CS311: Data Communication

Transmission Impairments and Channel Capacity

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Impairments

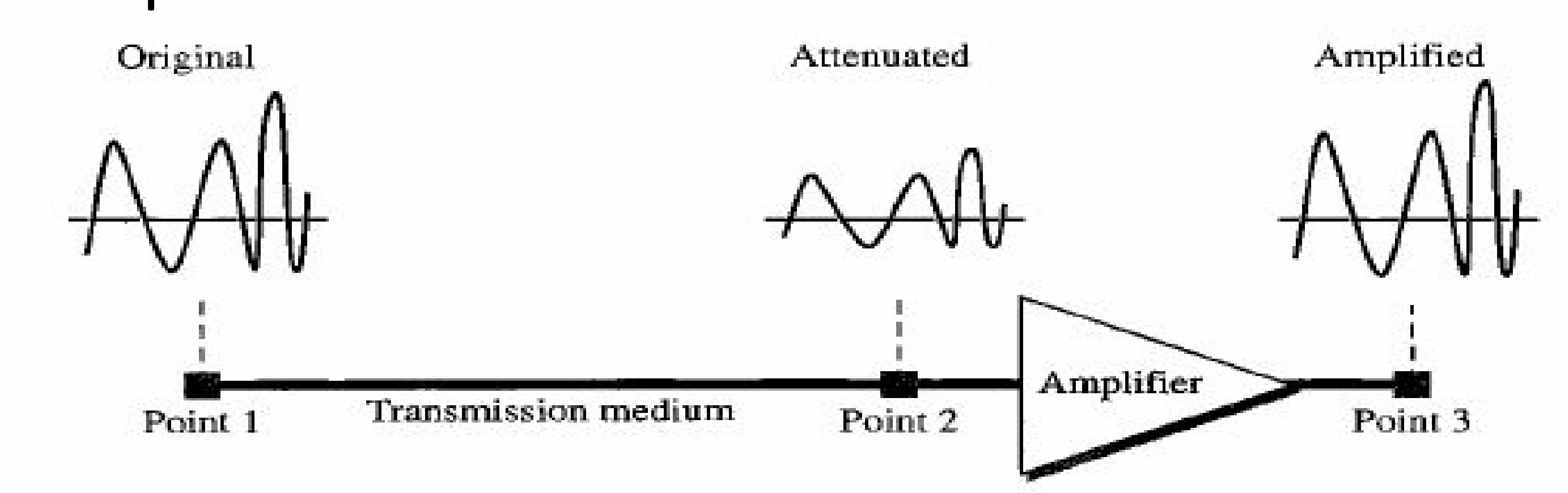
- To send data we have to send signal through a communication medium.
- A medium is not ideal. The imperfections cause impairments in the signal.
- Impairments:
  - Attenuation
  - Distortion
  - Noise

Attenuation

- Attenuation leads to loss of energy in decibel.

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

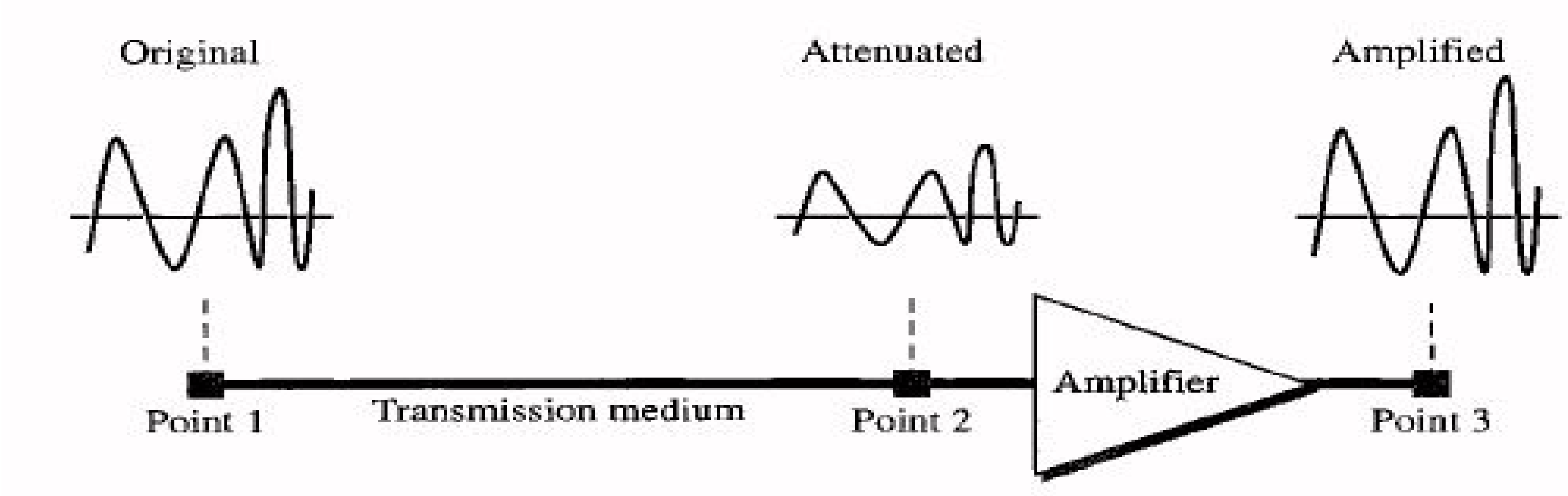
- It decides how far a signal can be sent without amplification.



- 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 **dB =** $\mathbf{10\log_{10}(P_2/P_1)}$



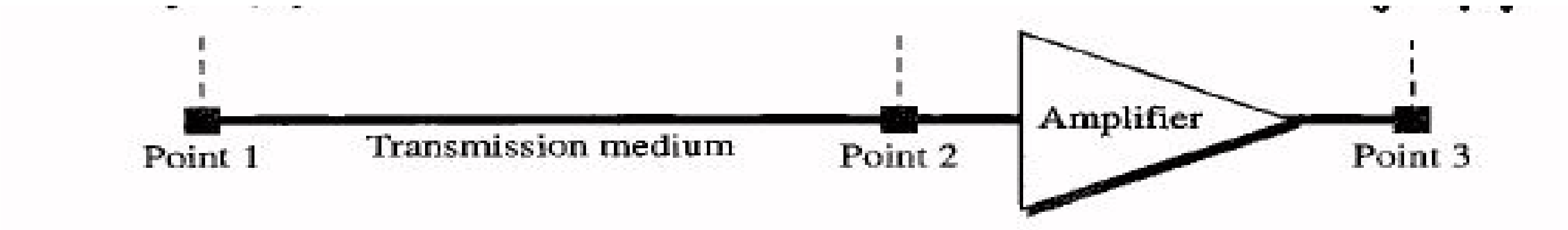
Decibel

- Example-1

- Let the energy strength of point 2 is 1/10th with respect to point 1. Then attenuation in dB is $10\log_{10}(1/10)$ = -10 dB. Note that loss ofpower 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.

Decibel

- It may be noted that signal strength at point 3 with respect to point 1 can be obtained by adding the two values; (-10) + 20 = 10 dB.



Data rate limits

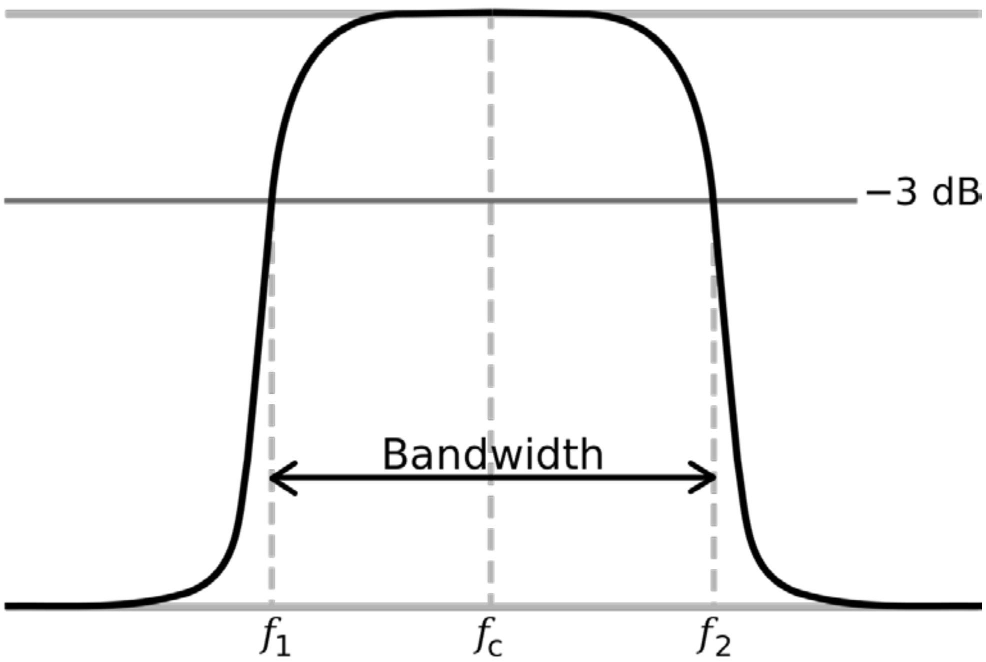
➢ **How fast data can be sent?**

- 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

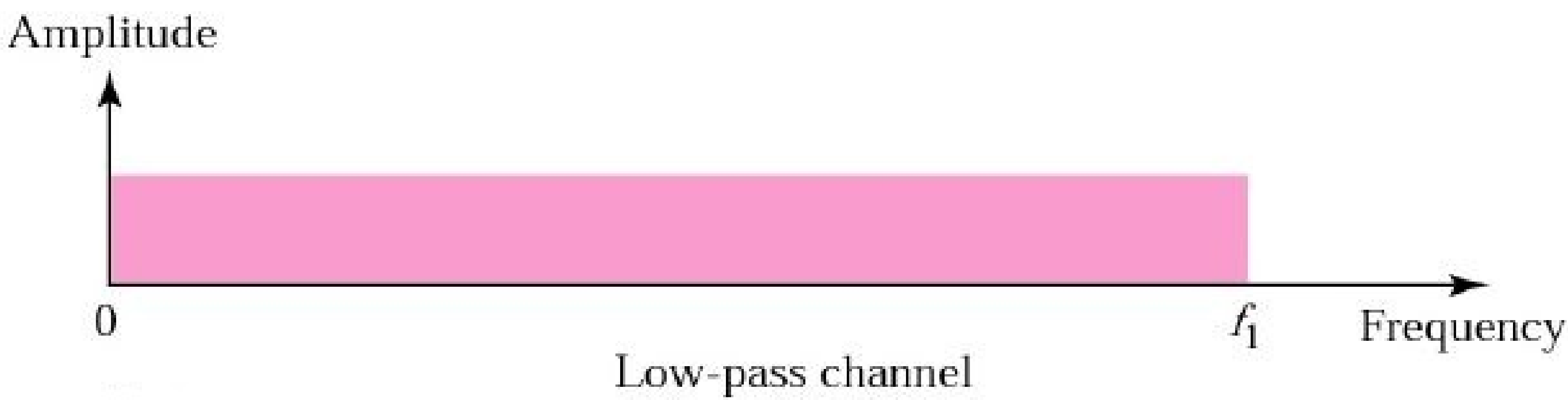
- Bandwidth refers to the range of frequencies that a medium can pass without a loss of one-half of the power (-3 dB) contained in the signal.

$$B = f_2 - f_1$$

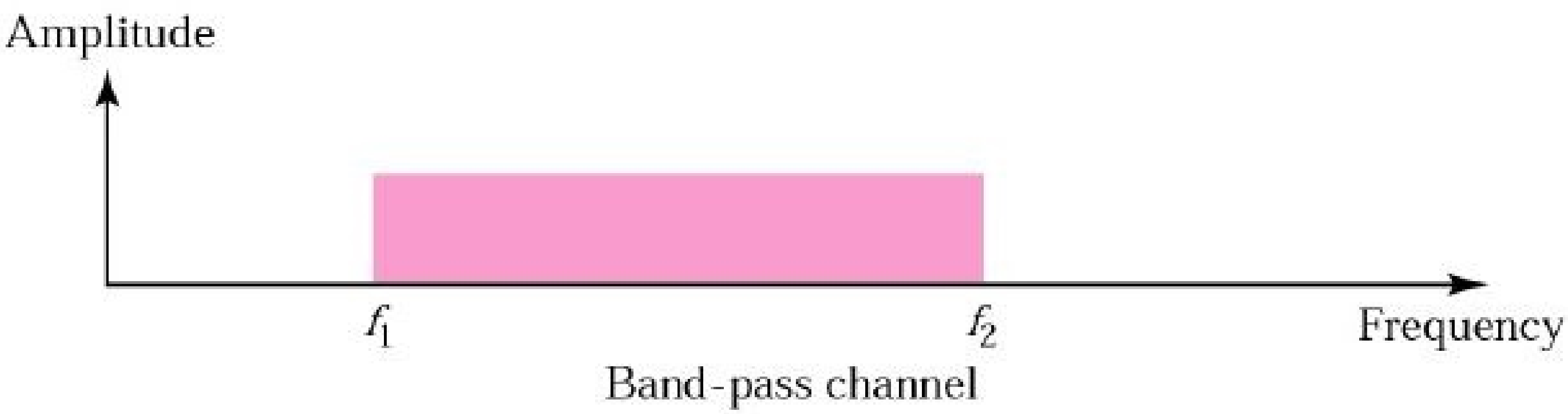


Digital signal requires low-pass channel

- 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.

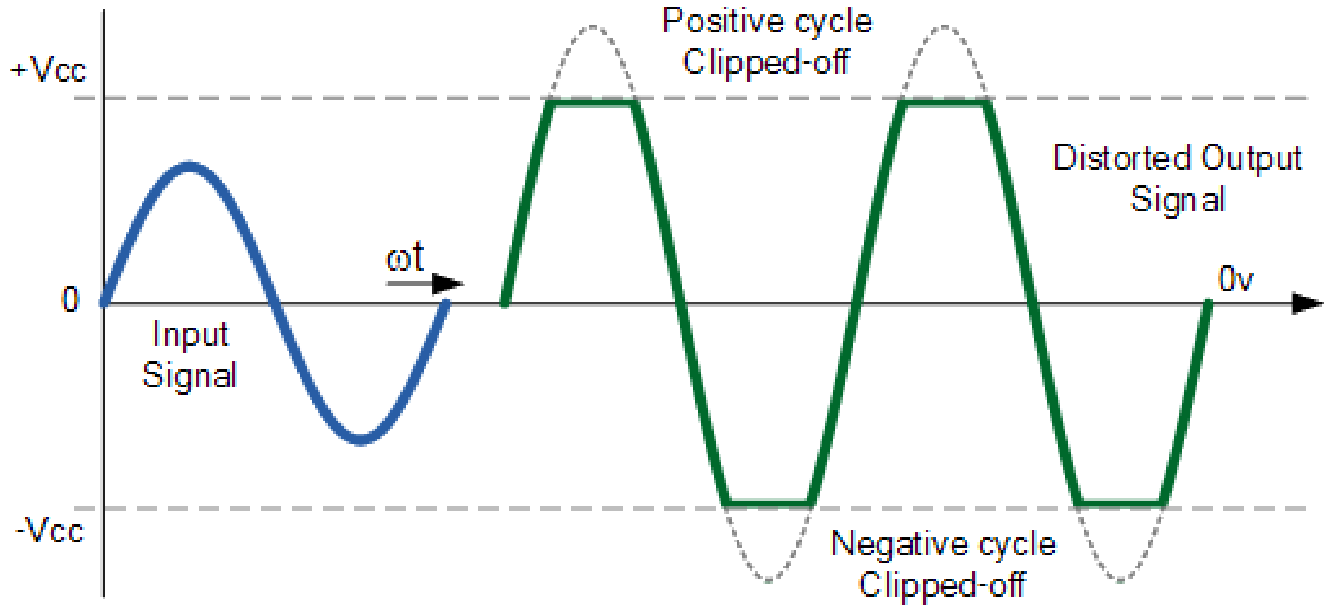


Analog signal requires band-pass channel

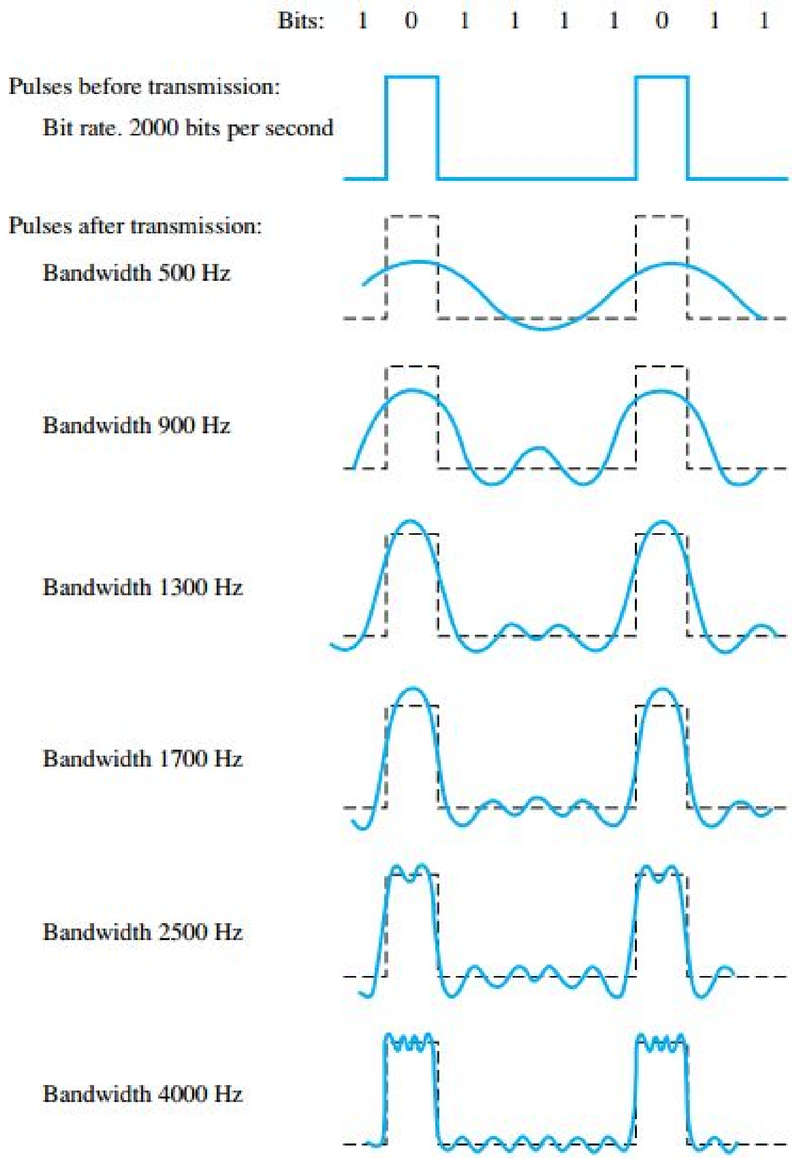


Distortion

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

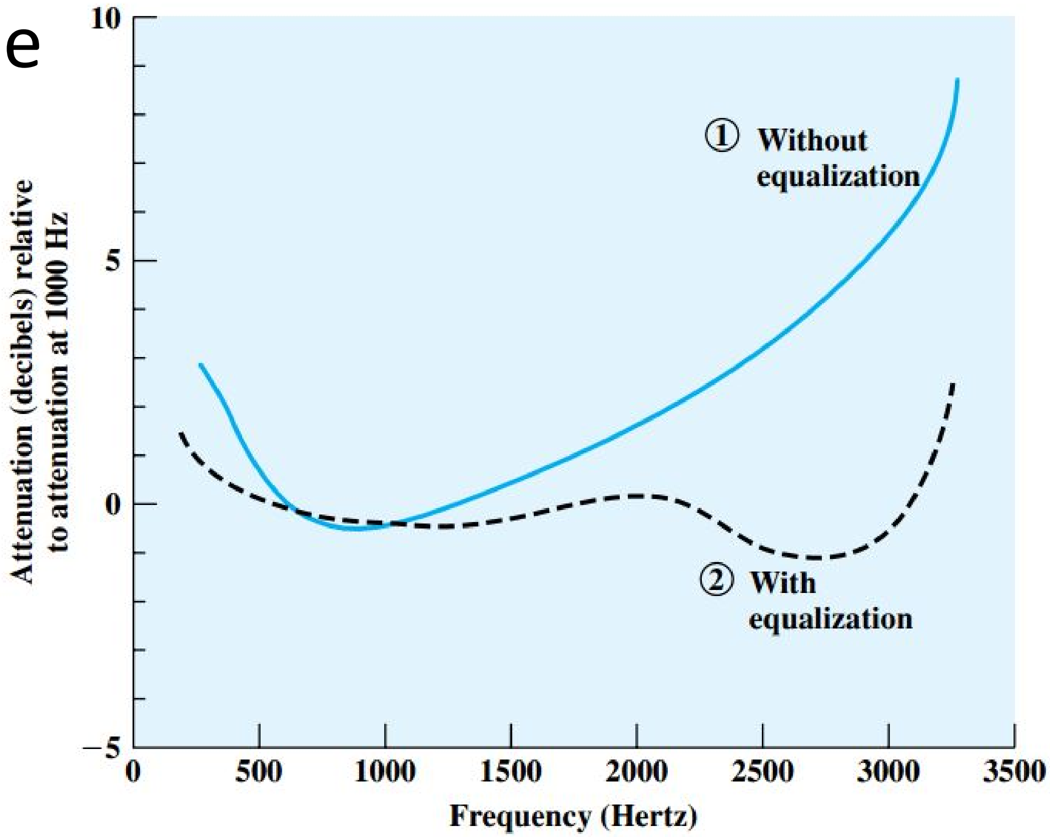


Effect on signal passing through a band-limited channel



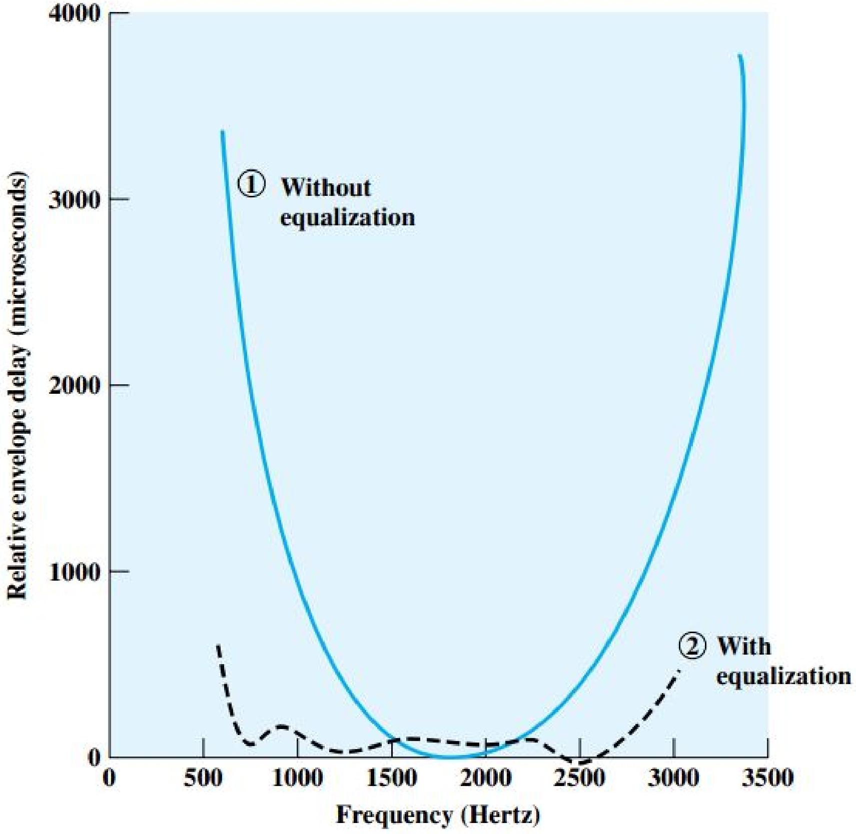
Attenuation Distortion

- 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.



Nyquist Bit Rate

- **(Noiseless channel)**

- In case of noiseless channel, the maximum bit rate is given by the Nyquist bit rate

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

Where C is known as the channel capacity

B is the bandwidth of the channel

and L is the number of signal levels used

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, L=2

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

Bit Rate

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

$$I = \text{Baud Rate x Bits per Baud}$$

$$= \text{Baud Rate x } N = \text{Baud Rate x } \log_2 \mathrm{M}$$

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

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

Example

- Let us consider the telephone channel having bandwidth B = 4 kHz. Assuming there is no noise, determine channel capacity for the following encoding levels:

  (i) 2 and (ii) 128

  (i) C = 2B = 2x4000 = 8 Kbit/s

  (ii) C = 2x4000x$\log_2 128$ = 8000x7 = 56 Kbit/s

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 P = average signal power

Let N = average noise power

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

$$\left(\frac{\mathrm{S}}{\mathrm{N}}\right)_{\mathrm{dB}} = 10 \log\left(\frac{\mathrm{S}}{\mathrm{N}}\right)$$

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.

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.

Example

A channel has B = 4 kHz. Determine the following channel capacity for each of the following signal-to-noise ratios: (a) 20 dB, (b) 30 dB, (c) 40 dB

(a) $C = B \log_2 \left[1 + \frac{S}{N}\right] = 4 \times 10^3 \times \log_2(1+100)$

$= 4 \times 10^3 \times 3.32 \times 2.004 = 26.6$ Kbit/s

(b) $C = B \log_2 \left[1 + \frac{S}{N}\right] = 4 \times 10^3 \times \log_2(1+1000)$

$= 4 \times 10^3 \times 3.32 \times 3.000 = 39.8$ Kbit/s

(c) $C = B \log_2 \left[1 + \frac{S}{N}\right] = 4 \times 10^3 \times \log_2(1+10^4)$

$= 4 \times 10^3 \times 3.32 \times 4.000 = 53.1$ Kbit/s

Example

- A channel has B = 4 kHz and a signal-to-noise ratio of 30 dB. Determine maximum information rate for 4-level encoding.

- For B = 4 kHz and 4-level encoding the *Nyquist Bit rate* is 16 Kbps.
- Again for B = 4 kHz and S/N of 30 dB the *Shannon Capacity* is 39.8 Kbps.
- The smallest of the two has to be taken as information capacity.

$$I = 16 \text{ Kbps}$$

Example

- A channel has B = 4 kHz and a signal-to-noise ratio of 30 dB. Determine maximum information rate for 128-level encoding.

- The *Nyquist Bit rate* for B = 4 kHz and M = 128 levels is 56 Kbps.
- Again the *Shannon Capacity* for B = 4 kHz and S/N of 30 dB is 39.8 Kbps.
- The smallest of the two values decides the channel capacity *C* = 39.8 Kbps

Example

- The digital signal is to be designed to permit 160 kbps for a bandwidth of 20 kHz. Determine (a) number of levels and (b) S/N ratio.

(a) Apply *Nyquist Bit rate* to determine number of levels.

$$C = 2B\log_2 M \text{ or } 160\text{x}10^3 = 2\text{x}20\text{x}10^3\log_2 M$$

$$M = 2^4 = 16 \quad \textit{meaning 4 bits/baud}$$

(b) Apply Shannon capacity to determine the S/N ratio.

$$C = B\log_2\left[1 + \frac{S}{N}\right]$$

$$\text{or } 160\text{x}10^3 = 20\text{x}10^3\log_2\left[1 + \frac{S}{N}\right]$$

$$\frac{S}{N} = 2^8 - 1 \text{ or } \left(\frac{S}{N}\right)_{dB} = 24.07 \text{ dB}$$

Noise

- ➢ Several types of noise may corrupt the signal.
- Common Noise Types:
  - Thermal: 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

Thanks!