Communication Systems Overview

Lathi & Ding Chapter 1

- Information representation
- Communication system block diagrams
- Analog versus digital systems
- Performance metrics
- Data rate limits

Next week: signals and signal space (L&D chapter 2)

Types of Information

- Major classification of data: analog vs. digital
- Analog signals
  - speech (but words are discrete)
  - music (closer to a continuous signal)
  - temperature readings, barometric pressure, wind speed
  - images stored on film
- Analog signals can be represented (approximately) using bits
  - audio: 8, 16, 24 bits per sample
  - digitized images (can be compressed using JPEG)
  - digitized video (can be compressed to MPEG)
- Bits: text, computer data
- Analog signals can be converted into bits by quantizing/digitizing

The word "bit" was coined in the late 1940s by John Tukey, co-inventor of Fast Fourier Transform

Analog Messages

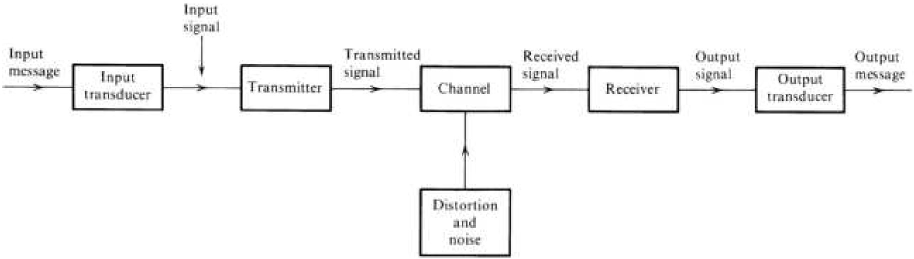
- Early analog communication
  - telephone (1876)
  - phonograph (1877)
  - film soundtrack (1923, Lee De Forest, Joseph Tykociński-Tykociner)
- Key to analog communication is the amplifier (1908, Lee De Forest, triode vacuum tube)
- Broadcast radio (AM, FM) is still analog
- Broadcast television was analog until 2009

Digital Messages

- Early long-distance communication was digital
  - semaphores, white flag, smoke signals, bugle calls, telegraph
- Teletypewriters (stock quotations)
  - Baudot (1874) created 5-unit code for alphabet. Today *baud* is a unit meaning one *symbol* per second.
  - Working teleprinters were in service by 1924 at 65 words per minute
- Fax machines: Group 3 (voice lines) and Group 4 (ISDN)
  - In 1990s the accounted for majority of transPacific telephone use. Sadly, fax machines are still in use.
  - First fax machine was Alexander Bains 1843 device required conductive ink
  - Pantelegraph (Caselli, 1865) set up telefax between Paris and Lyon
- Ethernet, Internet

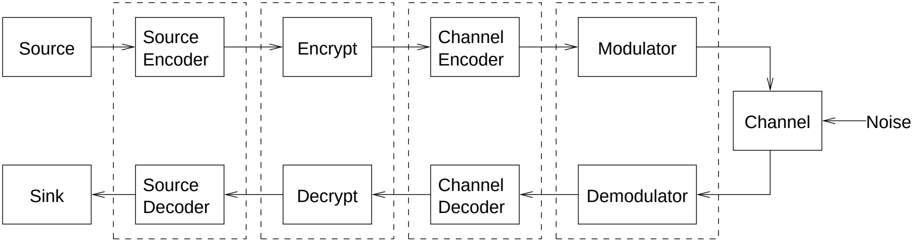
There is no name for the unit bit/second. I have proposed *claude*.

Communication System Block Diagram (Basic)



- Source encoder converts message into message signal (bits)
- Transmitter converts message signal into format appropriate for channel transmission (analog/digital signal)
- Channel conveys signal but may introduce attenuation, distortion, noise, interference
- Receiver decodes received signal back to message signal
- Source decoder decodes message signal back into original message

Communication System Block Diagram (Advanced)



- Source encoder compresses message to remove redundancy
- Encryption protects against eavesdroppers and false messages
- Channel encoder adds redundancy for error protection
- Modulator converts digital inputs to signals suitable for physical channel

Examples of Communication Channels

- Communication systems convert information into a format appropriate for the transmission medium
- Some channels convey electromagnetic waves (signals).
  - Radio (20 KHz to 20+ GHz)
  - Optical fiber (200 THz or 1550 nm)
  - Laser line-of-sight (e.g., from Mars)
- Other channels use sound, smell, pressure, chemical reactions
  - smell: ants
  - chemical reactions: neuron dendrites
  - dance: bees
- Analog communication systems convert (modulate) analog signals into modulated (analog) signals
- Digital communication systems convert information in the form of bits into binary/digital signals

Physical Channels

- Physical channels have constraints on what kinds of signals can be transmitted
  - Radio uses E&M waves at various frequencies
  - Submarine communication at about 20 KHz
  - Cordless telephones: 45 MHz, 900 MHz, 2.4 GHz, 5.8 GHz, 1.9 GHz
- Wired links may require DC balanced codes to prevent voltage build up
- Fiber optic channels use 4B5B modulation to accommodate time-varying attenuation
- CD and DVD media require minimum spot size but position can be more precise
- The process of creating a signal suitable for transmission is called *modulation* (modulate from Latin "to regulate")

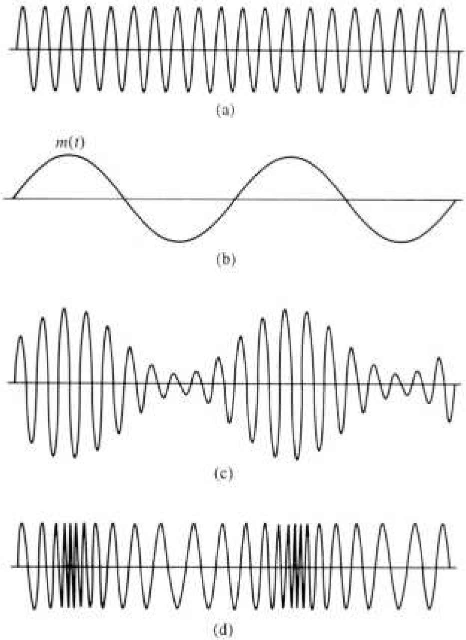
AM and FM Modulation

(a) Carrier

(b) Signal

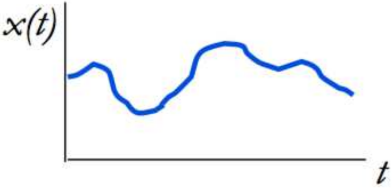
(c) Amplitude modulated

(d) Frequency modulated

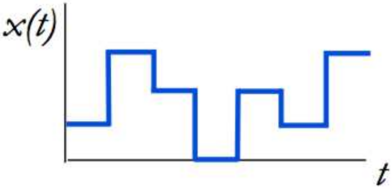


Analog vs. Digital Systems

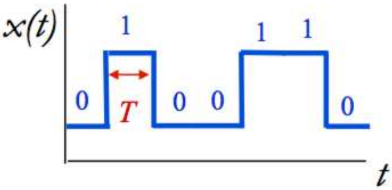
- Analog signals
  Values varies continously



- Digital signals
  Value limited to a finite set
  Digital systems are more robust

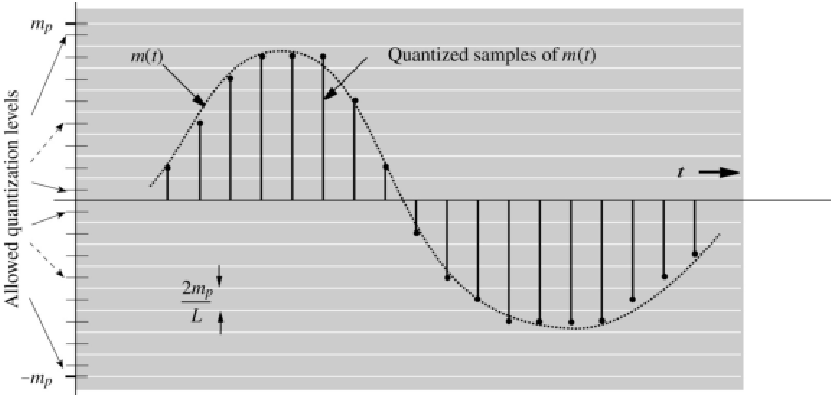


- Binary signals
  Have 2 possible values
  Used to represent bit values
  Bit time T needed to send 1 bit
  Data rate $R = 1/T$ bits per second



Sampling and Quantization, I

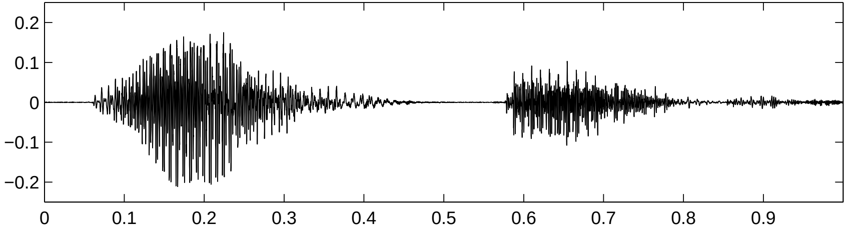
To transmit analog signals over a digital communication link, we must discretize both time and values.



Quantization spacing is $\dfrac{2m_p}{L}$; sampling interval is T, not shown in figure.

Sampling and Quantization, II

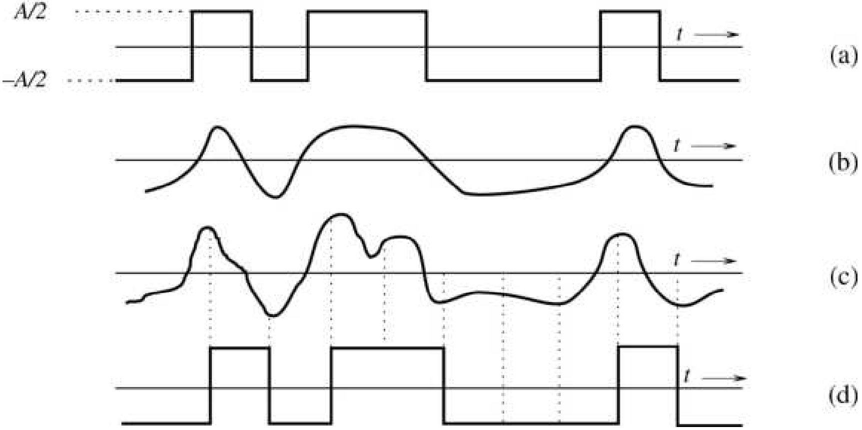
- Usually sample times are uniformly spaced.
- Higher frequency content requires faster sampling. (Soprano must be sampled twice as fast as a tenor.)



- Quantization levels are usually uniformly spaced (linear). Logarithmic compression is useful for greater dynamic range.

Digital Transmission and Regeneration

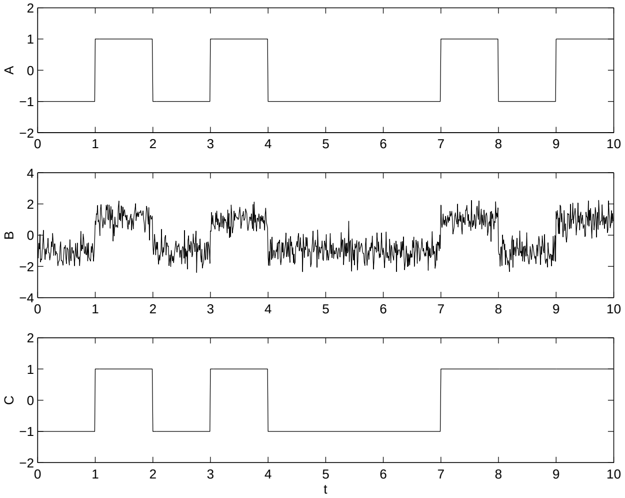
Simplest digital communication is binary amplitude-shift keying (ASK)



(a) binary signal input to channel; (b) signal altered by channel;
(c) signal + noise; (d) signal after *detection* by receiver

Channel Errors

If there is too much channel distortion or noise, receiver may make a mistake, and the regenerated signal will be incorrect. Channel coding is needed to detect and correct the message.



Pulse Code Modulation (PCM)

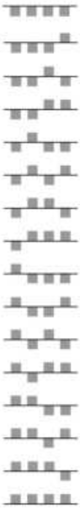
To communicate sampled values, we send a sequence of bits that represent the quantized value.

For 16 quantization levels, 4 bits suffice.

PCM can use binary representation of value.

The PSTN uses 8-bit companded PCM (similar to floating point)

Digit	Binary equivalent	Pulse code waveform
0	0000	
1	0001	
2	0010	
3	0011	
4	0100	
5	0101	
6	0110	
7	0111	
8	1000	
9	1001	
10	1010	
11	1011	
12	1100	
13	1101	
14	1110	
15	1111	



Performance Metrics

- Analog communication systems
  - Metric is *fidelity*, closeness to original signal
  - We want $\hat{m}(t) \approx m(t)$
  - A common measure of infidelity is *energy* of difference signal:

$$\int_0^T |\hat{m}(t) - m(t)|^2 \, dt$$

- Digital communication systems
  - Metrics are data rate R in bits/sec and probability of bit error

$$P_e = \mathrm{P}\{\hat{b} \neq b\}$$

  - Without noise, we never experience bit errors
  - With noise, P_e depends on signal power, noise power, data rate, and channel characteristics.

Data Rate Limits

- Data rate R is limited by signal power, noise power, distortion
- Without distortion or noise, we could transmit at $R = \infty$ and error probably $P_e = 0$
- The Shannon *capacity* is the maximum possible data rate for a system with noise and distortion
  - Maximum rate can be approached with error probability approaching 0
  - For additive white Gaussian noise (AWGN) channels,

$$C = \frac{1}{2} B \log(1 + \mathrm{SNR}) = \frac{1}{2} B \log\left(1 + \frac{P}{N}\right)$$

  - The theoretical result does not tell how to design real systems
- Shannon obtained $C \approx 32$ Kbps for telephone channels ($B = 3700 - 300 = 3400$ Hz)
- Modern modems achieve higher rates by using more bandwidth

Next

SDR (software-defined radio) lab on Friday

- We will give you your RTL SDR's
- Bring your laptops, and headphones
- We'll get you up and running!

Next week

- (Very brief) review of EE 102A
- Fourier series and Fourier transforms in $2\pi f$
- Vector space perspective on signal processing
- L&D Chapter 2 (skim this, most should look very familiar)