EEECS4214

Digital Communications

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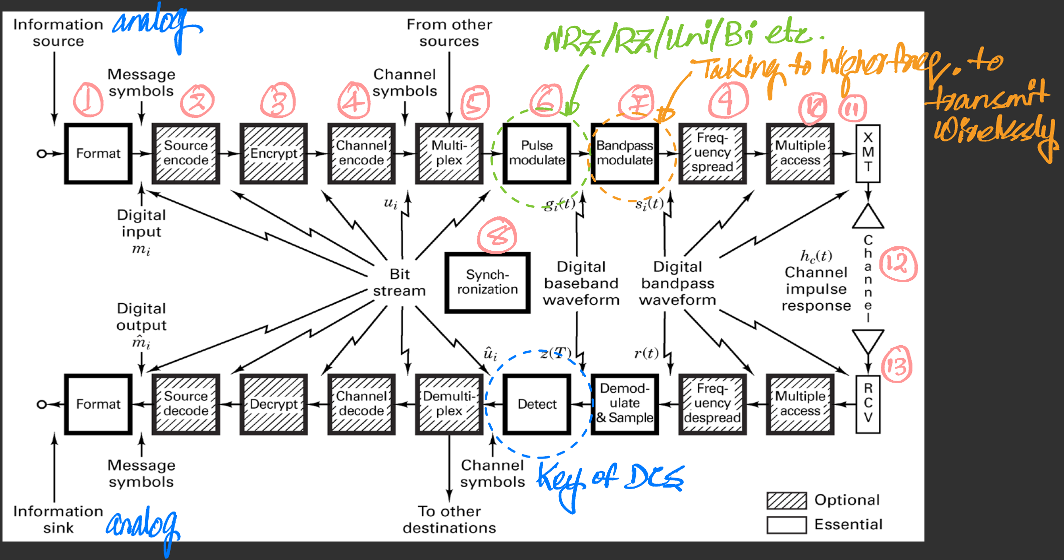
Lecture 2

1. Digital Communication System
2. Communication Channel
3. Review of Probability Concepts (Next lecture!)

Digital Communication System

Block Diagram of Digital Communication System (DCS)



Description of Each Block of DCS

1. Format
   - Transforms source information into bits

     will do in detail

     I
     - Sampling - makes signal discrete in time

     II
     - Quantization - makes signal discrete in value (good quantizers are able to use few bits and minimize distortion)

     III
     - PCM Coding - assign bits to the values
   - Ensure compatibility between source information and DCS
2. Source Encoder
   - Remove redundant bits from message - Data Compression

     Huffman / Shannon Fano Coding.

Description of Each Block of DCS

3 Encrypt

- To maintain privacy i.e., preventing unauthorized extraction of information (eavesdropping)
- To establish authentication i.e., preventing unauthorized injection of spurious signals (spoofing)

4 Channel Encoder   Error Detection & Correction.

- Takes k information bits, adds $(n-k)$ non-information bits in the signal to generate code word (or channel symbol) of length n
- Additional bits are used for error detection error correction. [Redundancy n/k code rate $= k/n$]

Description of Each Block of DCS

5 Multiplexing

- Provides resource sharing by combining different signals/symbols FDM/TDM. (T1 carrier)

6 Pulse Modulation

- Define Pulse Waveform (pulse shaping) to avoid intersymbol interference!
- Generate Baseband (low frequency) Waveform RZ/NRZ/Uni/Bi etc.
- When pulse modulation is applied to binary symbols the resulting waveform is called **pulse-code-modulation (PCM waveform)**
  - In telephone applications these waveforms are called **line-codes**

Description of Each Block of DCS

7 Bandpass Modulation - take sig. to high freq. as per channel characteris.

- Baseband signal is frequency translated by a carrier wave
- Required to meet transmission characteristics of channel
- Few Types:
  - Amplitude Shift Keying (ASK)
  - Frequency Shift Keying (FSK)
  - Phase Shift Keying (PSK)
  - + QAM

eg. microwave
Radio Freq (RF)
⋮
GHz etc
- Wireless medium.
(atmosphere attenuates low frequencies)

Description of Each Block of DCS

8. Synchronization (and clock signal)
   - Involved in the control of all signal processing within DCS
   - It plays a role in regulating operation of every block
9. Frequency Spread
   - Spread spectrum techniques are important for interference and privacy
   - Share bandwidth resources

Description of Each Block of DCS

10 Multiple Access

- Provide resource sharing for remote users

11 Transmitter Front End (Channel Coupler) Antenna + Amplifier etc.

- Injects signal into the channel

Description of Each Block of DCS

12 Channel

- Actual propagation medium
- The **wired** channel can be thought of as a Low Pass Filter (LPF)
  - Landlines, twisted-pair, coaxial cable, fiber-optic
- The **wireless** channel can be modeled as a frequency selective, time varying band-pass filter (BPF)
  - mobile phones, bluetooth, zigbee, infrared, X-ray
- The **Storage channels:** magnetic tape, magnetic disks, optical disks

Description of Each Block of DCS

13 Receiver

- Recovers the original signal that was passed to the transmitter
- Use decision theory to decide which symbol was transmitted

Detect

- **Example:** For binary symbols, compare received power/amplitude to decide whether zero or one was transmitted
- All the steps (except detect) preformed at transmitter are reversed at the receiver side
  - Frequency Translation
  - Amplification and Filtering
  - Demodulation
  - Decoding and Error Correction
  - Reconstruction and Formatting

Basic Digital Communication Transformations

Formatting

ASCII

- Character coding
- Sampling
- Quantization
- Pulse code modulation (PCM)

Source Coding

- Predictive coding
- Block coding
- Variable length coding
- Synthesis/analysis coding
- Lossless compression
- Lossy compression

Baseband Signaling

- PCM waveforms (line codes)
  - Nonreturn-to-zero (NRZ)
  - Return-to-zero (RZ)
  - Phase encoded
  - Multilevel binary
- *M*-ary pulse modulation
  - PAM, PPM, PDM

Equalization

- Maximum-likelihood sequence estimation (MLSE)
- Equalization with filters
  - Transversal or decision feedback
  - Preset or Adaptive
  - Symbol spaced or fractionally spaced

Synchronism is needed

Bandpass Signaling

Coherent

- Phase shift keying (PSK)
- Frequency shift keying (FSK)
- Amplitude shift keying (ASK)
- Continuous phase modulation (CPM)
- Hybrids

Noncoherent

- Differential phase shift keying (DPSK)
- Frequency shift keying (FSK)
- Amplitude shift keying (ASK)
- Continuous phase modulation (CPM)
- Hybrids

Channel Coding

Waveform

- *M*-ary signaling
- Antipodal
- Orthogonal
- Trellis-coded modulation

Structured Sequences

- Block
- Convolutional
- Turbo

Synchronization

- Frequency synchronization
- Phase synchronization
- Symbol synchronization
- Frame synchronization
- Network synchronization

Multiplexing/Multiple Access

- Frequency division (FDM/FDMA)
- Time division (TDM/TDMA)
- Code division (CDM/CDMA)
- Space division (SDMA)
- Polarization division (PDMA)

Spreading

- Direct sequencing (DS)
- Frequency hopping (FH)
- Time hopping (TH)
- Hybrids

Encryption

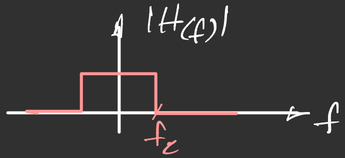
- Block
- Data stream

Communication Channel

Communication Channel

Actual propagation medium

- The **wired** channel can be thought of as a Low Pass Filter (LPF)
  - High-frequency components in the signal experience greater attenuation due to physical properties of the medium, such as:
    - Resistance
    - Skin effect in wires
    - Dispersion in optical fibers



  - The cutoff frequency is determined by the physical properties of the medium and the length of the cable
  - Time-invariant (Physical Medium is Fixed, Stationary Transmitter and Receiver)
  - Examples: Telephone lines support baseband signals with a bandwidth of up to a few kHz, twisted-pair, coaxial cable, fiber-optic

Communication Channel

- The **wireless** channel can be modeled as a frequency selective, time varying band-pass filter (BPF)
  - Frequency-selective due to multipath fading (reflection, diffraction, and scattering)
  - Time varying
    - The transmitter, receiver, or surrounding environment may be in motion
    - Doppler shift
  - Examples: mobile phones, bluetooth, zigbee, infrared, X-ray

Communication Distortion

- Broadly of two types:
  - **Additive** – channel output contains other signals beyond the input signal (examples, noise, interference)
  - **Non-Additive** – attenuation, spectral modification/filtering, non-linear distortion

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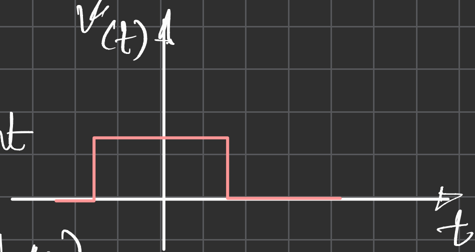
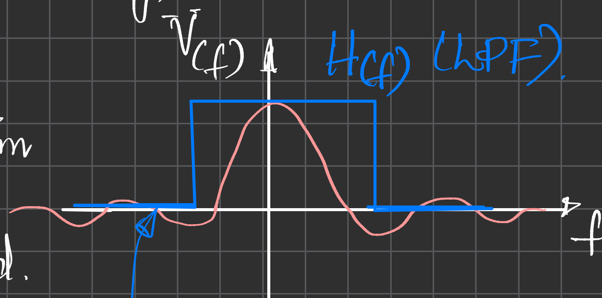
pulse to represent binary '0' or '1' (time-limited sig.)



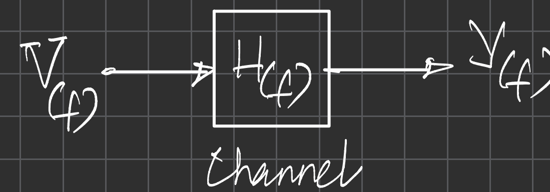
Sinc form freq. unlimited.



We limit $V(f)$ in freq. domain to transmit it through the channel by LPF ($H(f)$)

$$Y(f) = H(f)\,V(f)$$

✓ Channel is also either a LPF (Wired) or a BPF (Wireless).

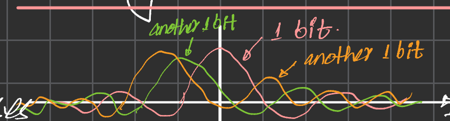


✓ Now the freq.-limited sig. result into time-unlimited sig.

✓ This results in smearing of pulses.

✓ Called Inter-Symbol Interference (ISI).

✓ smearing of pulses



Noise in Communication Systems

- Unwanted electrical signals that are always present in electrical systems e.g. spark plug ignition noise, switching transients, and other radiating electromagnetic signals
- Noise due to thermal agitation of electrons in electronic circuits (known as thermal noise) is the most dominant in communication systems
- Can describe thermal noise as a **Zero-mean Gaussian random process**

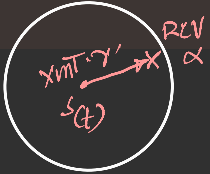
Additive White Gaussian Noise (AWGN): In later lecture.

Ideal Channel Model

r: distance b/w Txm & RCV!

$$r(t) = As(t) + n(t),$$

Attenuation



$\propto \frac{s(t)}{r^2}$

where

- $r(t)$ is the received signal
- A is the attenuation (in wireless transmissions, transmit power typically decreases as inverse of square distance)
- $s(t)$ is the transmitted signal
- $n(t)$ is the additive noise (in wireless transmissions, typically we refer to additive white Gaussian noise which is random)

Linear Time Invariant (LTI) Channel Model

$$r(t) = \overbrace{As(t) * h(t)}^{\text{In freq. domain: } AS(f)\cdot H(f)} + n(t), \text{ where } h(t) \text{ is the impulse response of the channel}$$

- Attenuation, additive noise, modification of frequency spectrum due to filter characteristics of the channel
- Linear filter can change only magnitude and phase
- Channel's impulse response remains constant during communication period

$h(t)$ – time invariant

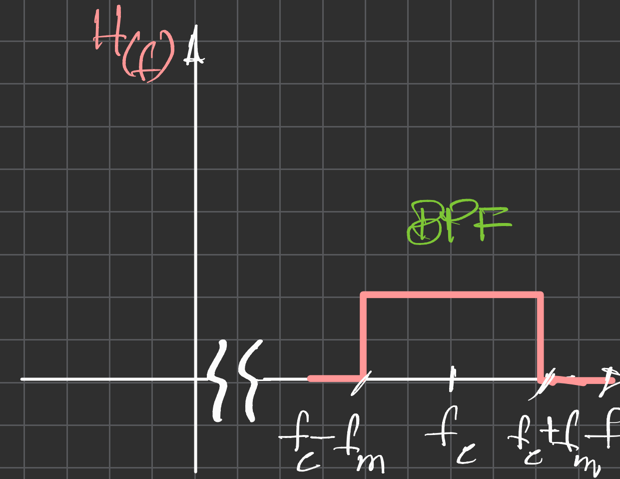
- Examples
  - Twisted Pair ($\sim$ 100 kHz)
  - Coaxial ($\sim$ 100 MHz)
  - Optical waveguide ($\sim$ 100 GHz)

Filtering: Channel can have a bandwidth that is small compared to the signal bandwidth (e.g., in a telephone channel). Subsequently, transmitted pulses will vary in shape and smeared out in time causing inter-symbol interference (ISI). as explained in the earlier slide!

Channel

Wired

Wireless



f_m: max^m freq. component of msg. sig.

f_c: Carrier freq.

$f_c >>> f_m$.

↓ To transmit wirelessly

Linear Time Variant (LTV) Channel Model

W/L

$$r(t) = As(t) * h(t, \tau) + n(t)$$

where $h(t, \tau)$ is the impulse response and τ is the path delay

Time-variant

Multi-path Fading:

- Signal amplitude can change in a random fashion
- Time-varying channels cause signal fading
- Different signal components can fade at different levels and this often causes random filtering of the signals (hence ISI)