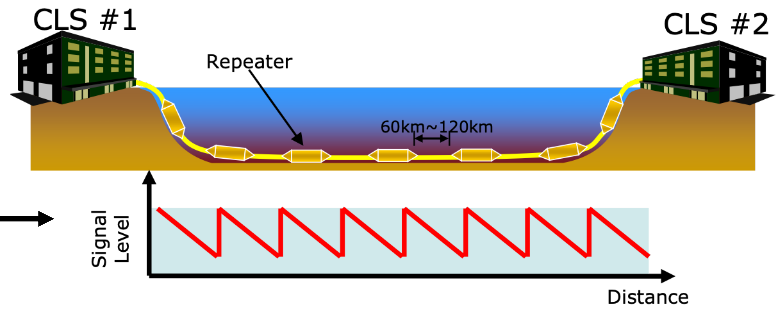
- PFE supplies constant current (CC) to subsea repeaters via submarine cable.
- To improve system power supply reliability, PFE assemblies capable of supplying all system voltage requirements are installed in the CLSs at both ends of the systems. The voltages to be supplied to subsea repeaters are allocated to provide PFE at both ends.
- Generally, each of the two CLSs supplies both positive and negative voltage corresponding to ½ of the total system voltage
- If any of the PFEs fail, the opposite CLS will supply the full system voltage to allow a constant current supply to the submarine repeaters.
- This system redundancy is intended to improve system reliability



Topology

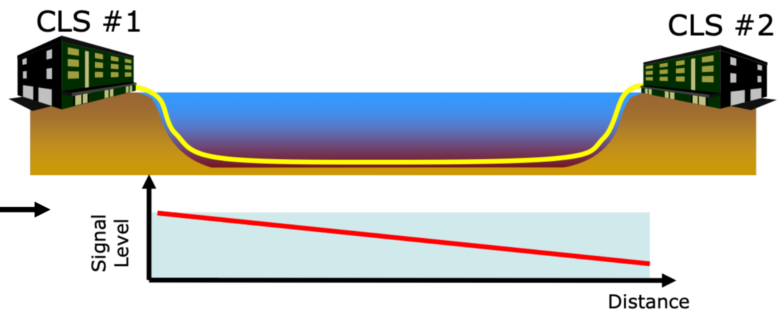
Submarine Cable: Key Elements – Topology
System Classify

- **Repeatered**
  - Amplified by chained repeaters
  - ~ 15.000km
  - Transoceanic application



Topology
Source: NEC

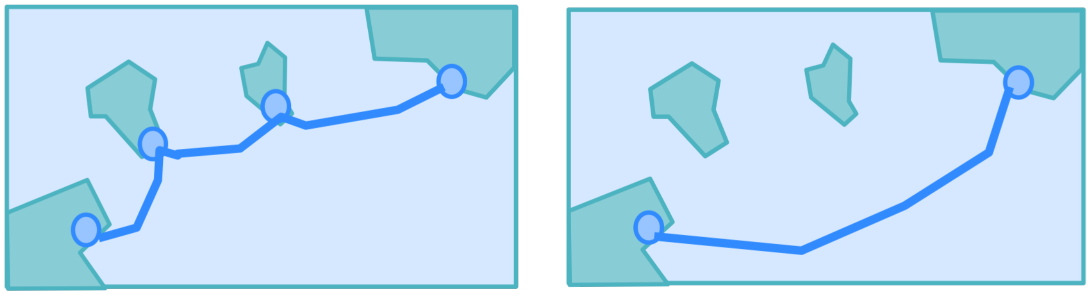
- **Un-Repeatered**
  - Non amplified
  - < 400km
  - Regional application



Submarine Cable: Key Elements – Topology
Regional system (Repeatered vs Un-Repeatered)

- **Regional systems**
  - Both repeatered and un-repeatered are candidates

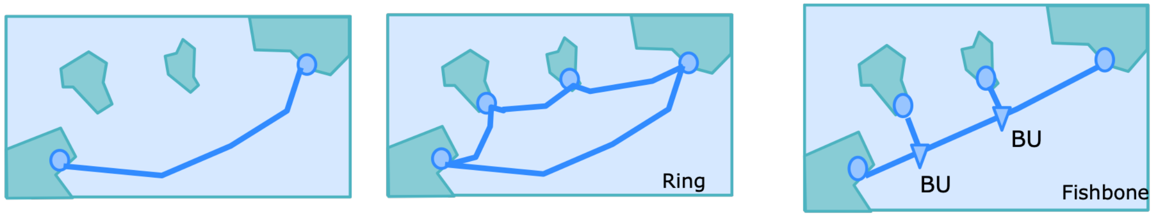
Topology
Source: NEC



	Repeatered	Un-repeatered (Festoon)
Connectivity	Point-to-Point	Festoon
Capacity (FPs)	2 ~ 20 FP	~ 50 FP
System Cost	Equipment: Repeater, Cable, PFE Installation: Vessel + Landing	Equipment: Cable w/o copper Installation: Vessel + Multiple Landing

Submarine Cable: Key Elements – Topology
Transoceanic repeatered system

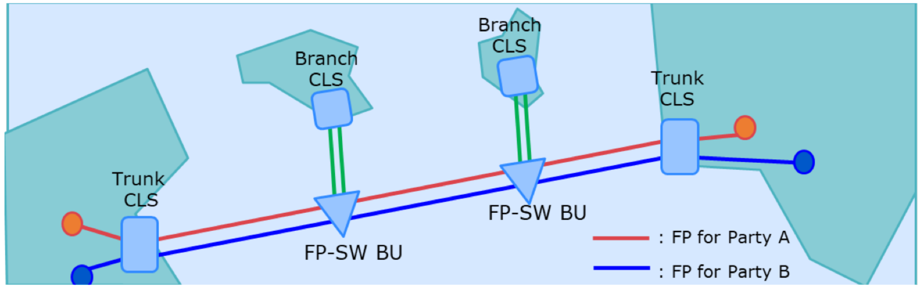
- **Transoceanic system**
  - In transoceanic systems, there are several options for the network topology
- **Point-to-Point**
- **Ring**
  - Cable redundancy as route diversity
- **Fishbone**
  - Fiber redundancy as collapsed ring
  - Various optical path (fixed OADM, selectable OADM, reconfigurable OADM)
  - Various powering path (non-switching, power switching)



Topology
Source: NEC

Submarine Cable: Key Elements – Topology
FP Switching Network

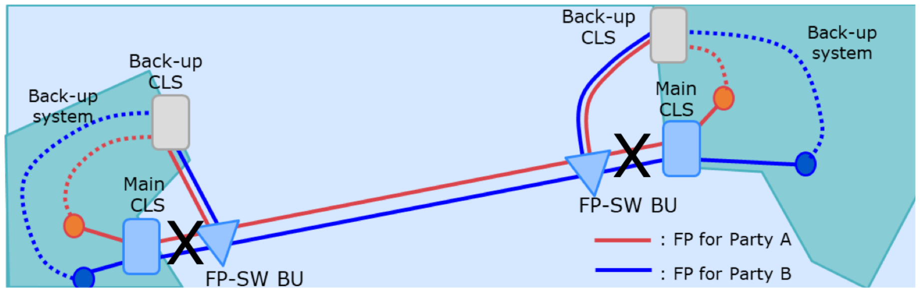
- **Trunk-Branch FP Sharing**
  - Party A / B share branch FP
  - Trunk – Branch FP Routing as needed



Topology
Source: NEC

- **Shore-end Protection Network**

- Cable fault at shore end to be restored by FP Switching



Cable Capacity

Submarine Cable: Cable Capacity

- **Cable Capacity = (Spectral Density) X (Fiber Bandwidth) X (No. Fiber Pairs)**
- **Spectral density (bits/s per Hz)**

- Has increased rapidly by increasing channel bit rate

- **Fiber bandwidth**

- Determined by the Erbium spectrum of EDFA

- **No. of Fiber Pairs**

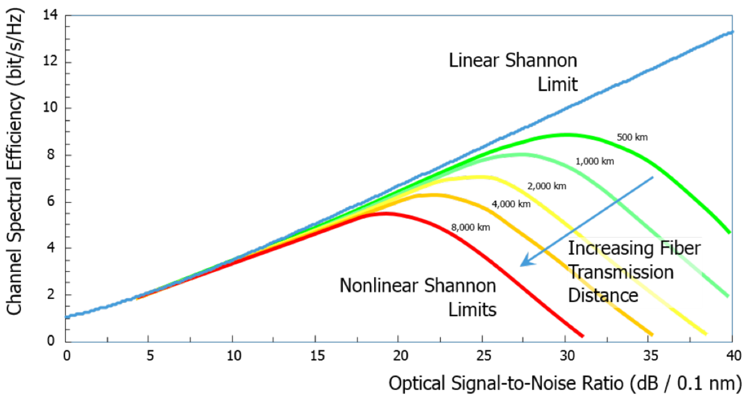
Number of fiber pair was typically 4FP to 6FP, max 8FP

- SDM cables enable 12, 16, 24 FP

Shannon Limit Factor

$$C = B \log_2(1 + \mathrm{SNR})$$

Channel capacity · Bandwidth · Signal to noise ratio



Submarine Fiber type: It can be a Sumitomo Z+ 130 or OFS SCUBA

The most modern fiber today for submarine cable is 0.15db/km and has another common feature which is the largest affective area, allowing to launch the signal with a higher power without cause linear effects.

Submarine Cable: Cable Capacity

- **How much information can a cable carry?**
- Cable capacities vary a lot. Typically, newer cables are capable of carrying more data than cables laid 15 years ago. Some transatlantic cables, for example is capable of carrying 208 Tbps
- ***There are two principal ways of measuring a cable's capacity.***
- **Potential capacity**
- Is the total amount of capacity that would be possible if the cable's owner installed all available equipment at the ends of the cable. This is the metric most cited in the market
- **Lit capacity**
- Is the amount of capacity that is actually running over a cable. This figure simply provides another capacity metric. Cable owners rarely purchase and install the transmission equipment to fully realize a cable's potential from day one. Because this equipment is expensive, owners instead prefer to upgrade their cable gradually, as customer demand dictates

Business Background

Submarine Cable: Business Background

- **Submarine Cables have a *Technical Complexity***
  - They are composed of various high tech components which require engineering knowledge to design, evaluate, operate and maintain
- **There is also an *Administrative Complexity***
  - Multi-national constraints
  - Long term supplier relationships
  - Geopolitical considerations
- ***Specific Skills*** are required for various aspects of a successful project
  - Marine Operations, Legal, Optical Engineering, Finance, Permitting, Planning, Negotiating, etc..
- **And the *Time-Scale is* significant**
  - From concept to contract-in-force: ~6 to ~24 months
  - Construction: ~12 to 24+ months
  - Operation: 25 years (technical) and ~17 years (commercial)

Submarine Cable: Business Background
How do we plan cables?

Business Case

- Traffic forecast & Capacity Planning
- Strategic considerations
- Regional considerations
- Decision analysis
- Budget approvals

Design + Pre-Build

- Design engineering
- Supplier selection
- Construction build agreement
- Permitting compliance
- Contract-in-force

Cable Deployment

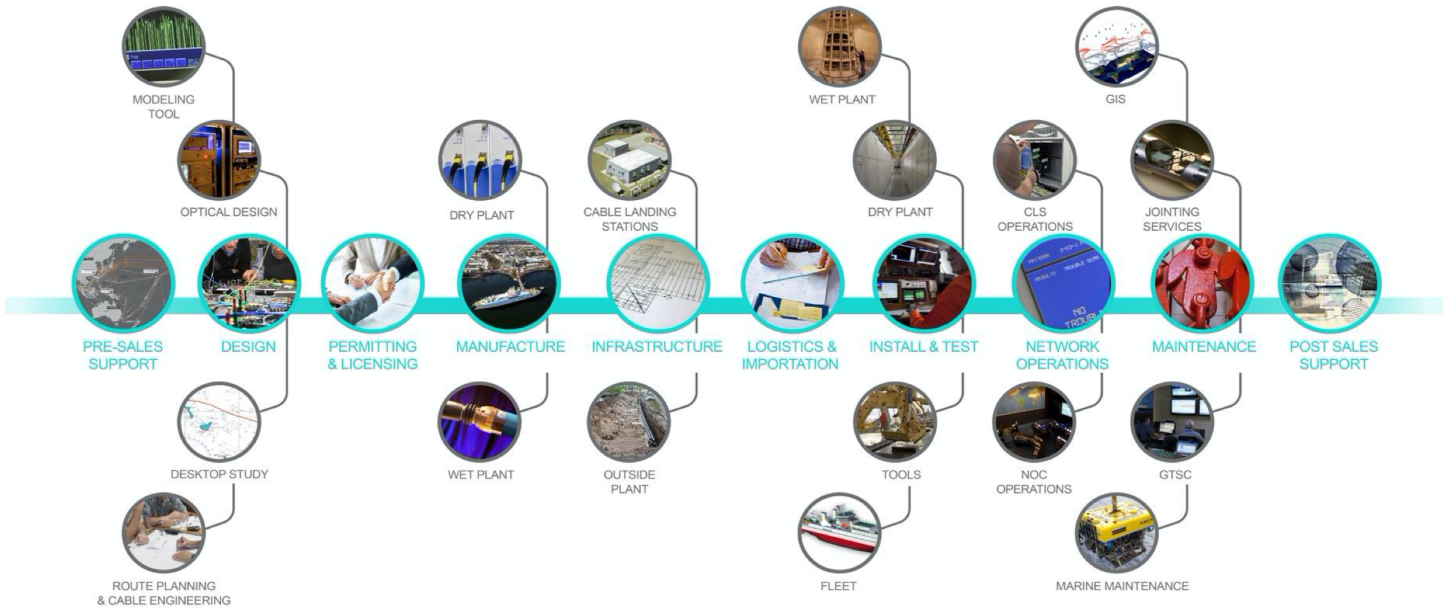
- Marine survey
- Cable lay
  * Trunk
  * Branches
- Cable landings
- Ready for service

Cable Maintenance

- Oinging marine maintenance
- Terrestrial network integration
- Upgrades

Submarine Cable: Business Background
How do we plan cables?

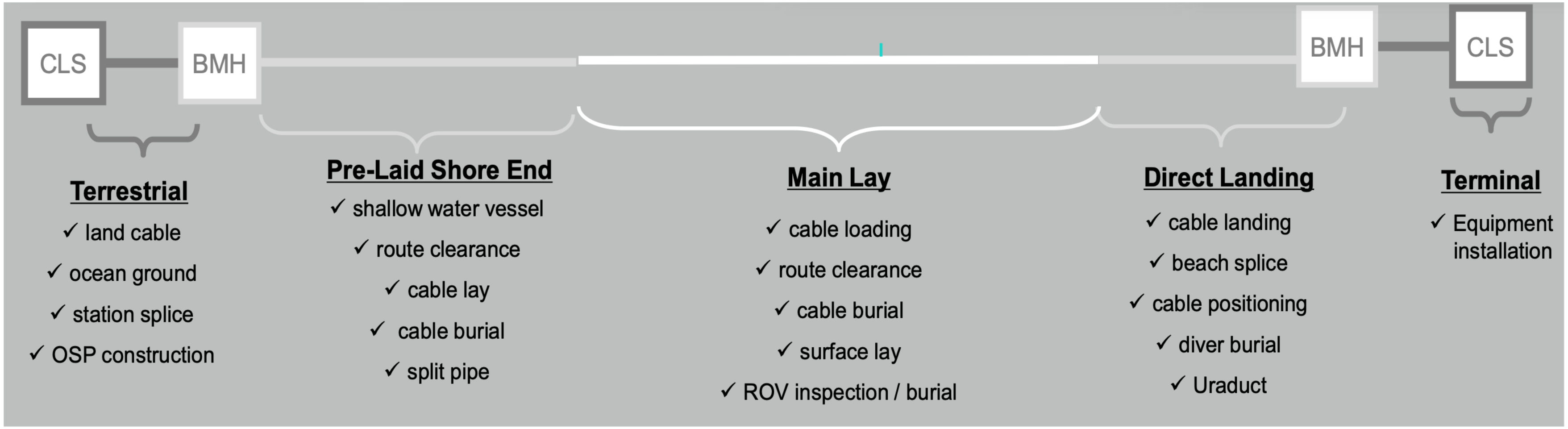
Business Case → **Design + Pre-Build** → **Cable Deployment** → **Cable Maintenance**



Submarine Cable: Business Background

How do we plan cables?

Scope of Marine Construction



Submarine Cable: Business Background

- **Price range of a subsea cable**

- **From** $10M → Point-to-point repeaterless system, short distance, though can still be international
- **To** $1B → Intercontinental transoceanic multipoint system

- **System quality has to meet requirements**

- Outages
- Planned system life
- High reliability
- Technical must haves (latency, redundancy, reliability, capacity, etc..)

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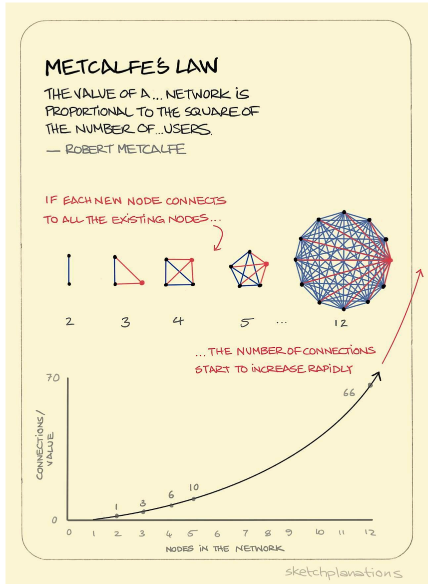
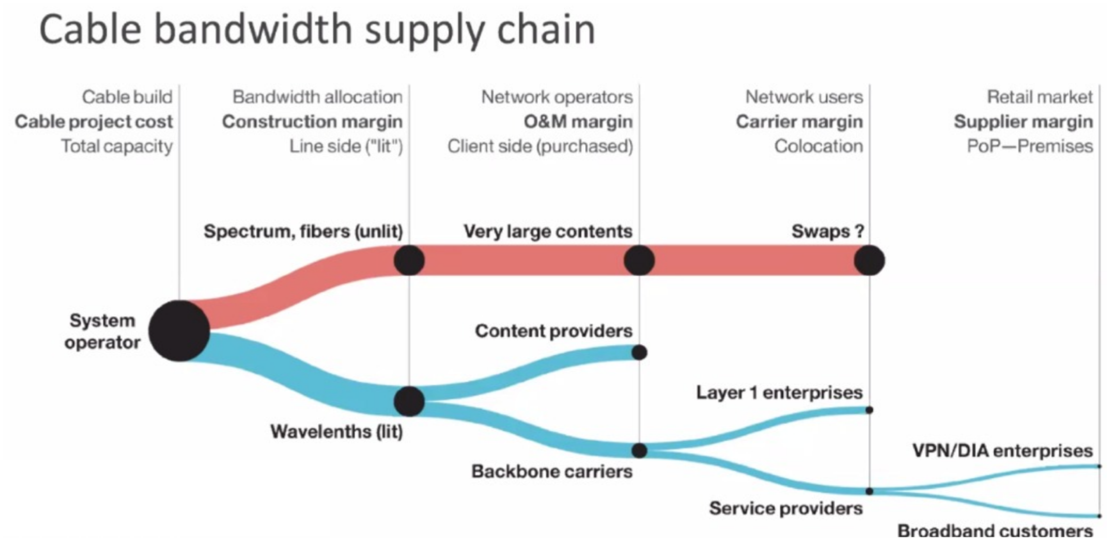
Submarine Cable: Business Background

- **What are the drivers for a new submarine cable?**
- **Connectivity analysis (connecting countries across oceans)**
  - Population
  - Internet penetration
  - Existing connectivity (Does it scale?)
  - Interconnection within global network (Does it fit?)
- **Financial analysis**
  - Is the a return on the investment?
  - In what time frame?
- **Metcalfe's Law**
  - The value of a telecommunications network is proportional to the square of the number of users of the system



Submarine Cable: Business Background

- **Submarine cable business case involves an assessment of:**
  - The opportunity
  - Potential benefits/revenues
  - Risk and mitigations
  - Technical solutions available
  - Cost (WACC/NPV)
  - Timeline
  - Impact on current operations
  - Capability to deliver the project



Submarine Cable: Business Background

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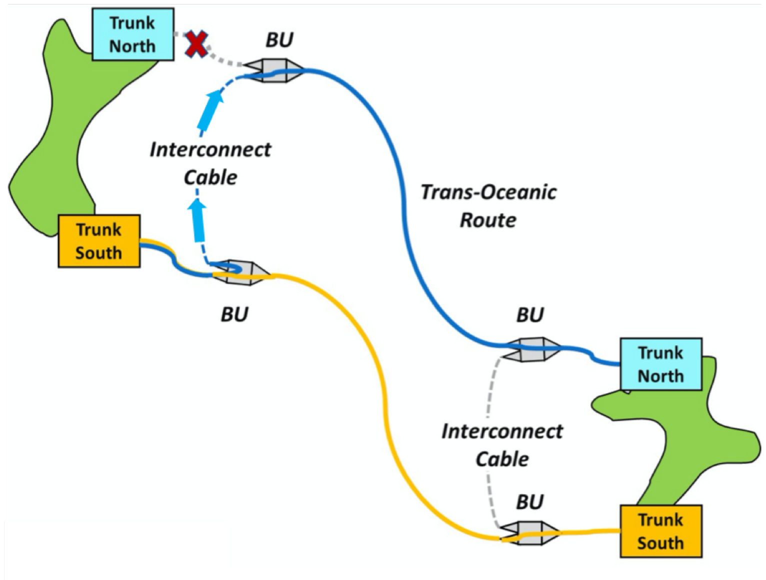
- **Market & traffic**
- **Transoceanic**
  - High demand, potentially many capacity sellers
  - Capacity tends to become a commodity
- **Regional**
  - Less demand, potentially fewer sellers
  - Less price pressure, long term purchase
  - Capacity remains a strategic resource

- **Market Assessment**
  - What is the addressable market for the cable?
  - Why is the cable needed?
  - Where does this cable go?
  - Who will make use of this cable?
  - When will this cable be ready for service?
  - How will this cable meet requirements now, and in the future?

Submarine Cable: Business Background

❑ **Submarine cable business system feature (design considerations):**

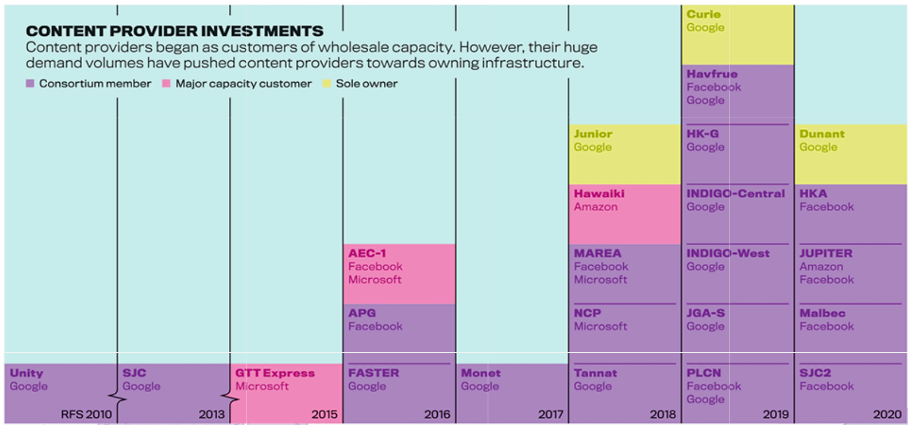
- Ultimate capacity
- Topology of system
- Closed system (turnkey end-to-end), Open Cable
- Traditional or SDM systems
- Wavelengths per fiber pair, fiber count
- Type of fiber and type of armoring
- Repeated or unrepeatered
- Branches and type
- Number, type and spacing of repeaters
- Power budget and design
- Type of landings, environmental considerations
- SLTE



Submarine Cable: Business Background

- **Who owns these submarine cables?**

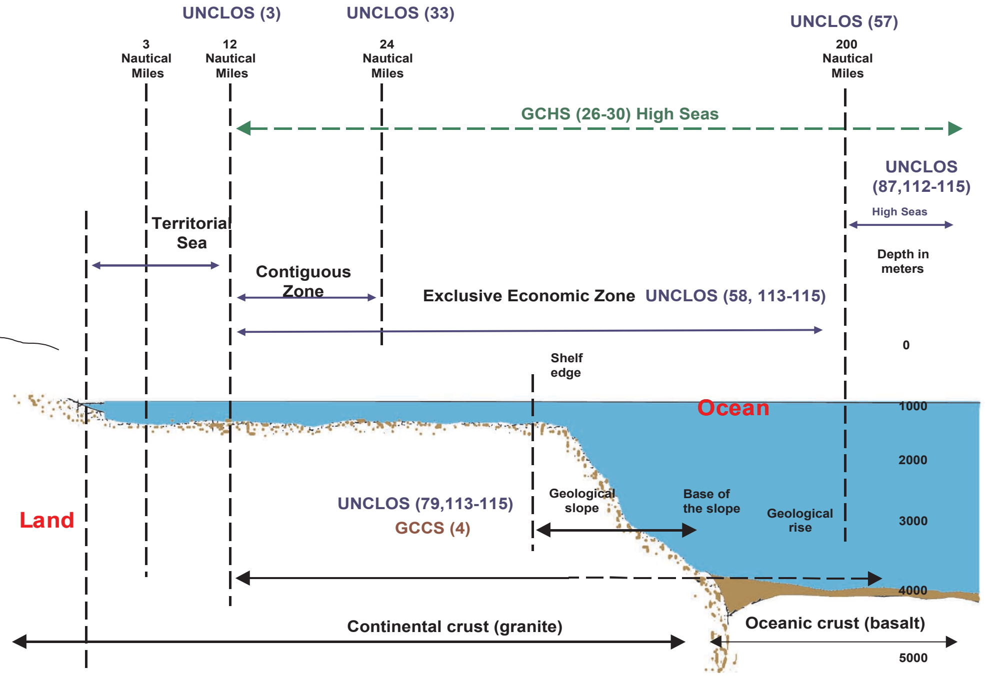
- Cables were traditionally owned by telecom carriers who would form a consortium of all parties interested in using the cable. In the late 1990s, an influx of entrepreneurial companies built lots of private cables and sold off the capacity to users.
- Both the **consortium** and **private cable** models still exist today, but one of the biggest changes in the past few years is the type of companies involved in building cables
- Content Providers such as Google, Facebook, Microsoft, and Amazon are major investors in new cable. The amount of capacity deployed by private network operators – like these content providers – has outpaced internet backbone operators in recent years. Faced with the prospect of ongoing massive bandwidth growth, owning new submarine cables makes sense for these companies.



Permitting

Submarine Cable: Permitting

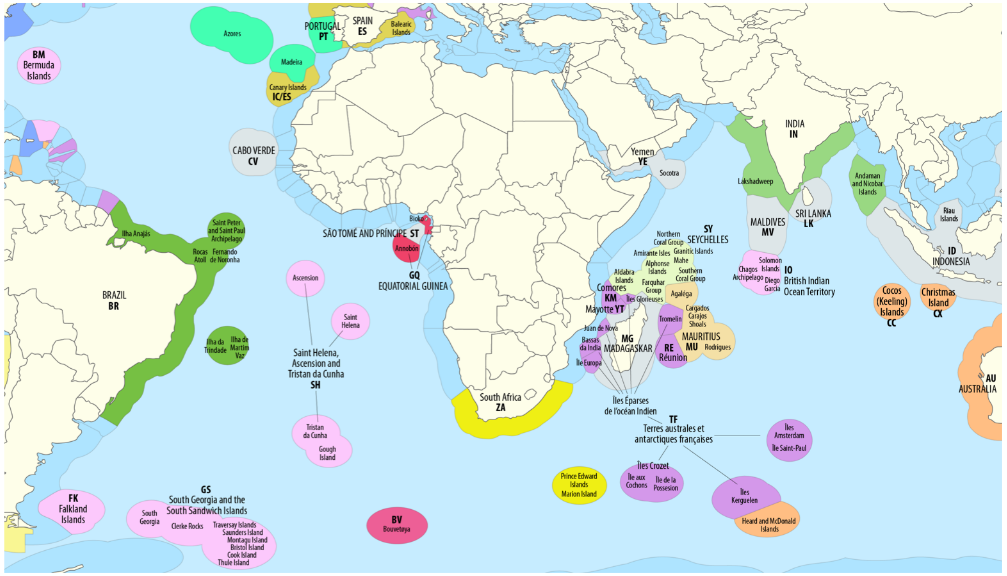
- **Landing & Operating**
  - Working permit: usually supplier's responsibility
  - Authorizations in principle: right to land/own a system on national territory, RoW, etc.. Usually cable owner's responsibility
  - Telecom licenses: Cable owner/operator's responsibility (possibly through local partnership)
- **The United Nations Convention on the Law of the Sea (UNCLOS)**
  - Also called Montego Bay Convention
  - 167 nations have ratified as of 2016
  - Waters are still disputed (south China sea)



Submarine Cable: Permitting

- **Proprietary Permits**
  - Right of way, easements, wayleaves and seabed lease agreements
  - Cable crossing agreements
  - Pipeline crossing agreements
  - Hydrocarbon and mineral lease blocks/concession agreement
  - Environmental impact assessments
  - EEZ notifications
- **Operational Permits**
  - Notices to mariners
  - Navy/coastguard permit/notifications
  - Local authorities and municipalities
  - Work visas
- **Other Permits**
  - Fisheries / Native communities
  - agreement

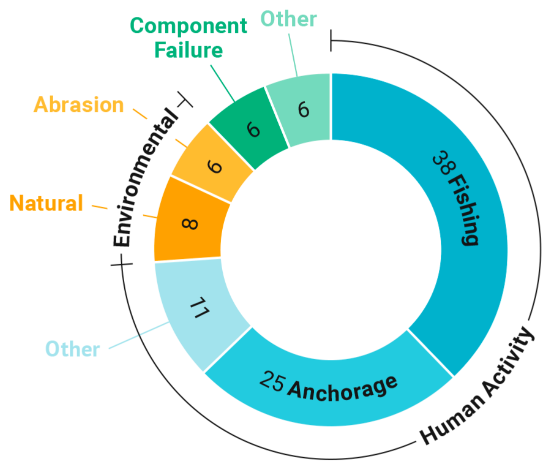
EEZs around the world



Submarine Cable Network Security

Submarine Cable: Network Security

- **Cable Network Security**
  - The submarine cable network is designed to be resilient, however there are several threats that can cause major disruption to the global economy
- **Don’t these cables ever break?**
  - Yes! Cable faults are common. On average, there are over 100 each year
  - You rarely hear about these cable faults because most companies that use cables follow a “safety in numbers” approach to usage, spreading their networks' capacity over multiple cables so that if one breaks, their network will run smoothly over other cables while service is restored on the damaged one

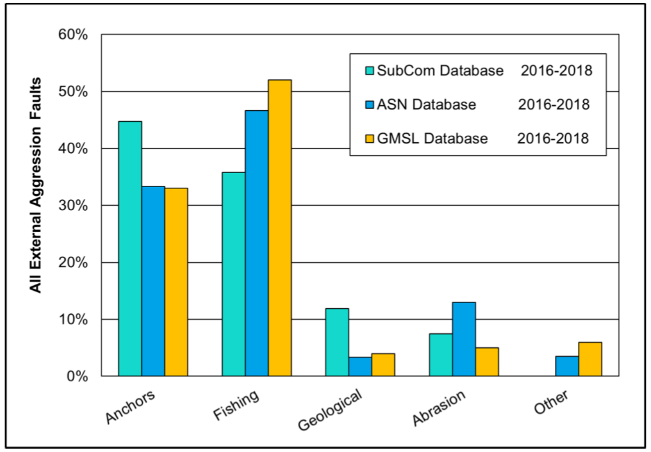


Submarine Cable: Network Security

- **Main fail causes**

- **Fishing** – high incidence but impact restricted to individual cables
- **Anchors** - medium incidence but can impact several cables
- **Natural Hazards** (e.g. earthquakes) – low incidence but can impact multiple cables
- Accidents like fishing vessels and ships dragging anchors account for two-thirds of all cable faults. Environmental factors like earthquakes also contribute to damage. Less commonly, underwater components can fail. Deliberate sabotage and shark bites are exceedingly rare.

80% of all cable faults are the result of external aggression (e.g. fishing & anchoring).



Suboptic 2019. M. Kordahi et al. New Orleans, LA, April 2019

Submarine Cable: Network Security

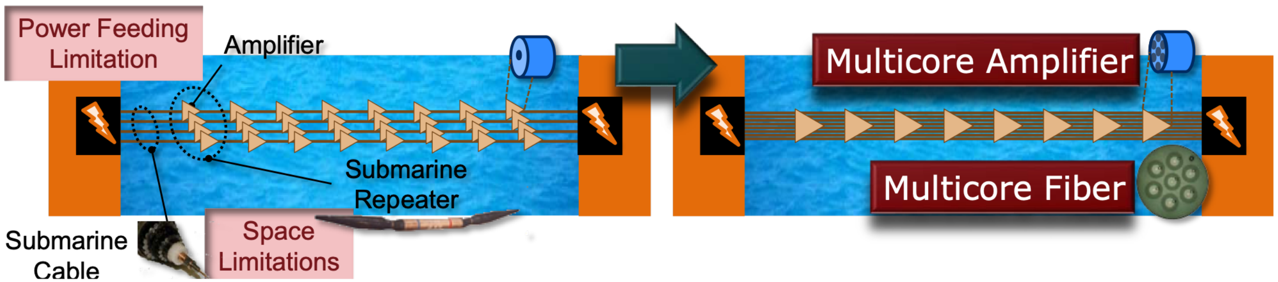
- **I've heard that sharks are known for biting cables. Is that true?**

- This is probably one of the biggest myths that we see cited in the press. While it's true that in the past sharks have bitten a few cables, they are not a major threat
- According to data from the International Submarine Cable Protection Committee fish bites (a category that includes sharks) accounted for zero cable faults between 2007 and 2014
- The majority of damage to submarine cables comes from human activity, primarily fishing and anchoring, not sharks

Trend and Challenges

Submarine Cable: Trend and Challenges
Spatial Division Multiplexing (SDM)

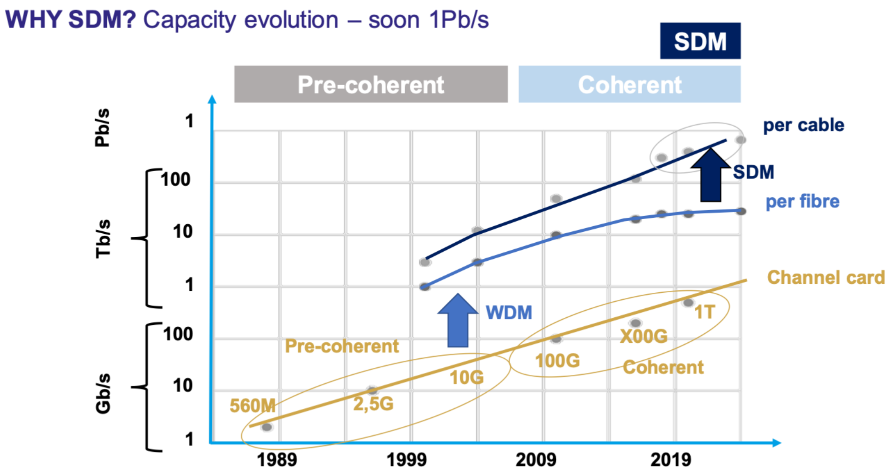
- **Trend: SDM**
  - Subsea systems have specific limitations (due to cable structure, manufacturing, handling and deployment, power limitations due to feeding of the optical amplifiers from the land
- **SDM can help increase capacity despite these limitations**
  - Higher signal density per cable area unit
  - Higher power efficiency through sharing and pumping techniques



Submarine Cable: Trend and Challenges
Spatial Division Multiplexing (SDM)

- **Trend: SDM**

- SDM economically increases cable capacity with additional fiber pairs (twelve instead of six or eight on traditional subsea cables) and energy-optimized repeater designs
- Traditional submarine cables are feed from the shore end and rely on a dedicated set of pump lasers to amplify the optical signal for each pair of fibers as the data traverses the length of the cable
- SDM technology now allows pump lasers and associated optical components to be shared between multiple pairs of fibers, while still working within the constraints of energy exclusive to the ocean floor
- Push the limits of theoretical design capacity by minimizing nonlinear effects that add complexity and cost;

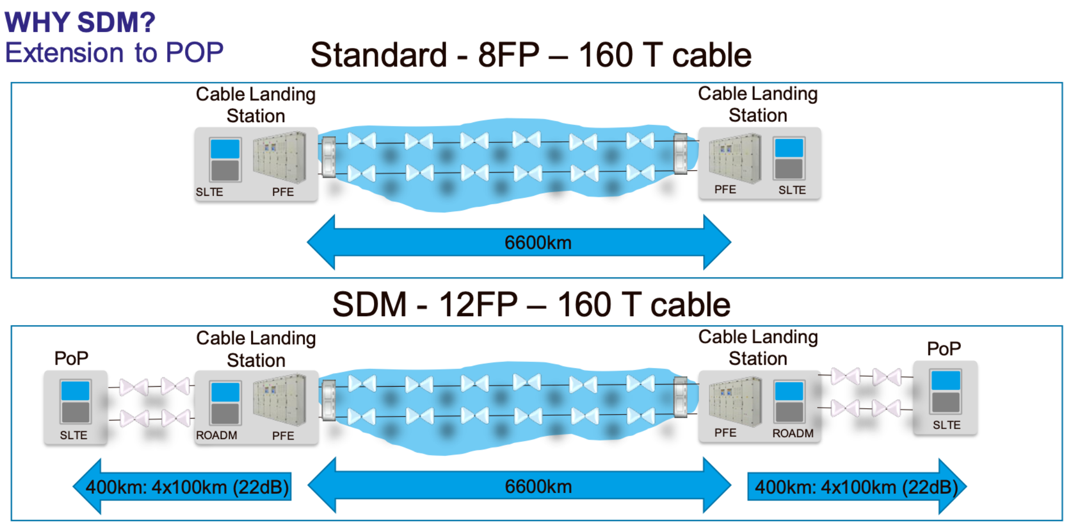


Submarine Cable: Trend and Challenges
Spatial Division Multiplexing (SDM)

- **Trend: SDM**

- Create and efficient optical and electrical network based on repeater pump farming, low Aeff submarine fibres, and higher fibre counts

- Work in the optimum spectral efficiency of SLTE: 2-3 b/s/Hz and lower chromatic dispersion compensation

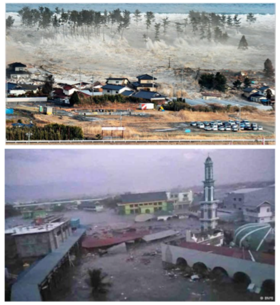


Submarine Cable: Trend and Challenges
Scientific Monitoring And Reliable Telecommunications (SMART)

- **Trend: SMART cables**

- Tsunamis colliding with the coast, causing enormous damage and lives. Rising sea levels engulfing islands and coastal communities. Warming oceans, agitating the extreme climate and melting the polar ice caps. Better monitoring and study of deep oceans can help us better prepare and mitigate all of these issues, but today scientists and disaster managers have few ways to do so. All of that can change, thanks to the submarine cables that already exist in the world today. **In this opportunity a SMART cable operates**

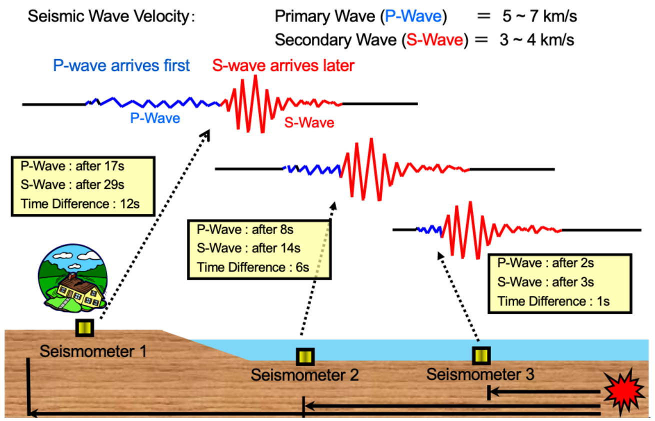
Tsunamis



Place	Year	Mag	H(m)	Deaths
Chile	1960	9.5	25	6,000
Alaska	1964	9.2	30	132
Mindinao	1976	7.9	9	7,800
Tumaco	1979	8.1	6	350
Hokkaido	1993	7.8	30	250
Papua New Guinea	1998	7.1	15	2,200
Sumatra	2004	9.2	33	230,000
Solomon Islands	2007	8.1	12	52
Samoa	2009	8.1	14	192
Tohoku	2011	9.0	10	19,000

Source: JTF

How fast do seismic waves travel?



Parameter	Normal Waves	Tsunami Waves
Wavelength	100m – 200m	100km – 500km
Period	5s – 20s	10m – 120m

Submarine Cable: Trend and Challenges

Scientific Monitoring And Reliable Telecommunications (SMART)

❑ **Trend: SMART cables**

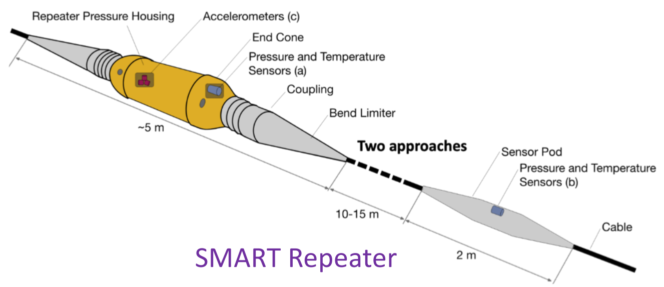
- The fundamental premise of SMART cables is to integrate environmental sensors into commercial submarine telecommunications cables. The crucial objectives are:

(a) obtain long-term temperature measurements on the ocean floor (to measure climate trends), pressure (to capture sea level rise, ocean currents and tsunamis) and seismic acceleration (to alert earthquakes and tsunamis; and seismology)

(b) have little or no impact on the operation of the telecommunications system that hosts the sensors,

(c) not requiring special methods of handling or implantation;

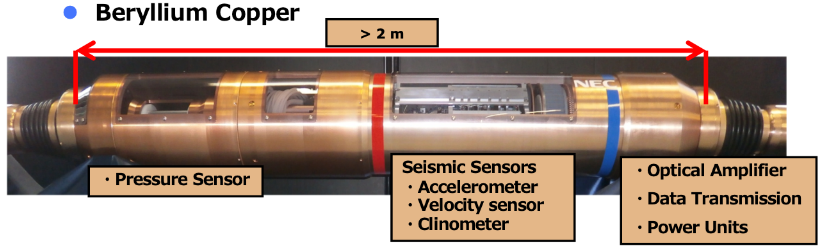
(d) be sufficiently reliable that 95% of all sensors operate for a minimum of 10 years without maintenance.



SMART Repeater

Unit Configuration
- **Pressure Sensor（Tsunami Sensor)**
- **Seismometer (ACC/VEL)**
- **Clinometer**
- **Optical Amplifier**
- **Data Transmission**
- **Power Units**

Pressure Tight Case
- **Resistant to 8,000m depth**
- **Beryllium Copper**



Submarine Cable: Trend and Challenges

Challenges

- **Challenges**

- Challenge 1 – Undersea fiber communication systems will continue to serve society?
- Challenge 2 – Continue exponetial push (more fibers or more cables)?
- Challenge 3 – Add developing countries on the digital train (too expensive to build and maintain)
- Challenge 4 – Develop low cost solutions (to feed internet everywhere to connect isoleted populations)
- Challenge 5 – Optimising cost of terminals (use of higher baud rates for cost efficiency)
- Challenge 6 - Wet plant cost (reducing material cost, targeting reduction of marine cost..)

- Traditional submarine cables are feed from the

Submarine Cable: Trend and Challenges
Long term challenges in submarine cable systems

- **Challenges are beyond optronics**

- High cost of cables and long Project durations limits ubiquitous connectivity
- Capacity growth is higher than unit cost reduction
- Need for cable and landing physical diversity for high-availability services
- Marine operations largely unchanged for decades
- Slow cable laying and repair times
- Cable breaks and demages

Doubts?

One more very important thing

Subsea Optical Fiber Communication International Summer School

Edition 2019 – Finland
Edition 2020 – Online
Edition 2021 – South Africa (coming soon)

More information:

https://www.osa.org/en-us/meetings/topical_meetings/subsea_optical_fiber_communication_international/

online meeting lacnic 34 lacnog 2020