

Lecture 3: The Physical Layer & Transmission Media

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EE426: Communication Networks

The Physical Layer

- Converts bit streams into electrical or optical (electromagnetic) signals that can transfer information from one part of the network to another over a transmission medium.
- An electromagnetic wave propagates through vacuum at a speed of $c = 3 \times 10^8$ m/s and at smaller speeds in other materials.
- Common transmission media are illustrated in the following slides.



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1. Copper Wires

- **Three Types:** Unshielded Twisted Pair (UTP); Shielded Twisted Pair (STP); Coaxial Cable.
- **Advantages:** Inexpensive; Easy to Install.
- **Disadvantages:** High Interference (except for coaxial cable); High Attenuation; Small Bandwidth.
- Very **common** in short-range and medium-range computer networks and telephone networks (i.e., in an office or building).
- Twisting of copper wires reduces outside interference.

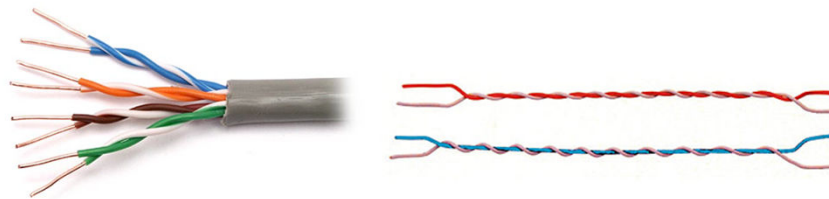


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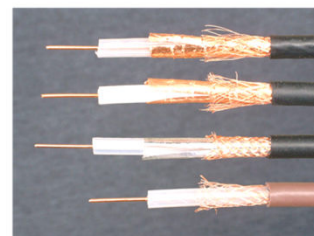
Copper Wires



UTP



STP



Coaxial Cables

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2. Optical Fibers

- Flexible fibers made of glass/plastic.
- **Advantages:** Minimal Interference; Small Attenuation (a repeater is needed every 100 km instead of every 5 km in copper wires); Wider Bandwidth; Need only a single fiber not a pair of wires to transmit a signal.
- **Disadvantages:** Expensive (specially lasers); Special equipment to install; If fiber breaks inside the plastic jacket finding the break point is difficult and requires special equipment to fix (create the splice).
- Very **common** in long-range computer networks (i.e., on the level of a city or a country).



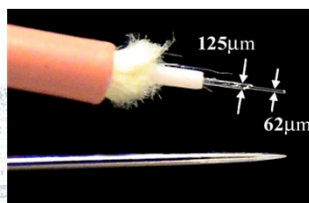
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Optical Fibers (Cont.)

- Can use Dense Wavelength Division Multiplexing (**DWDM**) to multiplex multiple carries on one fiber thus efficiently utilizing its huge bandwidth.
- The **main** transmission technology used on fiber is **SDH/SONET**.



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3. Wireless Channel

- Use the signal to modulate a high frequency carrier.
- Low frequency is **RF transmission**. Higher frequency is **Microwave** transmission. Even higher frequency is called Millimeter wave transmission.
- **Advantages:** Easy to setup. Lower cost (no cables).
- **Disadvantages:** High attenuation; High Interference; Radio transmission can harm humans if power is high; Microwave and Millimeter wave require line-of-sight.



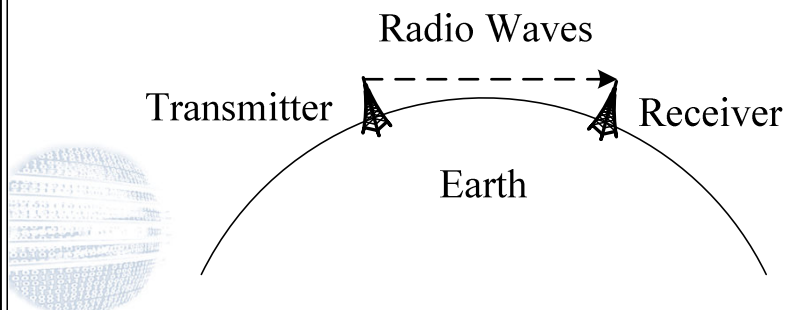
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Wireless Channel (Cont.)

- Wi-Fi, Wi-MAX and Bluetooth are examples of networks that use wireless links. Terrestrial TV & AM/FM Radio are older systems that use RF.



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4. Satellite

- Satellites contain **transponders** that receive signals from an earth station, amplify these signals and retransmit them to another earth station.
- **Advantages:** Larger coverage area compared to Radio/Microwave (suitable for broadcasting); Mobility is possible.
- **Disadvantages:** Expensive (Satellite/Earth Station cost); High attenuation; High Interference; Long delay (for GEO satellites).



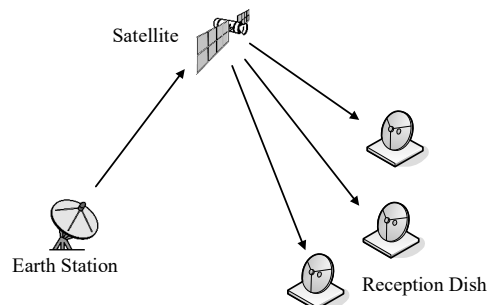
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Satellite (Cont.)

- Three orbits for satellite systems:
- Geostationary (Geosynchronous) Earth Orbit (**GEO**) [Examples: Thuraya, Inmarsat and TV broadcasting].
- Medium Earth Orbit (**MEO**) [Examples: GPS (Global Positioning System), Glonass, Galileo, and Satellites that cover North and South Poles].
- Low Earth Orbit (**LEO**) [Examples: Iridium, Globalstar, Teledesic, SpaceX Starlink].

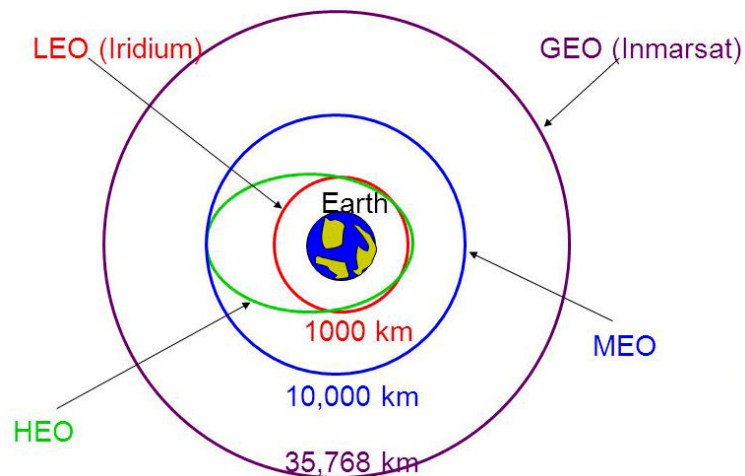


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Satellite Orbits

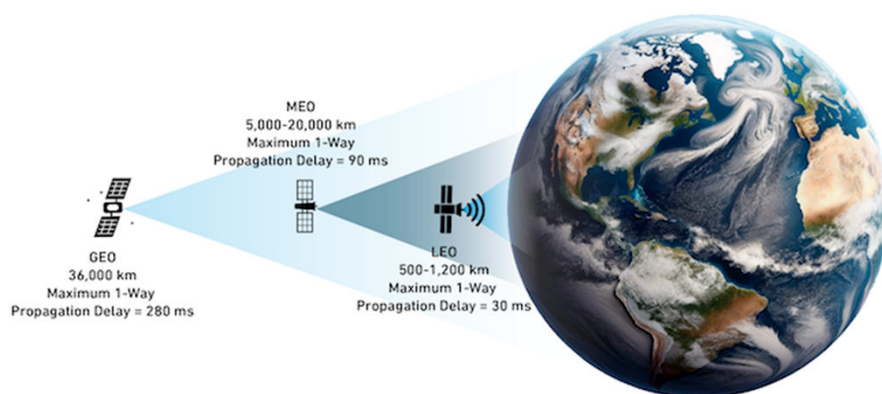


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Footprint (Coverage) & Delay

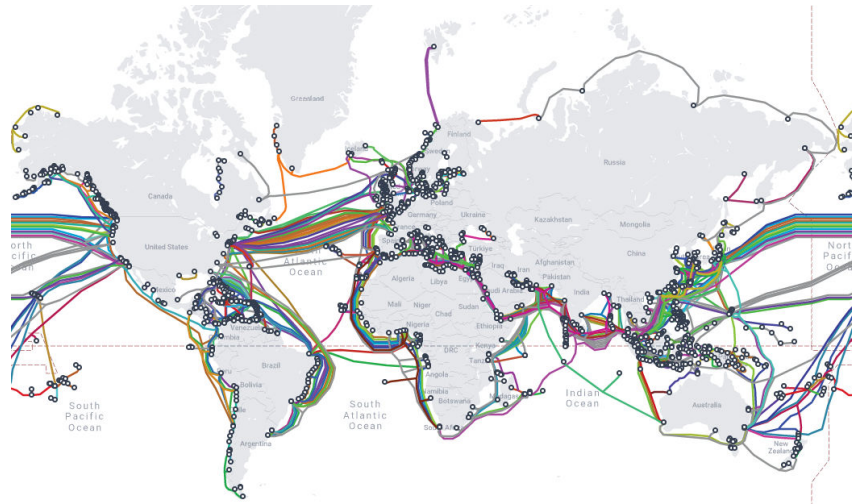


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Optical Fiber Submarine Cables

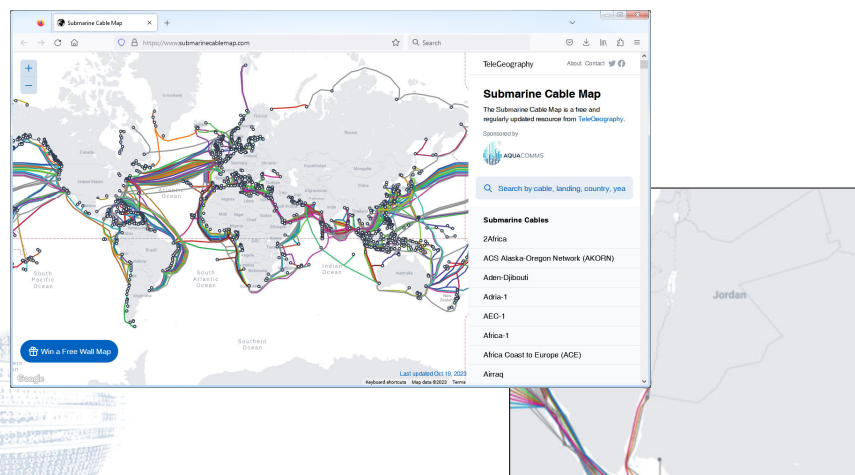


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Interactive map @
<http://www.submarinecablemap.com>



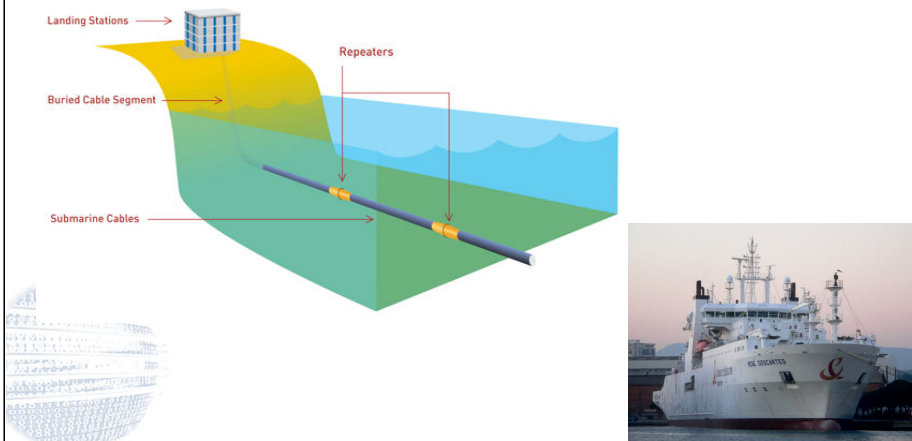
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Submarine Cable Laying

Submarine Cable System Components



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Cable Laying (Cont.)

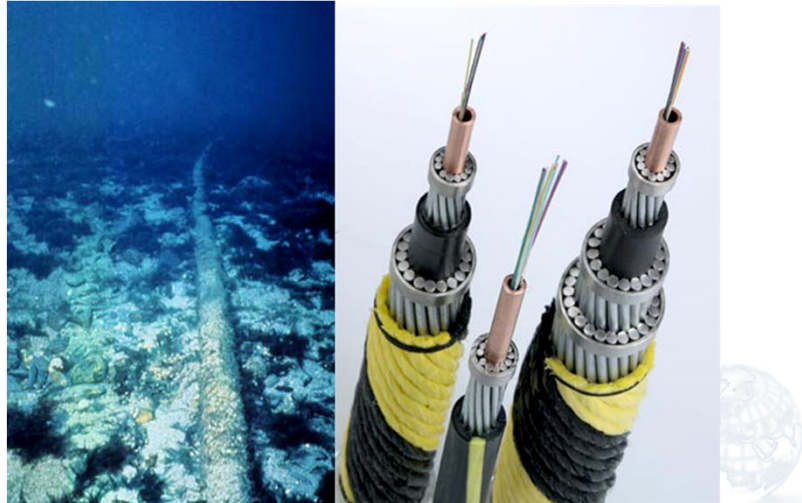


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Cable Laying (Cont.)

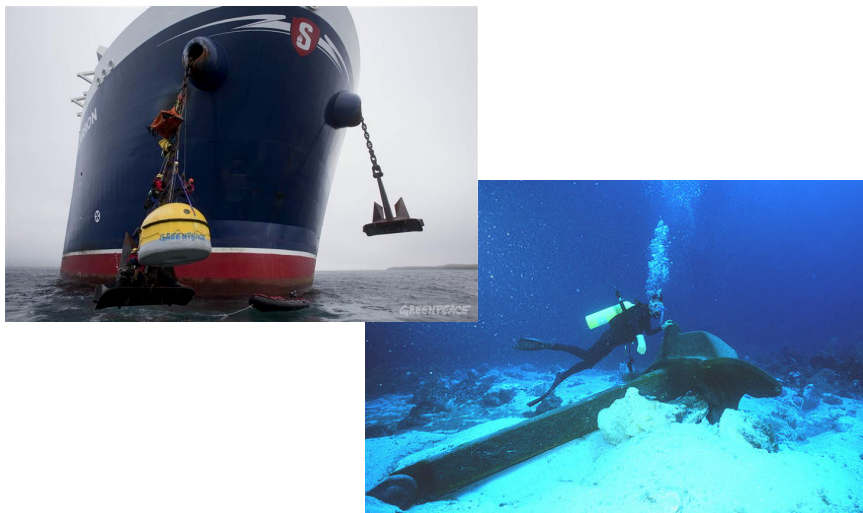


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Cable Cuts: Ship Anchors

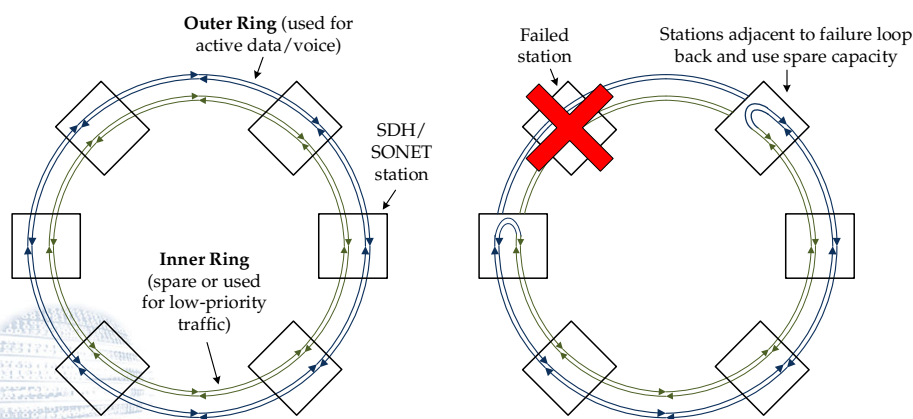


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Network Protection using SDH/SONET rings



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FLAG: Fiber Link Across the Globe

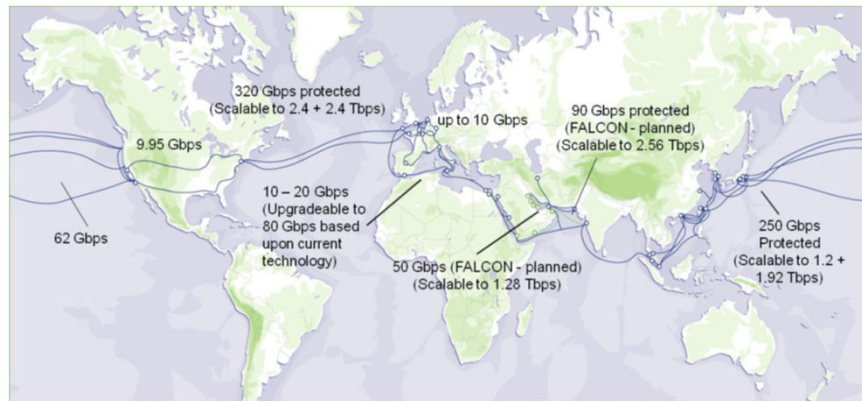
- **FLAG** (Fiber-optic Link Around the Globe) is one of the main operators of an optical fiber cable system that connects major cities around the world.
- FLAG is now part of Global Cloud Xchange.
- FLAG was built on multiple stages. The parts that cross the middle east are:
 - FLAG Europe-Asia (FEA)
 - FALCON (FLAG Alcatel ...)



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FLAG Submarine Cables



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FLAG Europe-Asia (FEA)

- Links Western Europe and Japan through the Middle East, India and China. The cable comes ashore at 16 landing points in 13 countries (China, Egypt, Hong Kong, India, Italy, Japan, **Jordan**, Korea, Malaysia, Saudi Arabia, Spain, Thailand, UAE and UK). It is a two fiber pair, multi-sectioned point-to-point system with a capacity of 20 Gbps on many segments. Went live on November 1997 and is 28,000 km in length. Allowed services include bandwidth purchase and lease of E1, DS-3, STM-1 and STM-4.

Initial Capacity (Gbps)	20	Capacity fully upgraded (Gbps)	80+
Fiber Pairs	2	Fiber Pairs	2
Wavelengths per Fiber Pair	1 – 2	Wavelengths per Fiber Pair	4
Gbps per Wavelength	5 – 10	Gbps per Wavelength	10

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FLAG Europe-Asia (FEA)



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FALCON

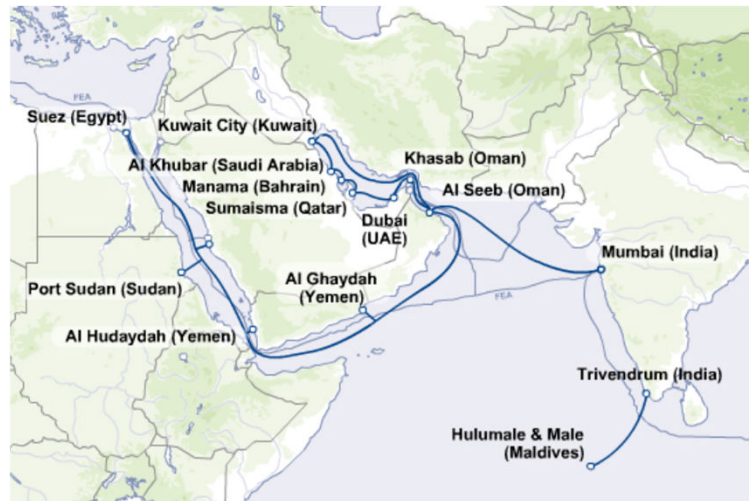
- FALCON delivers a high-capacity, self-healing submarine network ring (loop) with multiple landings throughout the Gulf region (Initial launch capacity 50 Gbps, Maximum design capacity of 1.28 Tbps) in addition to four fiber pair route linking the Gulf to Egypt and India (Initial launch at 90 Gbps, Design capacity of 2.56 Tbps). Announced on February 2004. Full service launch in September 2006. Cable length is 10,300 km.

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FALCON

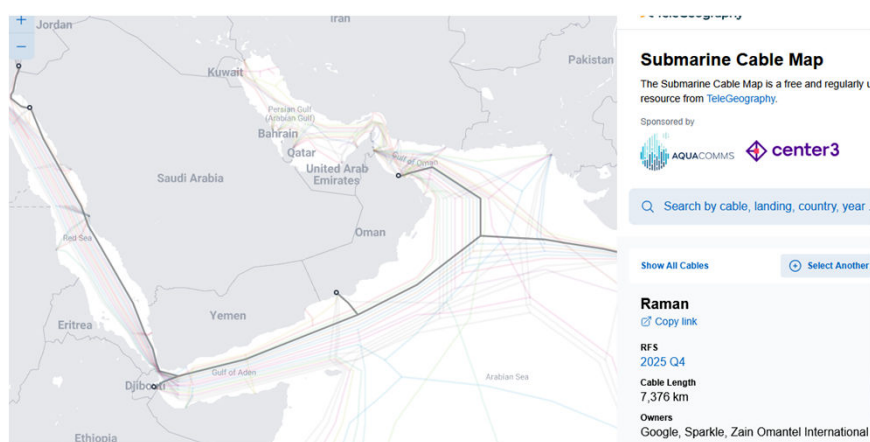


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Raman Cable (2025 Q4)



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Modern Cables: *Total* Capacity

MAREA	Q1 2018 (planned)	6,600 km	160 Tbit/s		Virginia Beach, US-VA; Bilbao, ES-PV	Facebook, Microsoft, Telefónica
Grace Hopper	September 2022	6,000km	352 Tbit/s		New York, US; Bude, UK; Bilbao, Spain	Google ^{[14][15]}
Amitié	July 2023	6,600km	320 Tbit/s		Lynn, Massachusetts, US; Bude, UK; Le Porge, France	A consortium comprising Facebook, Microsoft, Aqua Comms, Vodafone (through Cable & Wireless Americas Systems), Orange ^[16]

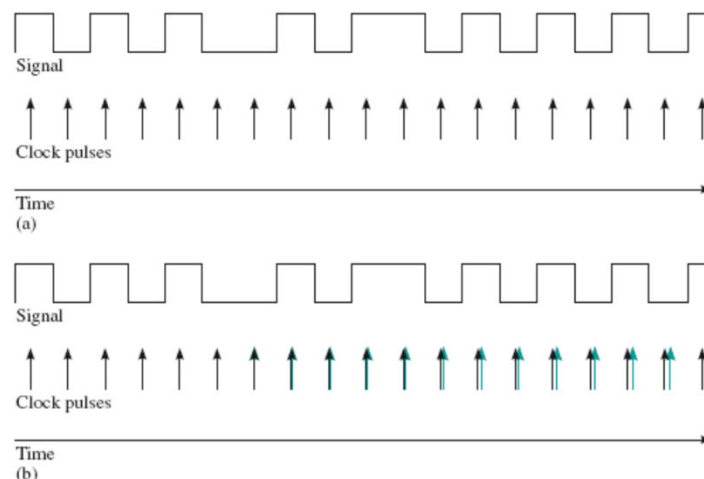
- MAREA cable initial capacity was 80 terabits per second (8 fiber pairs * 25 DWDM channels * 400 Gbit/s per single carrier (16-QAM modulation) = 80 Tbit/s (*Total*: 160 Tbit/s)).
- In 2019, a research team reported they had generated data rate of 26.2 Tbit/s (per fiber pair) on MAREA cable.

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Clock Drift between TX and RX



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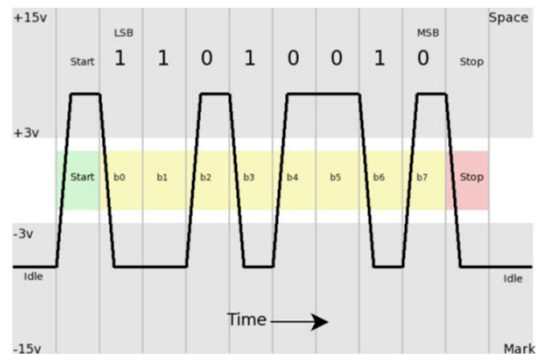
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Asynchronous Transmission



- This is an extreme case in which the transmitter and receiver clocks do not coordinate with each other except to set their circuitry to run at the same frequency.

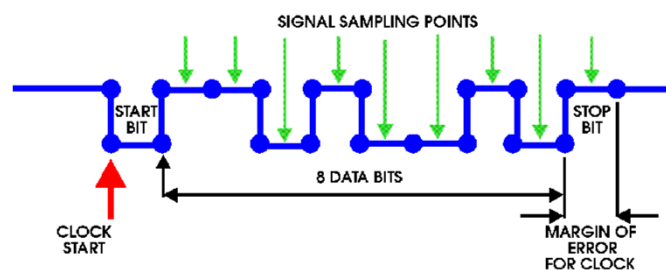
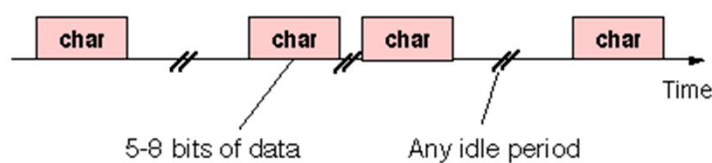


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Reset RX Clock After Idle



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Asynchronous Transmission

- Disadvantages:
 - Works only for short distance communication systems, as different temperature/humidity/etc increase clock drift significantly.
 - Only low data rate is possible (wider bits are more resilient to clock drifts).
 - Can send only in short bursts (8-10 bits) to minimize the possible effects of drift before the next clock reset.
- Advantages:
 - Simple to build.
 - Inexpensive.

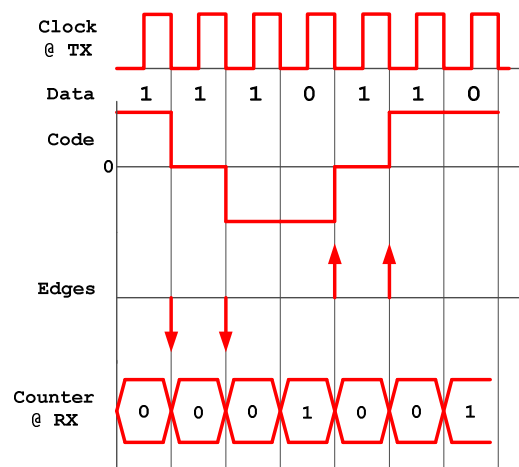


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Plesiochronous Transmission

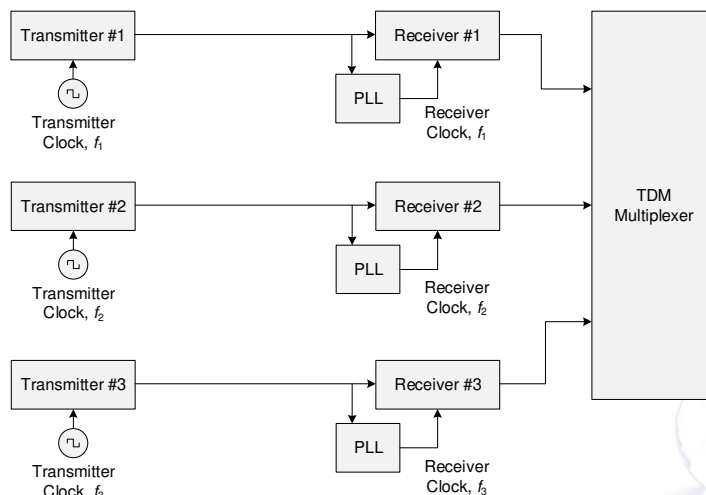
- To allow larger chunks of bits to be transmitted in higher data rate networks, the clocks of the transmitter and receiver must be continuously synchronized.
- This is done in plesiochronous transmission using special bit-encoding schemes that carry clock information along with bit information (called self-synchronizing codes).



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Buffering at High Data Rate



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Synchronous Transmission

- In this case, the clocks of the transmitter and receiver (and all other devices in the network) are controlled by a main clock.
- A special Distributed Clock Synchronization Protocol is used by the network.
- An example is SDH/SONET systems.
- High data rate possible, minimum buffering, flexible multiplexing, but expensive.

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