Computer Networks

Data Transmission

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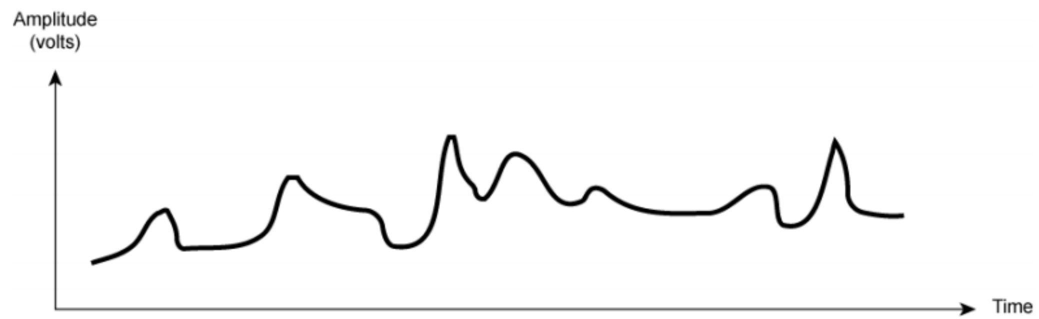
Types of Links

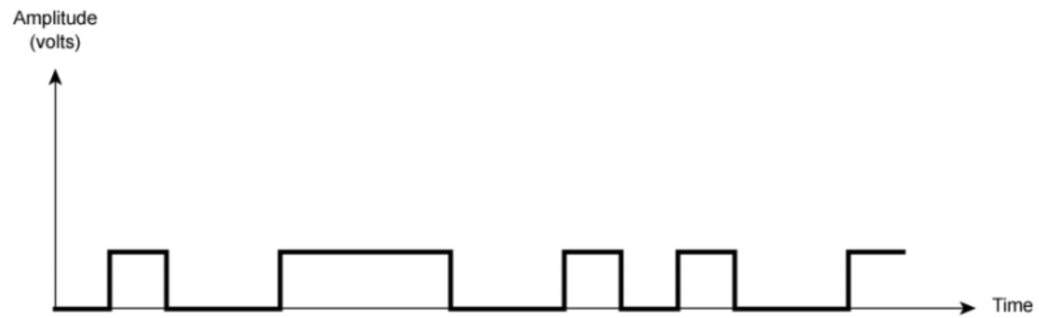
- Simplex:
  - Communication takes place in one direction
- Half Duplex:
  - Either direction, but only one way at a time
- Full Duplex:
  - Both directions at the same time
    - Example: Telephone

Time Domain Concepts

- Analog signal:
  - Varies in a smooth way over time
- Digital signal:
  - Maintains a constant level then changes to another constant level



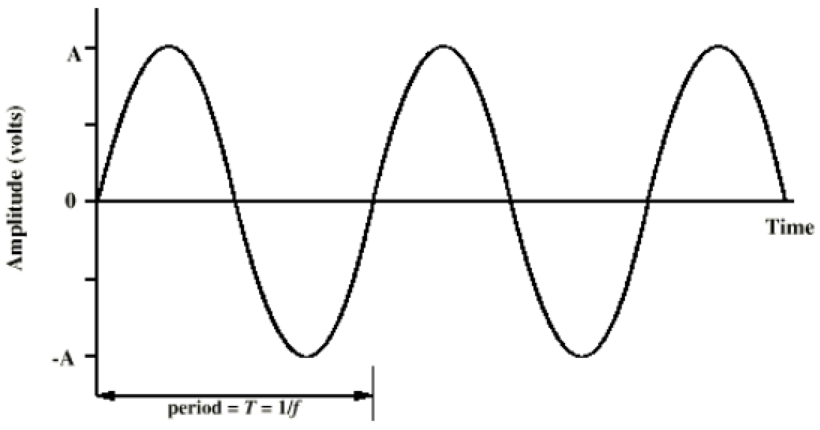
(a) Analog



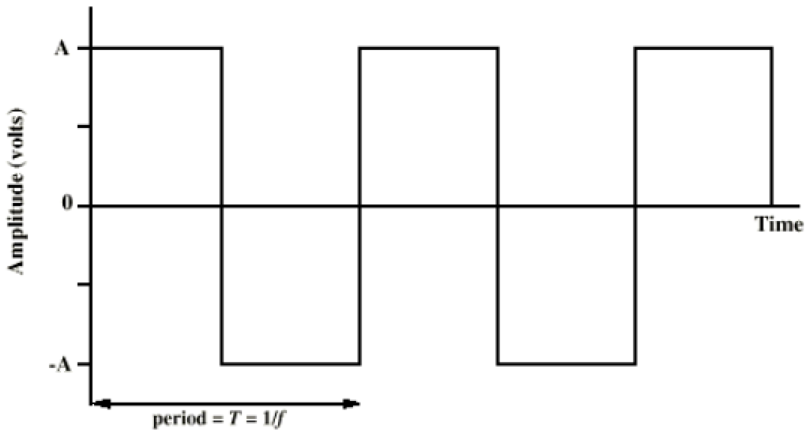
(b) Digital

Time Domain Concepts

- Periodic signal
  - Pattern repeated over time
- Aperiodic signal
  - Pattern not repeated over time



(a) Sine wave

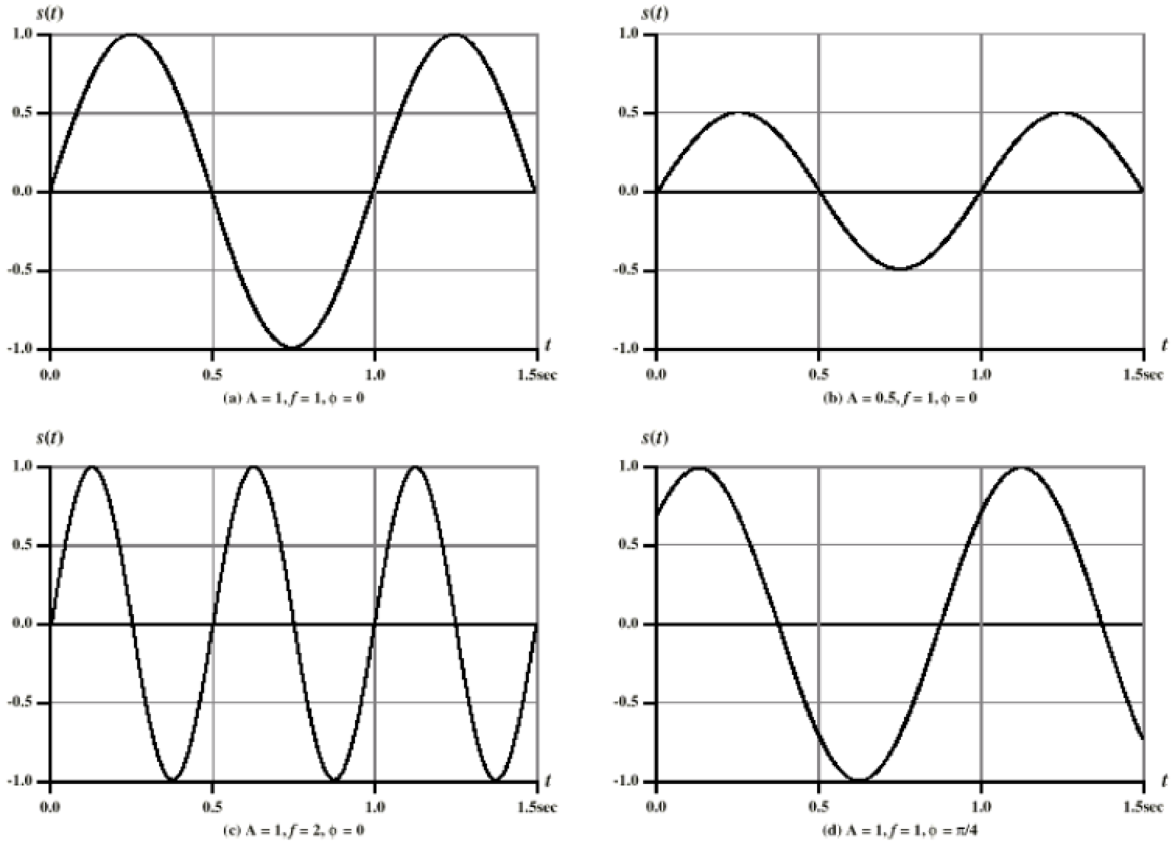


(b) Square wave

Sine Wave

- Peak amplitude
- Frequency
- Phase

$$s(t) = A \sin(2\pi f t + \Phi)$$



(a) A = 1, f = 1, ϕ = 0

(b) A = 0.5, f = 1, ϕ = 0

(c) A = 1, f = 2, ϕ = 0

(d) A = 1, f = 1, ϕ = π/4

Wavelength

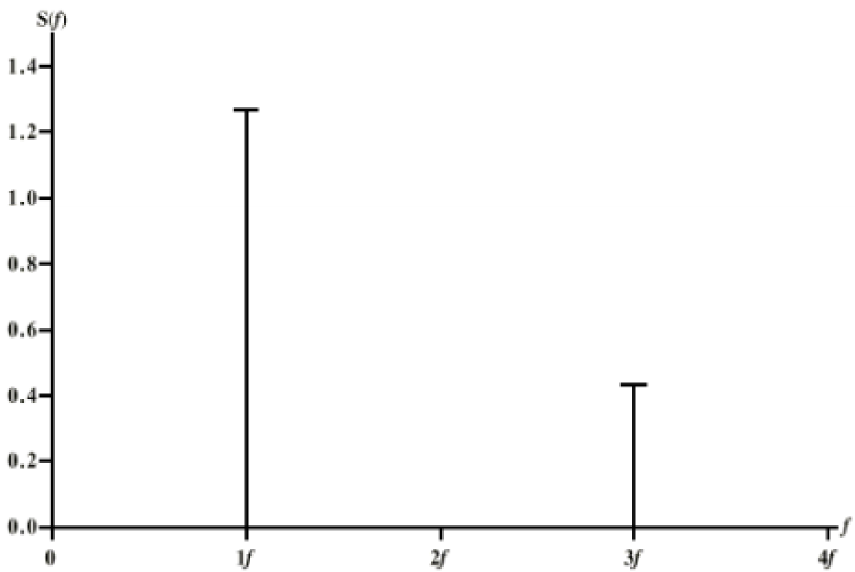
- Distance occupied by one cycle
- Between two points of corresponding phase in two consecutive cycles

- $\lambda = v.T = \frac{v}{f}$
  - λ = wavelength
  - v = velocity of signal
    - 3×10^8 meters/seconds in free space (speed of light)
  - T = time period
  - f = fundamental frequency

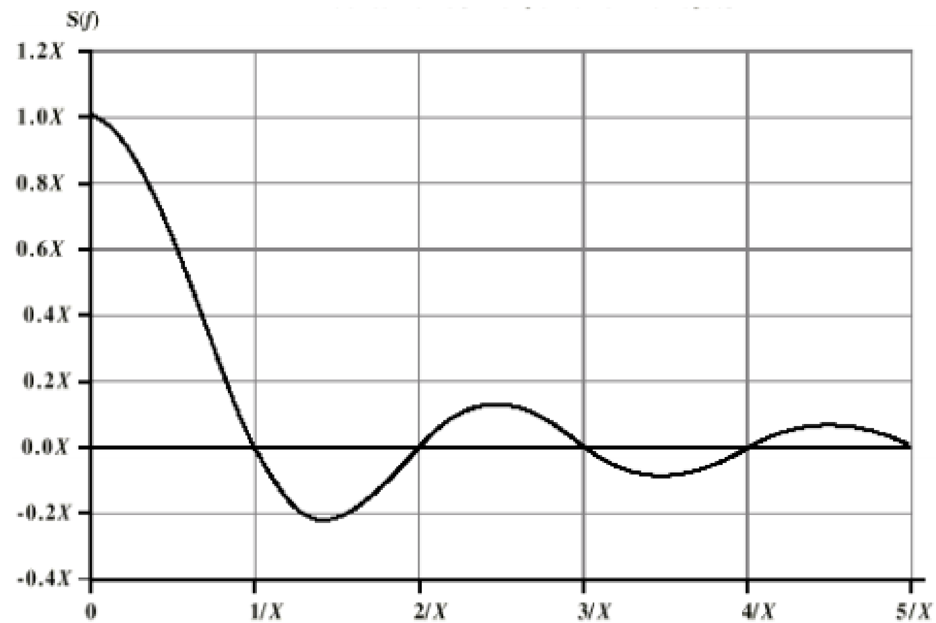
Frequency Domain Concepts

- Fourier analysis can shown that any signal is made up of component sinusoidal waves

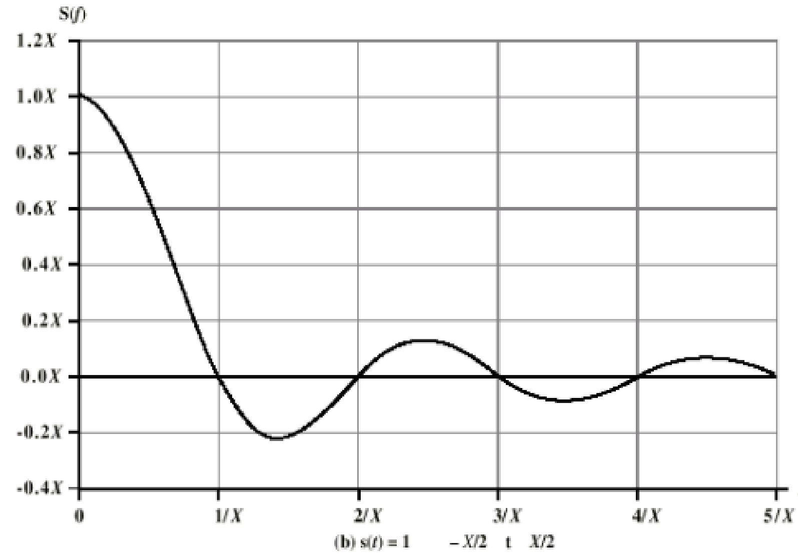
$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}\,dt \qquad\qquad x(t) = \int_{-\infty}^{\infty} X(f)e^{i2\pi ft}\,df$$



(a) s(t) = (4/) [sin (2 ft) + (1/3) sin (2 (3f)t)]



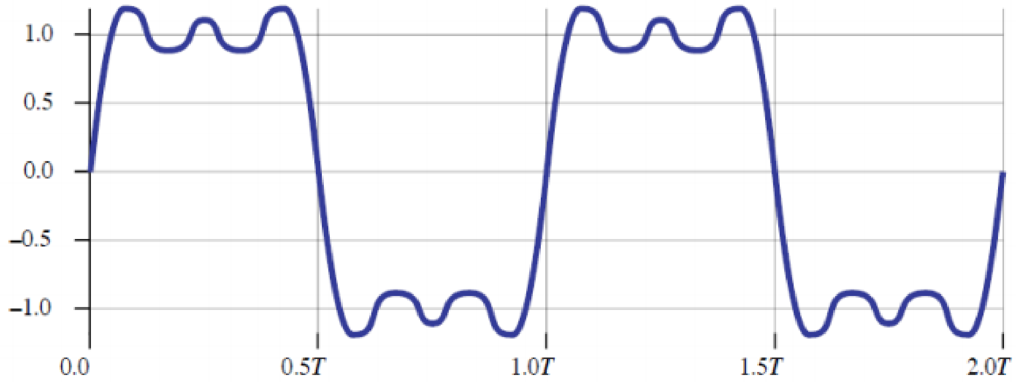
(b) s(t) = 1 – X/2 t X/2


S(f)
1.2X
1.0X
0.8X
0.6X
0.4X
0.2X
0.0X
-0.2X
-0.4X
0
1/X
2/X
3/X
4/X
5/X
(b) s(t) = 1 – X/2 t X/2

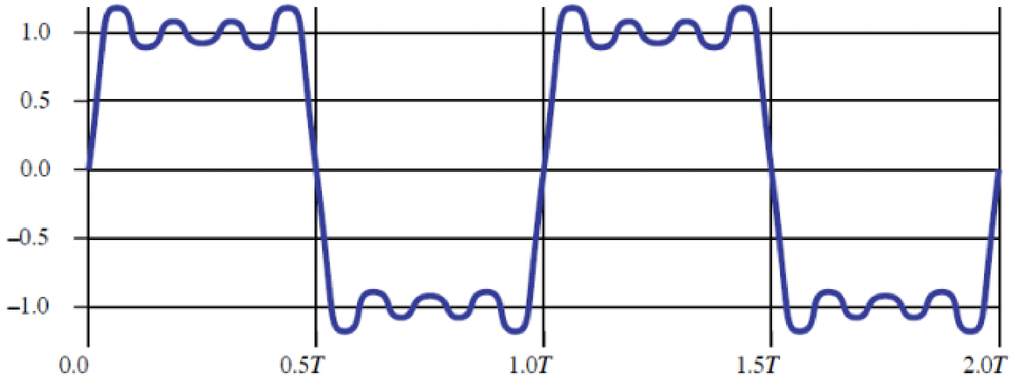
Spectrum and Bandwidth

- Spectrum:
  - Range of frequencies contained in the signal
- Absolute bandwidth:
  - Width of the signal
- Effective bandwidth:
  - Narrow band of frequencies containing most energy
- DC Component:
  - Component of zero frequency

Bandwidth?



(a) $(4/\pi)$ [sin $(2\pi ft)$ + (1/3) sin $(2\pi(3f)t)$ + (1/5) sin $(2\pi(5f)t)$]



(b) $(4/\pi)$ [sin $(2\pi ft)$ + (1/3) sin $(2\pi(3f)t)$ + (1/5) sin $(2\pi(5f)t)$ + (1/7) sin $(2\pi(7f)t)$]

Data Rate and Bandwidth

- Any transmission system has a limited band of frequencies
- This limits the data rate that can be carried
- Square have infinite components and hence infinite bandwidth
  - Most energy in first few components
- Limited bandwidth increases distortion
- Have a direct relationship between data rate & bandwidth
  - Higher the data rate → greater is its required bandwidth
  - Greater the bandwidth of a transmission system → higher is the data rate that can be transmitted

Analog and Digital

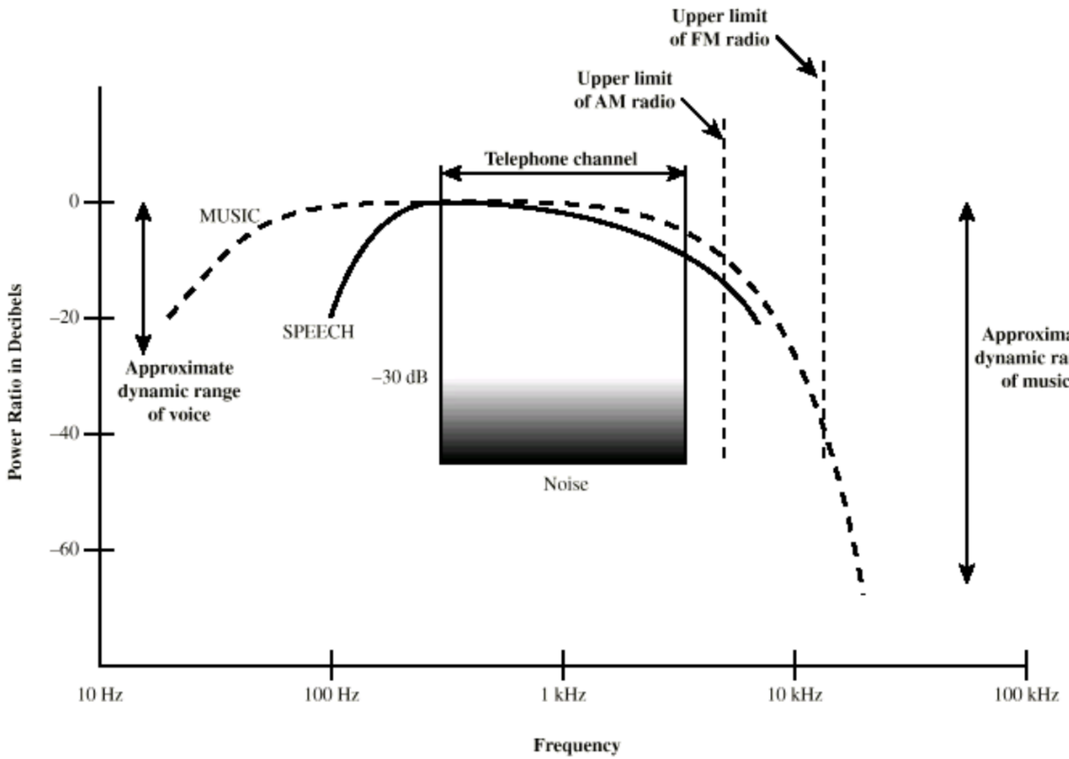
- Data:
  - Entities that convey meaning or information
  - Analog data take continuous values over time, i.e. voice, video, sensor data
  - Digital data takes discrete values, i.e. text

- Signals:
  - Electric and electromagnetic representation of data
  - Physically propagates along medium

- Transmissions:
  - Communication of data by propagation and processing of signals

Acoustic Spectrum

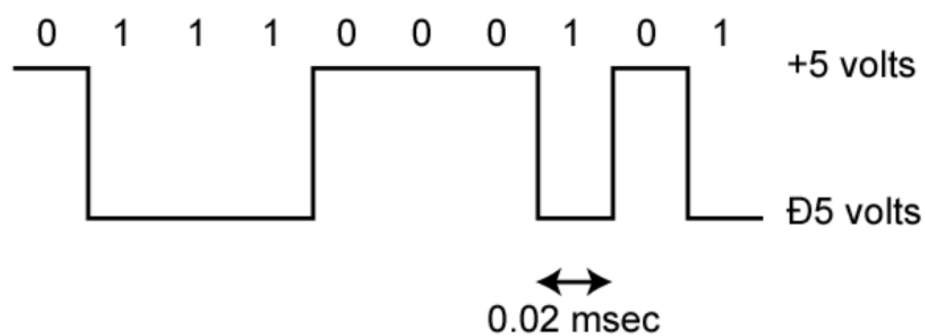
- Typical speech may be found between 100 Hz and 7 KHz



In this graph of a typical analog signal, the variations in amplitude and frequency convey the gradations of loudness and pitch in speech or music. Similar signals are used to transmit television pictures, but at much higher frequencies.

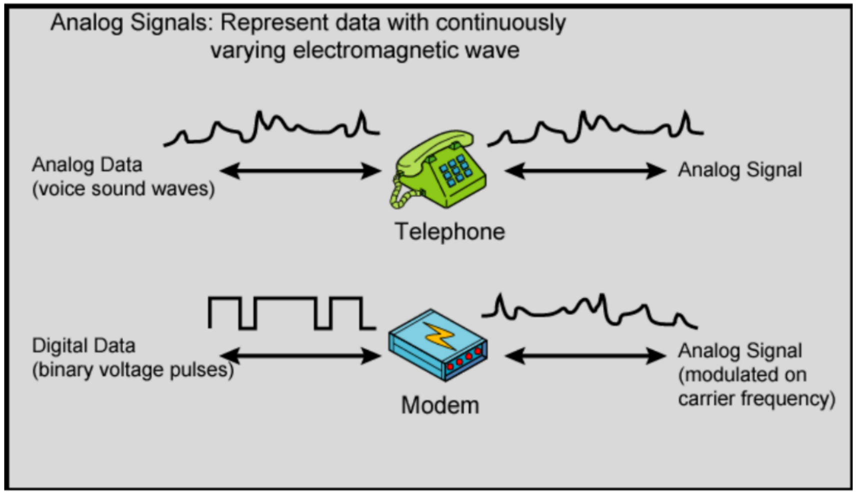
Digital Data

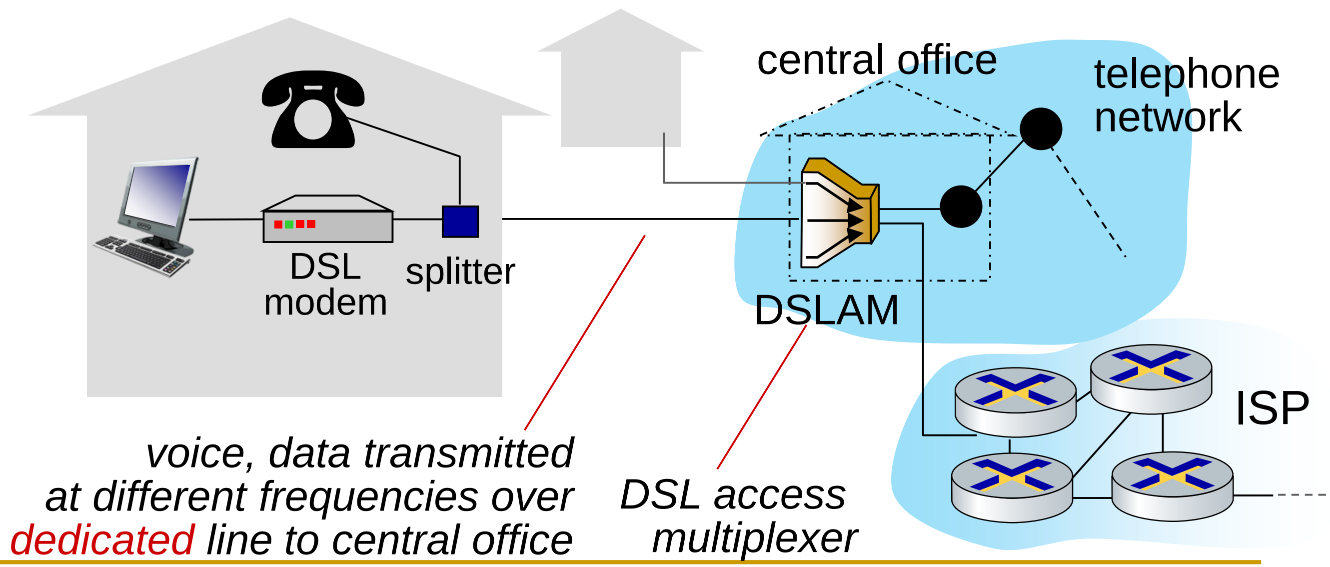
- Digital data takes discrete values, i.e. text
- Generated by computers etc.
- Has two DC components



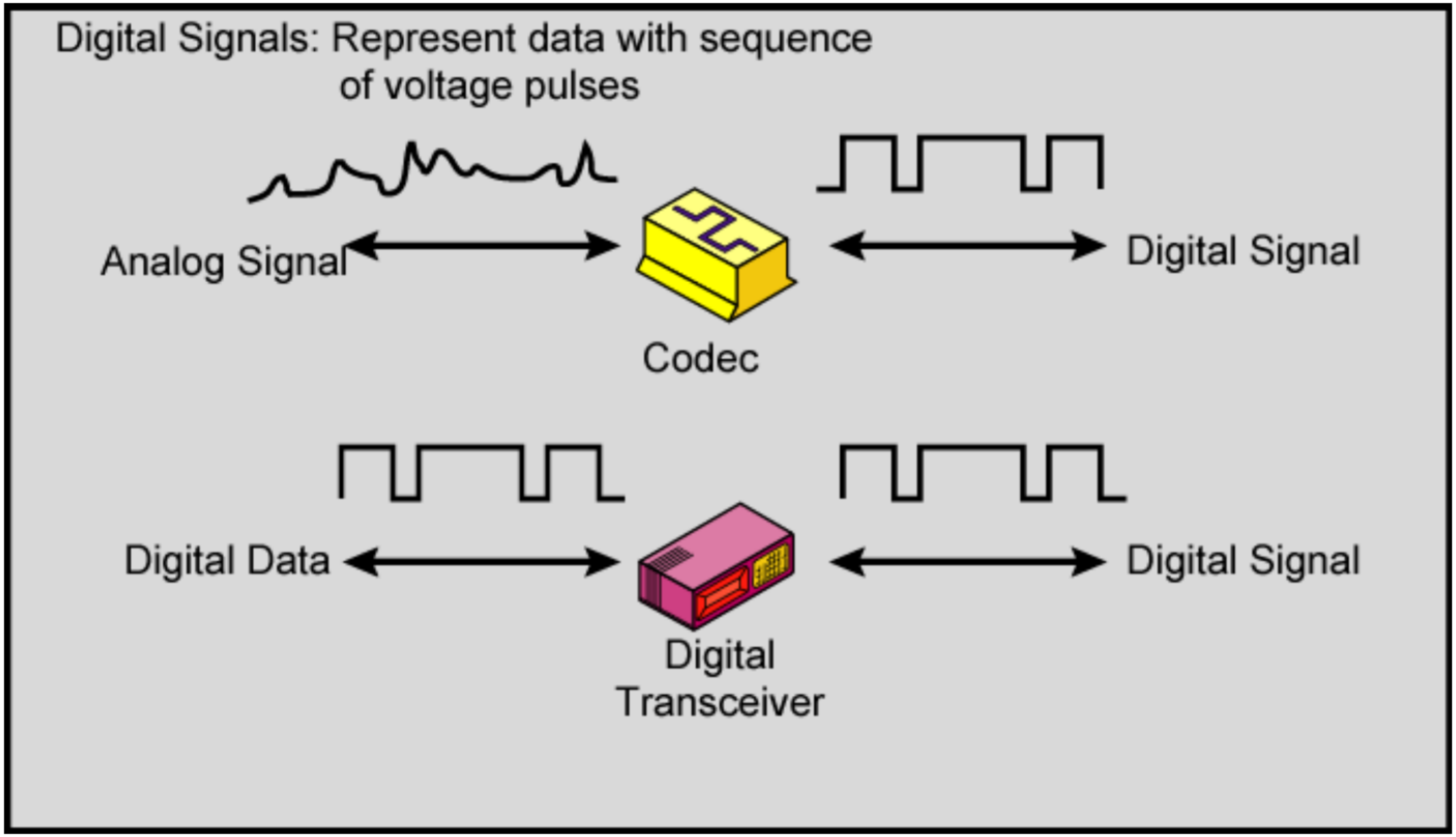
User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by Đ5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).

Analog Signal





Digital Signal



Transmission Impairments

- Signal received may be different from signal transmitted:
  - Analog: Degradation of signal quality
  - Digital: Bit errors

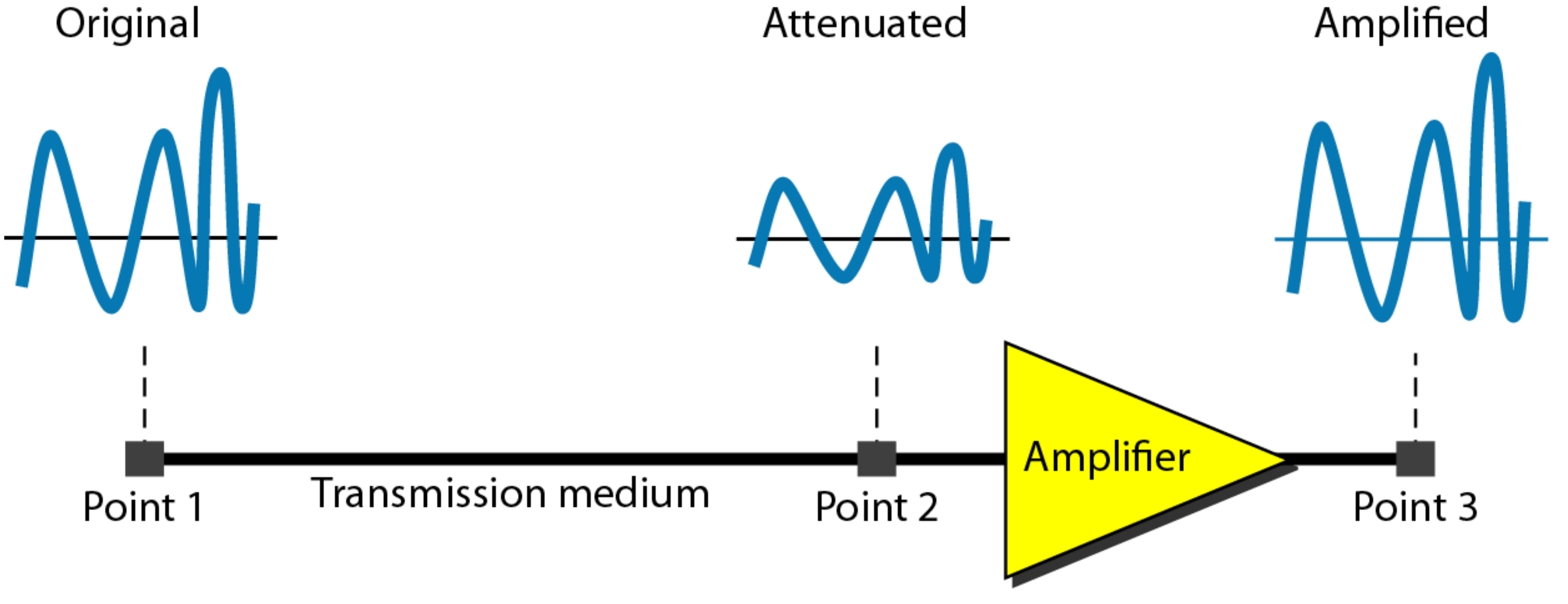
- Transmission Impairments are:
  - Attenuation and attenuation distortion
  - Delay distortion
  - Noise

Attenuation

- Signal strength falls off with distance
- Received signal strength must be:
  - strong enough to be detected
  - sufficiently higher than noise to receive without error
- So increase strength using amplifiers/repeaters
-

Attenuation

- Analog Transmission:
  - Use amplifier to get rid of attenuation → noise get amplified
- Digital Transmission:
  - Use repeaters



Attenuation

$$G_{dB} = 10log_{10}\frac{P_{out}}{P_{in}}$$

$$L_{dB} = -10log_{10}\frac{P_{out}}{P_{in}} = 10log_{10}\frac{P_{in}}{P_{out}}$$

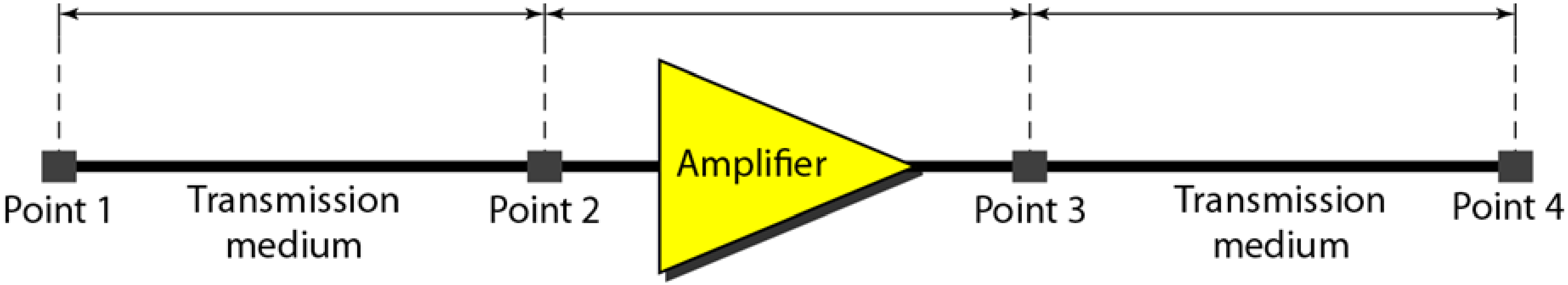
Attenuation

- If a signal with power level of 10 mW is inserted onto a transmission line, and the measured power some distance away is 5 mW, then what is the loss in dB?

$$L_{dB} = -10log_{10}\frac{P_{out}}{P_{in}} = 10log_{10}\frac{P_{in}}{P_{out}}$$

Attenuation

- Consider a scenario where the input power at the transmitter end is 4 mW. The first element in the transmission line is 12 dB loss, the second element is an amplifier with 35 dB gain, and the third element is a transmission line with 10 dB loss. What is the output power in mW?



Attenuation

- dbW (decibel-watt)

$$Power_{dBW} = 10log_{10}\frac{Power_{W}}{1\,W}$$

- dBm (decibel-milliwatt):

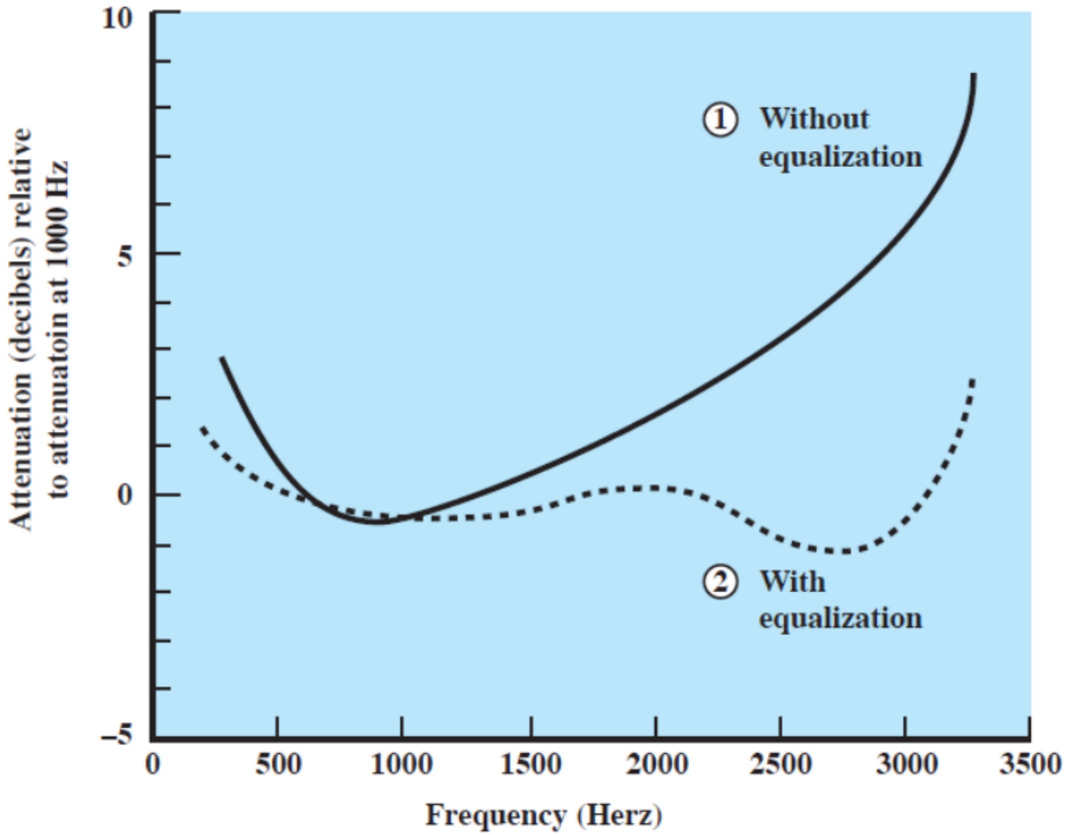
$$Power_{dBm} = 10log_{10}\frac{Power_{mW}}{1\,mW}$$

- 0 dBm = ? dBW

Attenuation distortion

- Signal strength falls off with distance
- Attenuation is greater at higher frequency → causes distortion
- Attenuation is also an increasing function of frequency
  - equalize attenuation across band of frequencies used

Attenuation and attenuation distortion

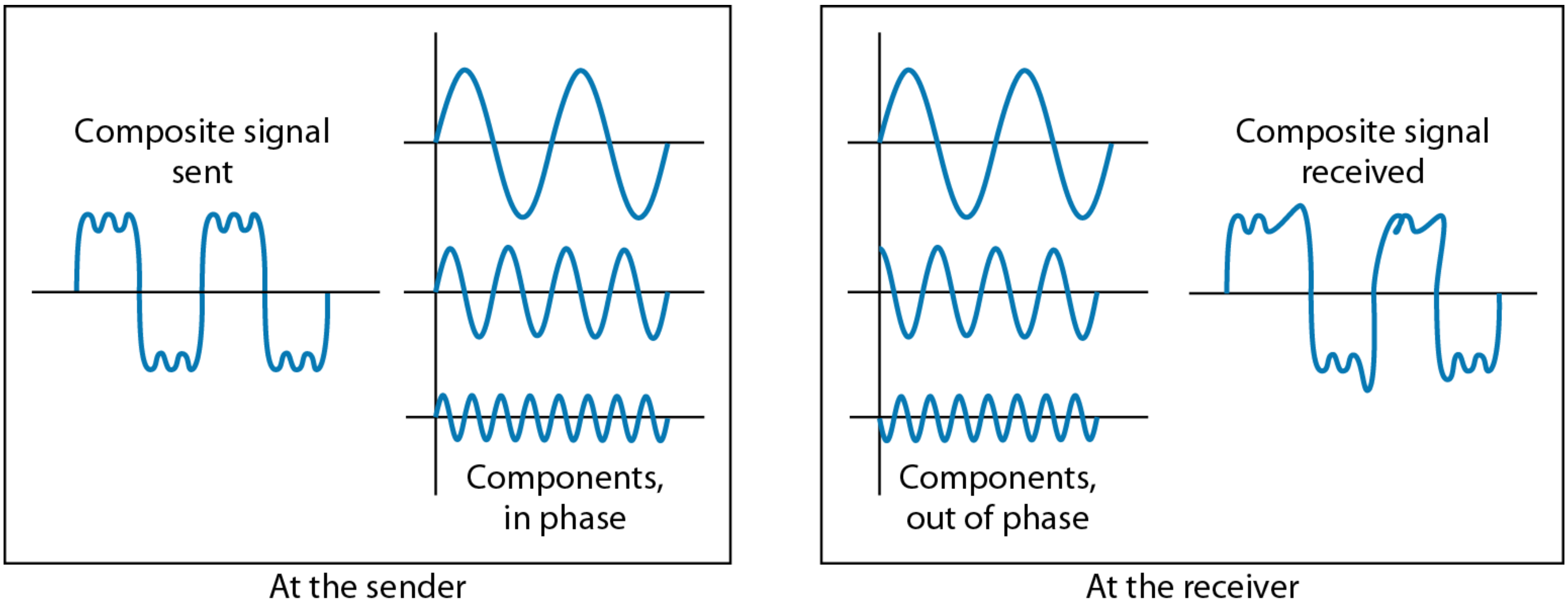


(a) Attenuation

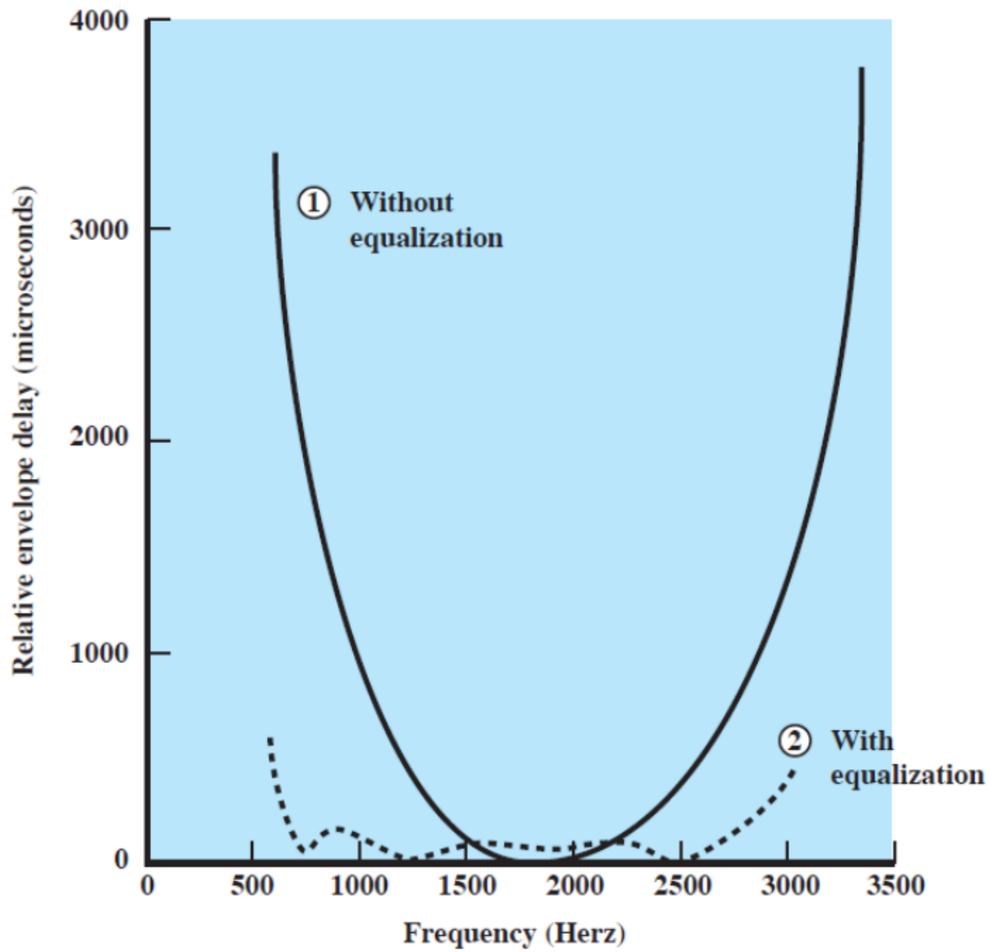
Delay Distortion

- Only occurs in guided media
- Propagation velocity varies with frequency
-
- Various frequency components arrive at different times
- Particularly critical for digital data
  - since parts of one bit spill over into others
  - causing intersymbol interference

Effect of Distortion



Delay Distortion

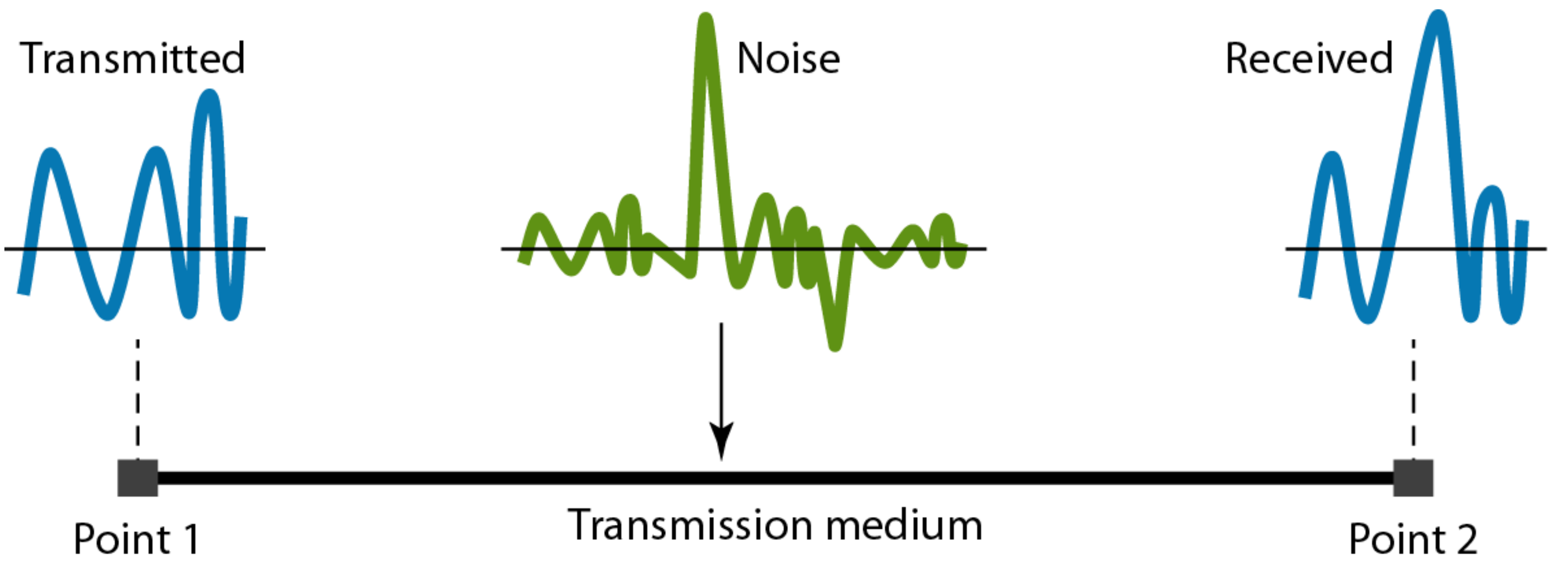


(b) Delay distortion

Noise

- Additional signals inserted between transmitter and receiver

- Thermal noise:
  - due to thermal agitation of electrons
  - uniformly distributed
  - white noise



Thermal Noise

- Noise power density (W/Hz): The amount of thermal noise to be found in a bandwidth of 1 Hz

$$\boldsymbol{N_0 = kT \text{ (W/Hz)}}$$

- Room temperature is usually specified as T = 17 C. What is the thermal noise power density?

Thermal Noise

- The thermal noise (in watts) present in a bandwidth of B Hz is given by

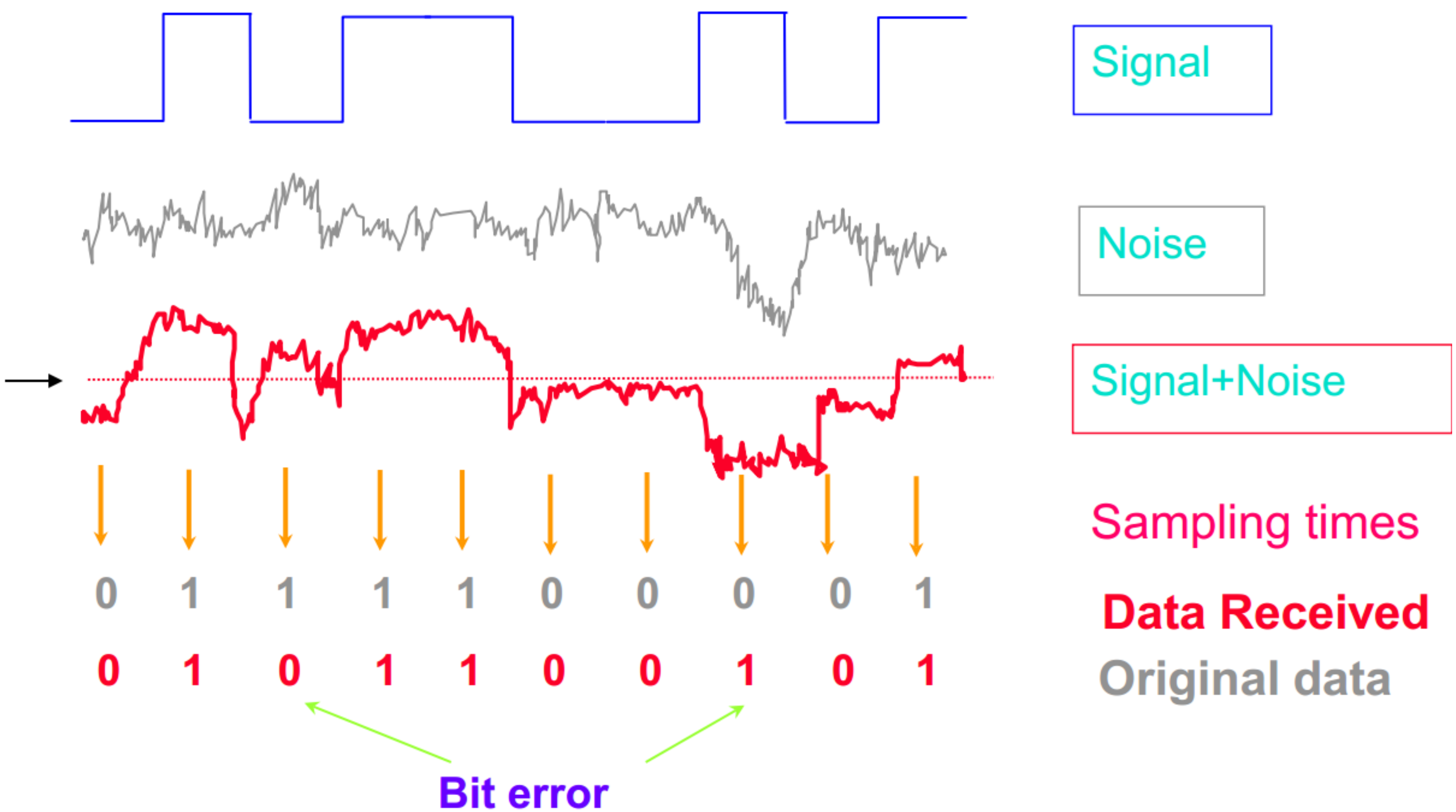
$$N = \mathbf{kTB\ (W)}$$

- Given a receiver with an effective noise temperature of 294 K and a 10 MHz bandwidth, what is the thermal noise level at the receiver?

Other Types of Noise

- Intermodulation:
  - signals that are the sum and difference of original frequencies sharing a medium
- Crosstalk:
  - a signal from one line is picked up by another
  - can occur by electrical coupling between nearby twisted pairs or when microwave antennas pick up unwanted signals
- Impulse:
  - irregular pulses or spikes
  - eg. external electromagnetic interference such as lightning, faults and flaws in the communication systems
  - short duration → high amplitude
  - a minor annoyance for analog signals
  - but a major source of error in digital data → a noise spike could corrupt many bits

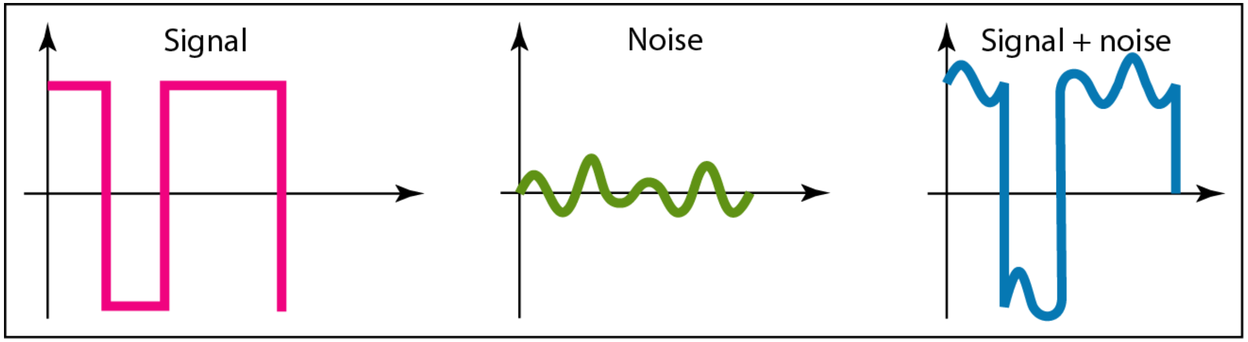
Effect of Noise



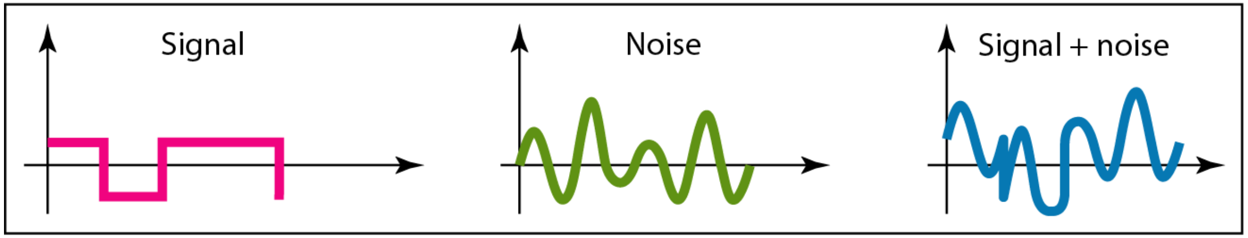
Signal-to-Noise ratio

$$SNR = \frac{Average\ signal\ power}{Average\ noise\ power}$$

$$SNR_{dB} = 10log_{10}\text{SNR}$$



a. Large SNR



b. Small SNR

Signal-to-Noise ratio

- The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB} ?

$$\mathrm{SNR} = \frac{10{,}000\ \mu\mathrm{W}}{1\ \mathrm{mW}} = 10{,}000$$

$$\mathrm{SNR}_{\mathrm{dB}} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

Channel Capacity

- Channel capacity: Maximum data rate at which data can be transmitted over a given communication channel

- Is a function of
  - Data rate – C, [bits per second]
  - Bandwidth – B, [cycles per second or Hertz]
  - Noise - on communication link
  - Error rate - of corrupted bits

- Two theoretical models:
  - Nyquist capacity: assumes noise-free environment
  - Shannon capacity: considers noise

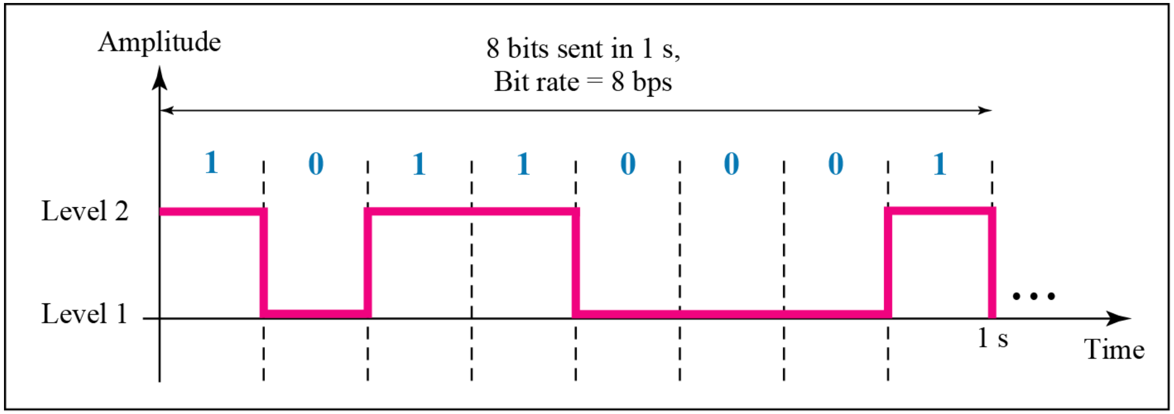
Nyquist capacity

- Considers channel is noise free
- Given a bandwidth of B, the highest signal rate is $2B$
- Signal element may carry more than 1 bit
- Signal of M level may carry $\boldsymbol{log_2 M}$bits

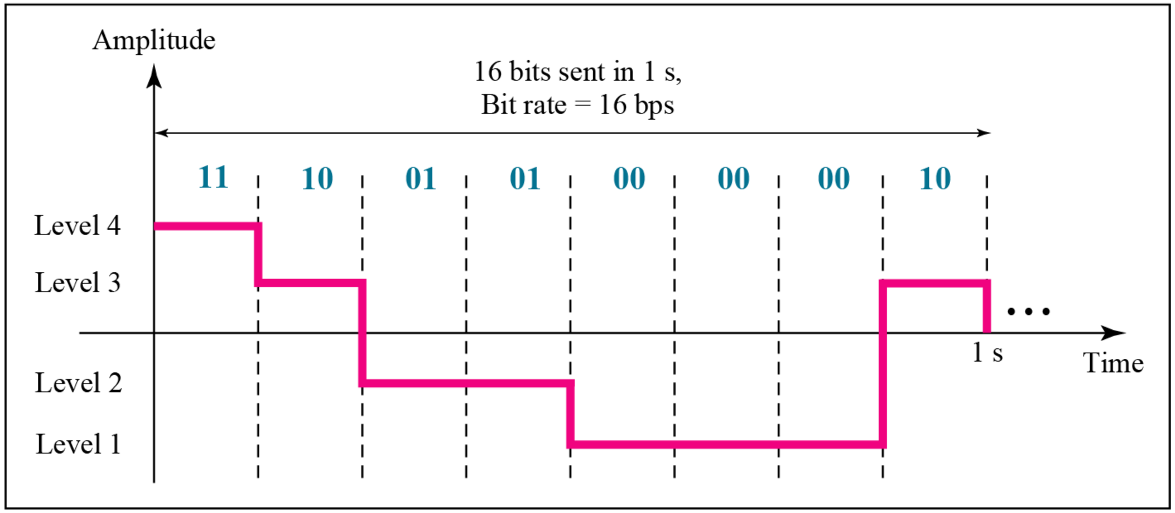
$$\boldsymbol{C = 2B log_2 M}$$

- Tradeoffs
  - Increase the bandwidth→ increase the data-rate
  - Increase the signal rate → increase the data-rate → at the cost of receiver complexity
    - Increase signal rate → harder for the receiver to interpret the bits → practical limit of M

Signal Rate vs Bit Rate



a. A digital signal with two levels



b. A digital signal with four levels

Illustration

Illustration

Shannon capacity

- Consider relation of data rate, noise & error rate
  - Faster data rate shortens each bit
  - Bursts of noise affects more bits

- Given noise level, higher rates means higher errors
- Increase signal strength overcome noise

- Signal-to-noise ratio: $SNR = \frac{Signal\ power}{Noise\ power}$

- Shannon capacity: $C = Blog_2(1 + SNR)$
  - Theoretical **maximum capacity**
  - Get lower in practice

- Tradeoffs
  - Increase the bandwidth or signal power → increase the data-rate
  - Increase the noise → reduce the data-rate
    - Increase bandwidth → more noise → reduced data-rate
    - Increase signal power → more intermodulation noise → reduced data-rate

Illustration

Illustration

Example

- The spectrum of a channel is between 3 MHz to 4 MHz and SNR (dB) = 24 dB. Assume that we can reach the Shannon's limit. Then how many signals levels are required?

SNR vs E_b/N_0

SNR vs E_b/N_0

SNR vs E_b/N_0

Example

- For a particular modulation scheme, $\frac{E_b}{N_0} = 8.4$ dB is required for a bit error rate of 10^{-4}. If the effective noise temperature is 290 K and the data rate is 2400 bps, then what received signal strength is required?

Example

- What is the minimum $\frac{E_b}{N_0}$ required to achieve a spectral efficiency of 6 bps/Hz?

THANK YOU

QUESTIONS???