King Fahd University of Petroleum & Minerals Computer Engineering Dept

COE 241 – Data and Computer Communications

Term 141

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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
   b. Delay Distortion
   c. Noise
5. Channel Capacity
   a. Nyquist Formula
   b. Shannon Capacity Formula
   c. Eb/No expression

Analog and Digital Data Transmission

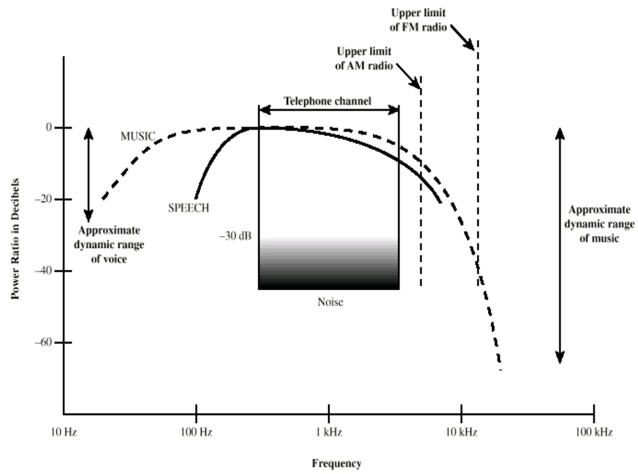
- **The terms:**
  - **Analogue ~ continuous**
  - **Digital ~ discrete**
- **They apply to:**
  - **A) Data: the information to be delivered**
  - **B) Signaling: the electrical or electromagnetic wave that propagates carrying the data**
  - **C) Transmission: the mechanism of delivering the data by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

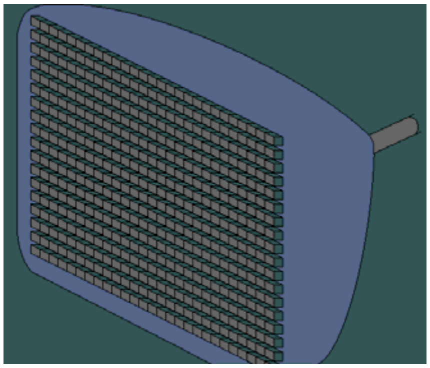


Examples of Data/Signalling: (2) VIDEO

- **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

- **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: (4) 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"**

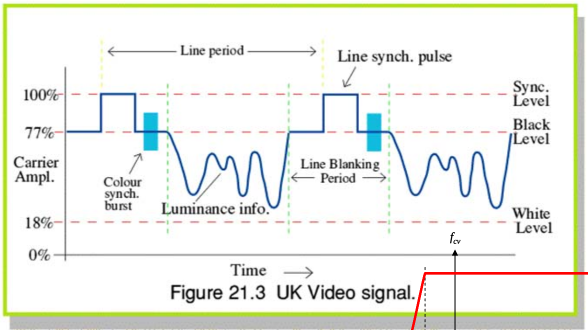
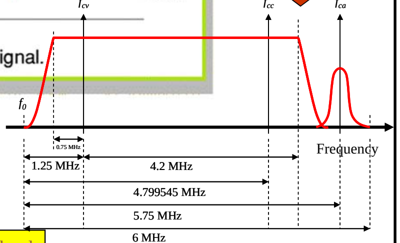


Figure 21.3 UK Video signal.

time domain

frequency domain



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

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

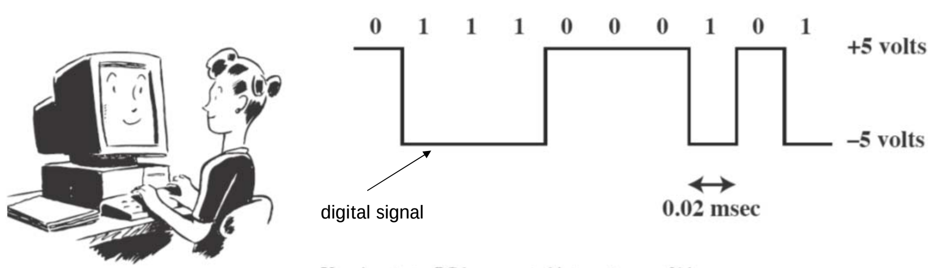
http://www.st-andrews.ac.uk/~jcgl/Scots_Guide/RadCom/part21/page3.html
GREAT site for tutorials on communication systems

Examples of Data/Signalling: (5) 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: (6) 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?**

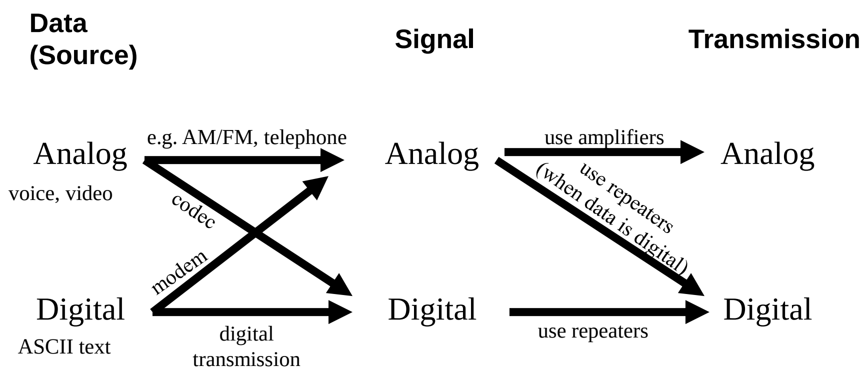


User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by –5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50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

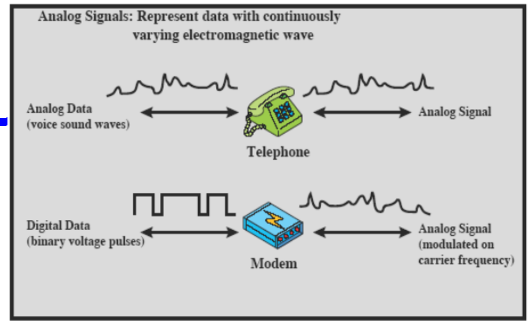
Transmission

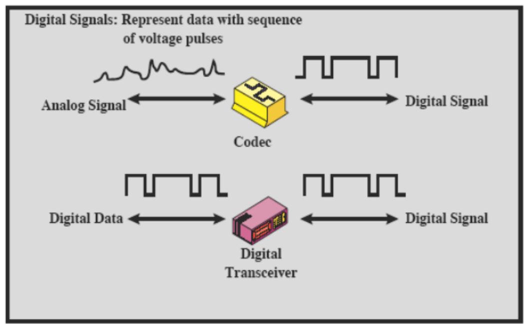
- **Analog Transmission:**
  - **Analog signal is propagated through amplifiers to compensate for attenuation and to achieve longer distance**
  - **Amplifiers:**
    - **Boost signal and noise equally**
    - **May distort original signal**
    - **Can not be used indefinitely**
- **Digital Transmission:**
  - **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**

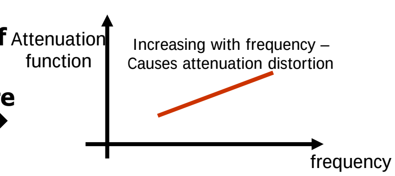
very important reasons the popularity of digital transmission

Transmission Impairments

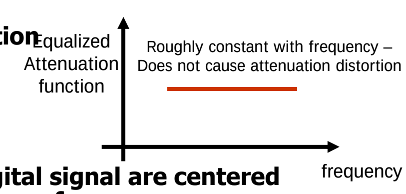
- **Impairments can degrade the quality of an analog signal or cause a bit (symbol) error for a digital signal**
- **Types of Impairments:**
  - **Attenuation and Attenuation Distortion**
  - **Delay Distortion**
  - **Noise**

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**



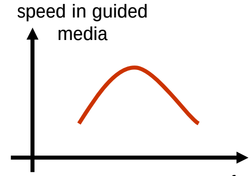
- **Solution: Equalize transmission**
  - **Results in almost equal attenuation (gain) for all frequencies of interest**



- **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**

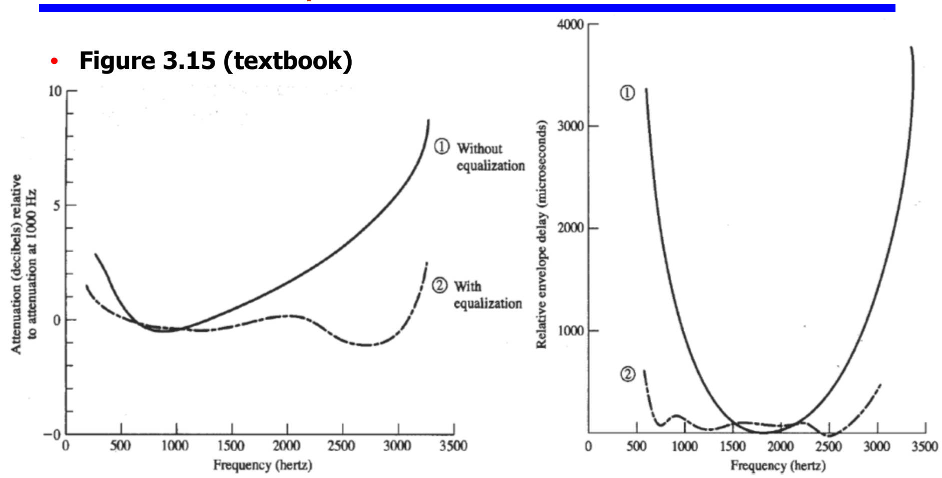
Delay Distortion

- **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 (Watts/Hz)

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

T is the temperature in degrees Kelvin

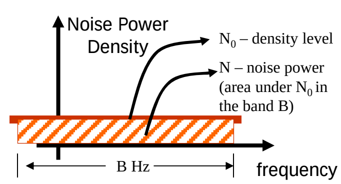
- **Hence, the thermal noise power in a bandwidth B Hz is given by**

$N = N_0 \times B = kT \times B$ (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: $H_L(S) = A_1 x S + A_0$

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

$$H_L(S_1+S_2) = A_1 x \cos(2\pi*f_1*t) + A_1 x \cos(2\pi*f_2*t) + A_0$$

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

- NonLinear System (example): $H_{NL}(S) = A_2 x S^2 + A_1 x S + A_0$

The output (for the same input) is

$$H_{NL}(S_1+S_2) = A_2 x [\cos(2\pi*f_1*t) + \cos(2\pi*f_2*t)]^2 + A_1 x [\cos(2\pi*f_1*t) + \cos(2\pi*f_2*t)] + A_0$$

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)

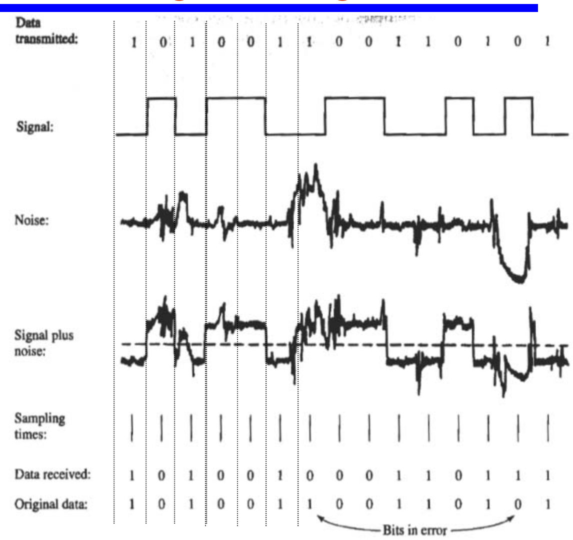
- Intermodulation noise: *undesired* signals at the frequency that is multiples of sum or difference of the two original input frequencies
- Caused by nonlinearity

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

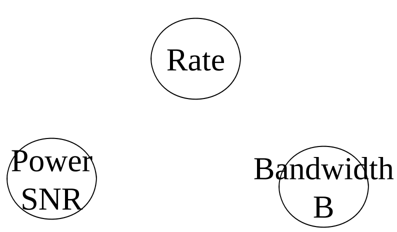
Effect of Noise on Digital Signal

- **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

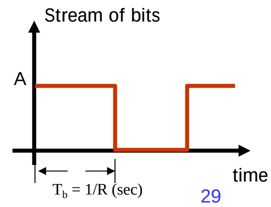
E_b/N_0 Expression

- **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^2X 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)

$= 10^{-151/10} / (1.38X10^{-23}X1500X2400)$

= 15.99

= 12 dB

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

$= -151 - 10\log(1.3810^{-23}) - 10\log1500 - 10\log2400$

= 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.