University of Pittsburgh

ECE 1150: Computer Networks

Physical Layer: Transmission Medium

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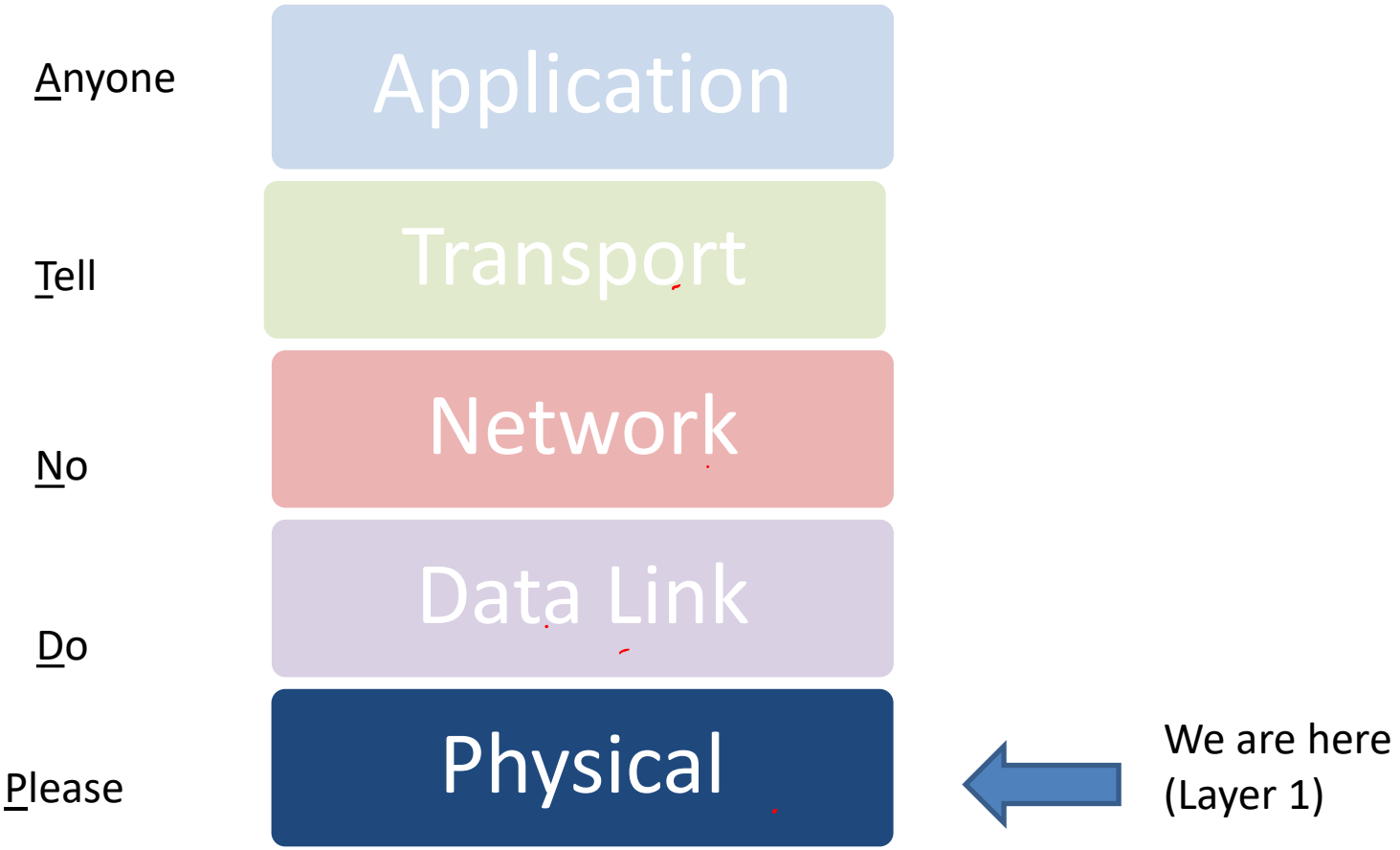
In Previous Units

- Introductory topics
- Circuit switching, Packet switching
- Propagation, transmission and queuing delays
- Throughput
- Layering
- Packetization, encapsulation
- OSI and TCP/IP reference models

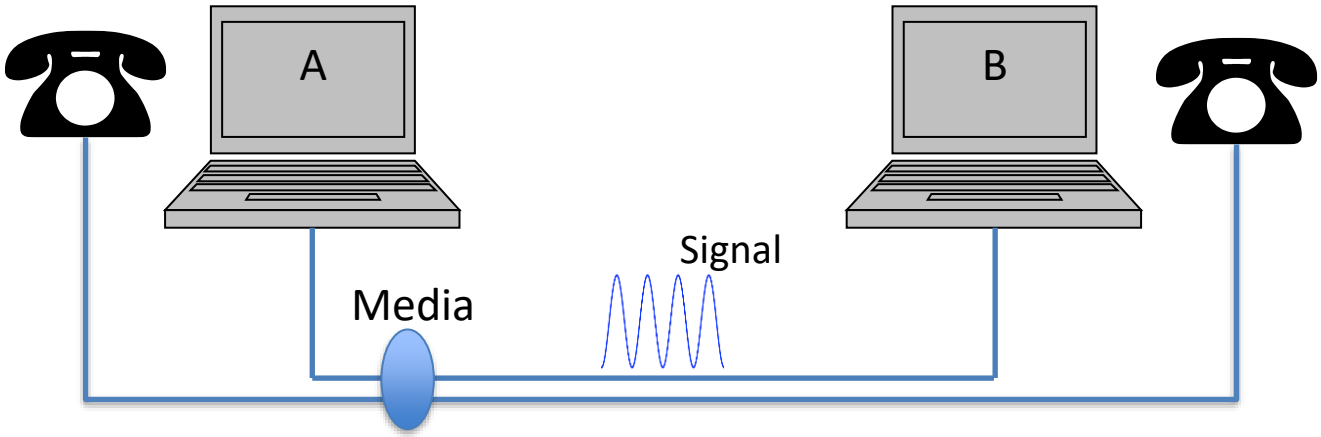
Objectives of This Unit

- Describe the function of the physical layer
- Define what is a medium
- Differentiate different types of medium: twisted pair, coaxial, fiber optic cables, wireless

Context

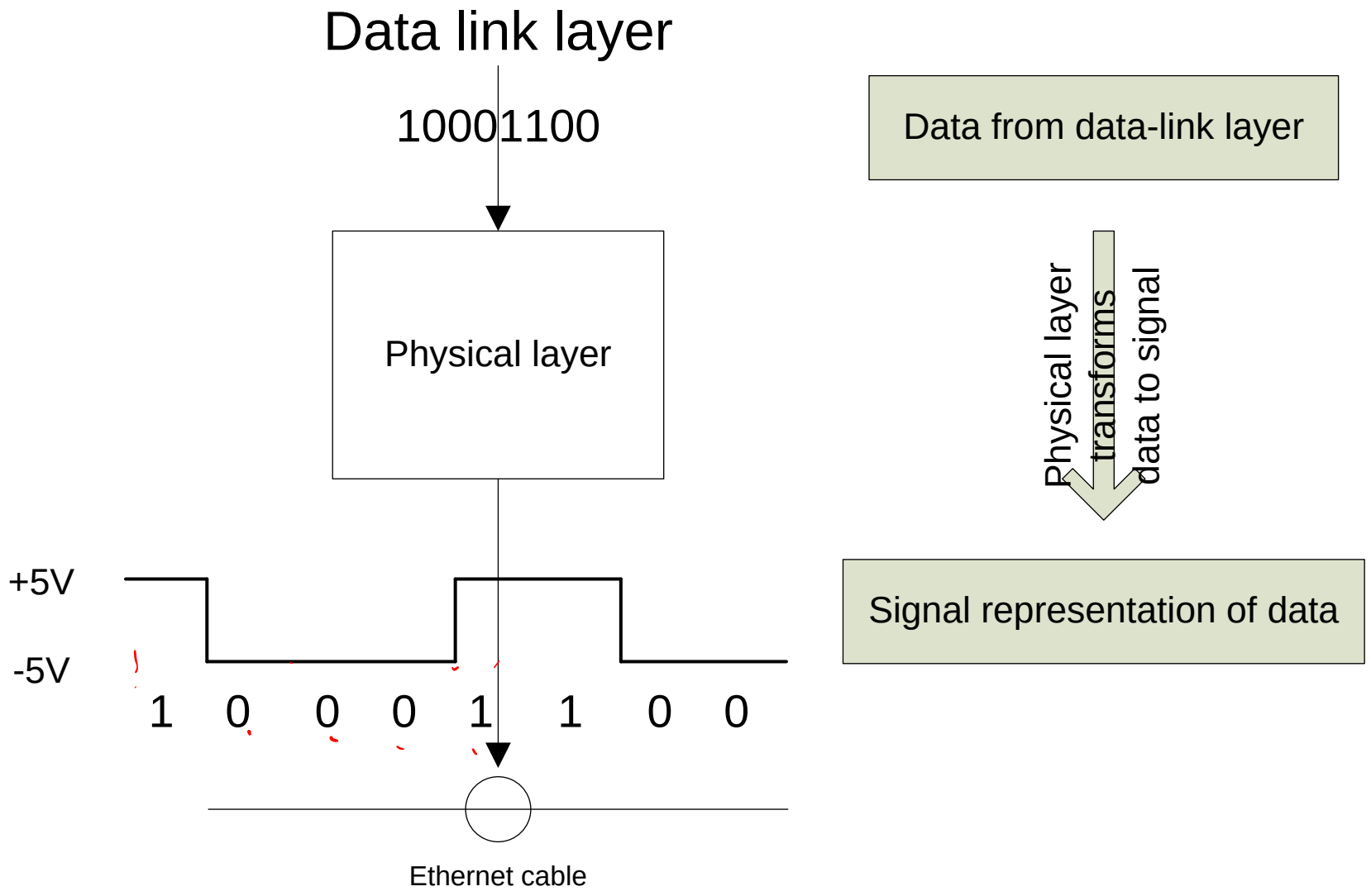

Anyone
Application
Tell
Transport
No
Network
Do
Data Link
Please
Physical
We are here
(Layer 1)

Context



- What is involved in getting **information** from A to B?
  - **Media** – what are different common transmission media?
  - **Signals** – what is a signal?
  - Bunch of other stuff (**standards**, **protocols**, etc.)

Signal


Data link layer
10001100
Physical layer
+5V
-5V
1 0 0 0 1 1 0 0
Ethernet cable
Data from data-link layer
Physical layer transforms data to signal
Signal representation of data

Special Feature of the Physical Layer

- Physical layer **interacts with nature**
- Converts **data to signals** for transmission on the physical media
- The **physical medium** is the link along which a signal propagates

Physical Medium

- **Medium**
  - Can be **guided or unguided**
    - Guided: copper wire, optic fiber (glass), coax cable
    - Unguided: air medium (radio, microwave, satellite)

- **Signals** generated by physical layer **comply with properties of the medium**
    - Examples: voltages in copper, light in fiber, electromagnetic radiation (radio frequency [RF] signals) in wireless

Impact of Physical Medium on Signals

- **Attenuation**
  - Function of distance and signal frequency
  - Representations in dB
- Susceptibility to **noise**
  - which affects the capacity/maximumdata rate
- **Generation of electromagnetic emissions (interference)**

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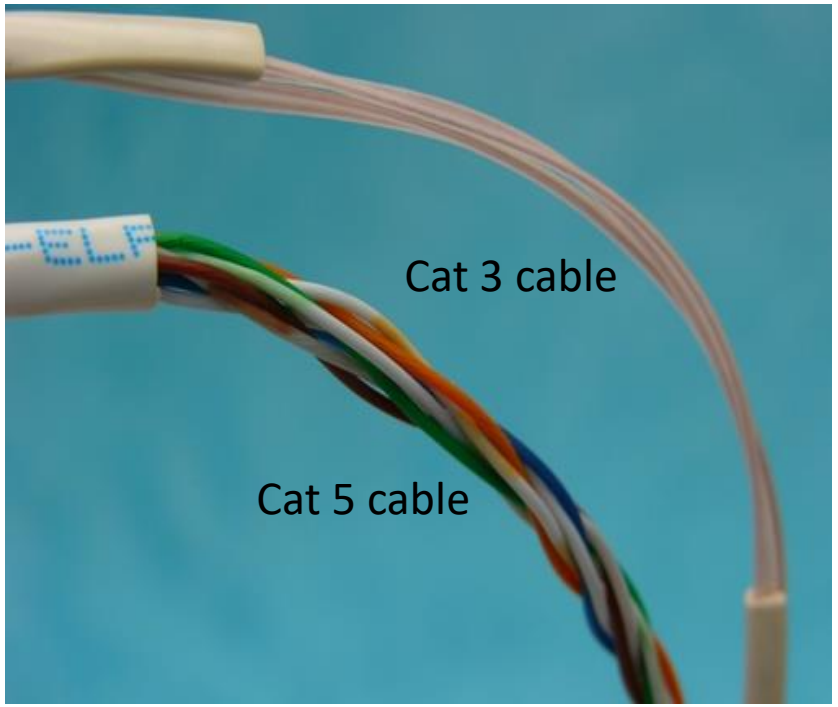
Copper Wire as Physical Medium

- Copper is a **good conductor** of electricity and is relatively abundantly **available**

- **Unshielded twisted-pair (UTP)**
  - **8 individual strands** of copper wire are organized as **four pairs**

- Each pair of wires is twisted around each other
  - Twisting **reduces interference,** reduces **noise**
  - **Tighter twisting improves data rates**



Categories of UTP cables

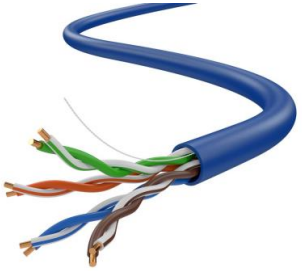
- Categories range from Cat-1 to Cat-6
  - The **higher** the **category**, the **higher** the **data rate**
    - Generally **more twists-per-inch**

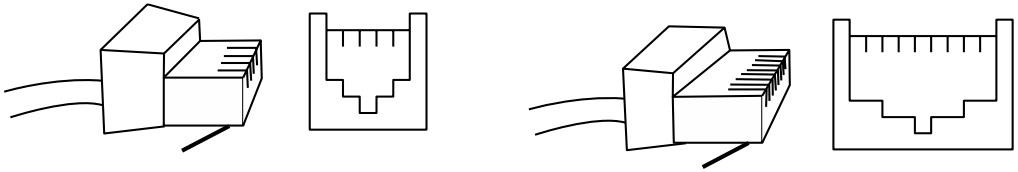
Cable type	Max data rate
Cat 3	10 Mbps
Cat 5e	1,000 Mbps = 1Gbps
Cat 6	10 Gbps

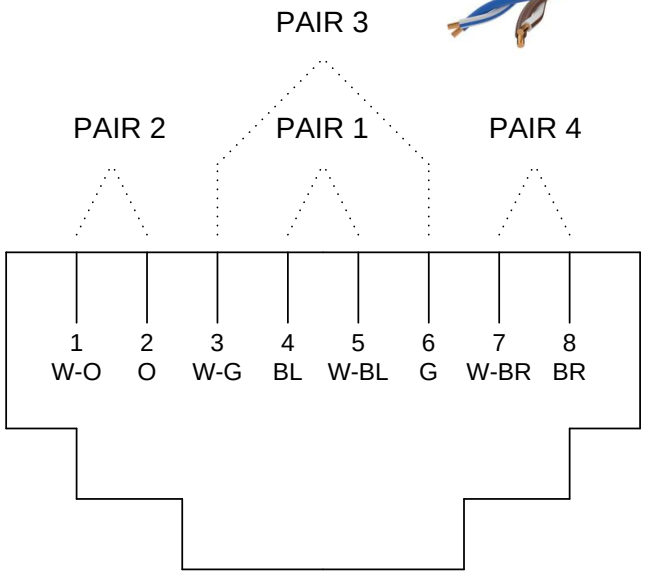
Unshielded Twisted Pair

Slide modified from Agrawal

Cable Connectors





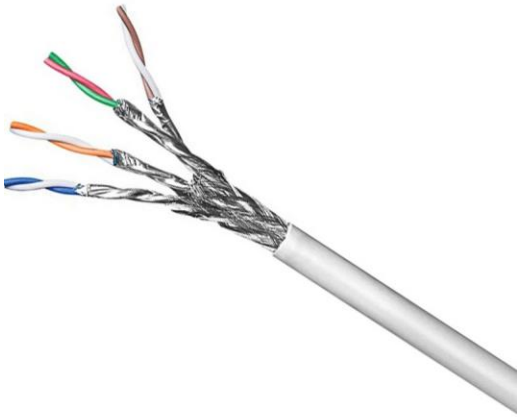


- Cat5e cables end in **RJ 45 connectors for Ethernet**
- Not all pairs are used in all cases
  - For **100Mbps** Ethernet, **2 pairs** are used
  - **1Gbps** Ethernet all **4 pairs** are used

Conductor identification	Color code	Use (for 100Mbps)
Pair 1	White-Blue/ Blue	-
Pair 2	White-Orange/ Orange	Transmit /receive data
Pair 3	White-Green/ Green	Receive /receive data
Pair 4	White-Brown/ Brown	-

In I Gbps Ethernet all pairs are used for transmit/receive

Shielded Twisted Pair (STP)



- Description
  - Twisted pair
  - **Outer metallic "shield" included**
  - More **expensive** than UTP
- Characteristics
  - **Lower noise** susceptibility than UTP
  - **Lower electromagnetic emissions** than UTP

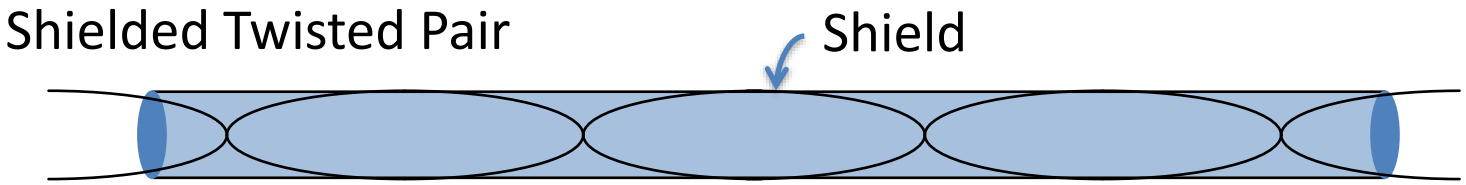
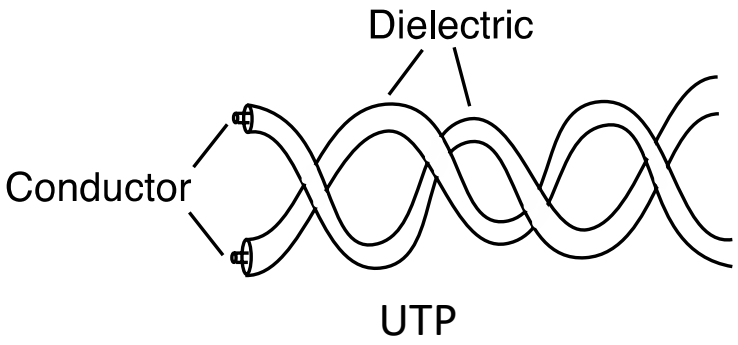
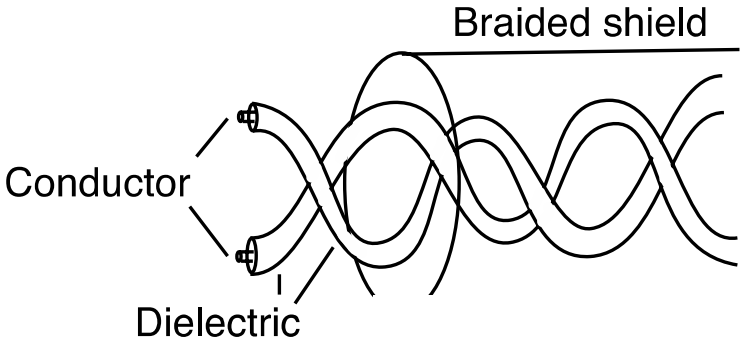
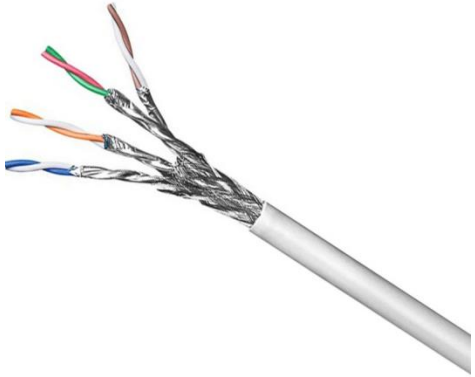


Figure Source: The Physical Layer of Communication Systems, by R.A. Thompson and Others

UTP and STP Again

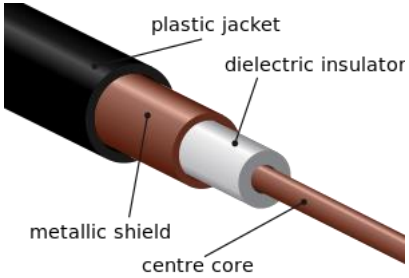


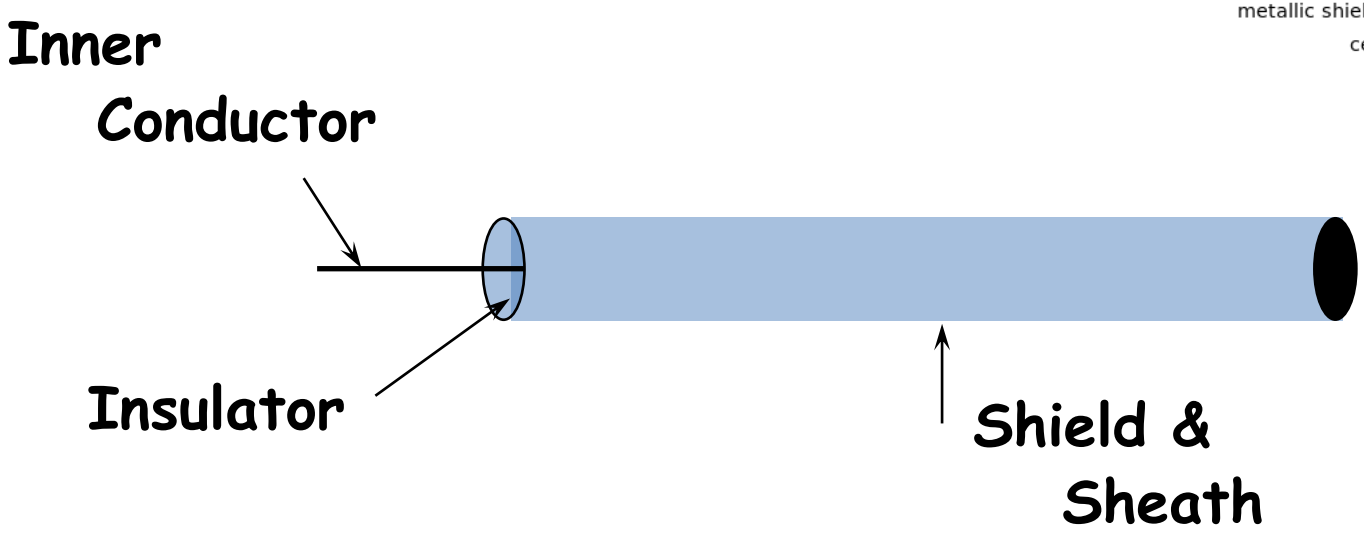




Coaxial Cable

- Used in TV cable





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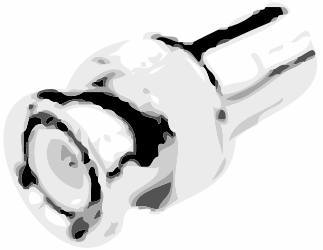
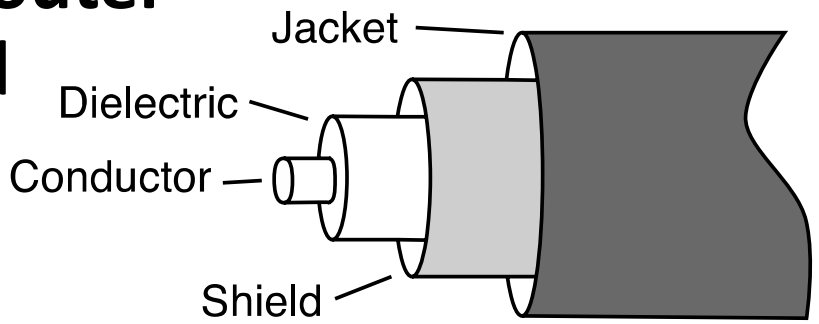
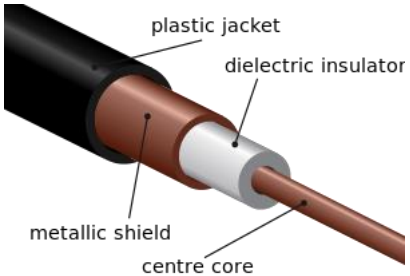
Coaxial cable



BNC connector

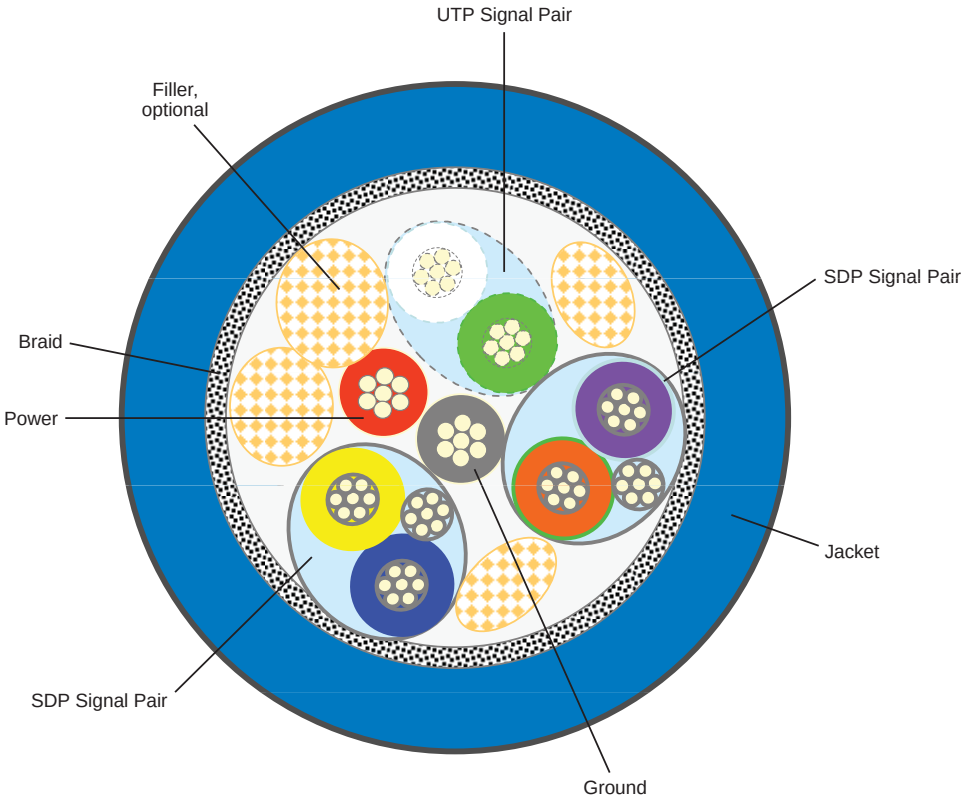
- Applications
  - Ethernet (until around 1987)
  - Cable TV
- Single **copper core**, plus **outer insulation**, shielding, and **inner insulation**
- Characteristics
  - Less prone to interference compared to UTP
  - Distance - up to 2 km (1.2 miles)





Copper is Used Almost Everywhere

- Example: USB SuperSpeed
  - Wire for power
  - Many wires are squeezed in the cable
  - 5 Gbps
- Short length!



Source: SuperSpeed USB PHY Layer Specification Presentation by Howard Heck, Intel

Characteristics of Copper Cables

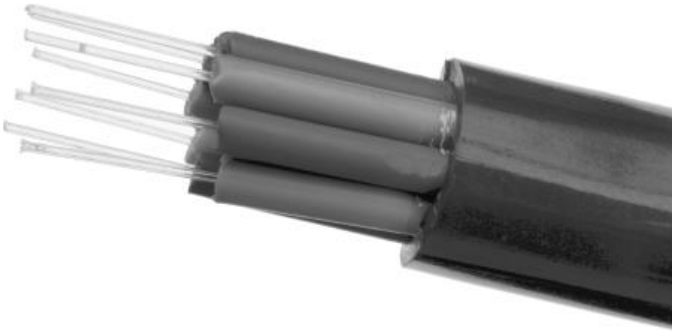
- Great for **short distances**
  - Local networking, few hundreds of meters
  - **Attenuation** and **loss** (to be visited)
- Data **rates** are limited
  - Can reach 10 Gbps
- **Weight** and **cost of installation**

Optical Fibers

- Optical fiber overcomes these problems

- Typically used for **long-distance** communications

Source: © Hugh Threlfall/Alamy



Slide modified from Agrawal

Optical Fiber as Physical Medium

- Backbone, LANs, high-speed Internet access
- Local networks are also using optical fiber
  - FiOS (Fiber optic service) = Fiber To The Home (FTTH) or Fiber to the Premises (FTTP)
    - Optical Fiber is now in the access network

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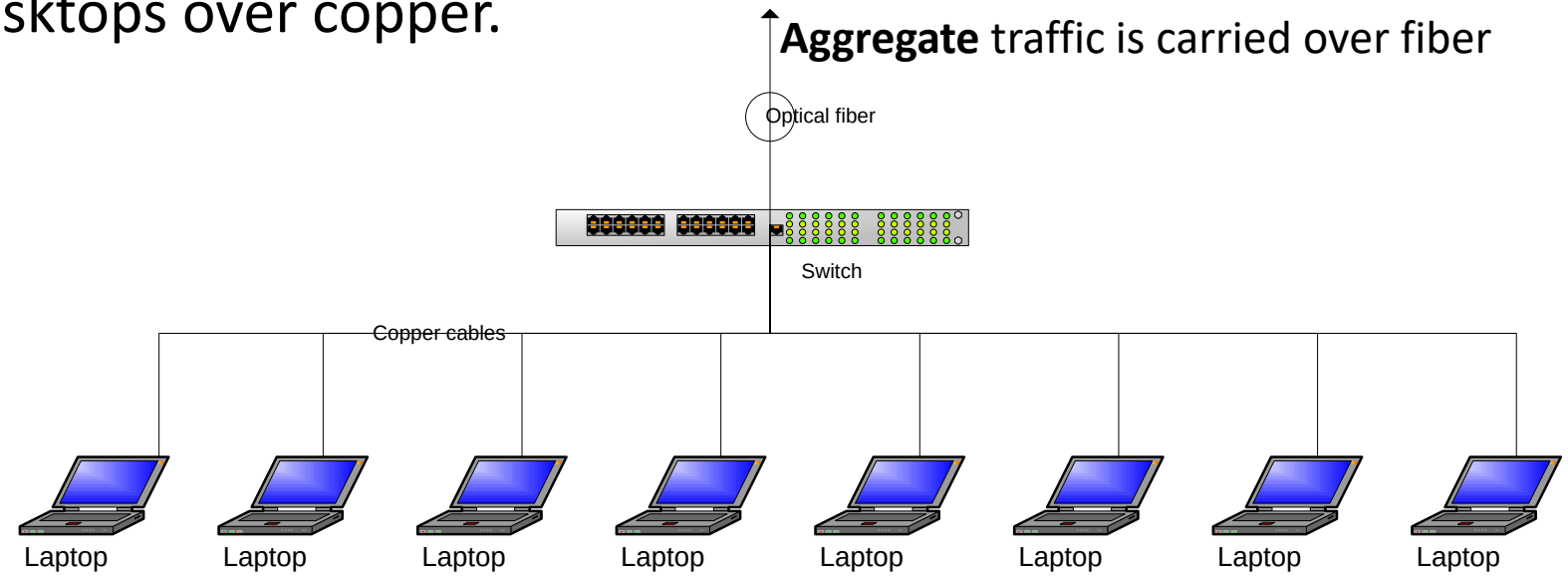
Optical Fiber as Physical Medium

- Optical fiber is thin **strand of glass** that guides **light**
  - Glass is a good **conductor of light**, **not heavy**
  - Can carry large volumes of data over long distances
- Data transmitted using light from **lasers** or **light emitting diodes** (LEDs)
- Extremely **fast data rates**
  - Hundreds of terabytes per sec possible (tera =10^{12})

Aggregating network traffic from copper to fiber

Typical setting: Optical fiber bring connectivity to a central location in buildings, then network connectivity is distributed to desktops over copper.



Few hundred pounds of optical fiber can carry data equivalent to hundreds of copper wires

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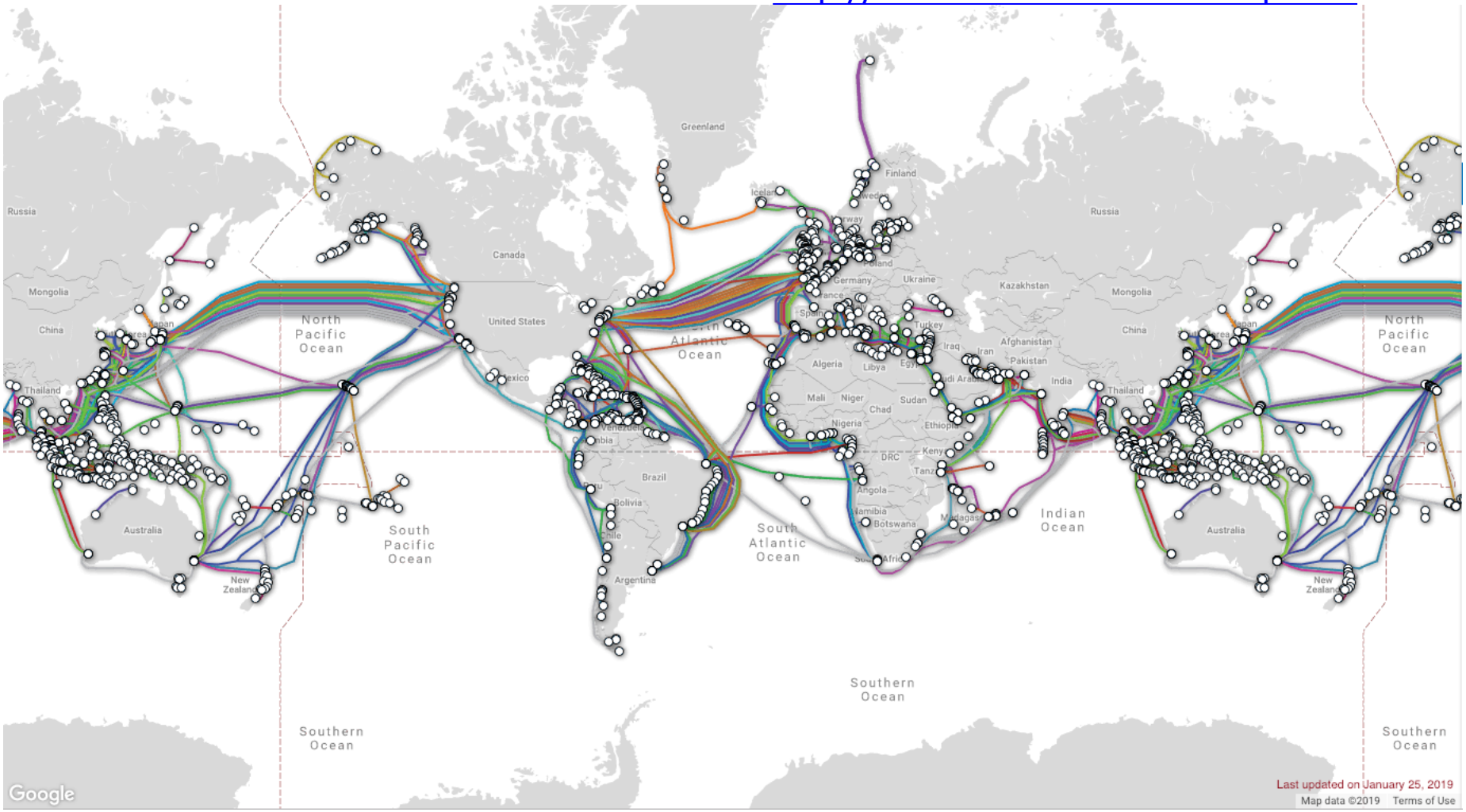
Submarine Optical Fiber Installation

http://www.submarinecablemap.com



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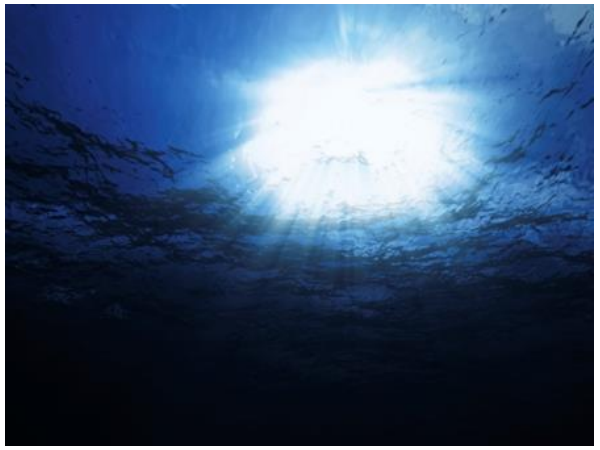
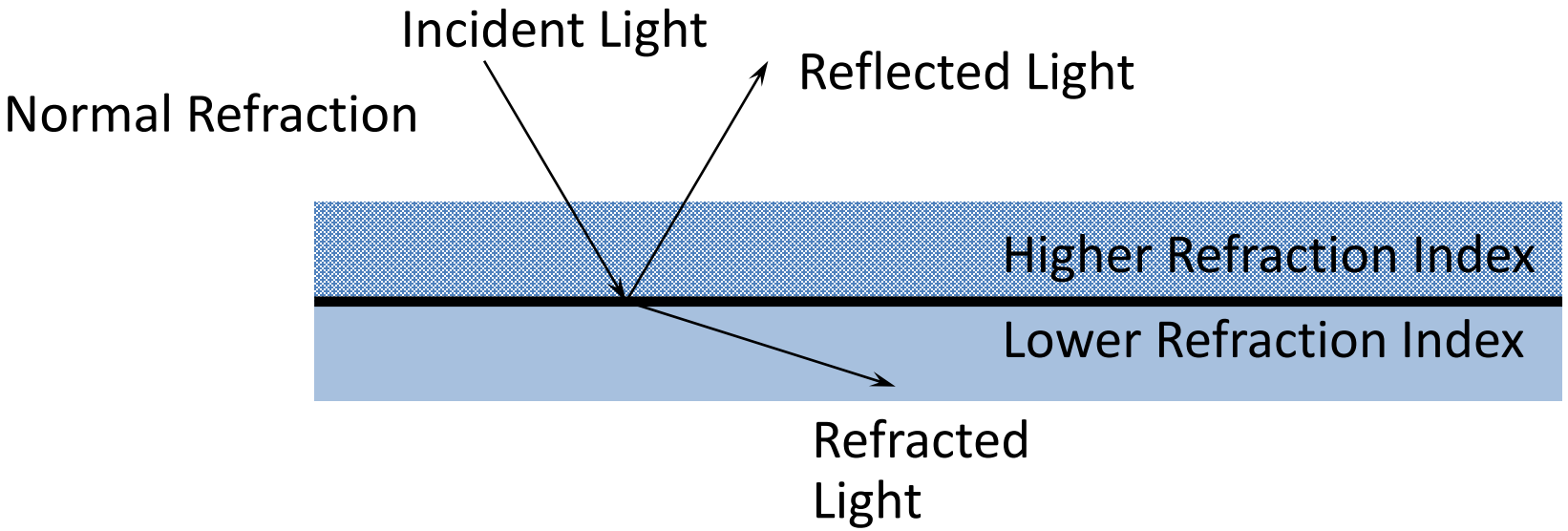
Optical Fiber as Physical Medium

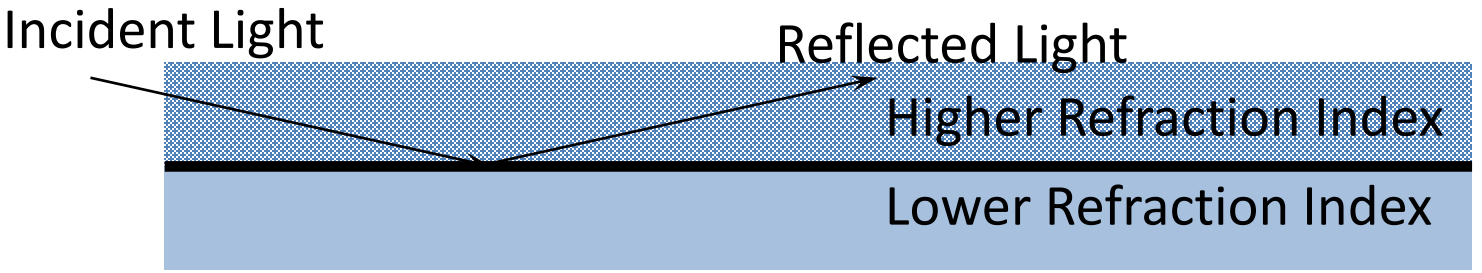
- Works on the principle of **total Internal Reflection**
  - Light can escape only if it hits boundary at right angles
  - **Due to little energy loss**, fiber can transmit signals over **huge distances without repeaters**



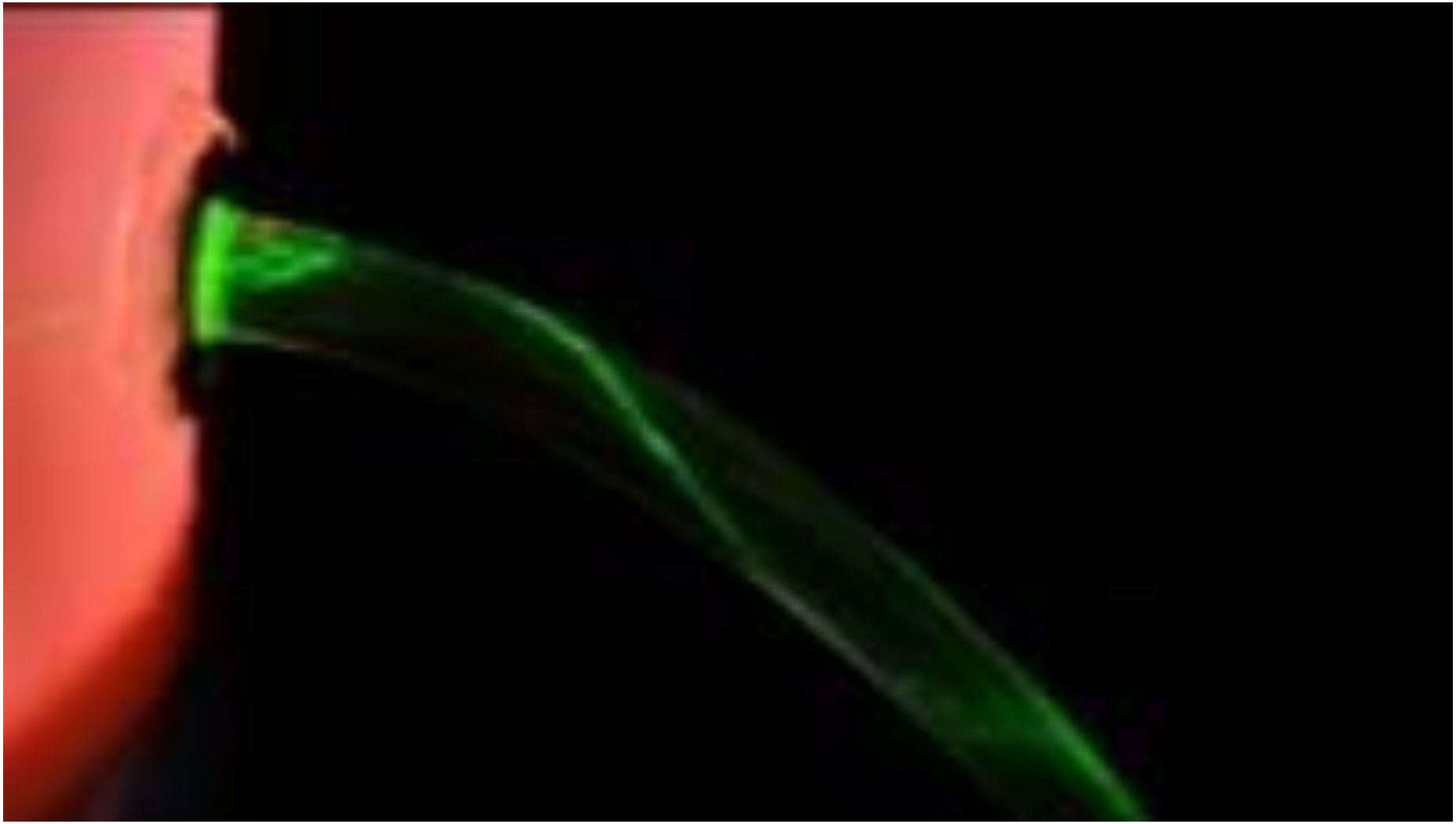
Principle of Operation of Optical Fibers



Total Internal Reflection



Angle of incidence greater than a critical angle



https://www.youtube.com/watch?v=0MwMkBET_5I

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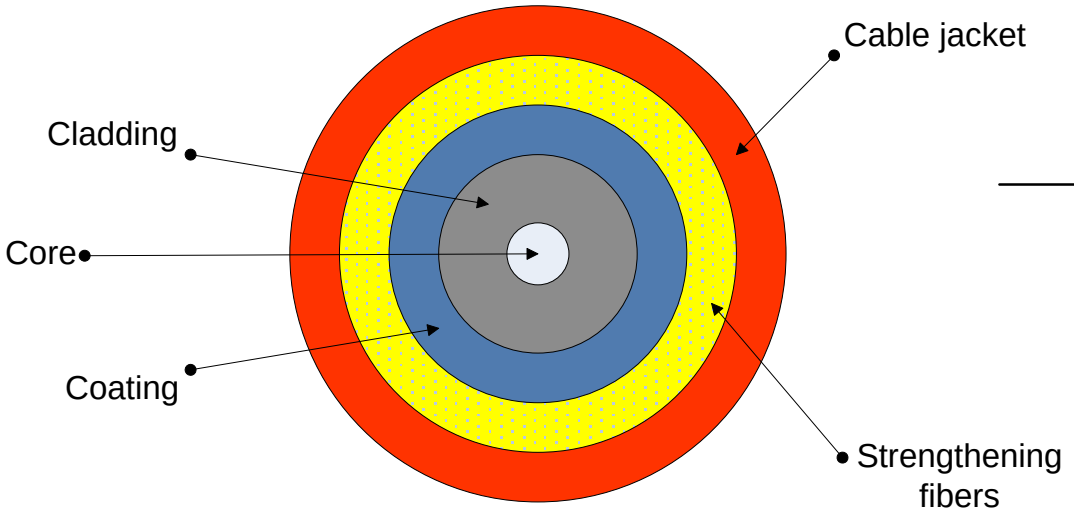
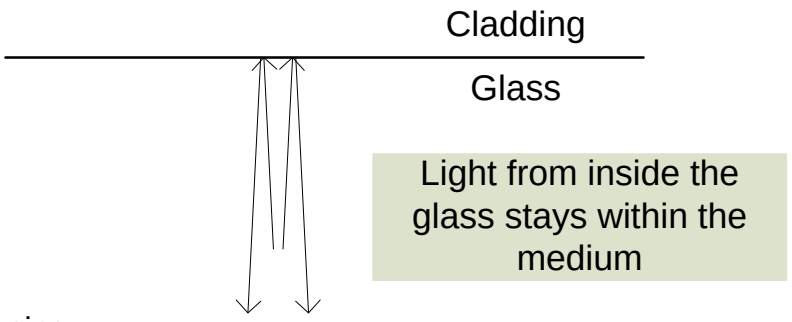
Construction of Optical Fiber





Characteristics of Optical Fibers

- **Two types**: multimode and single mode

Multimode Optical Fibers

- **Thicker fibers** (50-100 micron core)
- Can use **cheaper transmitters (LED's)**
- Many optical paths (modes) in fiber
  - Significant signal **dispersion over distances** which leads to inter-symbol interference (different symbols of same message interfere)

Single Mode Optical Fibers

- **Thin fibers** (~5 micron core)
- **Single optical path**

- Requires the use of **more costly laser transmitters**
- Good **for longer distances**

tophat

Q_Capacity and noise susceptibility

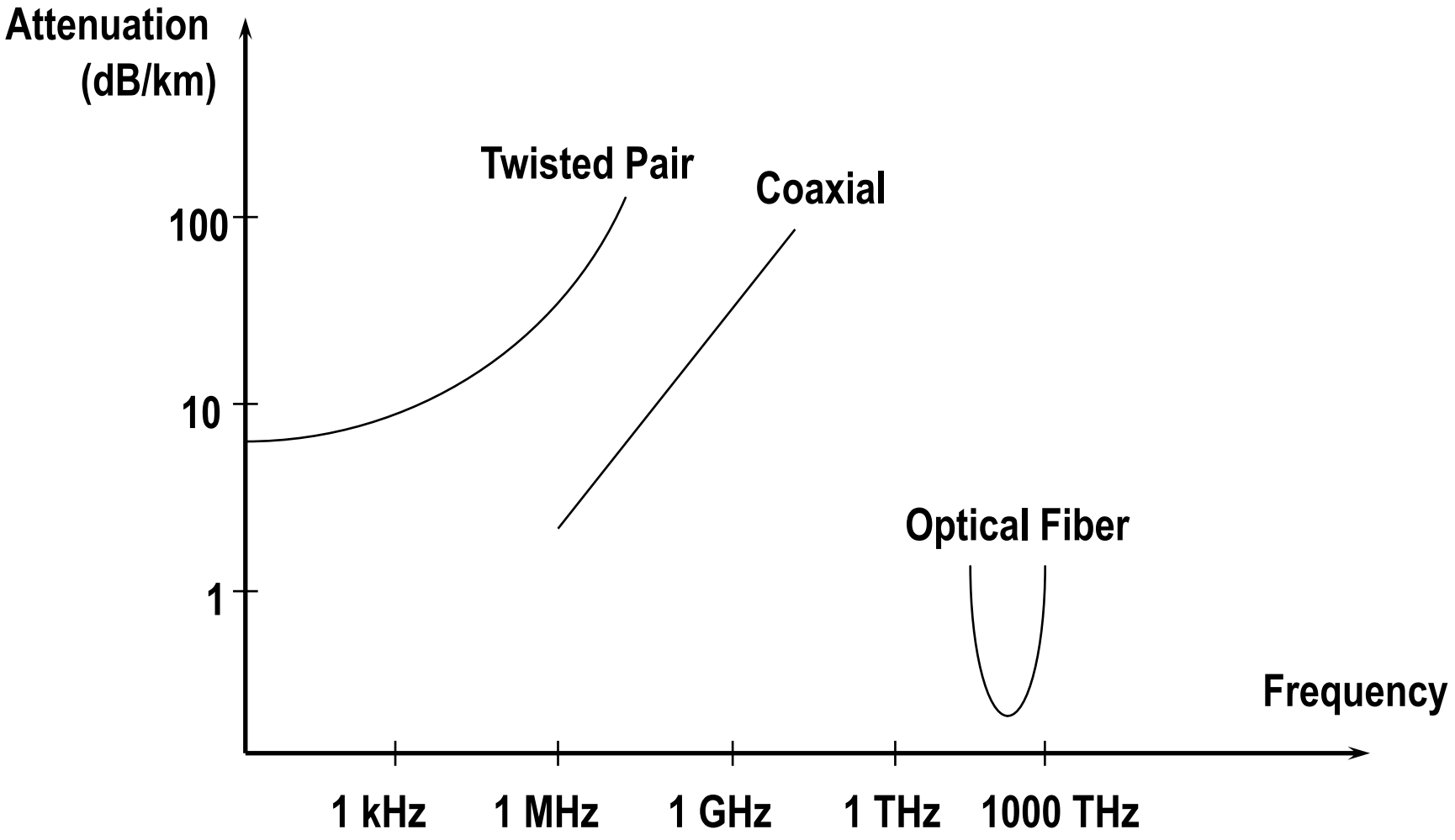
The relationship between capacity (maximum data rate) and noise susceptibility is that

A	As noise susceptibility of a link increases, capacity increases
B	As noise susceptibility of a link increases, capacity decreases

Cables

Cable type	Cost	Ease of use	Capacity	Noise Susceptibility	EM radiation
Twisted pair	Low	High	Low	High	High
Coax	Medium	Medium	Good	Lower	Lower
Multimode Fiber	Medium	Medium	High	Very low	Almost zero
Single mode fiber	Highest	Lowest	Highest	Very low	Almost zero

Comparison of Cable Types



Wireless

- Wireless communication system
  - Any communication system that uses a **naturally occurring communication medium**, such as **air**, **water**.
  - Advantages: Convenience, mobility
- Examples:
  - Simplex: Radio, TV
  - Duplex: Cell phones, satellite, WiFi, Bluetooth
- Fundamentally different from wired networks

Air as a Transmission Medium

- **Hard to slice** wireless transmissions **in "space"**
  - New technologies like MIMO (multiple input multiple output antennas) try to do some of this

Wireless Communications

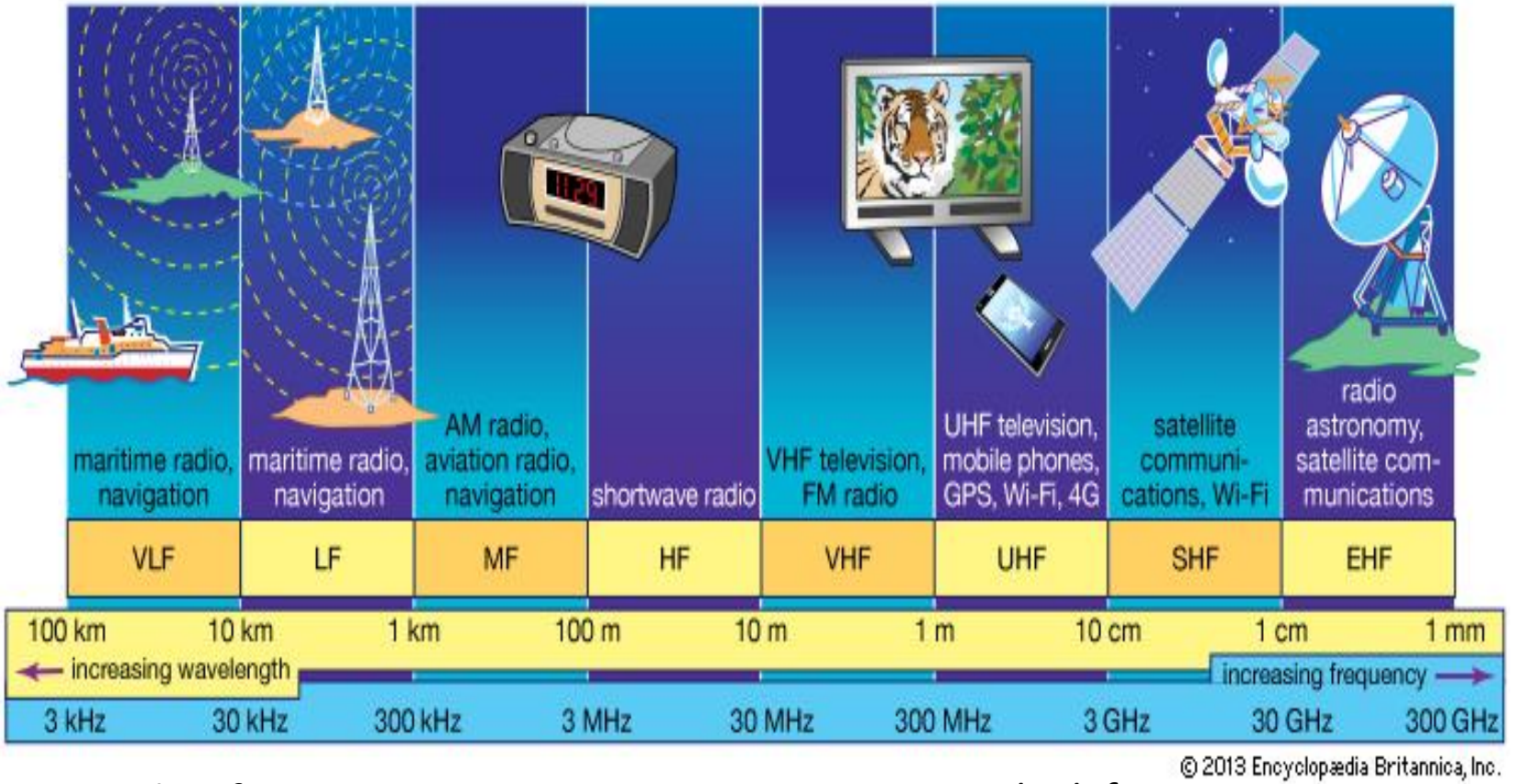
- The common way of slicing is to “allocate” different **frequency bands** to different applications

  - **Power**, **frequency bands**, **receiver capability**, all impact wireless

Wireless Communications

- Typically uses **electromagnetic radiation** for communication
  - **Free space optical** wireless started to gain a lot of attention

Electromagnetic Spectrum

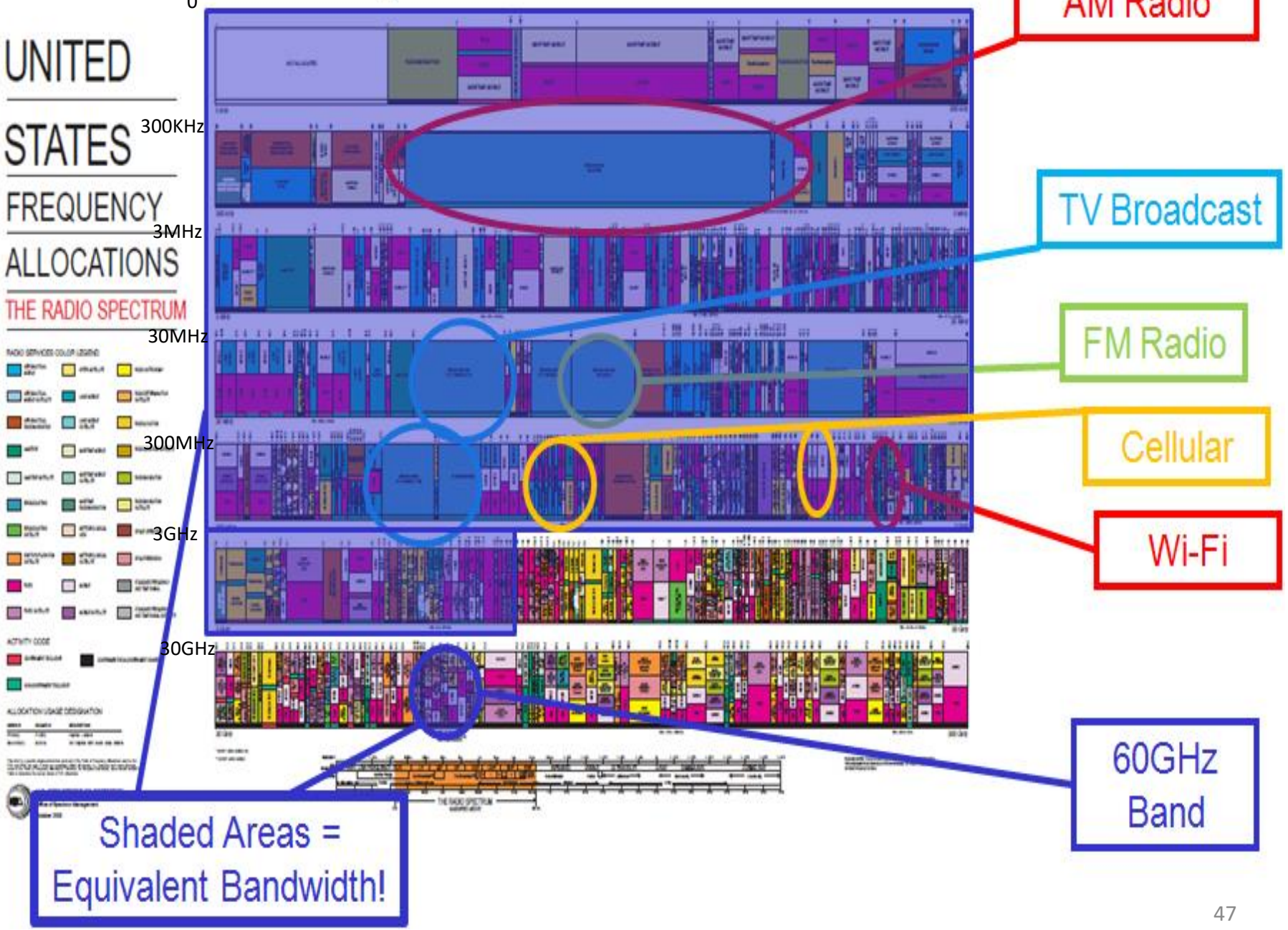


VLF: Very low frequency
LF: low frequency
MF: Medium frequency
HF: High frequency
VHF: Very high frequency
UHF: Ultra high frequency
SHF: super high frequency
EHF: Extremely high frequency

Spectrum allocation

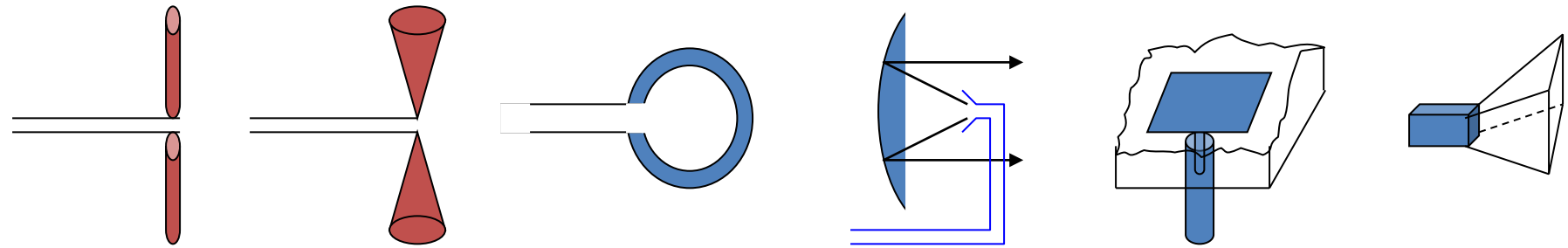
- The Federal Communications Commission (FCC) regulates spectrum in the US
  - Licensed Vs Unlicensed
    - Unlicensed: The industrial, scientific and medical (ISM) bands, e.g. in US, 900MHz, 2.4 GHz, 5.8 GHz
      - Now used by WiFi, Bluetooth, cordless phones, and others

• Bandwidth can be imagined as real estate



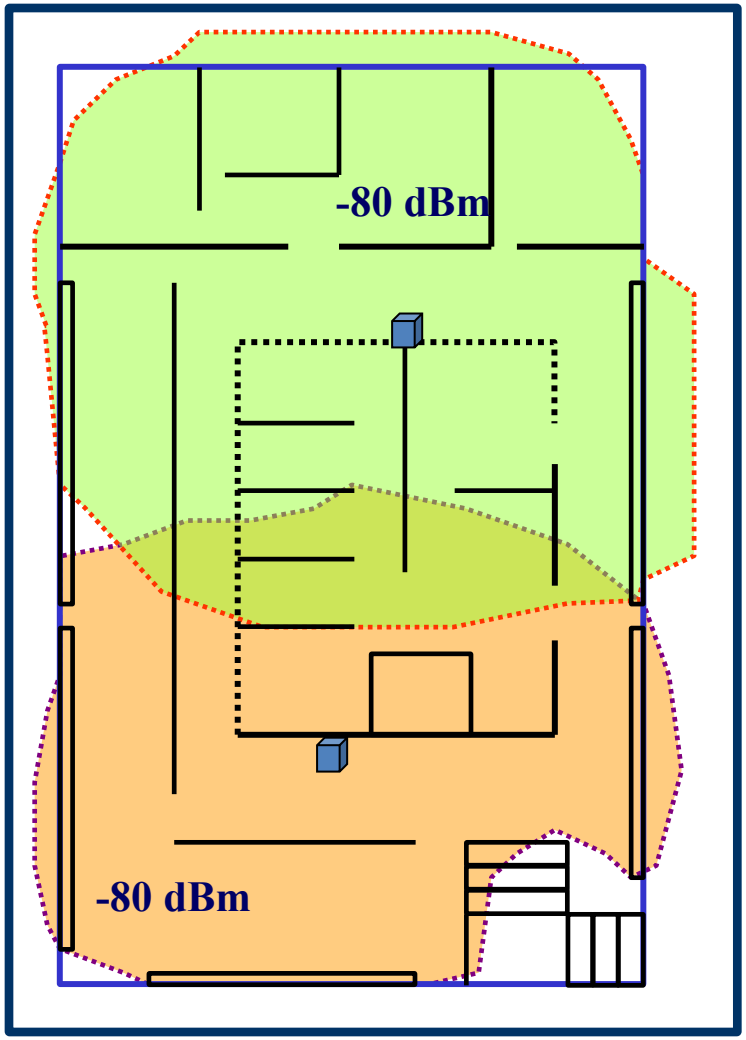
Wireless also Needs Antennas

- A transducer for **converting guided signals** into **electromagnetic radiation** in an unbounded medium or vice versa



Wired Vs. Wireless

- **Wireless more flexible, at the expense of higher attenuation, noise susceptibility and interference.**
- **Capacity?**



Transmission Media

Cable type	Cost	Ease of use	Capacity	Noise Susceptibility	EM radiation (interference)
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Coax	Medium	Medium	Good	Lower	Lower
Multimode Fiber	Medium	Medium	High	Very low	Almost zero
Single mode fiber	Highest	Lowest	Highest	Very low	Almost zero
Wireless	**Variable**	**Variable**	Low	High	High

Note that the **capacity** (i.e. rate) increases as the **noise** susceptibility improves