CS311: Data Communication

Transmission Impairments and Channel Capacity

by

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Outline of the Lecture

- Sources of Impairments
- Attenuation and unit of Attenuation
- Distortions
- Noise
- Data Rate Limits
- Bandwidth of a medium
- Nyquist Bit Rate
- Data Element and Signal Element
- Bit Rate and Baud Rate
- Shannon capacity in a Noisy channel

Analog and Digital Transmission

- Briefly, we define data as entities that convey meaning, or information.
- Signals are electric or electromagnetic representations of data.
- Signaling is the physical propagation of the signal along a suitable medium.

- Transmission is the communication of data by the propagation and processing of signals.

- An analog signal is a continuously varying electromagnetic wave that may be propagated over a variety of media depending on spectrum.

- A digital signal is a sequence of voltage pulses that may be transmitted over a wire medium; for example, a constant positive voltage level may represent binary 0 and a constant negative voltage level may represent binary 1.

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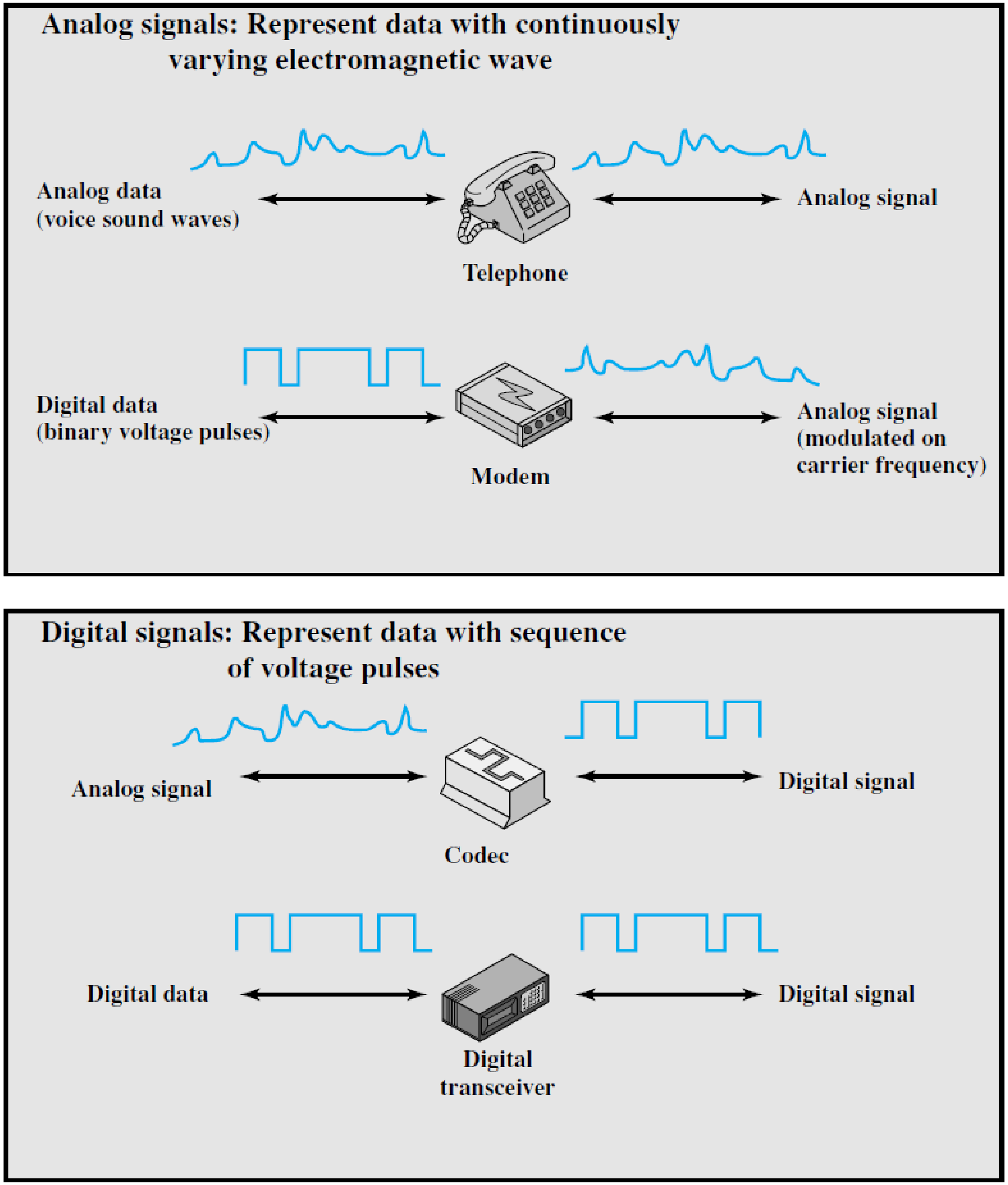

Figure 3.14 Analog and Digital Signaling of Analog and Digital Data

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- The principal advantages of digital signaling are that it is generally cheaper than analog signaling and is less susceptible to noise interference. The principal disadvantage is that digital signals suffer more from attenuation than do analog signals.

- **Analog transmission** is a means of transmitting analog signals without regard to their content; the signals may represent analog data (e.g., voice) or digital data (e.g., binary data that pass through a modem). In either case, the analog signal will become weaker (attenuate) after a certain distance.

- **Digital transmission**, in contrast, assumes a binary content to the signal. A digital signal can be transmitted only a limited distance before attenuation, noise, and other impairments endanger the integrity of the data.

Impairments

- To send data, we have to send signal through a communication medium.

- A medium is not ideal. The imperfections cause impairments in the signal.

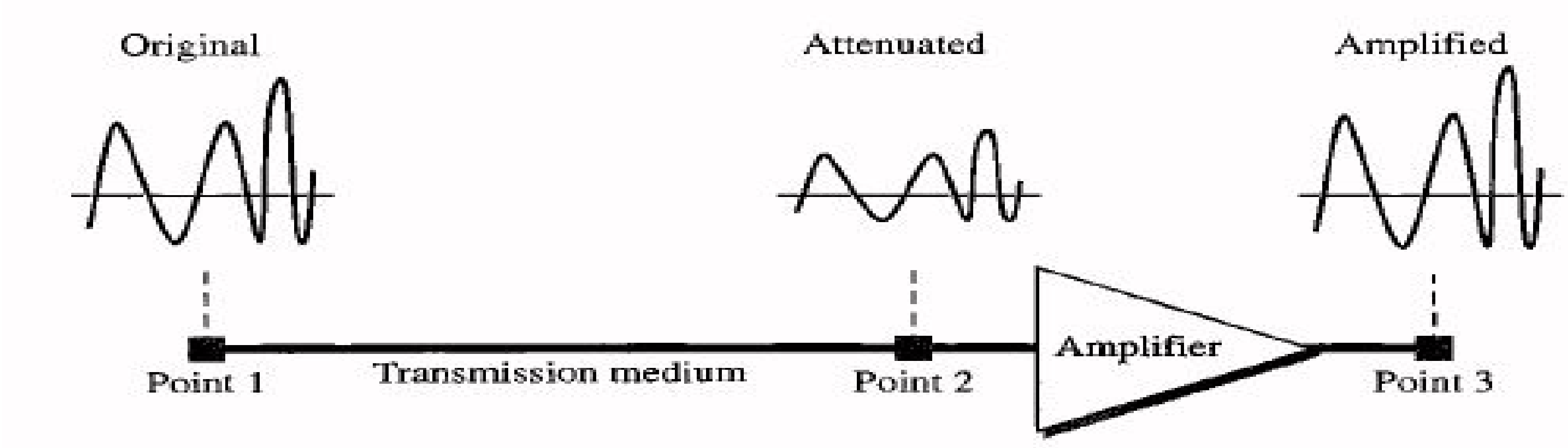
- Impairments:
  – Attenuation
  – Distortion
  – Noise

Attenuation

- The strength of a signal falls off with distance over any transmission medium.
- Attenuation leads to loss of energy in decibel.

$$\text{dB} = 10 \log_{10}(P_2/P_1)$$

- It decides how far a signal can be sent without amplification.

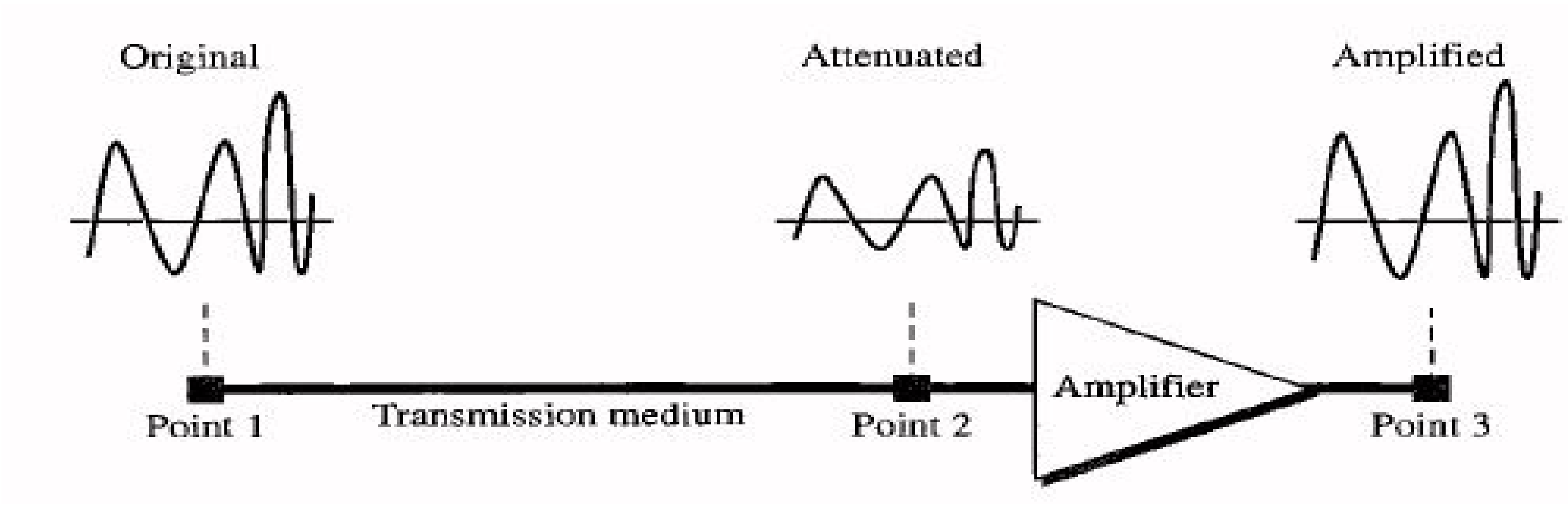


- An amplifier can be used to compensate the attenuation of the medium.

Decibel

- Decibel (dB) is a measure of the relative strengths of two signals.
- If P_2 and P_1 are signal strengths of two different points 2 and 1 respectively, then relative strength at the first point with respect to the second point in dB is

$$\text{dB} = 10\log_{10}(P_2/P_1)$$



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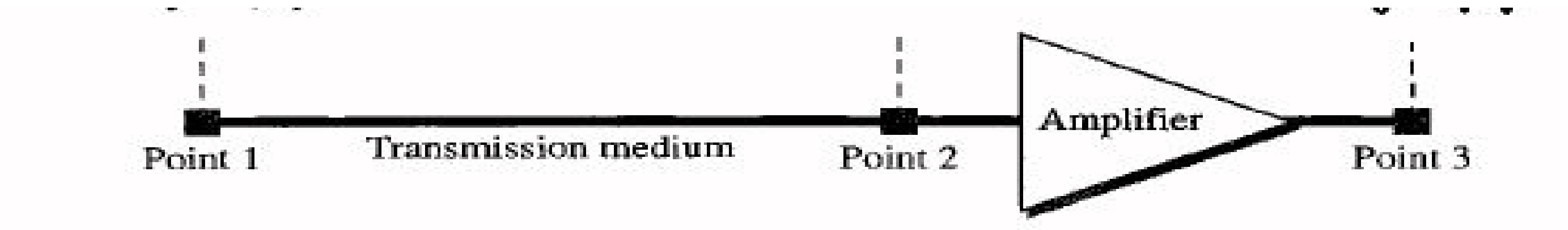
➢ Example-1

- Let the energy strength of point 2 is 1/10th w.r.t. point 1. Then attenuation in dB is $10 \log_{10}(1/10)$ = -10 dB.
- Note that loss of power is represented by negative sign.
- On the other hand let the gain is 100 times at point 3 with respect to point 2. Then gain in dB is $10 \log_{10}(100/1)$ = 20 dB, which is positive.

Cont…

- It may be noted that signal strength at point 3 w.r.t. point 1 can be obtained by adding the two values;

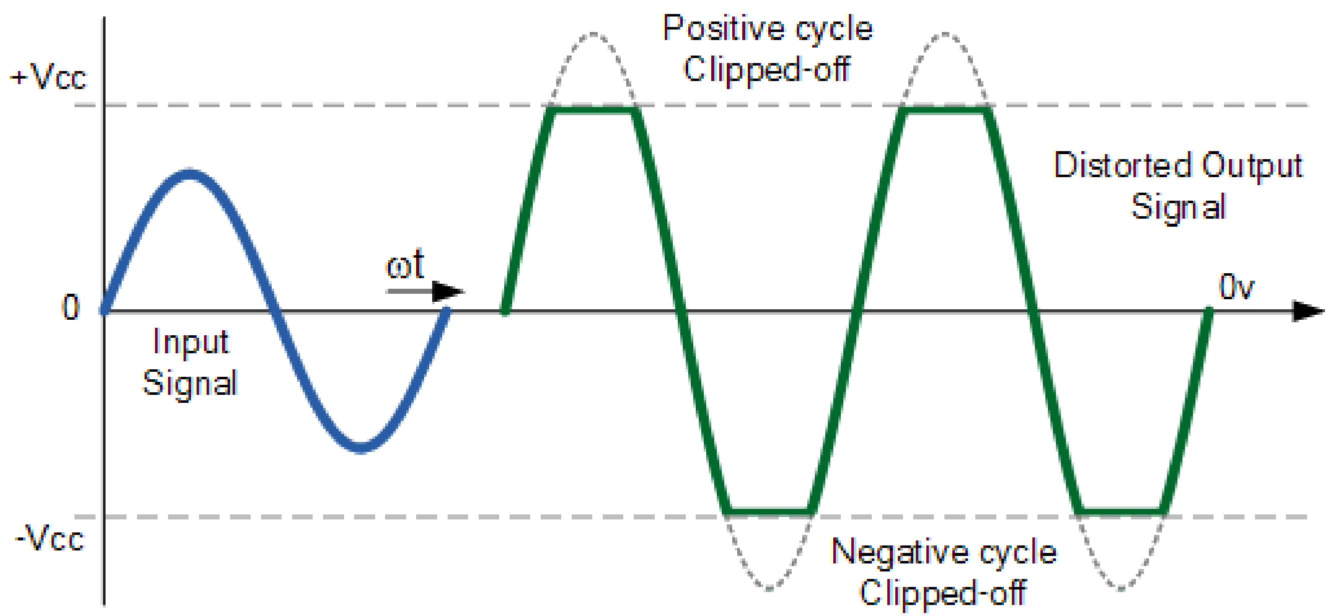
  (-10) + 20 = 10 dB.



- Attenuation introduces three considerations for the transmission engineer
  – a received signal must have sufficient strength so that the electronic circuitry in the receiver can detect the signal
  – the signal must maintain a level sufficiently higher than noise to be received without error
  – attenuation varies with frequency

Distortion

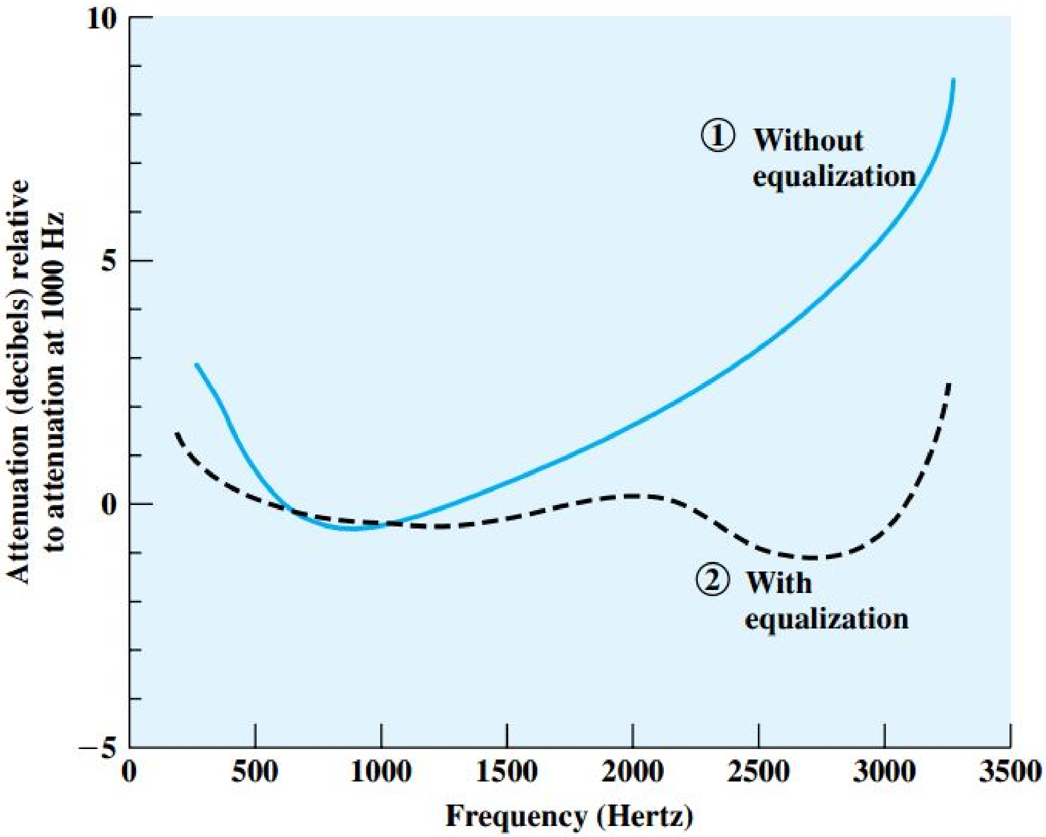
- Attenuation of all frequency components are not same.
- Some frequencies are passed without attenuation, some are weakened and some are blocked. This leads to delay distortion.



Attenuation Distortion

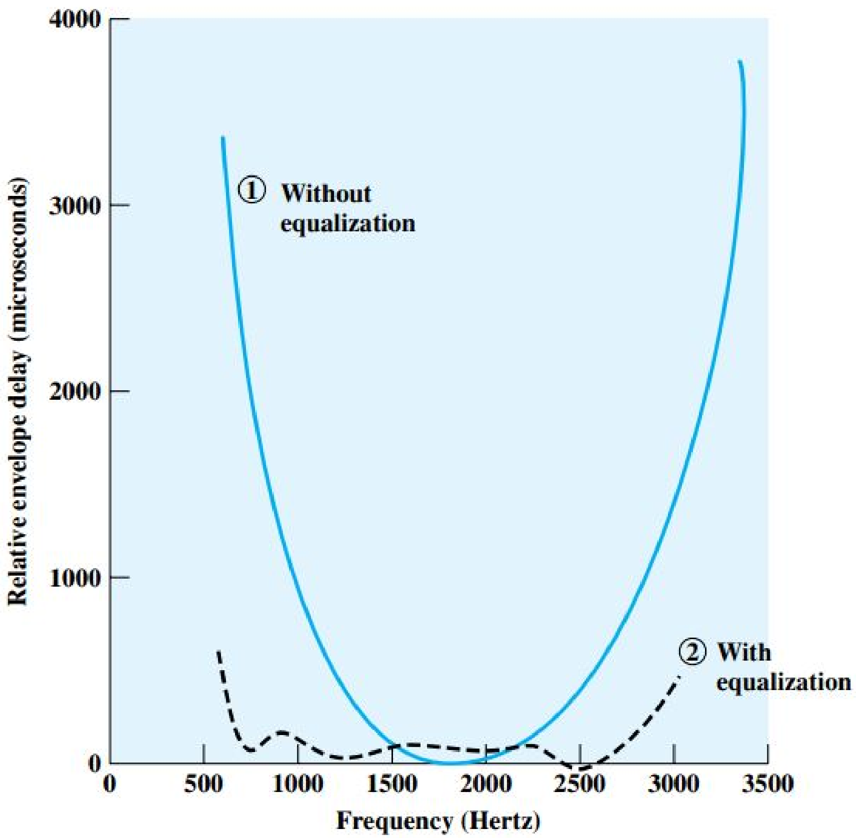
- Attenuation varies as a function of frequency.
- This is known as Attenuation distortion.

- Example: Voice Grade telephone line.
- Solution is to use equalizer.
- Problem is less in case of digital signal



Delay Distortion

- Arises in case of guided media.
- Velocity of propagation varies with frequency.
- This leads to delay distortion.



- Example: Voice Grade telephone line.

- Effect can be minimized using equalizer.
- Digital signal is more affected.

- Some of the signal components of one bit position will spill over into other bit positions, causing intersymbol interference.

Noise

- The received signal will consist of
  - the transmitted signal,
  - modified by the various distortions imposed by the transmission system,
  - plus additional unwanted signals (i.e. noise) that are inserted somewhere between transmission and reception.

➢ Several types of noise may corrupt the signal.

- Common Noise Types:
  - Thermal: due to thermal agitation of electrons, N = k.T.B
  - Intermodulation: Occurs when signals of different frequencies share the same medium.
  - Crosstalk: It is due to unwanted coupling between two media.
  - Impulse Noise: Arises due to disturbances such as lightning, electric sparks.
    - Digital signals are more affected than Analog signals

Effects of Noise

- When there is noise present in the medium, the limitation of both bandwidth and noise must be considered.
- A noise spike may cause a given level to be interpreted as a signal of greater level if it is in positive phase or a smaller level if it is in negative phase.
- Noise becomes more problematic as the number of levels increases.

Signal-to-Noise Ratio

Let S = average signal power

Let N = average noise power

$$\frac{S}{N} = \frac{\text{Average Signal Power}}{\text{Average Noise Power}}$$

$$\left(\frac{S}{N}\right)_{dB} = 10 \log_{10}\left(\frac{S}{N}\right) = 10 \log_{10}\left(\frac{P_{signla}}{P_{noise}}\right)$$

Thermal Noise

- **Thermal noise** is due to thermal agitation of electrons.
- It is present in all electronic devices and transmission media and is a function of temperature.
- Thermal noise is uniformly distributed across the bandwidths
- It is often referred to as **white noise**
- Thermal noise cannot be eliminated

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

$$N_0 = k\,T (W/Hz)$$

N_0 = noise power density in watts per 1 Hz of bandwidth

k = Boltzmann’s constant = $1.38 * 10^{-23}$ J/K

T = temperature, in kelvins (absolute temperature) where the symbol K is used to represent 1 kelvin

Data Rate Limits

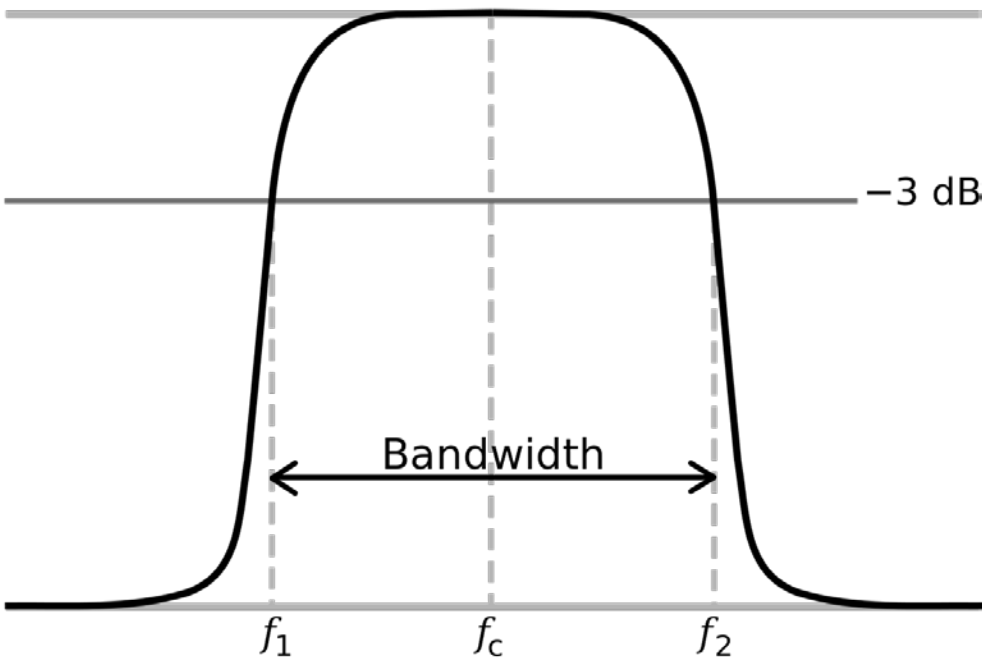
➢ **How fast data can be sent?**

- It depends on three factors:
  - Bandwidth of the channel
  - Number of levels used in the signal
  - Noise level in the channel

Bandwidth of a Medium

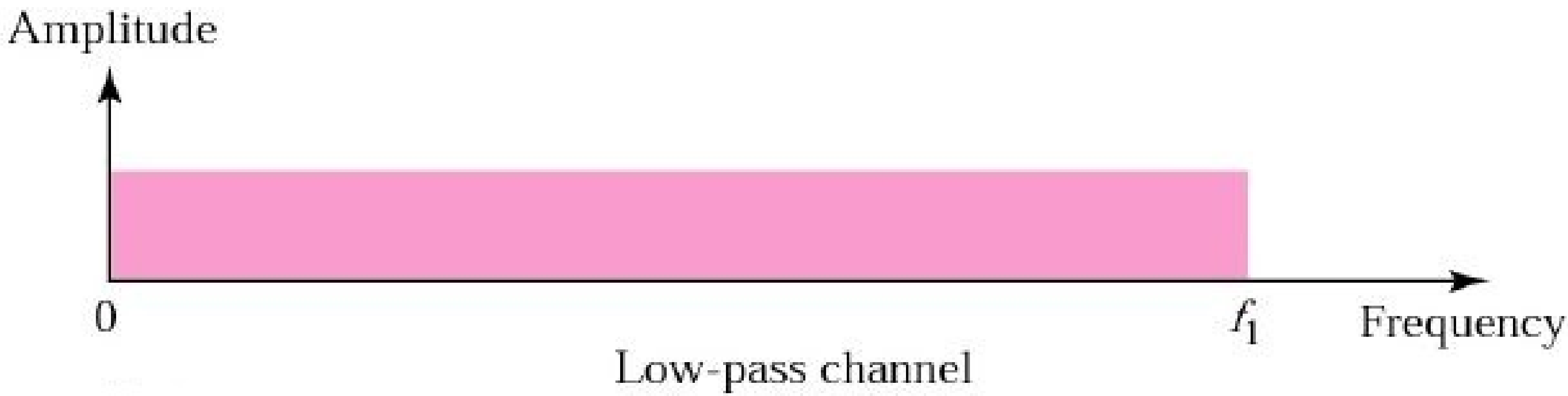
- Bandwidth refers to the range of frequencies that a medium can pass without a loss of one-half of the power (-3 dB) contained in the signal.

$$B = f_2 - f_1$$

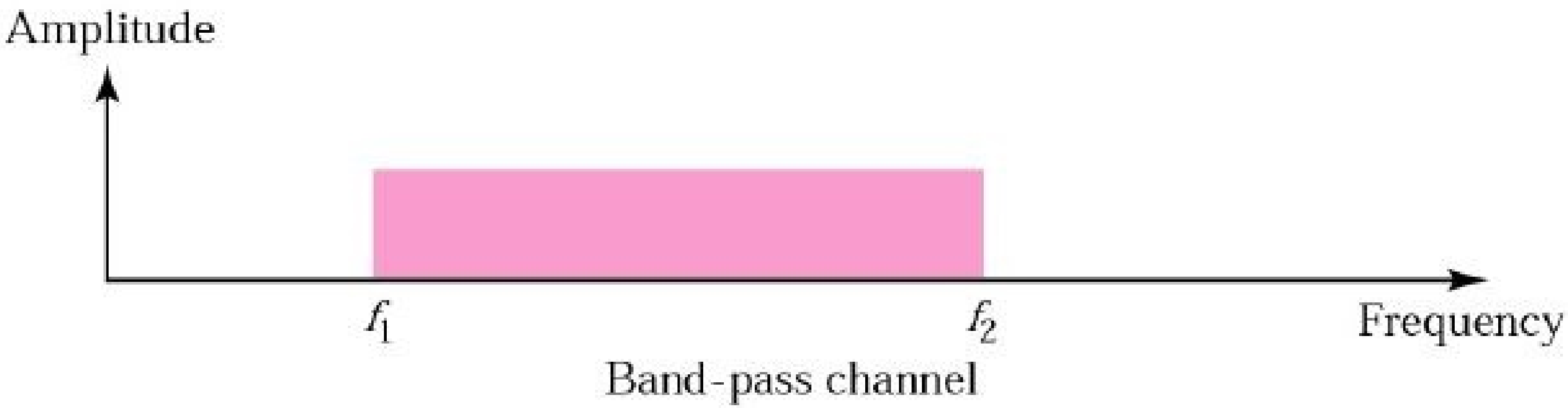


Digital Signal requires Low-pass Channel

- Bandwidth of a medium decides the quality of the signal at the other end.
- A digital signal (usually aperiodic) requires a bandwidth from 0 to infinity.
- So, it needs a low pass channel.



Analog Signal requires Band-pass Channel



Nyquist Bit Rate

➢ Noiseless channel

- the maximum bit rate is given by the Nyquist bit rate

$$C = 2.B.\log_2 M$$

Where, C is known as the channel capacity

B is the bandwidth of the channel

and M is the number of discrete signal or voltage levels used

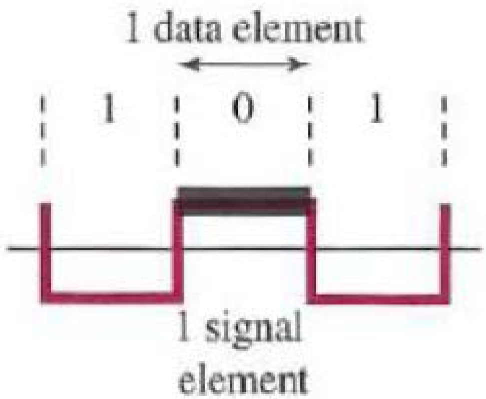
Data Element vs Signal Element

- Data element: it is the smallest entity that can represent a piece of information: this is in bit
- Signal Element: it carries data elements. It is the shortest unit (timewise) of digital signal.

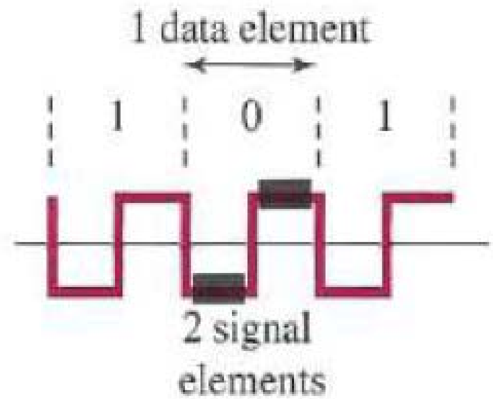
- Data elements are what we want to send; signal elements are what we can send.

- Units of data rate: bits per second
- Units of signal rate: baud per second

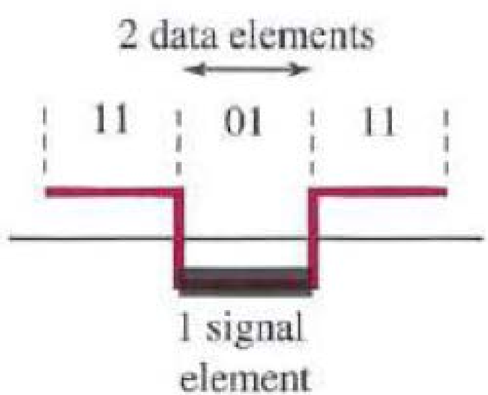
Example



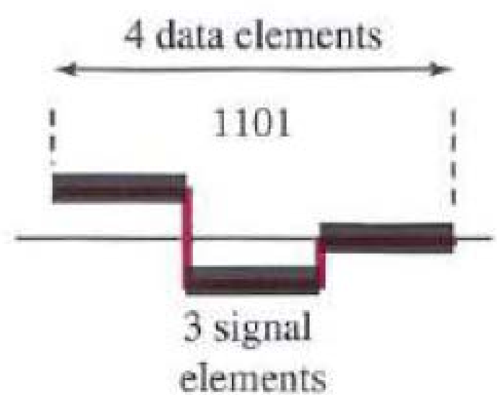
a. One data element per one signal element ($r = 1$)



b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$



c. Two data elements per one signal element ($r = 2$)



d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

Baud Rate

- The *baud rate* or *signalling rate* is defined as the number of distinct symbols transmitted per second, irrespective of the form of encoding.
- For baseband digital signal, M=2

Maximum baud rate = $\dfrac{1}{\text{Element width(in seconds)}}$ = 2B

Bit Rate

- The *bit rate* or *information rate* *(I)* is the actual equivalent number of bits transmitted per second.

$$
\begin{aligned}
I &= \text{Baud Rate x Bits per Baud} \\
&= \text{Baud Rate x } N \\
&= \text{Baud Rate x } \log_2 \mathrm{M}
\end{aligned}
$$

- For binary encoding, the bit rate and the baud rate are the same; i.e. ,

$$I = \text{Baud Rate}$$

Shannon Capacity

➢ Noisy Channel

Shannon Capacity gives the highest data rate for a noisy channel

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

Where, S/N is the signal-to-noise ratio.

B is the channel bandwidth.

In case of extremely noisy channel, C = 0

Between the Nyquist bit rate and the Shannon limit, the result providing the smallest channel capacity is the one that establishes the limit.

Thanks!

Figure and slide materials are taken from the following sources:

1. W. Stallings, (2010), Data and Computer Communications
2. NPTL lecture on Data Communication, by Prof. A. K. Pal, IIT Kharagpur
3. B. A. Forouzan, (2013), Data Communication and Networking