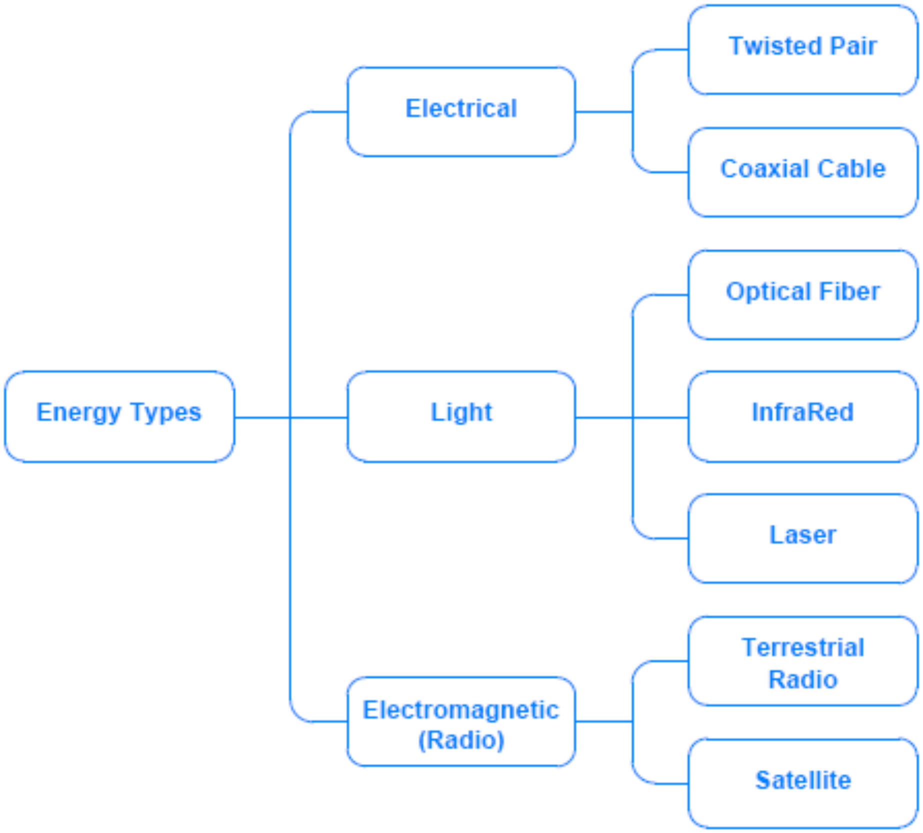
Chapter 7

Transmission Media

Guided and Unguided Transmission

- How should transmission media be divided into classes?
- There are two broad approaches:
  - By type of path: communication can follow an exact path such as a wire, can have no specific path, such as a radio transmission
  - By form of energy: electrical energy used on wires, radio transmission is used for wireless, and light is used f optical fiber
- We use the terms guided (wired) an unguided (wireless) transmission to distinguish between physical media

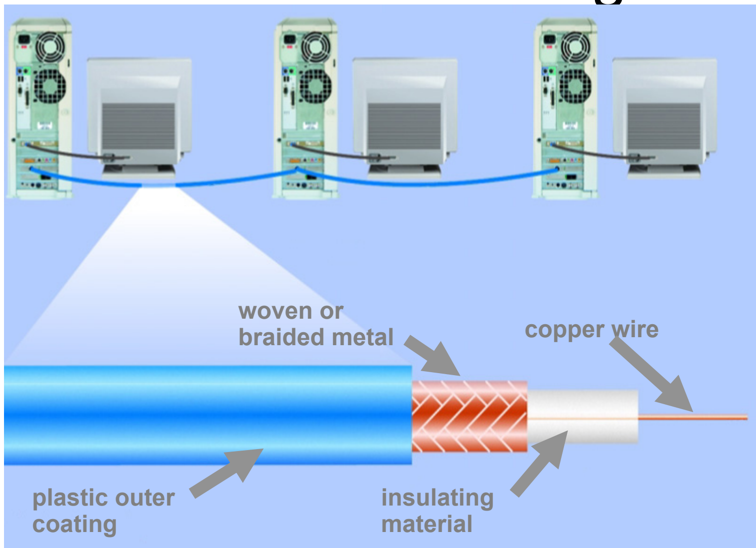


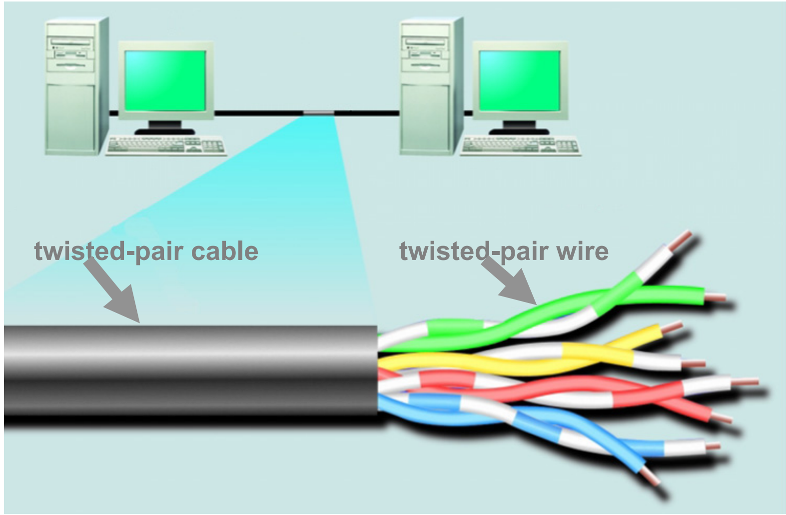
Background Radiation and Electrical Noise

- Electrical current flows along a complete circuit
  - all transmissions of electrical energy need two wires to form a circuit; a wire to the receiver and a wire back to the sender
- The simplest form of wiring consists of a cable that contains two copper wires
- Important facts:
  1. Random electromagnetic radiation, called noise, permeates the environment
     - In fact, communication systems generate minor amounts of electrical noise as a side-effect of normal operation
  2. When it hits metal, electromagnetic radiation induces a small signal
     - random noise can interfere with signals used for communication
  3. Because it absorbs radiation, metal acts as a shield

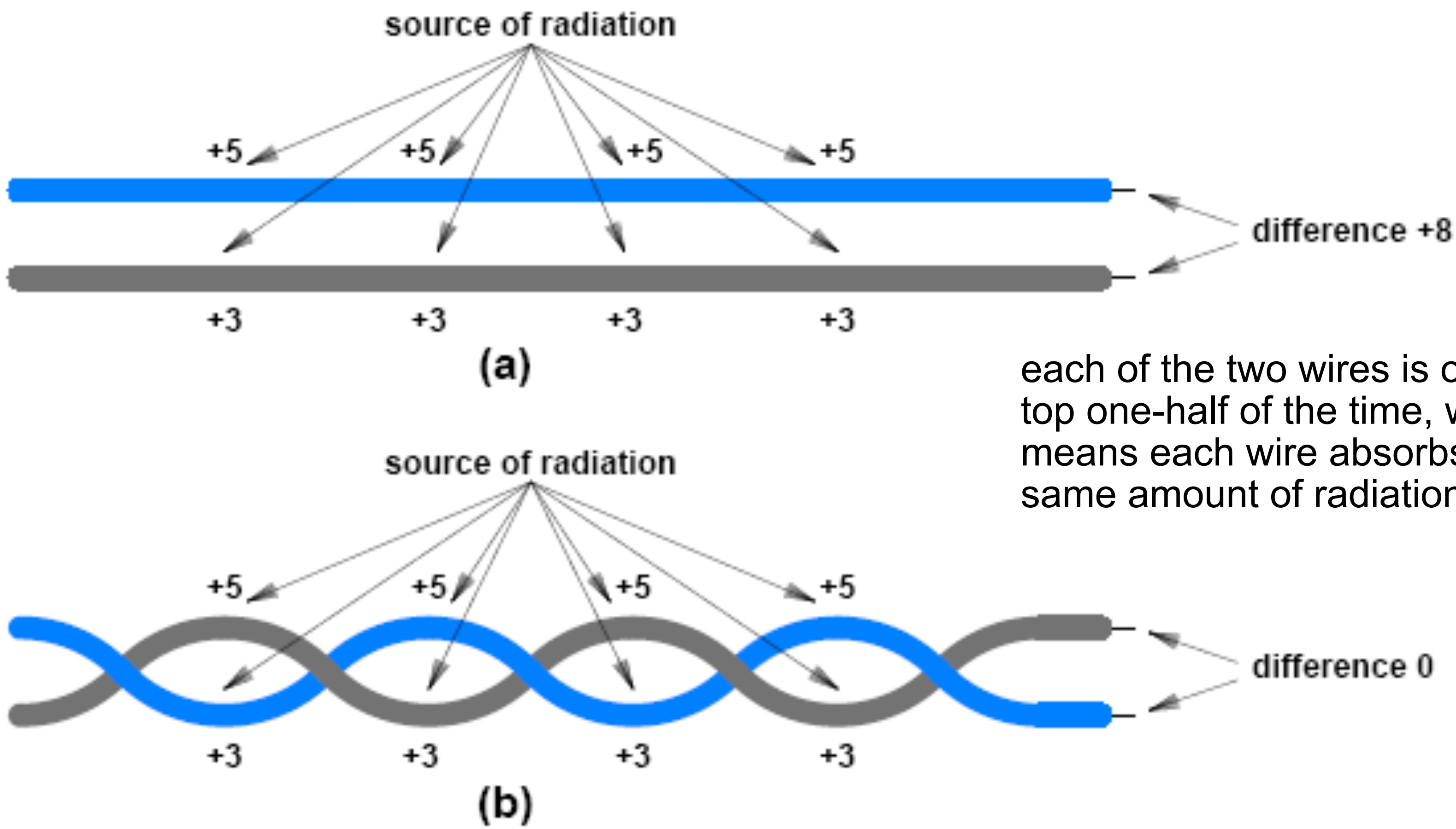
Twisted Pair Copper Wiring

- There are three forms of wiring that help reduce interference from electrical noise
  - Unshielded Twisted Pair (UTP)
    - also known as twisted pair wiring
  - Coaxial Cable
  - Shielded Twisted Pair (STP)
- Twisting two wires makes them less susceptible to electrical noise than leaving them parallel





Twisted Pair Copper Wiring



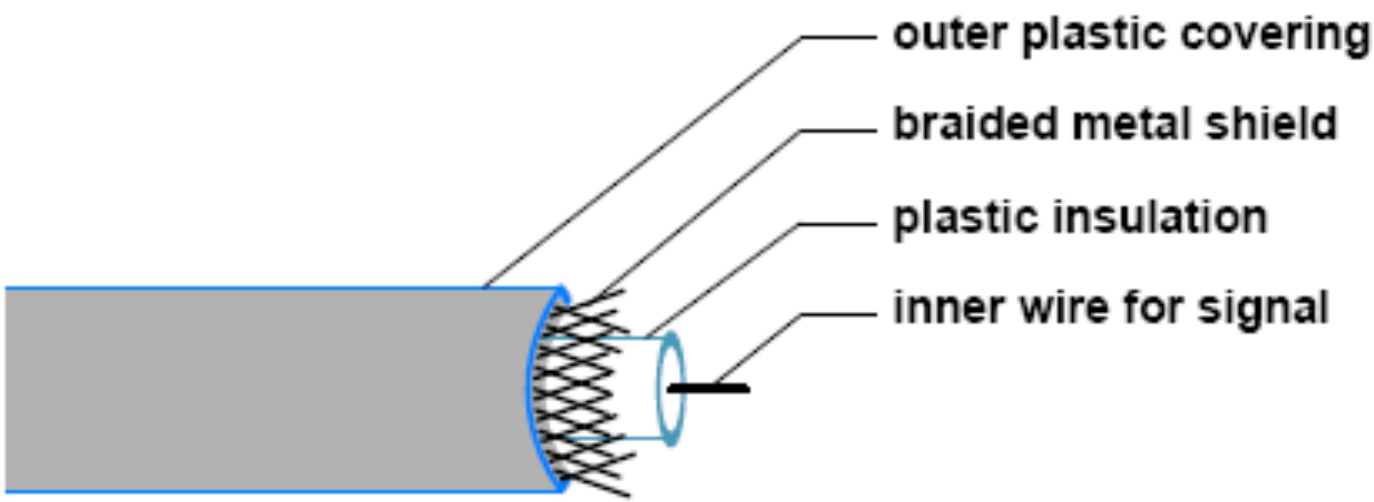
each of the two wires is on top one-half of the time, which means each wire absorbs the same amount of radiation

Current is balanced → EMR impact is reduced!

Shielding: Coaxial Cable and Shielded Twisted Pair

- Using braided wire instead of a solid metal shield keeps coaxial cable flexible
  - but the heavy shield does make coaxial cable less flexible than twisted pair wiring
- Variations of shielding have been invented that provide a compromise
  - the cable is more flexible, but has slightly less immunity to electrical noise
- One popular variation is known as shielded twisted pair (STP)
  - The cable has a thinner, more flexible metal shield surrounding one or more twisted pairs of wires
  - In most versions of STP cable, the shield consists of metal foil, similar to the aluminum foil used in a kitchen

Shielding: Coaxial Cable and Shielded Twisted Pair



Better Shielding → More Expensive

Categories of Twisted Pair Cable

Category	Description	Data Rate (in Mbps)
CAT 1	Unshielded twisted pair used for telephones	
CAT 2	Unshielded twisted pair used for T1 data	
CAT 3	Improved CAT2 used for computer networks	
CAT 4	Improved CAT3 used for Token Ring networks	
CAT 5	Unshielded twisted pair used for networks	
CAT 5E	Extended CAT5 for more noise immunity	
CAT 6	Unshielded twisted pair tested for 200 Mbps	
CAT 7	Shielded twisted pair with a foil shield around the entire cable plus a shield around each twisted pair	Higher

http://searchdatacenter.techtarget.com/sDefinition/0,,sid80_gci211752,00.html

Category	Maximum data rate	Usual application
CAT 1 (de facto name, never a standard)	Up to 1 Mbps (1 MHz)	analog voice (POTS) Basic Rate Interface in ISDN Doorbell wiring
CAT 2 (de facto name, never a standard)	4 Mbps	Mainly used in the IBM cabling system for Token Ring networks
CAT 3	16 Mbps	Voice (analog most popular implementation) 10BASE-T Ethernet.
CAT 4	20 Mbps	Used in 16 Mbps Token Ring. Otherwise not used much. Was only a standard briefly and never widely installed.
CAT 5	100 MHz	100 Mbps TPDDI 155 Mbps ATM. No longer supported; replaced by 5E. 10/100BASE-T 4/16MBps Token Ring Analog Voice

Category	Maximum data rate	Usual application
CAT 5E	100 MHz	100 Mbps TPDDI 155 Mbps ATM Gigabit Ethernet. Offers better near-end crosstalk than CAT 5
CAT 6	Up to 250 MHz	Minimum cabling for data centers in TIA-942. Quickly replacing category 5e.
CAT 6E	Up to 500 MHz (field-tested to 500 MHz)	Support for 10 Gigabit Ethernet (10GBASE-T.) May be either shielded (STP, ScTP, S/FTP) or unshielded (UTP). This standard published in Feb. 2008. Minimum for Data Centers in ISO data center standard.
CAT 7 (ISO Class F)	600 MHz 1.2 GHz in pairs with Siemon connector	Full-motion video Teleradiology Government and manufacturing environments Fully Shielded (S/FTP) system using non-RJ45 connectors but backwards compatible with hybrid cords. Until February 2008, the only standard (published in 2002) to support 10GBASE-T for a full 100m.

http://searchdatacenter.techtarget.com/sDefinition/0,,sid80_gci211752,00.html

Categories of Twisted Pair Cable – Some notes

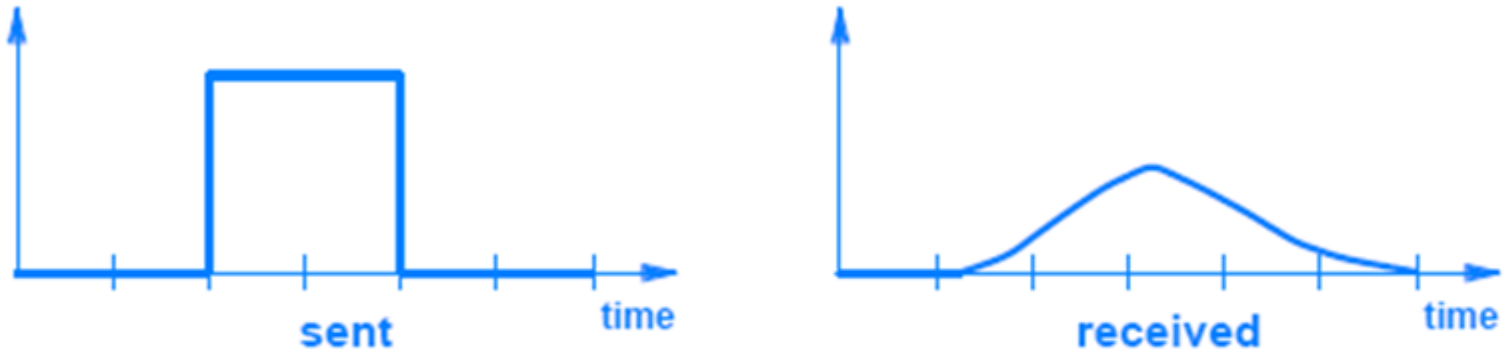
- **CAT 5** and **CAT 5E** UTP cables can support 10/100/1000 Mbps Ethernet.
  - Although Cat 5 cable may support to some degree in Gigabit Ethernet (1000 Mbps), it performs below standard during high-data transfer scenarios,
- **CAT 6** UTP cable is manufactured targeting on Gigabit Ethernet and backward compatible with 10/100 Mbps Ethernet.

Media Using Light Energy and Optical Fibers

- Three forms of media use light energy to carry information:
  - Optical fibers (most common)
  - InfraRed transmission
  - Point-to-point lasers

Media Using Light Energy and Optical Fibers

- Reflection in an optical fiber is not perfect
  - Reflection absorbs a small amount of energy
  - If a photon takes a zig-zag path that reflects from the walls of the fiber many times
    - the photon will travel a slightly longer distance than a photon that takes a straight path
  - The result is that a pulse of light sent at one end of a fiber emerges with less energy and is dispersed (i.e., stretched) over time
  - Dispersion is a serious problem for long optical fibers



Types of Fiber and Light Transmission

- Single mode fiber and the equipment used at each end are designed to focus light
  - A pulse of light can travel long distances without becoming dispersed
  - Minimal dispersion helps increase the rate at which bits can be sent
    - because a pulse corresponding to one bit does not disperse into the pulse that corresponds to a successive bit
- How is light sent and received on a fiber?
  - The key is that the devices used for transmission must match the fiber
- Two transmission technologies: LED or Injection Laser Diode (ILD)
- Reception: photo-sensitive cell or photodiode
  - LEDs and photo-sensitive cells are used for short distances and slower bit rates common with multimode fiber;
  - single mode fiber, used over long distance with high bit rates, generally requires ILDs and photodiodes

Infrared (IR) Communication Technologies

- IR uses the same type of energy as a TV remote control:
  - a form of electromagnetic radiation that behaves like visible light but falls outside the range that is visible to a human eye
- Like visible light, infrared disperses quickly
- Infrared signals can reflect from a smooth, hard surface
- An opaque object **(**not letting light pass through**)** as thin as a sheet of paper can block the signal
  - moisture in the atmosphere
- IR commonly used to connect to a nearby peripheral
- Many different technologies:
  - The **Infrared Data Association** (**IrDA**)
  - IrDA is a very short-range

Point-to-Point Laser Communication

- A pair of devices with a beam that follows the line-of-sight
- IR is classified as providing point-to-point communication
- Other point-to-point communication technologies also exist
  - One form of point-to-point communication uses a beam of coherent light produced by a laser
- Laser communication follows line-of-sight, and requires a clear, unobstructed path between the communicating sites
  - Unlike an infrared transmitter, however, a laser beam does not cover a broad area; the beam is only a few centimeters wide
  - The sending and receiving equipment must be aligned precisely to insure that the sender's beam hits the sensor in the receiver
  - They are suitable for use outdoors, and can span great distances
  - As a result, laser technology is especially useful in cities to transmit from building to building

Electromagnetic (Radio) Communication

- Skip this section up to 7-19.

Tradeoffs Among Media Types

- The choice of medium is complex
- Choice involves the evaluation of multiple factors, such as:
  - Cost
    - materials, installation, operation, and maintenance
  - Data rate
    - number of bits per second that can be sent
  - Delay
    - time required for signal propagation or processing
  - Affect on signal
    - attenuation and distortion
  - Environment
    - susceptibility to interference and electrical noise
  - Security
    - susceptibility to eavesdropping

Channel Capacity

- Defined as how fast the data (in bits) can be communicated
- Many factors impact channel capacity
  - Data rate
  - Bandwidth
  - Noise
  - Error rate
- What is the relation between these factors?

Nyquist Formula and Bandwidth

- Assuming noise free system and assuming that only one bit is provided to represent the signal:
- Nyquist's formula states the limitation of the data rate due to the bandwidth:
  - If the signal transmission rate is 2B (bps), then a signal with frequency of less or equal B (Hz) is required to carry this signal: $TR(f)=2B \rightarrow f \leq B$
  - If bandwidth is B (Hz) → the highest signal rate that can be carried is 2B (bps): $f=B \rightarrow TR(f) \leq 2B$
- Example: if the highest frequency is 4KHz (bandwidth) a sampling rate of 8 Kbps is required to carry the signal
- Note: data rate in bps= (number of bit per symbol) x (modulation rate in baud)

Example: Log2(8)=ln(8)/ln(2)=3

Channel Capacity

Nyquist's formulation when multilevel signaling is present

- channel capacity (C) is the tightest upper bound on the amount of information that can be reliably transmitted over a communications channel (max. allowable data rate)
- What if the number of signal levels are more than 2 (we use more than a single bit to represent the sate of the signal)?

$$C = 2B\log_2(M)$$

$$M = 2^n$$

$$\text{Re}\,meber:$$

$$\log_2(M) = \ln(M)/\ln(2)$$

- C = Maximum theoretical Channel Capacity in bps
- M = number of discrete signals (symbols) or voltage levels
- n = number of bits per symbol

Remember: More bits per symbol → more complexity!

Channel Capacity Example:

- Voice has a BW of 3100 Hz. calculate the maximum channel capacity
  - Assuming we use 2 signal levels
  - Assuming we use 8 signal levels

Channel Capacity Example:

- Voice has a BW of 3100 Hz. calculate the maximum channel capacity
  - Assuming we use 2 signal levels
  - Assuming we use 8 signal levels
- → channel capacity required to pass a voice signal:
- Max. Channel capacity (or Nyquist capacity) is 2 x 3100 cycles/sec = 6.1Kbps – note in this case one bit is being used to represent two distinct signal levels.
- If we use 8 signal levels: channel capacity: 2x3100x3=18600 bps → higher capacity!

So, in real world, how much can Channel Cap. Be increased by?

:Data rate is how fast we are communicating
BW is constrained by the medium and the system property

S/N Ratio

- The signal and noise powers *S* and *N* are measured in watts or volts^2, so the signal-to-noise ratio here is expressed as a power ratio, *not* in decibels (dB)

$$SNR_{dB} = 10\log_{10}\frac{SignalPower(watt/Volt^2)}{NoisePower(watt/Volt^2)}$$

$\mathrm{Re}\,meber:$

$$10^x = y \longrightarrow \log_{10} y = x$$

$$Power(dB) = 10\log_{10}(Pout / Pin)$$

$$Power(dBm) = 10\log_{10}(P(mW) / 1mW)$$

Example:
Assume signal strength is 2 dBm and noise strength is 5 mW. Calculate the SNR in dB.

2dBm→ 1.59 mW
SNR = 10log(1.59/5)=-5dB

Channel Capacity with Noise and Error

- An application of the channel capacity concept to an additive white Gaussian noise channel with *B* Hz bandwidth and signal-to-noise ratio *S/N* is the Shannon–Hartley theorem:

$$C = B \log_2(1 + S/N).$$

Note:
S/N is not in dB and it is log base 2!

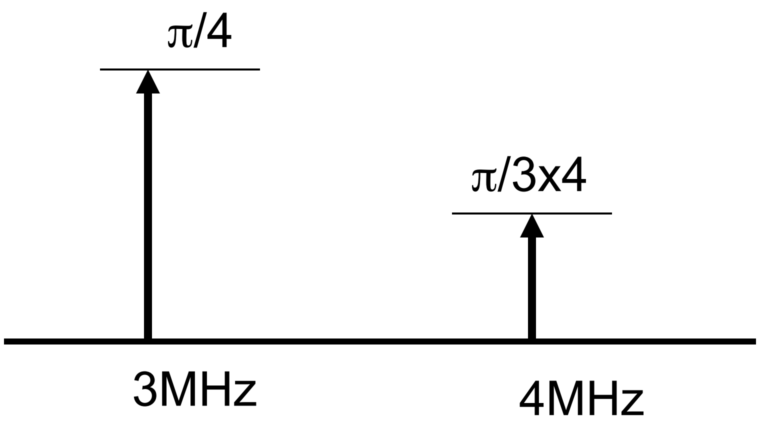
- Establishing a relation between error rate, noise, signal strength, and BW
- If the signal strength or BW increases, in the presence of noise, we can increase the channel capacity
- Establishes the upper bound on achievable data rate (theoretical)
  - Does not take into account impulse and attenuation

Noise Impact on Channel Capacity

- Presence of noise can corrupt the signal
- Unwanted noise can cause more damage to signals at higher rate
- For a given noise level, greater signal strength improves the ability to send signal
  - Higher signal strength increases system nonlinearity → more intermodulation noise
  - Also wider BW → more thermal noise into the system → increasing B can result in lower SNR

Example of Nyquist Formula and Shannon–Hartley Theorem

- Calculate the BW of this signal.
- Assuming the SNR = 24 dB, Calculate the maximum channel capacity.
- Using the value of the channel capacity, calculate how many signal levels are required to generate this signal?
- How many bits are required to send each signal level?
- Express the mathematical expression of this signal in time domain.



B=4-3=1 MHz

$SNR_{dB}(24) \rightarrow \log^{-1}(24/10)$

$10^{2.4} = 251$

$C = B\log_2(1+S/N) = 8Mbps$

$C = 2B\log_2 M \rightarrow M = 16$

$2^n = M \rightarrow n = 4$

$$s(t) = A \times \frac{4}{\pi} \sum_{K=1/odd}^{\infty} \frac{\sin(2\pi kft)}{k}$$

http://www.adec.edu/tag/spectrum.html

Channel Capacity Example:

- Voice has a BW of 3100 Hz. Assume SNR =24 dB. calculate the maximum channel capacity
  - Assuming we use 8 signal levels

$SNR_{dB}(24) \rightarrow \log^{-1}(24/10)$

$10^{2.4} = 251$

$C = B\log_2(1+S/N)$

3100.8=24,800 bps

Signal Impairments
Attenuation

- Strength of a signal falls off with distance over transmission medium
- Attenuation factors for guided media:
  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Typically signal strength is reduced exponentially
  - Expressed in dB

$$Attenuation(dB) = 10\log_{10}\left(\frac{4\pi d}{\lambda}\right)^2$$

$$Attenuation(dB) = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)$$

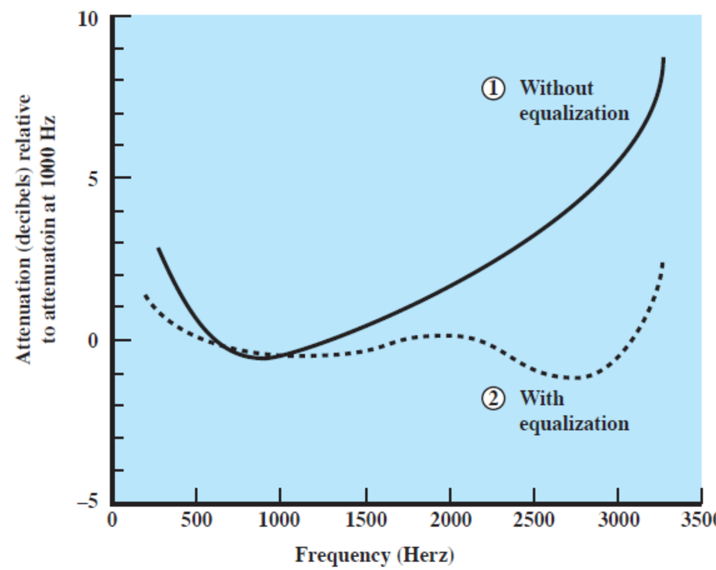
Where:

$\lambda = wavelength; d = distance$

Attenuation is greater at higher frequencies, causing distortion

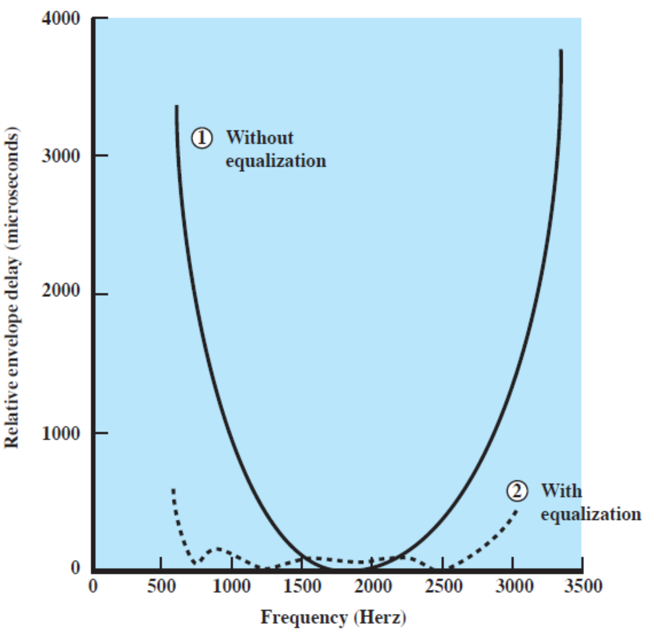
Signal Impairments
Attenuation Impacts

- Lowers signal strength
- Requires higher SNR
- Can change as a function of frequency
  - More of a problem in analog signal (less in digital)
  - Higher frequencies attenuate faster
  - Using equalization can improve – higher frequencies have stronger strength



Signal Impairments Delay Distortion

- In bandlimited signals propagation velocity is different for different frequencies
  - Highest near the center frequency
  - Hence, bits arrive out of sequence
  - → resulting in intersymbol interference
  - →limiting the maximum bit rate!



Categories of Noise

- Thermal Noise
- Intermodulation noise
- Crosstalk
- Impulse Noise

Thermal Noise

- Thermal noise due to agitation of electrons
- Present in all electronic devices and transmission media
- Cannot be eliminated
- Function of temperature
- Particularly significant for satellite communication
  - When the signal that is received is very weak

Thermal Noise

- Amount of thermal noise to be found in a bandwidth of 1Hz in any device or conductor is:

$$N_0 = \mathrm{k}T \left(\mathrm{W/Hz}\right)$$

  - N_0 = noise power density in watts per 1 Hz of bandwidth
  - k = Boltzmann's constant = 1.3803×10^{-23} J/K
  - T = temperature, in Kelvins (absolute temperature) – zero deg. C is 273.15
  - Expressed in dBW 10log(No/1W)

Thermal Noise

- Noise is assumed to be independent of frequency
- Thermal noise present in a bandwidth of *B* Hertz (in watts):

$$N_0 = \mathrm{k}T\left(\mathrm{W/Hz}\right) \quad \rightarrow \quad N = \mathrm{k}TB$$

or, in decibel-watts

$$N = 10\log \mathrm{k} + 10\log T + 10\log B$$

k = Boltzmann's constant = 1.3803×10^{-23} J/K

Thermal Noise (dB)

(MATLAB Example)

```
%MATLAB CODE:
T= 10:1:1000;
k= 1.3803*10^-23;
B=10^6;
No=k*T;
N=k*T*B;
N_in_dB=10*log10(N);
semilogy(T,N_in_dB)
title( ‘Impact of temperature in generating
      thermal noise in dB’ )
xlabel( ‘Temperature in Kelvin’ )
ylabel( ‘Thermal Noise in dB’ )
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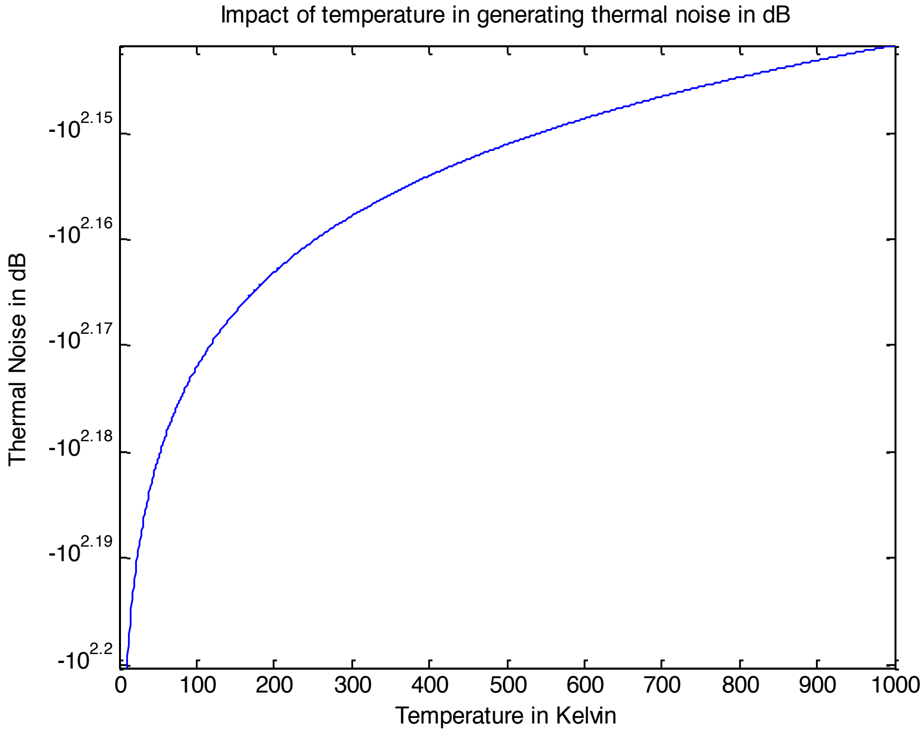


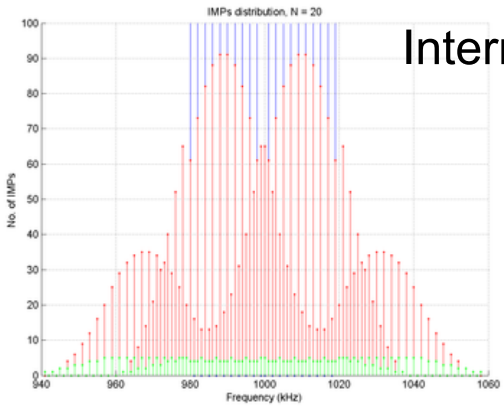
Other Types of Noise

- Intermodulation noise – occurs if signals with different frequencies share the same medium
  - Interference caused by a signal produced at a frequency that is the sum or difference of original frequencies
  - Note: $\cos A + \cos B = 2 \cos \frac{1}{2}(A + B) \cos \frac{1}{2}(A - B)$
- Crosstalk – unwanted coupling between signal paths
- Impulse noise – irregular pulses or noise spikes
  - Short duration and of relatively high amplitude
  - Caused by external electromagnetic disturbances, or faults and flaws in the communications system

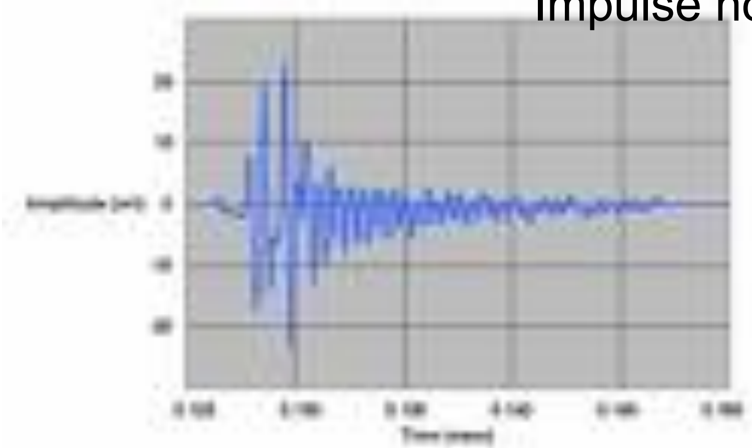
> Question: Assume the impulse noise is 10 msec. How many bits of DATA are corrupted if we are using a Modem operating at 64 Kbps with 1 Stop bit? (Burst of data errors)

One stop bit means the actual data rate is 56 Kbps: (64 x (7/8))=56
56000*.01 = 560 bits.

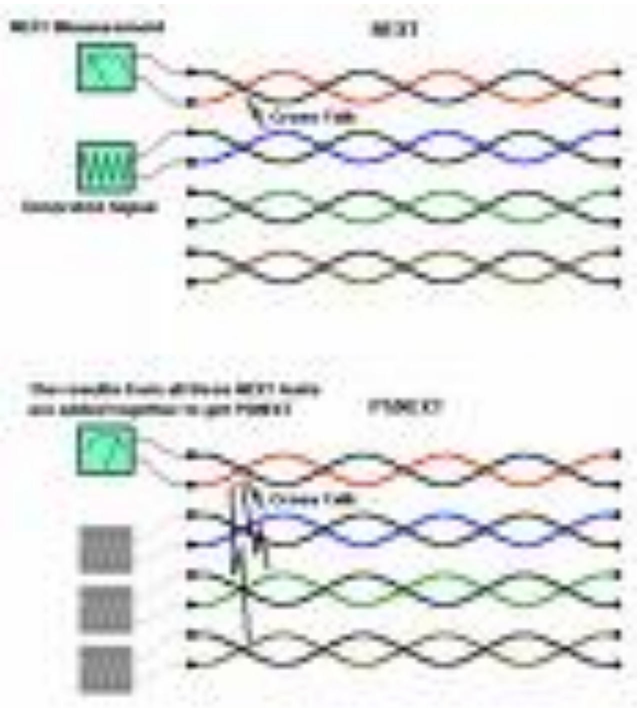
Other Types of Noise - Example



Intermodulation noise



Impulse noise



Crosstalk

Remember

$$C = B \log_2(1 + S/N).$$

$$N = 10\log \mathrm{k} + 10\log T + 10\log B$$