

# **King Fahd University of Petroleum & Minerals Computer Engineering Dept**

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**COE 341 – Data and Computer  
Communications**

**Term 082**

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## **Lecture Contents**

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1. Fourier Analysis
  - a. Fourier Series Expansion
  - b. Fourier Transform
  - c. Ideal Low/band/high pass filters
2. Data/Signals
  - a. Audio/Voice
  - b. Video
  - c. Text
3. Transmission
  - a. Analog Transmission
  - b. Digital Transmission
4. Transmission Impairments
  - a. Attenuation and Attenuation Distortion
  - b. Delay Distortion
  - c. Noise
5. Channel Capacity
  - a. Nyquist Formula
  - b. Shannon Capacity Formula
  - c. Eb/No expression

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## **Analog and Digital Data Transmission**

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- **The terms:**
  - **Analogue** ~ continuous
  - **Digital** ~ discrete
- **They apply to:**
  - **A) Data:** the information to be delivered
  - **B) Signaling:** the electrical or electromagnetic wave that propagates carrying the data
  - **C) Transmission:** the mechanism of delivering the data by processing and propagation of signal

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## **Examples of Data/Signaling: (1) AUDIO**

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- **Most familiar type of *analogue* data**
- **Human Ear (Receiver) bandwidth is ~10 Hz to ~20KHz**
  - **You can not hear sounds with frequencies much higher than 20KHz or much lower than 10 Hz – Some other animals can do that (bats, whales, etc)**
- **Human speech (Data) is mostly between 100 Hz and 7K Hz – with most of the energy concentrated in the lower part of this range**

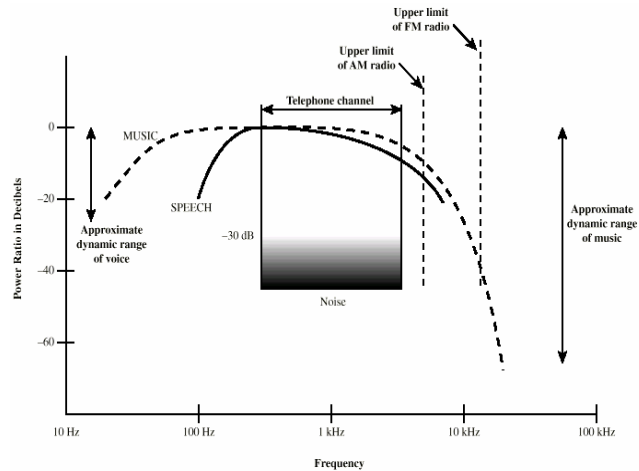
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## Examples of Data/Signaling: (1) AUDIO – cont'd

- Typical Speech has a dynamic range of 25 dB – ratio of strongest speech signal to weakest speech signal is 25 dB or  $10^{25/10} = 300$  (in linear scale)
- The *Telephone Channel* has a bandwidth of about 3.1KHz (from 300 Hz to 3400 Hz)
- Note that Music has a much wider bandwidth than speech (~10 Hz to ~20 KHz) – Hence a good audio system (CD player, high end speakers, etc) should be able to reproduce these signals
- Music has also a higher dynamic range too – What is the dynamic range of your audio system?



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## Examples of Data/Signalling: (2) VIDEO

- Another common example of analog data
- The original scene (source) is scanned and its image recorded by the camera – RASTER image
- In the TV: a moving electron beam scan the screen producing the picture
  - For black and white: the amount of illumination produced (on a scale from black (lowest) to white (highest) at any point is proportional to the beam intensity
- Hence the original brightness is REPRODUCED on the screen
- Video Image ↔ Time varying analog signal

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## Examples of Data/Signalling: (3) VIDEO – cont'd

- **Total of 525 horizontal lines (vertical resolution)**
  - 483 visible lines (241.5 even and 241.5 odd)
    - Subjective vertical resolution is  $70 \times 483 = 338$  lines
    - Hence, horizontal resolution is  $(4/3) \times 338 = 450$  pixels per line
  - 42 blanked during vertical retrace
- **Basic line duration = 63.5  $\mu$ sec:**
  - 52.5  $\mu$ sec scanning horizontally
  - 11  $\mu$ sec for horizontal retrace
- **High number of scans per second  $\rightarrow$  smoother picture but expensive hardware**
- **Low number of scans per second  $\rightarrow$  jittery picture (flickering)**
- **Interlacing: scan odd lines first at 30 scan per second and then scan even lines at 30 scans per second  $\rightarrow$  To the human eye, the screen is 60 refreshed 60 times per second, i.e. no flickering**

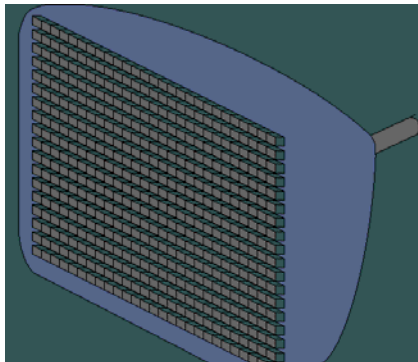
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## Examples of Data/Signalling: (4) VIDEO – cont'd

- **Scanning Process:**
  - Starts at the far left – near top
  - Scans 241.5 lines
  - Ends at middle of screen – lowest part
  - Beam is repositioned at the top again
  - Scanning starts again for the other 241.5 lines (interlaced with the previous lines)



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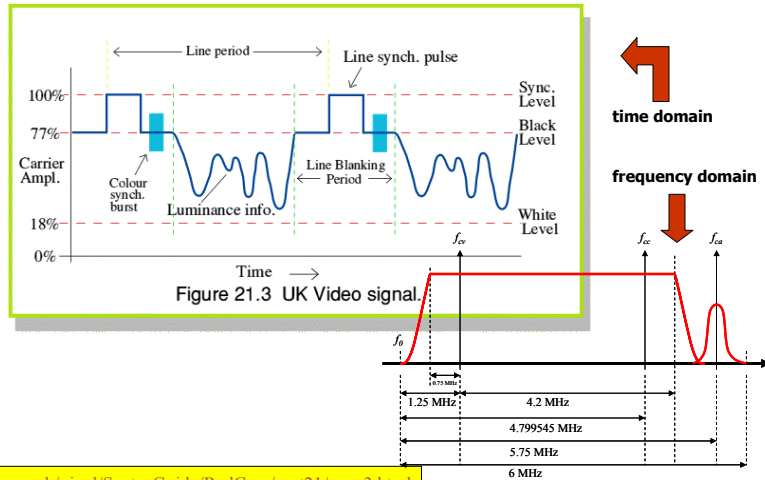
## Examples of Data/Signalling: (5) VIDEO – Example of a Video Signal

- For B/W TV you ignore the color synch bursts

- **Note**

- the high voltage level corresponds to "BLACK"
- the low voltage level corresponds to "WHITE"

- What is the line synch pulse?
- What is the purpose of the line blanking period?



[http://www.st-andrews.ac.uk/~jegl/Scots\\_Guide/RadCom/part21/page3.html](http://www.st-andrews.ac.uk/~jegl/Scots_Guide/RadCom/part21/page3.html)  
GREAT site for tutorials on communication systems

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## Examples of Data/Signalling: (6) VIDEO – cont'd – Bandwidth Calculation

- 525 lines per scan at 30 scans per second → 15,750 lines/sec or 63.5  $\mu$ sec per line
  - 52.5  $\mu$ sec is the actual time spent in illuminating horizontal pixels
- There are 450 horizontal pixels per line
  - For maximum bandwidth calculation
    - Let illumination alternative from white to black and visa versa for consecutive pixels → 225 cycles / line
    - But line scanning is done in 52.5  $\mu$ sec/line.
    - Hence, the beam does  $(225/52.5 \mu\text{sec}) = 4.2 \times 10^6$  cycles per second
  - For minimum bandwidth
    - Let all pixels has same illumination level (no change in picture) → DC component –  $f_{\min} = 0$  Hz
- Adding audio and color information does not increase bandwidth
- Hence NTSC video signal bandwidth is about 4 MHz

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### **Example:**

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- **Problem 3.12:** For a video signal, what increase in a ) horizontal b) vertical resolution is possible if a bandwidth of 5 MHz is used?

### **Example:**

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- **Solution:**

For increase in horizontal resolution - keeping same vertical resolution (483 lines); each horizontal lines occupies 52.5  $\mu$ sec, therefore new horizontal resolution H is given by

$$5 \text{ MHz} = (H/2) / 52.5 \mu\text{sec} \rightarrow H = 525 \text{ lines}$$

For increase in vertical resolution – keeping same horizontal resolution of H = 450 lines, hence the new time for each horizontal line T is

$$5\text{MHz} = (450/2) / T \rightarrow T = 45 \mu\text{sec}$$

The horizontal retrace still takes 11  $\mu$ sec, therefore total time for horizontal line is 56  $\mu$ sec.

$$(1/30 \text{ sec/scan}) / V \text{ lines/scan} = 56 \mu\text{sec/line} \rightarrow V = 595 \text{ lines/scan}$$

## Examples of Data/Signalling: (3) TEXT

- Digital Data (pre-defined set of symbols)
  - Same as Morse Code
- IRA (or ASCII in the US) define 128 character using 7-bit words
- When transmitted or stored 1B or 8-bit words are used
  - A parity bit is added as a simple error detection technique
- The signal representing this data:
  - One DC level for binary one
  - Another DC level for binary zero
- Bandwidth representing this signal:
  - Maximum bandwidth is required when bits alternate between 0 and 1 → This results in a periodic square waveform (see Figure 3.13 in text)
  - Theoretical BW is infinite, but most of the energy is located for  $f \leq$  fundamental frequency
  - Minimum frequency is zero (DC) – when all bits are equal

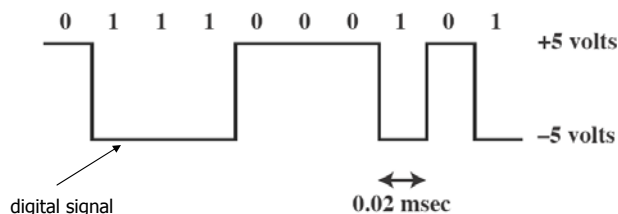
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## Examples of Data/Signalling: (4) TEXT

- Figure 3.13 (textbook) – conversion of PC input digital signals.
- What is the minimum frequency for the shown signal?
- What is the maximum frequency for the shown signal?
- What is the APPROXIMATE bandwidth for the shown signal?



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 -5 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).

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## Transmission

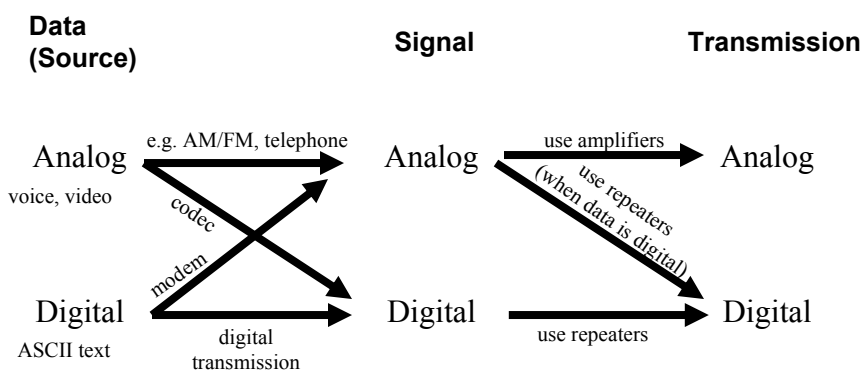
- **Analog Transmission:**
  - Analog signal is propagated through amplifiers to compensate for attenuation and to achieve longer distance
  - **Amplifiers:**
    - Boost signal and noise equally
    - May distort original signal
    - Can not be used indefinitely
- **Digital Transmission:**
  - To overcome the higher attenuation, repeaters are used at appropriately spaced points
  - **Repeaters:**
    - Recover original digital data
    - Transmit new signal
    - Can be used indefinitely

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## Transmission (2)



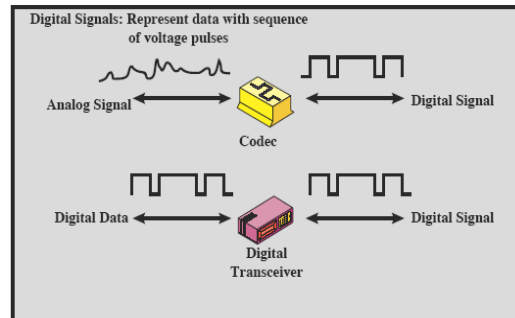
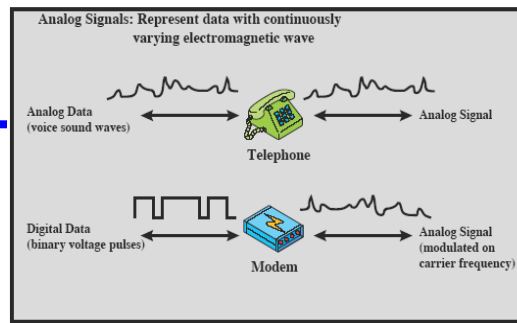
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## Analog and Digital Signaling of Analog and Digital Data



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## Transmission (3)

- **Digital Transmission is the prevailing technology:**
  - **Digital Technology:** Capitalize on advances in digital circuitry
  - **Data Integrity:** With the use of repeaters, the effects of noise and other signal impairments are not cumulative
  - **Capacity Utilization:** It is easier to multiplex several digital signals (using TDM) on one high capacity link as opposed to multiplexing analog sources using FDM
  - **Security and Privacy:** Use of encryption
  - **Integration:** Provides a uniform vehicle to transport both analog and digital data

very important reasons the popularity of digital transmission

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## Transmission Impairments

- Impairments can degrade the quality of an analog signal or cause a bit (symbol) error for a digital signal
- Types of Impairments:
  - Attenuation and Attenuation Distortion
  - Delay Distortion
  - Noise

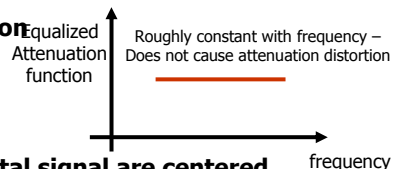
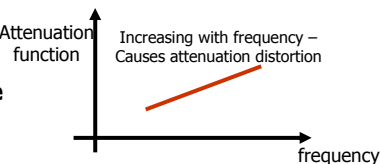
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## Attenuation and Attenuation Distortion

- A received signal must have sufficient strength for proper detection at receiver
- For error-free communication signal strength relative to noise must be high
- Attenuation is an increasing function of frequency:
  - Different components of signal are subject to different attenuation → Distortion in time domain
- Solution: Equalize transmission
  - Results in almost equal attenuation (gain) for all frequencies of interest
- Attenuation Distortion is less of a problem for digital signals:
  - Frequencies of interest for a digital signal are centered around the fundamental frequency,  $f$
  - Attenuation function has to be flat around  $f$  only



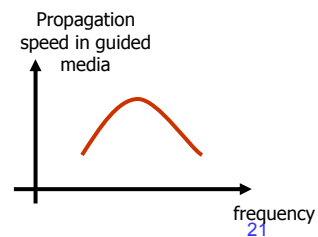
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## Delay Distortion

- For guided media – different frequency components have different propagation speeds
- For unguided media – multipath (signal being received through more than one path) causes delay distortion
- Received signal is distorted due to varying delays experienced at its constituent frequencies
- Critical for digital data: Causes Intersymbol interference – a major limitation on maximum bit rate over a transmission channel
- Solution: Equalization



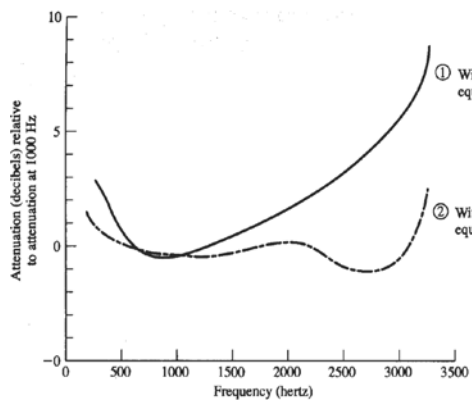
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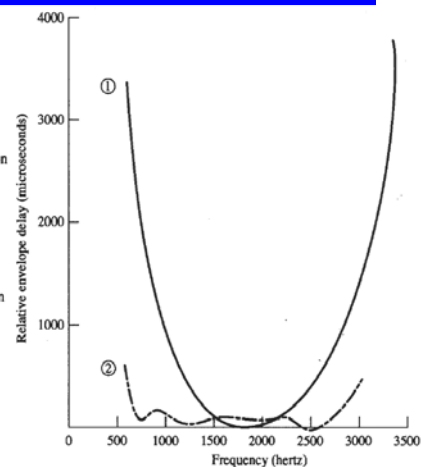
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## Attenuation and Delay Distortion – Effect of Equalization

- Figure 3.15 (textbook)



(a) Attenuation



(b) Delay Distortion

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## Noise

- Major limiting factor in communication system performance
- Types of Noise:
  - Thermal Noise
  - Intermodulation Noise
  - Crosstalk
  - Impulse Noise

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## Thermal Noise

- Due to agitation of electrons
- Function of temperature (energy of electrons)
- Can not be eliminated → limits communication system performance
- Noise power density (noise power found in 1 Hz) ,  $N_0$ , is given by
$$N_0 = kT \quad (\text{Watts/Hz})$$

Where  $k$  is Boltzman constant =  $1.3803 \times 10^{-23}$  J/degree Kelvin

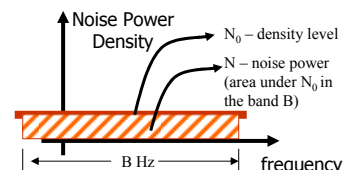
$T$  is the temperature in degrees Kelvin

- Hence, the thermal noise power in a bandwidth  $B$  Hz is given by

$$N = N_0 \times B = kT \times B \quad (\text{Watts})$$

- In decibels:

$$\begin{aligned} \text{NdB} &= 10\log k + 10\log T + 10\log B \\ &= -228.6 \text{ dBW} + 10\log T + 10\log B \end{aligned}$$



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## **Examples:**

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- **Problem 3.14:** Given an amplifier with effective noise temperature of 10,000 degrees Kelvin, and a 10-MHz bandwidth, what thermal noise we expect at the output

## **Examples:**

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- **Solution:**

$$N = kT \times B$$

$$k = 1.38 \times 10^{-23} \text{ J/Kelvin}, T = 10,000 \text{ degrees Kelvin}, B = 10 \times 10^6 \text{ Hz},$$

$$N = 1.38 \times 10^{-12} \text{ Watts}$$

$$N_{\text{dBW}} = 10 \log N = -118.6 \text{ dBW}$$

In dBmW, one can write

$$N_{\text{dBmW}} = 10 \log N \times 1000 = -88.6 \text{ dBmW or simply, } N_{\text{dBmW}} = N_{\text{dBW}} + 30$$

## Intermodulation Noise

- **Lineal System:**  $H_L(S) = A_1xS + A_0$

E.g. Consider the input  $S_1+S_2$ , where  $S_1 = \cos(2\pi*f_1*t)$  and  $S_2 = \cos(2\pi*f_2*t)$ . The system output is

$$H_L(S_1+S_2) = A_1x \cos(2\pi*f_1*t) + A_1x \cos(2\pi*f_2*t) + A_0$$

Note the output signal has frequencies  $f_1$  and  $f_2$  **ONLY**.

- **NonLinear System (example):**  $H_{NL}(S) = A_2xS^2 + A_1xS + A_0$

The output (for the same input) is

$$H_{NL}(S_1+S_2) = A_2x [\cos(2\pi*f_1*t) + \cos(2\pi*f_2*t)]^2 + A_1x [\cos(2\pi*f_1*t) + \cos(2\pi*f_2*t)] + A_0$$

Note that  $[\cos(2\pi*f_i*t)]^2 = 1/2 + 1/2 \cos(2\pi*2f_i*t)$ , and

$$\cos(2\pi*f_1*t) \cos(2\pi*f_2*t) = 1/2 \cos(2\pi*(f_1+f_2)*t) + 1/2 \cos(2\pi*(f_1-f_2)*t)$$

Output signal contain terms with multiples of  $(f_1+f_2)$  and  $(f_1-f_2)$

- **Intermodulation noise:** *undesired* signals at the frequency that is multiples of sum or difference of the two original input frequencies
- Caused by nonlinearity

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## Crosstalk/Impulse Noise

- **Crosstalk:**
  - Unwanted coupling between signal paths
  - E.g. electrical coupling between near by twisted pair wires
  - Coax cables are more immune to cross talk compared to twisted pairs
- **Impulse Noise:**
  - Unlike previous types of noise, this one is:
    - Noncontinuous – irregular pulses or spikes for short duration and high amplitude
  - Causes:
    - Lightening
    - Faults or flaws in communication systems
  - Major concern for digital data

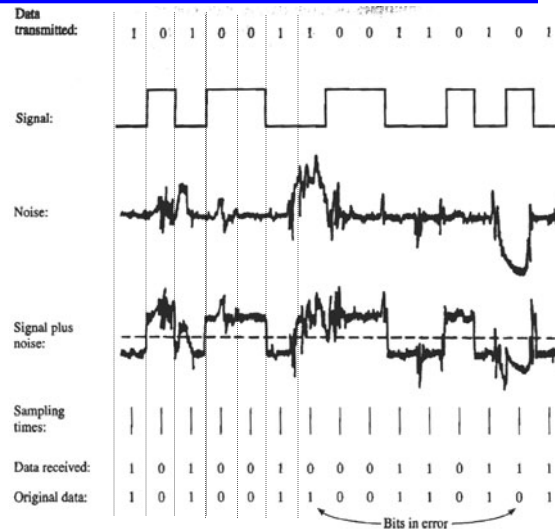
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## Effect of Noise on Digital Signal

- **Figure 3.16 (textbook)**
- **Data → Signal: Encoding – to be covered in chapter 5**
- **Noise – the subject of this section**
- **Note the sampling times – middle of bit time**
- **Errors – Error control to be covered in chapter 5**



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## Channel Capacity

- **Terminology:**
  - **Data Rate (R):** bit rate of channel – bits per second
  - **Bandwidth (B):** bandwidth of transmitted signal – Hz
  - **Noise power (N):** average noise power level for communication channel – Watt/Hz for density or Watt for noise power
  - **Error rate (Pe):** rate at which an erroneous detection is made (detecting 0 for 1 and 1 for 0)

Rate

Power  
SNR

Bandwidth  
B

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## Nyquist Bandwidth

- For a noise-free channel → data rate is limited by B of channel
- A bandwidth of B Hz is enough to support 2B bits per second
- Example: B = 3100 Hz (telephone channel) → C = 6200 b/s
- What if we use multilevel signaling :

$$C = 2B \log_2 M$$

Where M is the number of discrete levels used

- Example: for M = 8, same telephone channel can support C = 2X3100X log<sub>2</sub>8 = 18.6 kb/s
- M = 2 – receiver recognizes two signal levels 1s and 0s
- M > 2 – receiver recognizes discrete levels other than 1 and 0
- In general, multilevel signaling requires more sophisticated receiver structure and perhaps more power for the same bandwidth

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## Shannon Capacity Formula

- Capacity in the presence of noise

$$C = B \log_2(1 + \text{SNR})$$

where SNR is the ratio of signal power to noise power – a measure of the signal quality

- Example: f<sub>min</sub> = 3 MHz, f<sub>max</sub> = 4 MHz, SNR = 24 dB, C = ?

$$B = 4 - 3 = 1 \text{ MHz}$$

$$\text{SNR} = 10^{24/10} = 251 \text{ (on the linear scale)}$$

$$C = 1 \times 10^6 \log_2(1 + 251) \sim 8 \times 10^6 \text{ b/s or } 8 \text{ M b/s}$$

One can also calculate the required signaling levels, M, using Nyquist formula:  $C = 2B \log_2(M) \rightarrow M = 2^{C/(2B)} = 16$

- Note the C (calculated by Shannon formula) is the theoretical (error-free) limit of the channel for the given B and SNR

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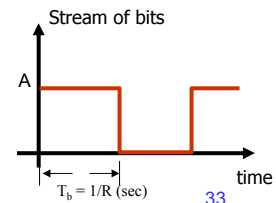
## $E_b/N_0$ Expression

- An alternative representation of SNR
- Consider the bit stream shown in figure – for bit of rate  $R$ , then each bit duration is equal to  $T_b = 1/R$  seconds
- Energy of signal for the bit duration is equal to  $A^2 \times T_b$ , where its power is equal to bit energy /  $T_b$  or  $A^2$ .
- Noise power is equal to  $N_0 \times B$  (refer to thermal noise section)
- Hence, SNR is given by signal power / noise power or

$$SNR = \frac{\text{signalpower}}{N_0 B} = \frac{E_b}{N_0} \times \frac{R}{B}$$

- One can also write

$$\left( \frac{E_b}{N_0} \right)_{dB} = \text{SignalPower}(dBW) - 10 \log R - 10 \log k - 10 \log T$$



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## Examples:

- **Problem 3.19:** Given a channel with the intended capacity of 20 Mb/s, the bandwidth of the channel is 3 MHz. What signal to noise ratio is required to achieve this capacity?

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## ***Examples:***

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- **Solution:**

Shannon Limit:  $C = B \log_2(1 + \text{SNR})$ ,  $C = 20 \times 10^6$  b/s,  $B = 3 \times 10^6$  Hz

$\log_2(1 + \text{SNR}) = 6.67 \rightarrow \text{SNR} = 101 = 20$  dB

## ***Examples:***

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- **Problem 3.21:** If the received signal level for a particular digital system is -151 dBW and the receiver system effective noise temperature is 1500 degrees Kelvin. What is the  $E_b/N_0$  for a link transmitting 2400 b/s

## **Examples:**

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- **Solution:**

$$E_b/N_0 = (\text{signal power} / \text{noise power}) * (B/R)$$

$$\text{Noise power} = kT \times B$$

$$\text{Hence } E_b/N_0 = (\text{signal power}) / (kT R)$$

$$= 10^{-151/10} / (1.38 \times 10^{-23} \times 1500 \times 2400)$$

$$= 15.99$$

$$= 12 \text{ dB}$$

$$\text{Or } (E_b/N_0)_{\text{dB}} = \text{Signalpower}_{\text{dBW}} - 10\log k - 10\log T - 10\log R$$

$$= -151 - 10\log(1.38 \times 10^{-23}) - 10\log 1500 - 10\log 2400$$

$$= 12 \text{ dB}$$

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## **Spectral Efficiency**

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- Spectral Efficiency = ratio of useful bits/sec (capacity, C) to channel bandwidth, B in Hz.

- Therefore, Spectral Efficiency = C/B

- Remember that

$$E_b/N_0 = S/(N_0 \times R) = S/N * B/C$$

- But using Shannon  $\rightarrow S/N = 2^{C/B} - 1$ , or

$$E_b/N_0 = B/C (2^{C/B} - 1)$$

- Very useful formula relating the achievable spectral efficiency for a given  $E_b/N_0$ .

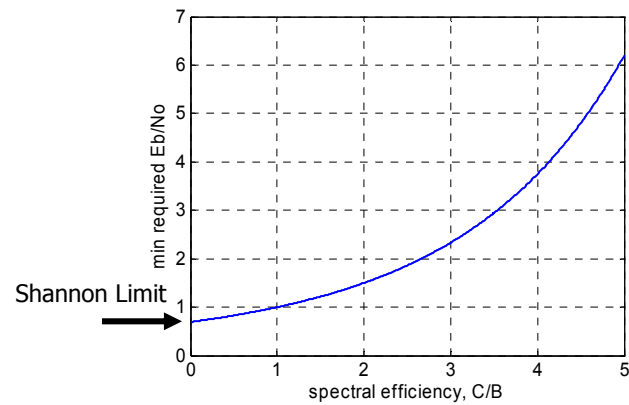
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## Spectral Efficiency – cont'd

- Note that the minimum required  $E_b/N_0$  for ANY communication system to work error-free is 0.6956 or -1.6 dB → This is known as the SHANNON LIMIT.



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