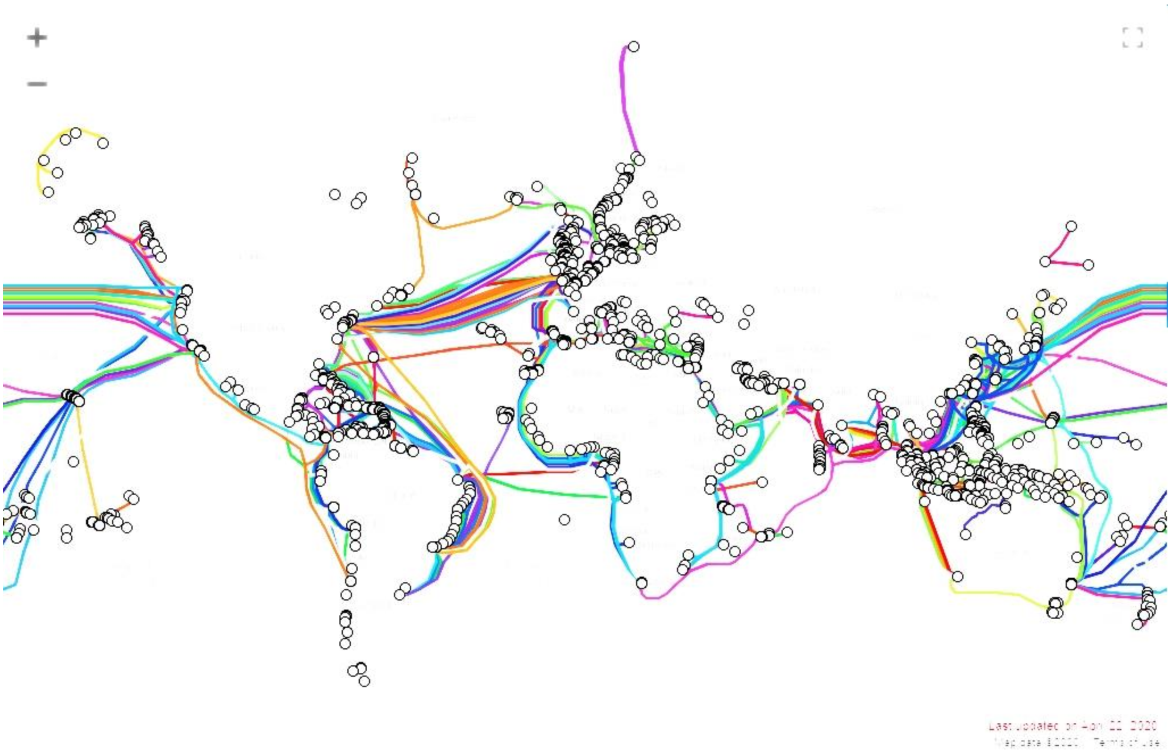

Submarine cables map

SUBMARINE CABLES: CONNECTING WORLD

A CASE STUDY

Prepared by:

PRABHAT

B.Sc. (Hons) PHYSICS

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INTRODUCTION

NEED AND DEPENDENCE:

(Why should we even care about reading this)

SUBMARINE CABLES, which are optical fibres above (sometimes in the) the sea bed of nearly the whole world as could be seen in picture, is considered as the backbone of communication. Currently **99% of the data traffic** that is crossing oceans is carried by undersea cables. Also, the total carrying capacity of submarine cables is in **the terabits per second**, while satellites (rival of submarine cable) typically offer only 1,000 megabits per second and display higher latency (the delay in processing the signal). Submarine cable network is so important for world-wide-web that during the Cold War, the United States Navy and National Security Agency (NSA) placed wire taps on Soviet underwater communication lines. As of early 2020, there are approximately **406 submarine cables** in service around the world, which will continue to grow for better.

ORIGIN:

(How did this thing came to be like what it is now)

The name, Submarine, speaks for itself. They are cable laid out underwater to connect countries and now even continents. The network was getting started to lay out in 1850s. But surprisingly the early cables were not for communication, rather to provide power.

POWER SUBMARINE CABLES

The purpose of submarine power cables is to transport the electric current at high voltage. The electric core is a concentric assembly of **inner conductor** (generally copper), electric **insulation** (could be any polymer with suitable properties, oil-filled channels which is profitable for **high-voltage-non-aerial transmission** to avoid voids in insulators) and **protective layers** (give it strength during laying and protection afterwards). They are used in **three-phase AC system** in which three separate, single-core underwater cables, are used carrying one of the three phase electric current.

Figure 2: A cross-section of power cable containing metal sheaths to carry AC high voltages. Notice that the core is not one beam but stranded from small wires; the sole reason for this is greater flexibility, even though the resistance will be higher and construction will be tougher.

GREAT VENTURE IN ATLANTIC

(Could be said as place of revolution in submarine cable technology)

Figure 2: Maker's sample case for the 1858, 1865, and 1866 Atlantic Cables Photographed April 2009, Science Museum, London

It all started with one ambitious and visionary business man, as it always does, **Cyrus Field**, when he proposed this impossible idea of laying out wire through Atlantic in 1854 when the longest cable was of 20 miles in that time. After two failed attempts, then in 1858 first ever submarine cable was planted connecting Newfoundland to Ireland. Progresses were being made in design to improve **efficiency, durability, accuracy, transmission rate, weight of armoury and costs and after doing surveys of sea-beds** in subsequent 50 years. In first half of 20th century, it continuously faced competition by wireless communication like radio and satellite communication but due to security reasons, submarine cables kept to prosper. Fortunately, fibre optic cable came to the rescue, and here we enter the present era of cable communications. **1988** saw the introduction of **TAT-8**, the first fibre optic cable across the Atlantic.

*Despite all the changes, many things have stayed the same in **150 years**. Cables still have a conductor to carry the signal (**glass instead of copper**), an insulator to protect the circuits against water (**polyethylene instead of gutta percha** (a rubber-like material found in England)), and a strength member (**steel instead of iron**). Cable routes are surveyed with the aid of **satellite navigation instead of celestial navigation**, but cables are still laid by* *dropping them off a ship while steaming ahead, using a cable engine to regulate the paying out speed. Repairs are made as they always have been, by hauling the fault section (whose search has a complicated procedure) of cable up from the depths and splicing as needed.*

TIMELINE

This is showing how things were changing, and which of the things accelerated the growth of submarine cables.

- **1843**: Samuel Morse gave the idea of possibility of submarine cable
- **1849**: American naval vessels began systematic deep-sea soundings in the Atlantic
- **1854:** Cyrus Field proposal of Atlantic cable
- **1857/58:** Atlantic cable expedition had a tragic end
- **1858:** First cable was successfully laid in Atlantic thus the expansion began.
- **1872:** Bombay was linked to London
- **1874:** Special Cable ships, named FARADAY, was built
- **1875:** Telephone was invented and thus telegraph lines were replaced by telephonic
- **1930s:** Polyethylene was introduced in place of Gutta-percha
- **1950s:** In-line Amplifier were used, paving way to telephonic communication
- **1960:** LASER was invented
- **1966:** Charles K Kao experimented with the world's first **single-mode optical** communication fibre, which was made of glass.
- **1970:** low loss optical-fibre was developed
- **1987:** working model for optical amplifier were realised
- **1988:** TAT-8, first optics fibre cable across Atlantic (any ocean in fact)
- **2012:** The huge speed of 100 Gbps was demonstrated up to 6,000 km which is still getting improved faster than ever.

DESIGN OF CABLE

Over 100 years of history the main structure is more or less the same for submarine cables as discussed earlier. They consist of conductor, insulation and armour encasing the entire structure. Gutta-percha and rubber are replaced by **polyethylene** which has made the cable narrower and lighter. Copper conductor is replaced by glass with doping which has lowered the attenuation and so the number of **repeaters** drastically. The tar-soaked-jute is replaced by **steel strands,** which was really a blessing for engineers because of the weight reduced and flexibility increased. In the figure below (figure 3), one can see different structures. For deep water because there is less turbulence and disturbance and human intervention, they are laid directly on the ocean floor. **LW or LWP** are particularly come in service for that. In the shallow sea **SA or DA** are used and are buried under the sea-bed for protection, which explains why you don't see cables when you go the beach.

BANDWIDTH PROBLEM

During *TELEGRAPHIC AGE*, the loss due to resistance was generally coped with sending the high voltages, which end up decreasing the **bandwidth (the capability of wire to carry the information, frequencies)** drastically. And there were not any repeater technology there at that time so at the receivers end, there used to be **mirror-galvanometer**, which is highly sensitive, to detect small telegraph signals. Due to which transmission rate was 6-8 words per minute. In *TELEPHONIC AGE* transoceanic cables were coaxial cables that transmitted **frequency-multiplexed-voice-band-signals (**a single cable was assigned to hold various channels)**.** A high-voltage direct current on the inner conductor powered repeaters (two-way amplifiers, placed at specific distances along the cable). That time they could support from 36 to 4000 channels. In *fibre-optic communications*, wavelength-division multiplexing (**WDM**) which is a technology to multiplex a number of optical carrier signals onto a single optical fibre by using different wavelengths of laser light. This technique enables bidirectional communications over one strand of fibre, as well as multiplication of capacity. There's a very subtle fact which has been employed here that light waves don't interact with each other. Basically different frequencies were sent and in de-multiplexing site (receiver's end) there is an

Etalon named device which filter different frequencies on the principle of **Fabry-Parot Interferometers** (resonance of light wave). This dramatically increases the capacity of the fibre to the point where, there is **for all practical purposes unlimited bandwidth** to almost every part of the world at a very low cost.

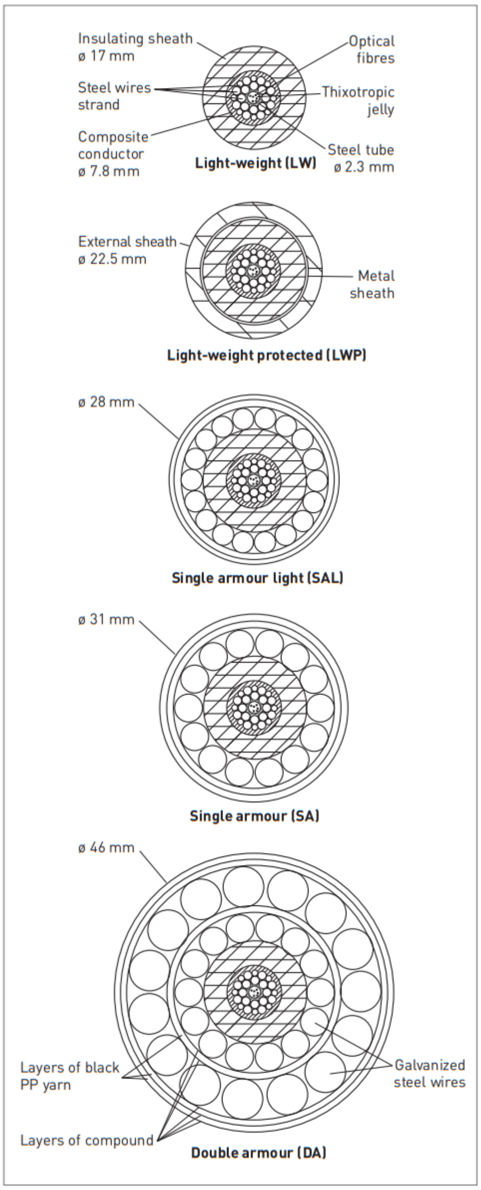

Figure 3: As mentioned the conductor is only a part of submarine cable they are large due to armour of cable which help them to withstand adverse conditions in deep oceans. With time and place the design of cable was improvised and these are some of the

Optical Fibre

SIGNAL PROCESSING

(What does really communication mean anyway)

The most basic form of a signal is switching the state of some system, a pulse (turning off and on the light, moving your hand up and down). Every information (text, image, video, audio) can be boil down to these binary signals and therefore we need something for transmission of these “signals”. *Though internet (telegraph too) uses digital signals, the signals in communication are Analog*, in which a modulation (either Frequency modulation or Amplitude modulation) of signal wave on carrier wave is done. The carrier wave is of that frequency which is favourable to the optical fibre to carry.

These signals can be afterwards be interpreted using algorithms and produce information on the other side. This is called **decoding an encoded signal**. The first established information encoded in signals were Telegraphs, involved the transmission of coded electrical impulses through a conductor.

The light-wave communication was backed with invention of ***LASER*** which is a highly coherent source, phenomenon of total internal reflection which is driving principle behind optical fibre.

TIR

It refers to the 100% reflection from an interface of two media having different refractive index. But this doesn’t mean that the electric field in the rarer medium is 0. This electric field decays exponentially away from the surface and therefor called **evanescent wave.** This becomes important while we talk about **single mode fibres**. Since there is a critical angle after which the internal reflection happens, this limit translates itself into a specific **cone, called acceptance cone**, light coming from outside of which at the entrance of fibre won’t be able to incident on the core-cladding interface with the angle greater than critical angle resulting in **partial refraction**, leading to attenuation. So one can think that it will be easy if a material having huge refractive index is used, that will solve all the problems. But that’s not true cause in denser (optically) material, light will travel much slower decreasing the transmission rate. Therefore engineers’ job is to find a sweet spot for efficient and quicker communication.

PULSE DISPERSION

Basically a light wave, being a **Gaussian wave** (range of frequencies), tend to broadens up (the beam expands geometrically) in time as it propagates through the fibre, this phenomenon is called **pulse dispersion.** This can happen due to difference in their geometrical position or difference in their wavelengths which cumulates to give appreciable errors in signals. This provides a limitation to transmission capacity of fibre as the signal will wither down and becomes unresolvable (information is un-retrievable). Generally, in place of **step-index fibre, graded-index** (there is no steep change in refractive index of material) is used to minimize this lose. Apart from these, we have **Absorption, splice and Radiative losses** also amounts significantly in signal loss.

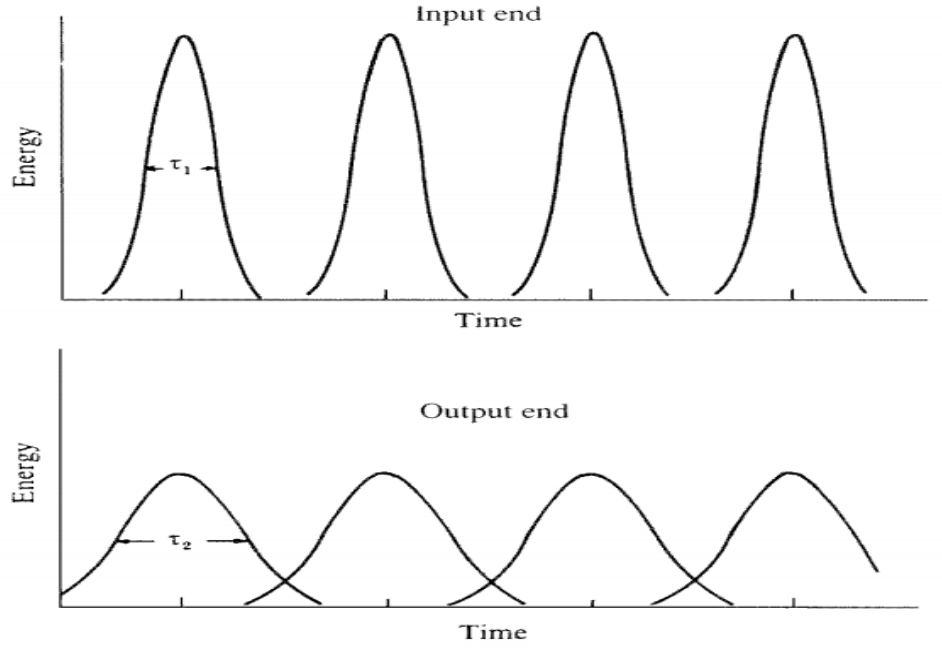

Figure 4 : Signal is pulses, and a specific pattern of pulses gives you a signal. If that signal is unresolvable like as shown, the information cannot be retrievable.

OPTICAL AMPLIFIER

(Because signals are worth repeating)

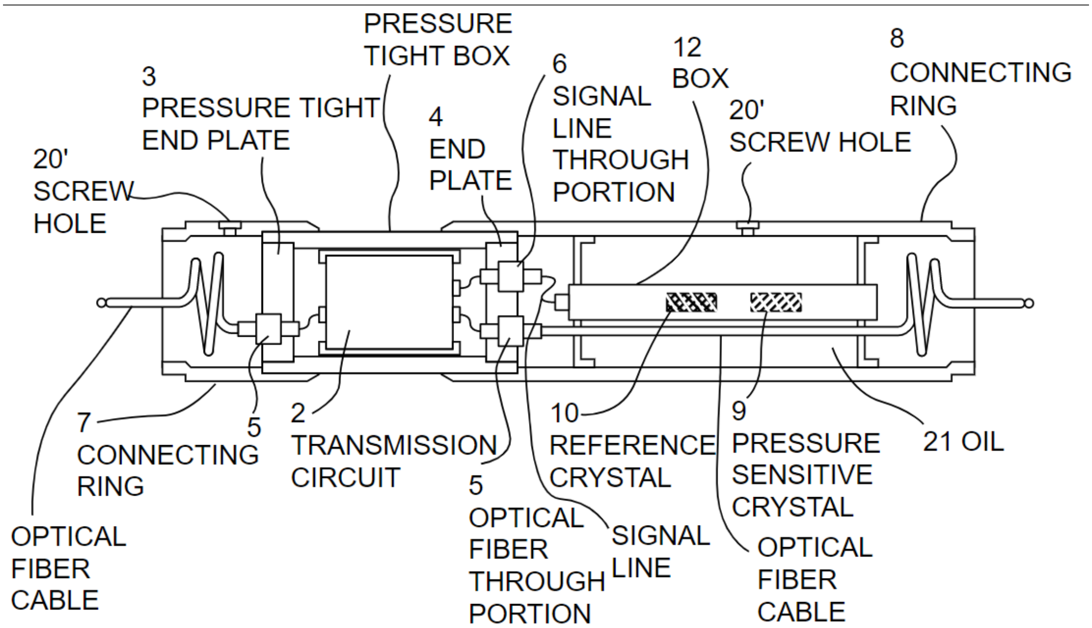

Figure 4: A schematic diagram of optical repeater, which is a device which amplifies the light signals without converting them to electrical signals. Important components in this are transmission circuit, reference crystal, pressure sensitive crystal where amplification of signal happens.

The signals tend to weaken down (in case of light, the number of photons decreases) over large distance due to **fibre attenuation, connecting loss, splice loss** (both of which is based on that information is lost at interfaces), etc. Before Optical amplifier, signal used get converted into electrical signals, then get amplified and after that reverting to optical signals through **repeaters**. That was inefficient, as they added too much noise to the system, and uneconomical, because you have to power amplifiers too which used to add extra load to submarine cables. Typical **EDFA** (Erbium doped fibre amplifier) amplifier contain **pump LASER** which supplies the energy for amplifier by exciting **ERBIUM crystal** and light wave is made to pass through that and **signal simulates** the emission, giving out the amplified signal. This emission happens throughout the length of fibre doped with Erbium which can provide output as large as 100mW as shown in the figure 5. The range of wavelengths for erbium-doped-fibres is from 1450nm to 1650nm. The figure 5 describes the emmsion of 1500-1600nm wavelengths which is generally used in optical communication. Erbium is particularly used because of two reasons, one is that it is easily diffusable (easily dopable) to fibre glass and second is that it produces emmision of the wavelenghts. As can be seen, the **900nm** pump-LASER excites the doped fibre which in turn emits photon on simulation by signal photons giving exponentially more photons replicating the signal.

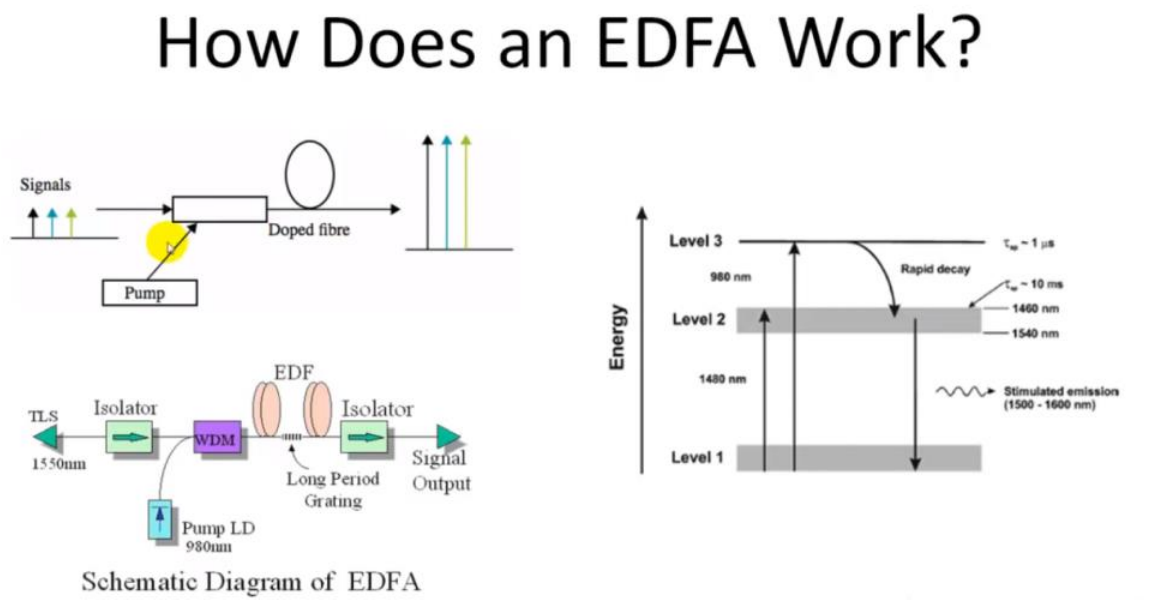

Figure 5: Entire working of EDFA

DISCUSSION

INTERNET AND ECONOMY

(Why submarine cable became a huge success)

At the time when optical fibres were getting laid out, replacing telephonic co-axial cables, **internet** was growing fast. As newer and higher-capacity cable systems evolved, they had large bandwidth at sufficiently low cost to provide the necessary economic base to allow the internet to grow. In essence, these two technologies **complemented each other** perfectly: cables carried large volumes of voice and data traffic with speed and security; the internet made that data and information accessible and usable for a multitude of purposes. As a result, communications, business, commerce, education and entertainment underwent radical change to take the current shape. We are still seeing huge investments in submarine cable which shows it is going to stay there in the market for at least 100 years.

Also a quote from Henry David Thoreau (American essayist) :

"Our inventions are wont to be pretty toys, which distract our attention from serious things. They are but improved means to an unimproved end, we are in great haste to construct a magnetic telegraph from Maine to Texas; but Maine and Texas, and it may be, have nothing important to communicate."

This tells you about the **global position** of country or even continent sometimes. Denser the network is there, the richer, more impactful the country is, because then only more clients would invest in separate connections. For example, there's just not much data that needs to go between Australia and South America directly, so numbers are lesser. If that situation were to change, you can be sure someone would build a new cable in the South Pacific.

OBSTACLES

SECURITY IMPLICATIONS

Though it is safe than satellites cause directed and encrypted messages are sent, submarine cables are problematic from the security perspective now because maps of submarine cables are widely available. Publicly available maps are necessary so that shipping can avoid damaging vulnerable cables by accident. However, the availability of the locations of easily damaged cables means the information is also easily accessible to criminal agents.

MARINE LIFE

Noise emission, heat dissipation, occurrence of electromagnetic fields, contamination and disturbance were identified potential environmental issues associated with submarine cables. When electricity runs through the cables, they emit an electromagnetic field that many marine creatures can detect. Some marine animals use the Earth's magnetic field to guide their migratory movements; others use electromagnetic signals to detect prey. They do disturb the marine ecosystem but the implications are not yet understood.

COMPETING WITH SATTELITE COMMUNCATION

Satellites are great for certain applications. Satellites do a wonderful job of reaching areas that aren't yet wired with fiber (Like discussed earlier, places which have negligible traffic, rural areas, places where cable-network is not feasible like Antarctica). All **mobile networks** use satellite communication. They are also useful for distributing content from one source to multiple locations (**broadcasting**). That's why submarine cable didn't throw the satellites away altogether and we have companies like Google and Facebook still investing in wireless devices, just to connect less developed parts of world. However, on a bit-for-bit basis, there's just no beating fibre-optic-cables. Cables can carry far more data at far less cost than satellites.

MAINTANENCE

Cable faults are common. On average, there are over 100 each year. And because these faults are so often and inevitable in some sense, that companies always give a backup-connection and the network is spread over number of connections.

The **age of cable** is said to be about 25 years if not damaged before that. But since with time the technology advances and a better cable replaced these cable before this span, generally.

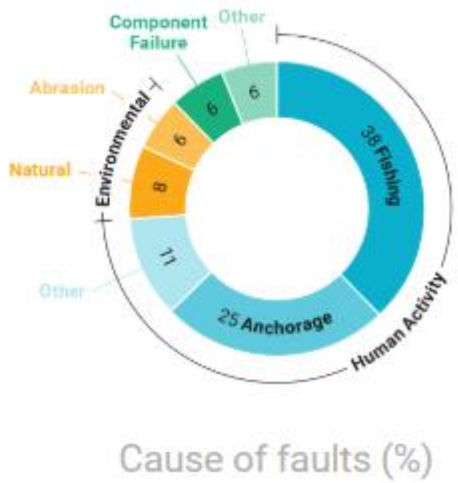

Figure 5: There is a distribution of causes of cable-failure over a year is given. As you can see major failure (about two-third) are caused by human intervention, though the cable routes are supposed to be well known to these people. Though popular in media, shark bites are rare.

REFERENCES

- A.G., K.T. ; Introduction To Optical Fibre
- www.submarinecablemap.com
- https://circuitglobe.com/oil-filled-cables.html
- https://en.wikipedia.org/wiki/Submarine_power_cable
- http://www.bdloops.com/solid_vs_stranded_loop_wire.html
- http://www.submarinecablesystems.com/default.asp.pg-history
- http://www.atlantic-cable.com/
- https://www.wired.com/1996/12/ffglass/
- https://en.wikipedia.org/wiki/Mirror_galvanometer
- https://en.wikipedia.org/wiki/Wavelength-division_multiplexing
- FOA Lecture 32 Fiber Amplifiers:
- https://www.fiberoptics4sale.com/pages/knowledge-base
- https://en.wikipedia.org/wiki/Optical_fiber
- https://www.bfn.de/fileadmin/BfN/meeresundkuestenschutz/Dokumente/BfN_Literaturstudie_Effekte_marine_Kabel_2007-02_01.pdf