King Fahd University of Petroleum & Minerals
Computer Engineering Dept

COE 341 – Data and Computer Communications

Term 112

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Lecture Contents

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
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   c. Noise
5. Channel Capacity
   a. Nyquist Formula
   b. Shannon Capacity Formula
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Analog and Digital Data Transmission

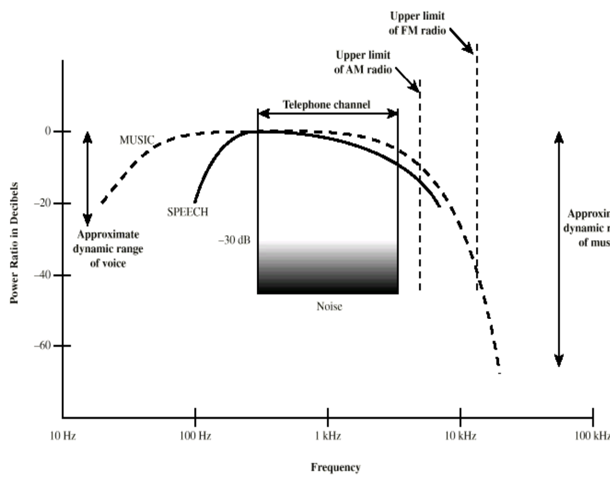
- **The terms:**
  - **Analogue ~ continuous**
  - **Digital ~ discrete**
- **They apply to:**
  - **A) Data: the information to be delivered**
  - **B) Signaling: the electrical or electromagnetic wave that propagates carrying the data**
  - **C) Transmission: the mechanism of delivering the data by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

Examples of Data/Signaling: (1) AUDIO

- **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**

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?**



Examples of Data/Signalling: (2) VIDEO

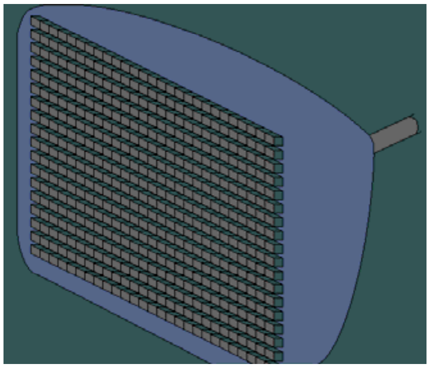
- **Another common example of analog data**
- **The original scene (source) is scanned and its image recorded by the camera – RASTER image**
- **In the TV: a moving electron beam scan the screen producing the picture**
  - **For black and white: the amount of illumination produced (on a scale from black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

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 70X483 = 338 lines**
    - **Hence, horizontal resolution is (4/3)X338 = 450 pixels per line**
  - **42 blanked during vertical retrace**
- **Basic line duration = 63.5 μsec:**
  - **52.5 μsec scanning horizontally**
  - **11 μsec for horizontal retrace**
- **High number of scans per second → smoother picture but expensive hardware**
- **Low number of scans per second → jittery picture (flickering)**
- **Interlacing: scan odd lines first at 60 scan per second and then scan even lines at 60 scans per second → To the human eye, the screen is 60 refreshed 60 times per second, i.e. no flickering**
  - **Interlacing**

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)**



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?

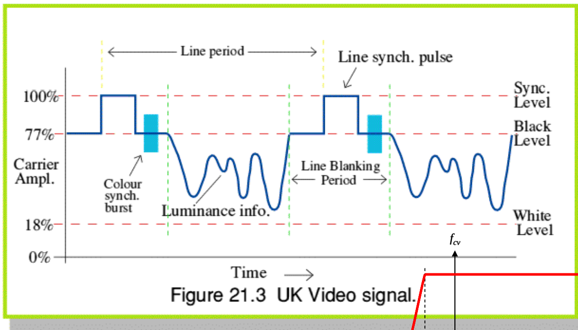
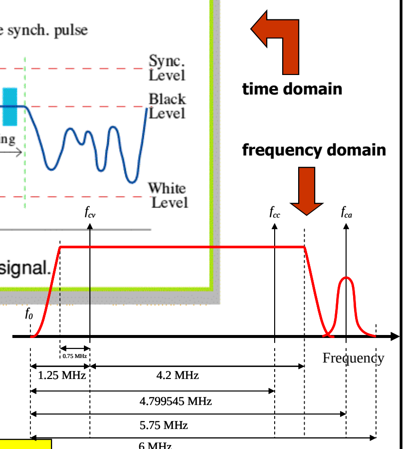


Figure 21.3 UK Video signal.



|M(f)| = Magnitude spectrum of RF video signal

http://www.st-andrews.ac.uk/~jcgl/Scots_Guide/RadCom/part21/page3.html
GREAT site for tutorials on communication systems

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 μsec per line**
  - **52.5 μsec 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 μsec/line.**
    - **Hence, the beam does (225/52.5 μsec) = 4.2X10^6 cycles per second**
    - **For minimum bandwidth**
      - **Let all pixels has same illumination level (no change in picture) ➔ DC component – fmin = 0 Hz**
- **Adding audio and color information does not increase bandwidth**
- **Hence NTSC video signal bandwidth is about 4 MHz**

Example:

- **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:

- **Solution:**

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

5 MHz = (H/2) / 52.5 μsec ➔ H = 525 lines

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

5MHz = (450/2) / T ➔ T = 45 μsec

The horizontal retrace still takes 11 μsec, therefore total time for horizontal line is 56 μsec.

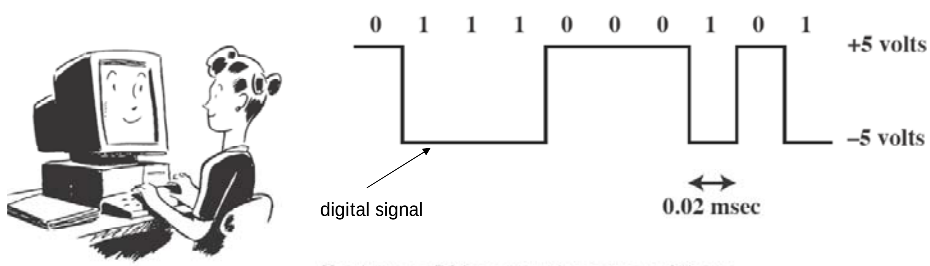
(1/30 sec/scan) / V lines/scan = 56 μsec/line ➔ V = 595 lines/scan

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 ≤ fundamental frequency**
  - **Minimum frequency is zero (DC) – when all bits are equal**

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?**

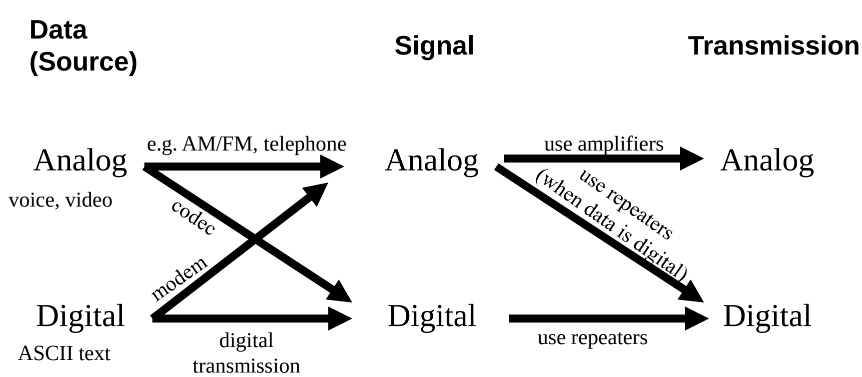


User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by –5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50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

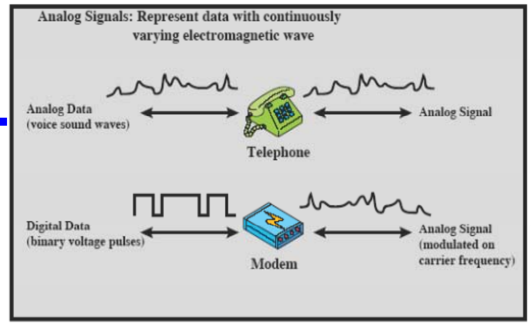
Transmission

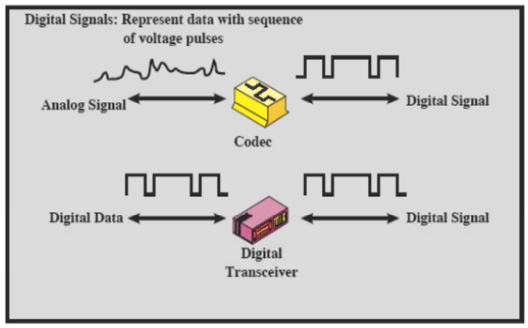
- **Analog Transmission:**
  - **Analog signal is propagated through amplifiers to compensate for attenuation and to achieve longer distance**
  - **Amplifiers:**
    - **Boost signal and noise equally**
    - **May distort original signal**
    - **Can not be used indefinitely**
- **Digital Transmission:**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

Transmission (2)



Analog and Digital Signaling of Analog and Digital Data





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**

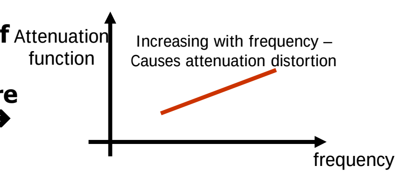
very important reasons the popularity of digital transmission

Transmission Impairments

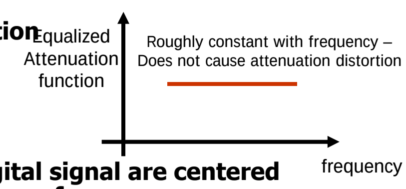
- Impairments can degrade the quality of an analog signal or cause a bit (symbol) error for a digital signal
- Types of Impairments:
  - Attenuation and Attenuation Distortion
  - Delay Distortion
  - Noise

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



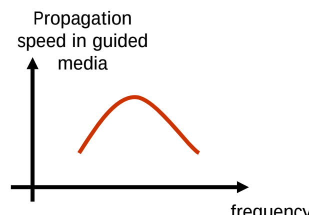
- Solution: Equalize transmission
  - Results in almost equal attenuation (gain) for all frequencies of interest



- 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

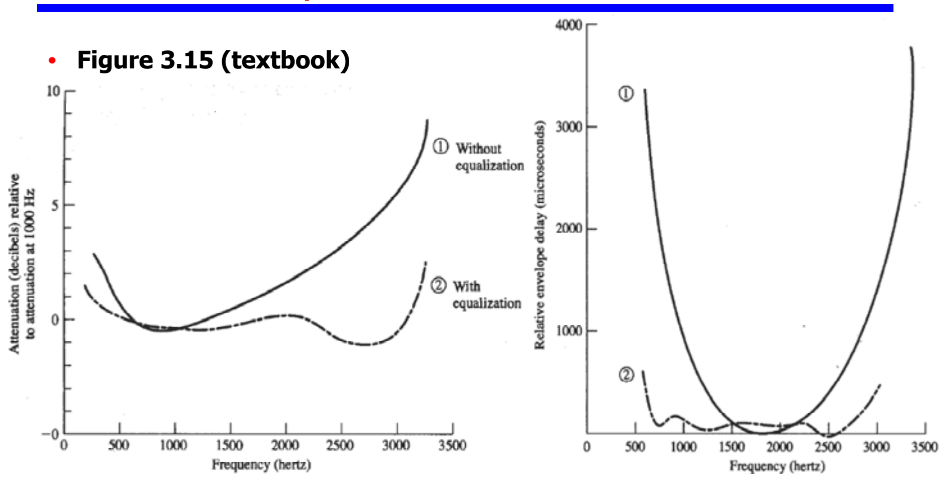
Delay Distortion

- **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**



Attenuation and Delay Distortion – Effect of Equalization

- **Figure 3.15 (textbook)**



(a) Attenuation (b) Delay Distortion

Noise

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

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**

$$No = kT \quad \text{(Watts/Hz)}$$

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

T is the temperature in degrees Kelvin

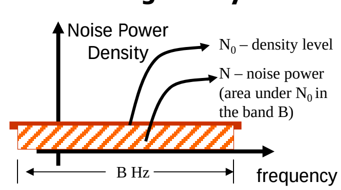
- **Hence, the thermal noise power in a bandwidth B Hz is given by**

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

- **In decibels:**

  NdB = 10logk + 10logT + 10logB

  = -228.6 dBW + 10logT + 10logB



Examples:

- **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:

- **Solution:**

N = kT X B

k = 1.38x10^{-23} J/Kelvin, T = 10,000 degrees Kelvin, B = 10X10^{6} Hz,

N = 1.38X10^{-12} Watts

N_{dBW} = 10 log N = -118.6 dBW

In dBmW, one can write

NdBmW = 10 log N*1000 = -88.6 dBmW or simply, NdBmW = N_{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 $[\cos(2\pi*f_i*t)]^2 = ½ + ½ \cos(2\pi*2f_i*t)$, and

$$\cos(2\pi*f_1*t) \cos(2\pi*f_2*t) = ½ \cos(2\pi*(f_1+f_2)*t) + ½ \cos(2\pi*(f_1-f_2)*t)$$

Output signal contain terms with multiples of (f1+f2) and (f1-f2)

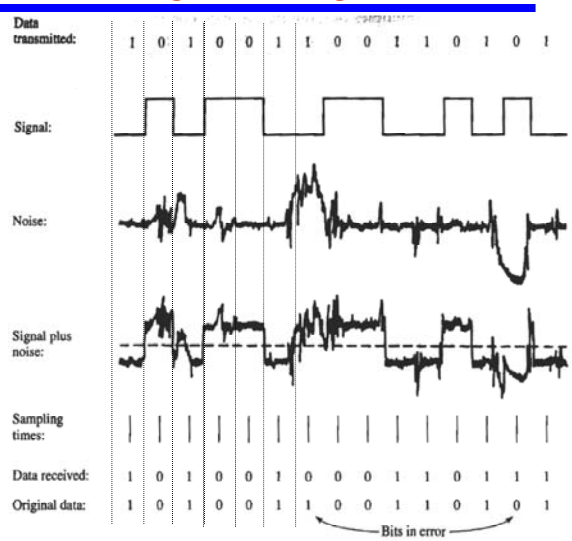
- **Intermodulation noise: *undesired* signals at the frequency that is multiples of sum or difference of the two original input frequencies**
- **Caused by nonlinearity**

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**

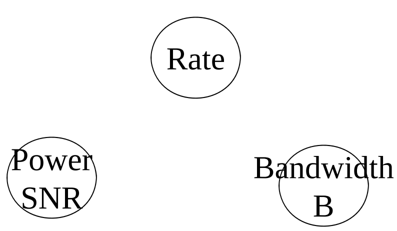
Effect of Noise on Digital Signal

- **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**



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)**



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 $\log_2 8$ = 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

Shannon Capacity Formula

- Capacity in the presence of noise

$$C = B \log_2(1 + SNR)$$

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

- Example: fmin = 3 MHz, fmax = 4 MHz, SNR = 24 dB, C = ?

  B = 4 – 3 = 1 MHz

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

  C = $1X10^6 \log_2(1 + 251) \sim 8 X 10^6$ b/s or 8 M b/s

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

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

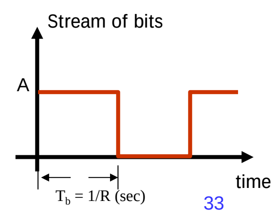
E_b/N_0 Expression

- **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 $A^2 X\ T_b$, where its power is equal to bit energy / T_b or A^2.**
- **Noise power is equal to N_0 X B (refer to thermal noise section)**
- **Hence, SNR is given by signal power / noise power or**

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

- **One can also write**

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



Examples:

- **<u>Problem 3.19</u>: 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?**

Examples:

- **Solution:**

Shannon Limit: $C = B \log_2(1 + SNR)$, $C = 20X10^6$ b/s, $B = 3X10^6$ Hz

$\log_2(1 + SNR) = 6.67$ → SNR = 101 = 20 dB

Examples:

- **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 Eb/N0 for a link transmitting 2400 b/s**

Examples:

- **Solution:**

Eb/No = (signal power / noise power) * (B/R)

Noise power = kT X B

Hence Eb/No = (signal power) / (kT R)

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

= 15.99

= 12 dB

Or (Eb/N0)dB = Signalpower_dBW – 10logk – 10logT – 10logR

$= -151 - 10\log(1.3810^{-23}) – 10\log 1500 - 10\log 2400$

= 12 dB

Spectral Efficiency

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

Eb/N0 = S/(No x R) = S/N * B/C

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

$Eb/No = B/C \quad (2^{C/B} – 1)$

- Very useful formula relating the achievable spectral efficiency for a given Eb/No.

Spectral Efficiency – cont'd

- Note that the minimum required Eb/No for ANY communication system to work error-free is 0.6956 or -1.6 dB ➔ This is known as the SHANNON LIMIT.