ECE230X Lectures 10–11

Data and Computer Communications Eighth Edition
By William Stallings
Section 5.2 – “Digital Data, Analog Signals”

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Adapted from Prentice Hall instructor resources
Basics of Signal Encoding

- Important function of the physical layer: Convert data (e.g. bits) to signals (e.g. voltages).
- The signal must be designed to efficiently propagate through the medium.
- The signal must also be designed so that the receiver can correctly interpret it.
How to convey digital information with signals

- Need two things:
  - A set of $2^N$ distinct signals
    - Each signal is called a “symbol”
    - The set is called an “alphabet”
  - A unique mapping between blocks of N bits and each signal

- Example (N=2)
  - Signal set = {□ □ □ □} ($2^2 = 4$ signals)
  - Unique mapping
    - Logical 00 <-> □
    - Logical 01 <-> □
    - Logical 10 <-> □
    - Logical 11 <-> □

What does this signal mean? □ □ □ □
An Example of a Bad Alphabet

Why is this alphabet bad?
• Recall “digital” signaling, e.g.

\[ \begin{array}{cccccccc}
0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\
\end{array} \]

• Digital signaling is inappropriate in many scenarios (interference with other signals or inefficient propagation):
  - Wireless communication
  - Optical communication
  - Cable modems
  - Digital subscriber loops (DSL)
  - Even basic voiceband modems (300Hz–3400Hz channel)

• Need “analog” signals in these cases
Common “Analog” Signals for Communication

- Main idea: Alphabet composed of **sinusoidal** signals with distinct amplitude, frequency, and/or phase shifts
- Sinusoidal signals allow control of signal spectrum
  - Efficient propagation in desired medium
  - Avoid interference with other signals
- Pure methods:
  - Amplitude shift keying (ASK)
  - Frequency shift keying (FSK)
  - Phase shift keying (PSK)
- Hybrid methods:
  - Quadrature amplitude modulation (QAM) (signals distinguished by both amplitude and phase shifts)
Amplitude Shift Keying

- encode data in signal amplitude, e.g.
  - Logical 0 → 0sin(\(wt\))
  - Logical 1 → Asin(\(wt\))
- Can have more than two amplitudes, e.g.
  - Logical 00 → 0sin(\(wt\))
  - Logical 01 → Asin(\(wt\))
  - Logical 10 → 2Asin(\(wt\))
  - Logical 11 → 3Asin(\(wt\))
- Used for
  - up to 1200bps telephone modems
  - optical fiber (light on/off)

Higher data rate but either increased power or likelihood of error at receiver.
Frequency Shift Keying

- encode data in signal frequency, e.g.
  - Logical 0 $\rightarrow$ sin(wt)
  - Logical 1 $\rightarrow$ sin(2wt)
- Can have more than two frequencies, e.g.
  - Logical 00 $\rightarrow$ sin(wt)
  - Logical 01 $\rightarrow$ sin(2wt)
  - Logical 10 $\rightarrow$ sin(3wt)
  - Logical 11 $\rightarrow$ sin(4wt)
- Better error resistance than ASK
- Used in old voiceband modems (300 bps)

Higher data rate but either increased bandwidth or increased likelihood of error at receiver
Phase Shift Keying

- encode data in signal phase, e.g.
  - Logical 0 \rightarrow \sin(wt+0)
  - Logical 1 \rightarrow \sin(wt+\pi)
- Can have more than two phases, e.g.
  - Logical 00 \rightarrow \sin(wt+0)
  - Logical 01 \rightarrow \sin(wt+\pi/2)
  - Logical 10 \rightarrow \sin(wt+\pi)
  - Logical 11 \rightarrow \sin(wt+3\pi/2)
- This is called quadrature PSK (QPSK) – very popular for wireless communication

Higher data rate but increased likelihood of error at receiver
QPSK Modulator Block Diagram

- Binary input
- 2-bit serial-to-parallel converter
- $R = \frac{1}{T_b}$
- I(t) $a_n = \pm 1$
- Carrier oscillator
- $\frac{\cos 2\pi f_c t}{\sqrt{2}}$
- Phase shift
- $\frac{-\sin 2\pi f_c t}{\sqrt{2}}$
- Q(t) $b_n = \pm 1$
- Signal out $s(t)$
Summary of “Pure” Binary Analog Modulation Techniques

(a) ASK

(b) BFSK

(c) BPSK
Hybrid method: Quadrature Amplitude Modulation (QAM)

- Basic idea: encode data in both **phase** and **amplitude**, e.g.
  - Logical 00 → $\cos(\omega t) + \sin(\omega t)$
  - Logical 01 → $\cos(\omega t) - \sin(\omega t)$
  - Logical 10 → $-\cos(\omega t) + \sin(\omega t)$
  - Logical 11 → $-\cos(\omega t) - \sin(\omega t)$

- No binary methods, but lots of higher order QAM:
  - 4QAM (2 bits per signal, like QPSK)
  - 16QAM (4 bits per signal)
  - 64QAM (6 bits per signal)
  - 256QAM (8 bits per signal)
  - ...

- Used in applications where spectral efficiency is critical, e.g. DSL and high data rate wireless
QAM Modulator Block Diagram
Which “Analog” Modulation Scheme Should I Use?

- **Power efficiency** important?
  - FSK is energy efficient but not bandwidth efficient

- **Spectral efficiency** important?
  - QAM, PSK, ASK are more bandwidth efficient but less energy efficient

- **Optical systems**?
  - ASK (very difficult to control/detect phase in optical transmission)

- **Bottom line**: Lots of tradeoffs. Best choice depends on the application.
Figure 7.66  Comparison of several modulation methods at $10^{-5}$ symbol error probability.

From Communication Systems Engineering
Proakis & Salehi