Modulation Techniques

- Signal Encoding Techniques
- Digital Data, Analog Signals
  - Amplitude Shift Keying
  - Frequency Shift Keying
  - Phase Shift Keying
Analog and Digital Signaling

Both digital data and analog data can be represented, hence propagated by either analog or digital signals.
Digital Signals: Represent data with sequence of voltage pulses

Analog Signal  →  Codec  →  Digital Signal

Digital Data  →  Digital Transmitter  →  Digital Signal
Signal Encoding Criteria

What determines how successful a receiver will be in interpreting an incoming signal?

- Signal-to-noise ratio
- Data rate
- Bandwidth

An increase in data rate increases bit error rate.
An increase in SNR decreases bit error rate.
An increase in bandwidth allows an increase in data rate.
Factors Used to Compare Encoding Schemes

Signal spectrum
- With lack of high-frequency components, less bandwidth required

Clocking
- Ease of determining beginning and end of each bit position

Signal interference and noise immunity
- Performance in the presence of noise

Cost and complexity
- The higher the signal rate to achieve a given data rate, the greater the cost
Basic Encoding Techniques

Digital data to analog signal

- **Amplitude-shift keying (ASK)**
  - Amplitude difference of carrier frequency

- **Frequency-shift keying (FSK)**
  - Frequency difference near carrier frequency

- **Phase-shift keying (PSK)**
  - Phase of carrier signal shifted
Amplitude-Shift Keying

One binary digit represented by presence of carrier, at constant amplitude

Other binary digit represented by absence of carrier

\[ s(t) = \begin{cases} 
    A \cos(2\pi f_c t) & \text{binary 1} \\
    0 & \text{binary 0} 
\end{cases} \]

- where the carrier signal is \( A \cos(2\pi f_c t) \)
Amplitude-Shift Keying

- very simple
- low bandwidth requirements
- susceptible to interference
- Susceptible to sudden gain changes
- Inefficient modulation technique
- Used to transmit digital data over optical fiber
Binary Frequency-Shift Keying (BFSK)

Two binary digits represented by two different frequencies near the carrier frequency

\[ s(t) = \begin{cases} 
A \cos(2\pi f_1 t) & \text{binary 1} \\
A \cos(2\pi f_2 t) & \text{binary 0} 
\end{cases} \]

where \( f_1 \) and \( f_2 \) are offset from carrier frequency \( f_c \) by equal but opposite amounts.
Binary Frequency-Shift Keying (BFSK)

needs larger bandwidth
Less susceptible to error than ASK
On voice-grade lines, used up to 1200bps
Used for high-frequency (3 to 30 MHz) radio transmission
Can be used at higher frequencies on LANs that use coaxial cable
Multiple Frequency-Shift Keying (MFSK)

More than two frequencies are used

More bandwidth efficient but more susceptible to error

\[ s_i(t) = A \cos 2\pi f_i t \quad 1 \leq i \leq M \]

- \( f_i = f_c + (2i - 1 - M)f_d \)
- \( f_c = \) the carrier frequency
- \( f_d = \) the difference frequency
Phase-Shift Keying (PSK)

Two-level PSK (BPSK)

- Uses two phases to represent binary digits

\[
s(t) = \begin{cases} 
A \cos(2\pi f_c t) & \text{binary 1} \\
A \cos(2\pi f_c t + \pi) & \text{binary 0} 
\end{cases}
\]

More resistant to interference but receiver and transmitter are also more complex.
Phase-Shift Keying (PSK)

Differential PSK (DPSK)

- Phase shift with reference to previous bit
  - Binary 0 – signal burst of same phase as previous signal burst
  - Binary 1 – signal burst of opposite phase to previous signal burst
Phase-Shift Keying (PSK)

Four-level PSK (QPSK)

- Each element represents more than one bit

\[ S(t) = \begin{cases} 
A \cos \left( 2\pi f_c t + \frac{\pi}{4} \right) & \text{11} \\
A \cos \left( 2\pi f_c t + \frac{3\pi}{4} \right) & \text{01} \\
A \cos \left( 2\pi f_c t - \frac{3\pi}{4} \right) & \text{00} \\
A \cos \left( 2\pi f_c t - \frac{\pi}{4} \right) & \text{10} 
\end{cases} \]