Modulation

02/06/06

Modulation

- Digital modulation: digital data (0 and 1) is translated into an analog signal --- the baseband signal.
- E.g., dial-up modem. The telephone line can only transmit analog signals.
- In wired LAN, digital transmission is used.
- Wireless networks: digital transmission can not be used.

The basic sine signal

- $s(t) = A \sin(2\pi f t + \phi)$
  - Amplitude: A
  - Frequency: f
  - Phase: ϕ
  - Wavelength: λ, $\lambda f = v$ (speed of light).

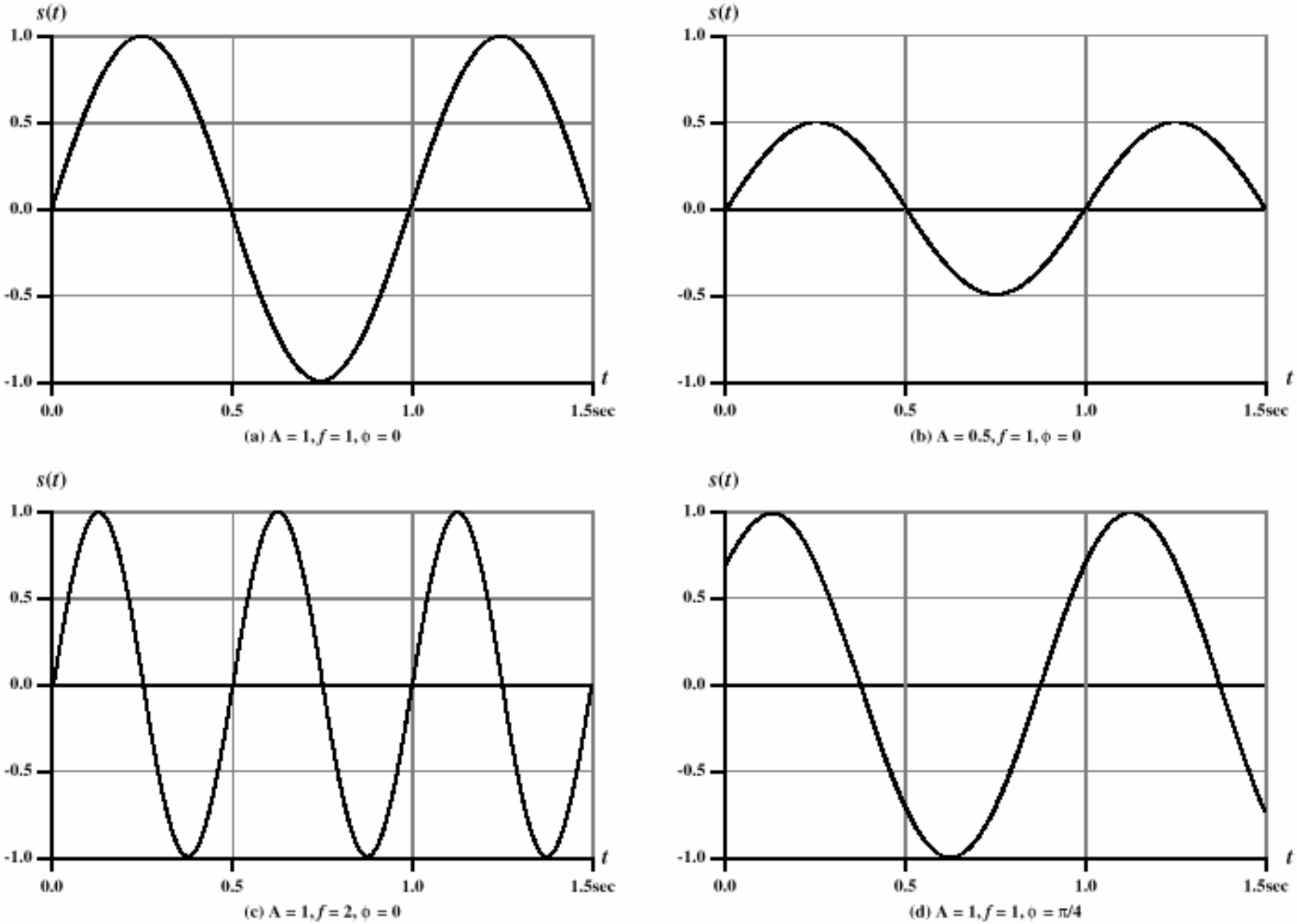


Figure 2.3 $s(t) = A \sin(2\pi ft + \phi)$

Digital modulation

- Three basic methods
  - Amplitude shift keying (ASK)
  - Frequency shift keying (FSK)
  - Phase shift keying (PSK)

Analog modulation

- Shift the center frequency of the baseband signal generated by the digital modulation up to the radio carrier.
- Antennas: the size of an antenna must be in the order of the signal's wavelength to be effective.
  - The wavelength of 1MHz signal is about hundreds of meters; while that of 1GHz signal is about .1 meters.
  - Recall the frequency of the cordless phone: 2.4 GHz or 5.8 GHz.

Analog modulation

- Frequency division multiplexing
  - Analog modulation shifts the baseband signals to different carrier frequencies.

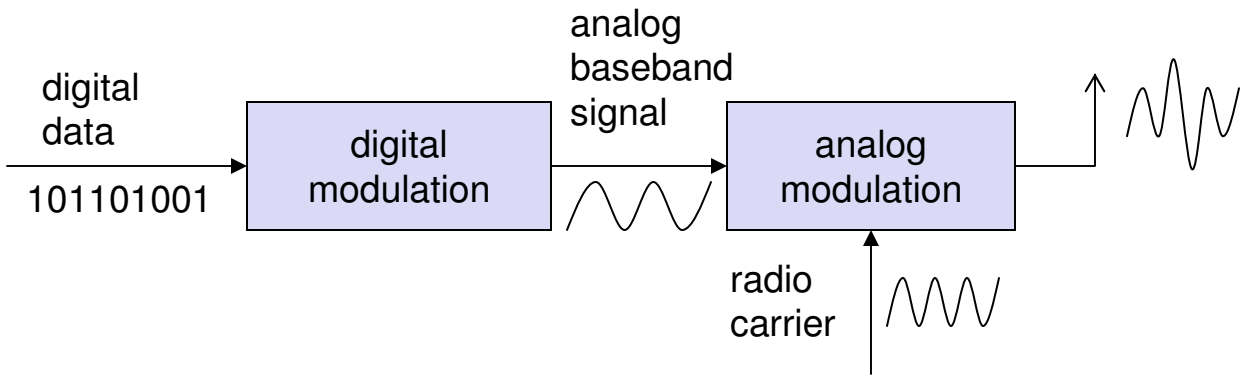
Analog modulation

- Medium characteristics
  - Signal propagation depends heavily on the wavelength of the signal.
  - The larger the wavelength, the better the penetration.
  - The smaller the wavelength, the more the behavior resembles that of light.
  - Long waves for submarines, short waves for handheld devices, very short waves for directed microwave transmission.

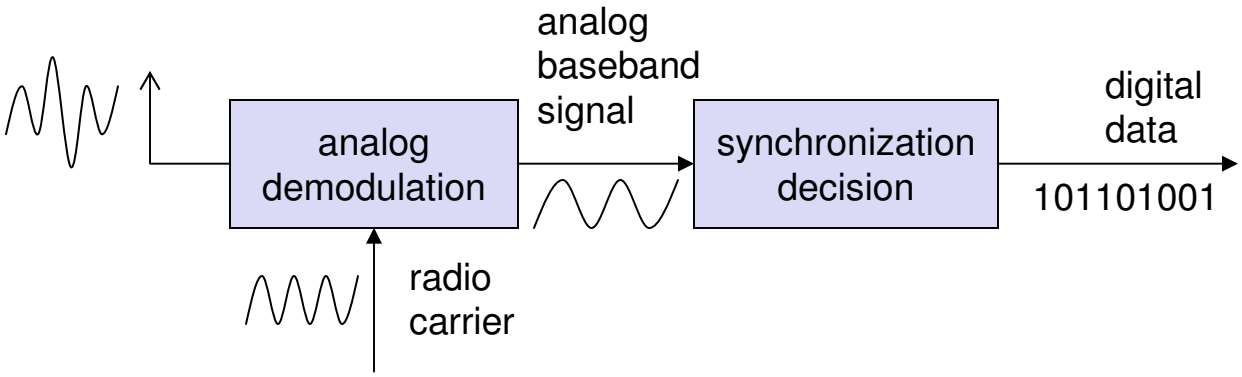
Analog modulation

- Amplitude modulation (AM)
- Frequency modulation (FM)
- Phase modulation (PM)

Modulation



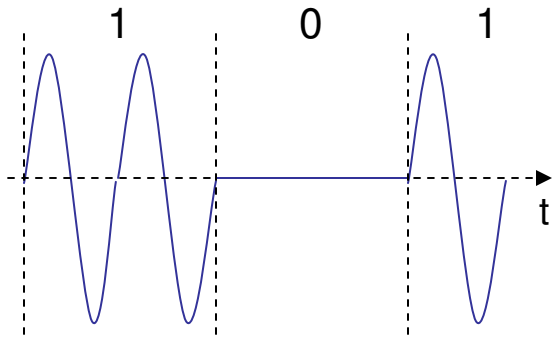
radio transmitter



radio receiver

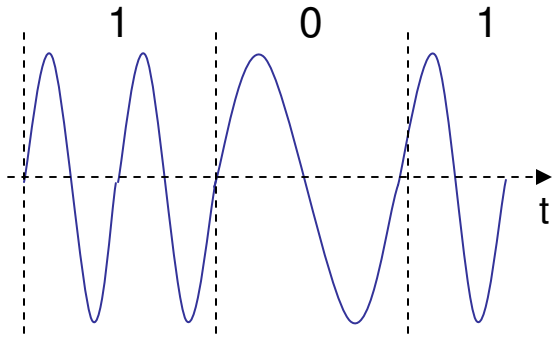
Amplitude shift keying (ASK)

- Use different amplitude to represent 0 and 1.
  - Simple, low bandwidth
  - Sensitive to interference.
    - Multi-path propagation, noise or path loss heavily influence the amplitude.
  - A constant amplitude in wireless environment can not be guaranteed.
- Used in wired optical communication.
  - A light pulse =1, no light =0.



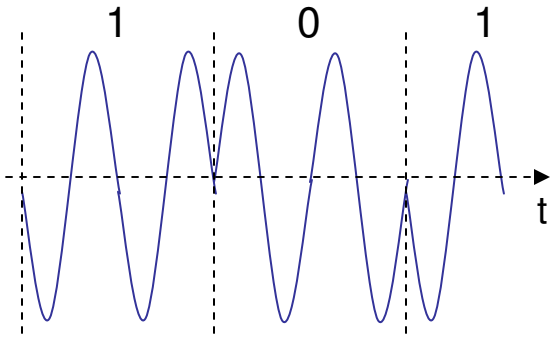
Frequency shift keying (FSK)

- Binary FSK (BFSK)
  - One frequency for 0 and one frequency for 1.
  - needs larger bandwidth
- Avoid discontinuity
  - Discontinuity creates high frequencies as side effects.
  - Continuous phase modulation (CPM) can be used.
- Demodulation:
  - Use two bandpass filters for 2 frequencies.



Phase shift keying (PSK)

- Use shift in phase to represent data.
- Binary PSK (BPSK)
  - Shift the phase by 180.
- Synchronization is important
- More resistant to interference
- More complex transmitters and receivers.



ASK, FSK and PSK

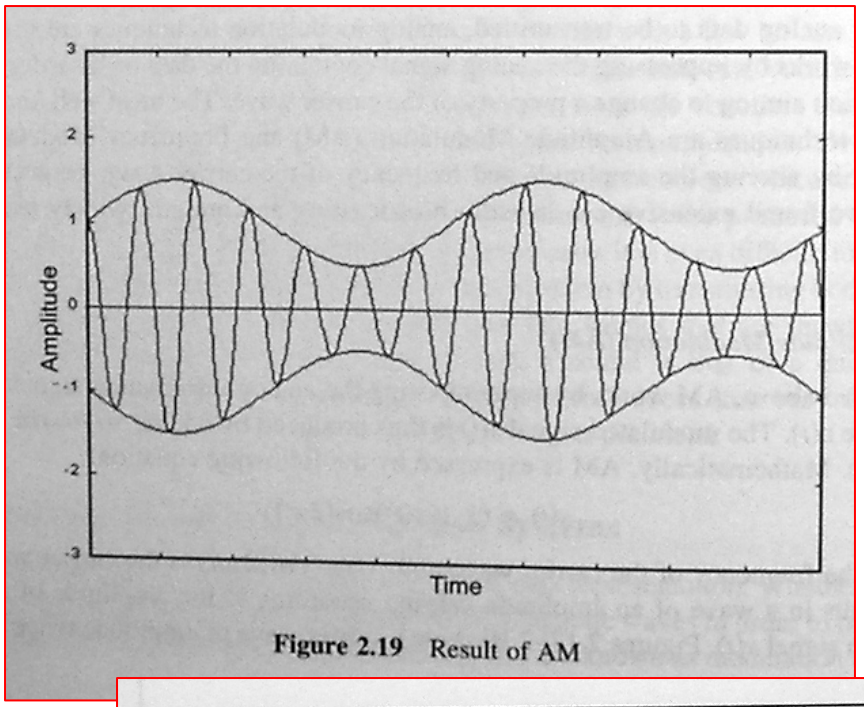


Figure 2.19 Result of AM

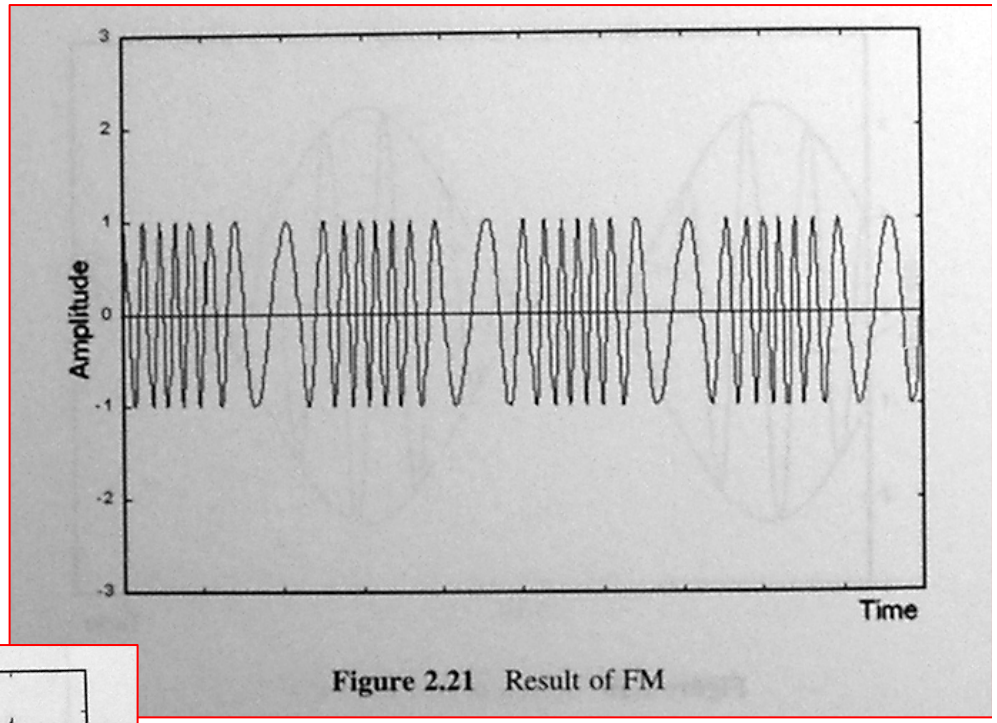


Figure 2.21 Result of FM

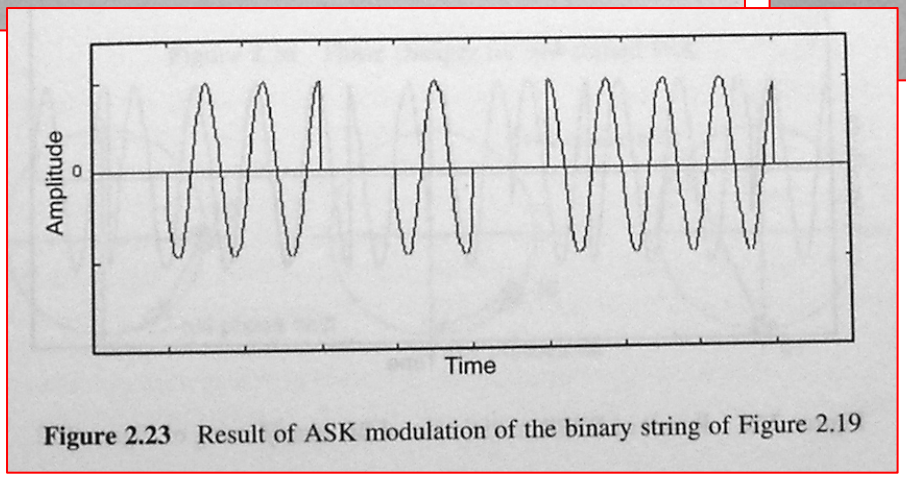


Figure 2.23 Result of ASK modulation of the binary string of Figure 2.19

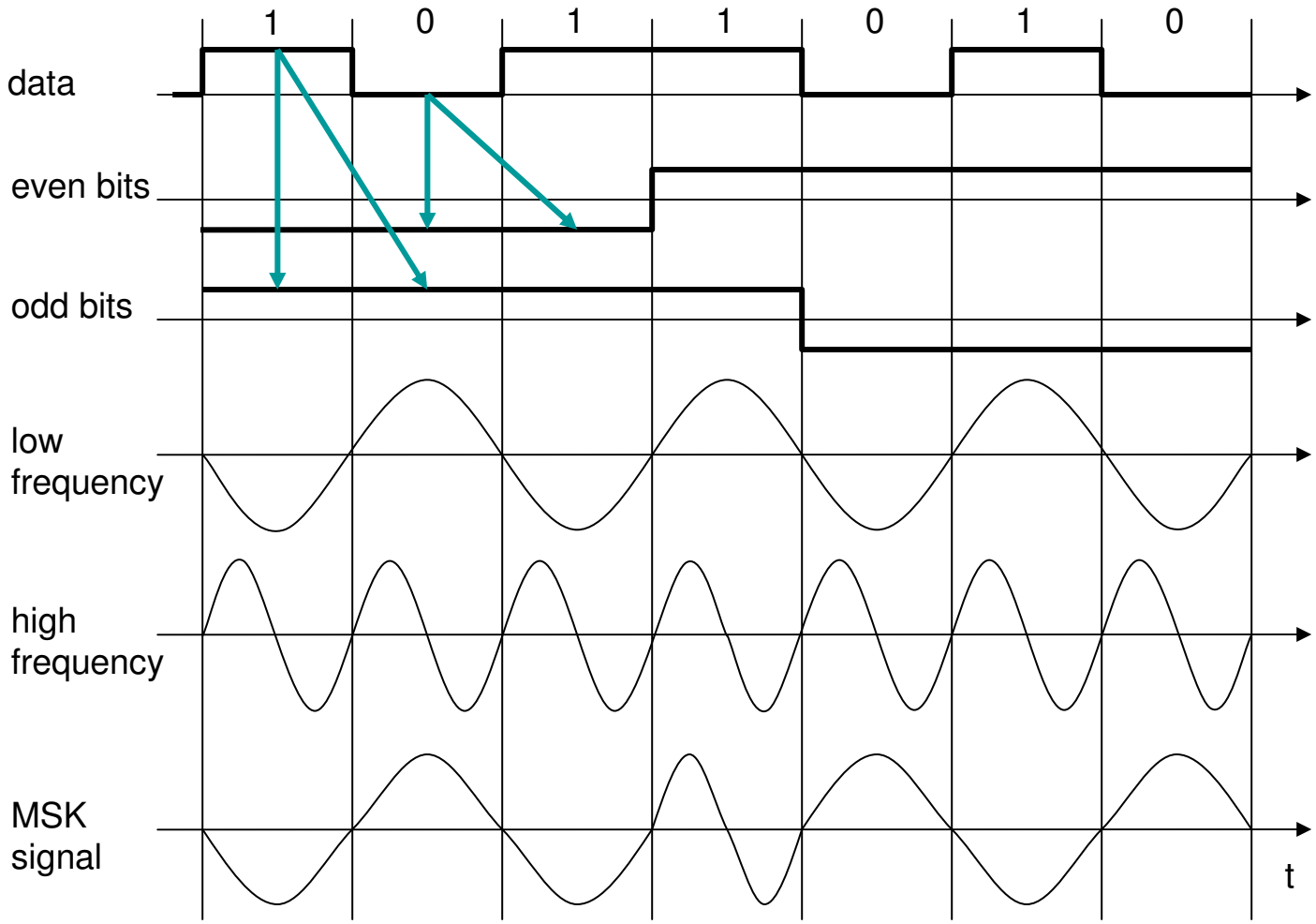
Advanced modulation

- Advanced Frequency Shift Keying
- Advanced phase shift keying
- Quadrature Amplitude Modulation
- Hierarchical Modulation

Advanced Frequency Shift Keying

- Minimum shift keying (MSK)
- Goal: avoid sudden change.
- Two frequencies are used, $f_2 = 2f_1$.
- Separate into even and odd bits.
- The duration of each bit is doubled.
  - A higher frequency is chosen if even and odd bits are equal.
  - The signal is inverted if the odd bit equals 0.
- Exercise: verify that this scheme does not have phase shift.

MSK



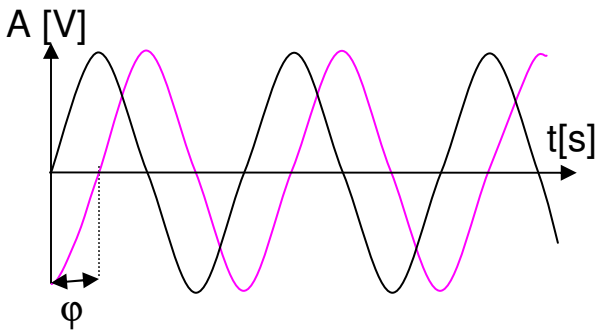
bit	
even	0 1 0 1
odd	0 0 1 1
signal value	h n n h - - + +

h: high frequency
n: low frequency
+: original signal
-: inverted signal

No phase shifts!

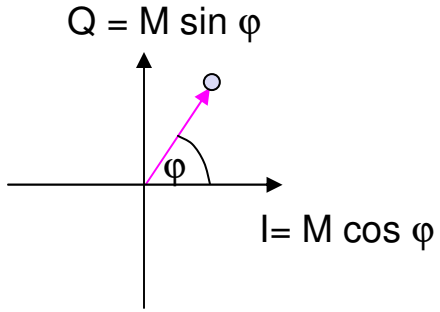
Advanced phase shift keying

- Phase domain: use a vector (or a point) in the plane to represent the signal.
- Length of the vector: amplitude:
- Angle: phase.



Time domain

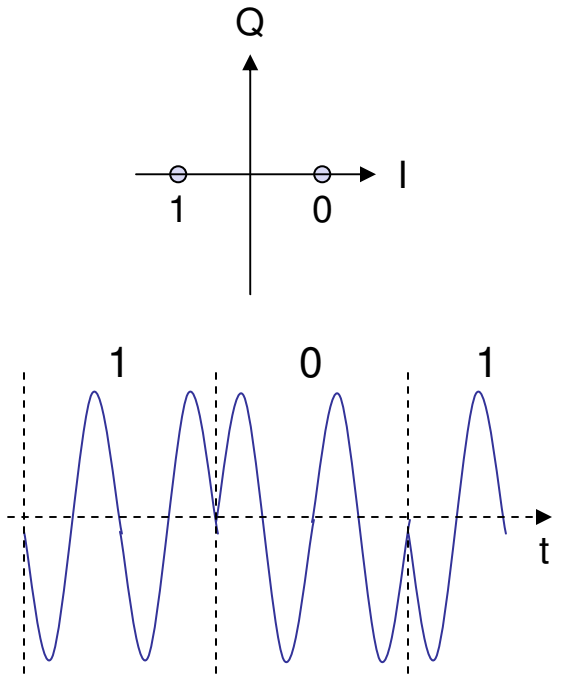
Frequency domain



Phase domain

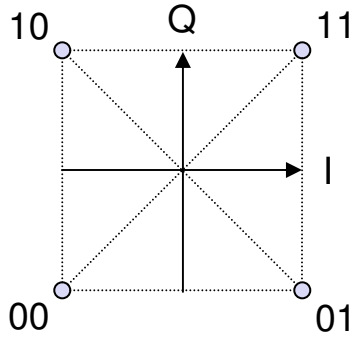
Advanced phase shift keying

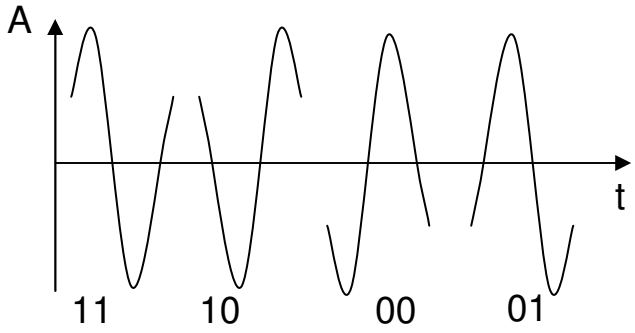
- BPSK (Binary Phase Shift Keying):
  - bit value 0: sine wave
  - bit value 1: inverted sine wave
  - very simple PSK
  - robust, used in satellite systems



QPSK (Quadrature Phase Shift Keying)

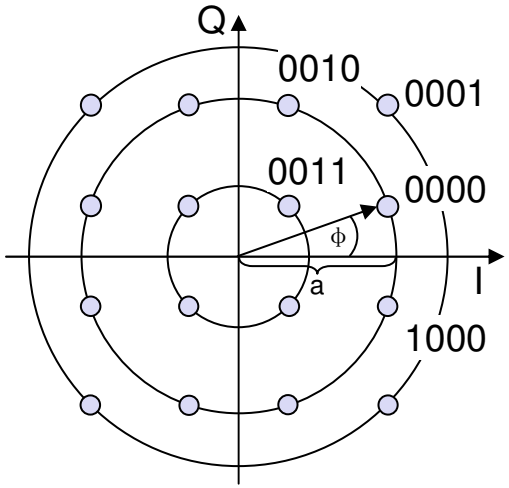
- QPSK (Quadrature Phase Shift Keying):
  - 2 bits coded as one symbol
  - symbol determines shift of sine wave
  - needs less bandwidth compared to BPSK
  - more complex
- Transmitter and receiver are synchronized very often.





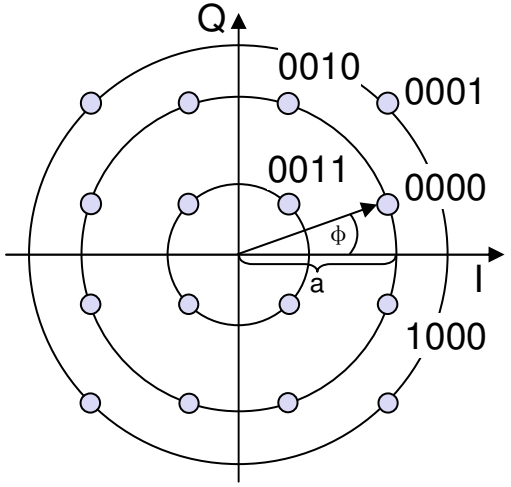
Quadrature Amplitude Modulation

- Quadrature Amplitude Modulation (QAM): combines amplitude and phase modulation
- it is possible to code n bits using one symbol
- 2^n discrete levels, n=2 identical to QPSK
- bit error rate increases with n, but less errors compared to comparable PSK schemes



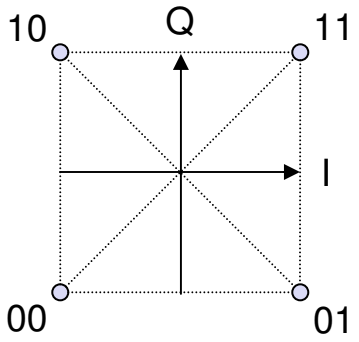
Quadrature Amplitude Modulation

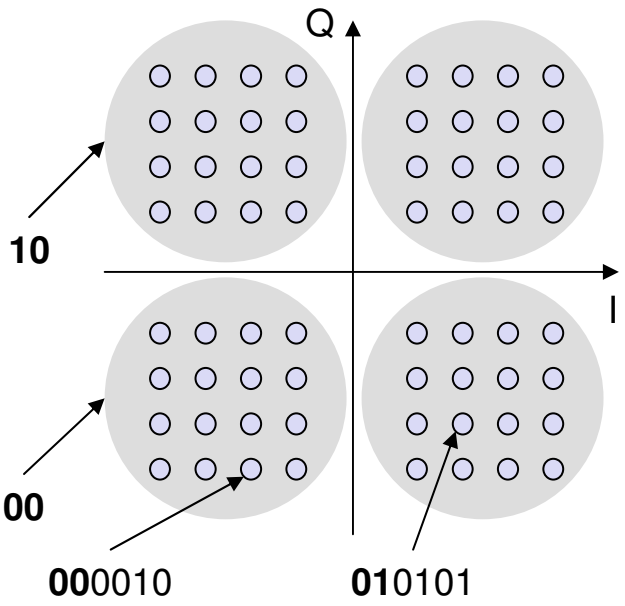
- Example: 16-QAM (4 bits = 1 symbol)
- Symbols 0011 and 0001 have the same phase ϕ, but different amplitude *a*. 0000 and 1000 have different phase, but same amplitude.
- ➔ used in standard 9.6K bit/s modems



Hierarchical Modulation

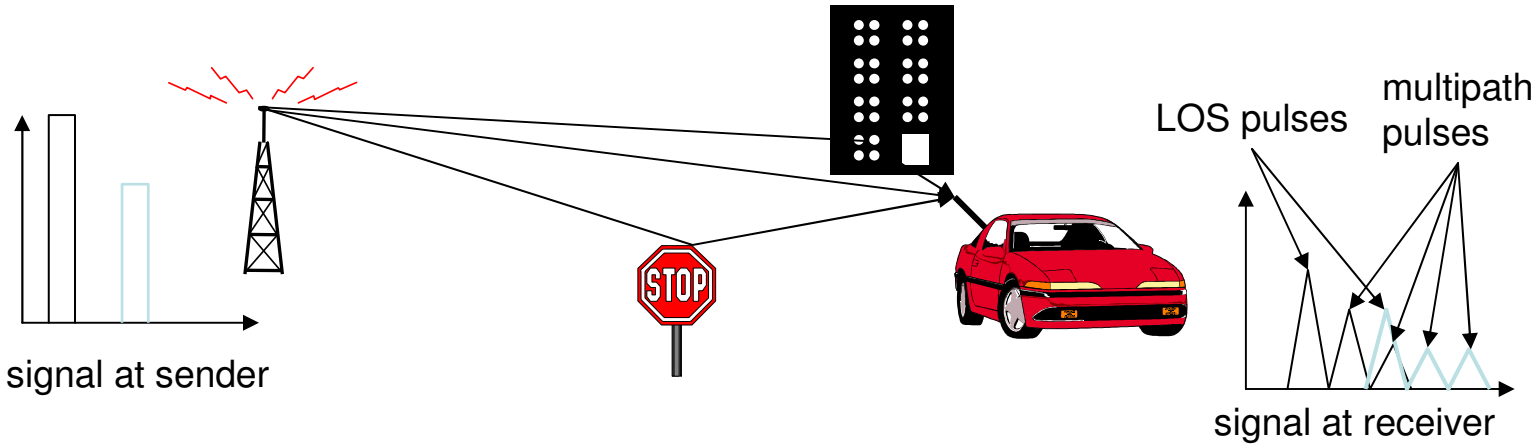
- DVB-T (Digital TV standard) modulates two separate data streams onto a single DVB-T stream.
  - A 64 QAM can code 6 bits per symbol.
  - The 2 most significant bits are used for the QPSK signal.
  - good reception: resolve the entire 64QAM constellation.
  - poor reception: resolve only QPSK portion.
  - Standard resolution data is coded with high priority.
  - High resolution data is coded with low priority.





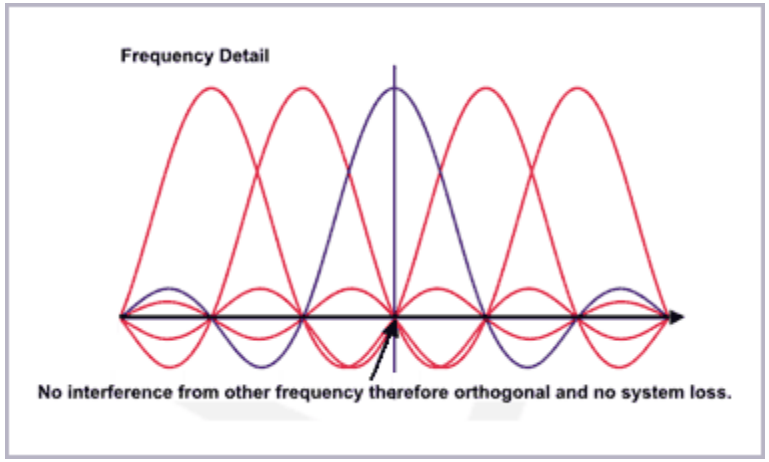
Multi-carrier modulation

- This is used to improve the robustness to multi-path fading and Inter Symbol Interference (ISI).
- ISI: adjacent symbols get messed up, due to multi-path fading.
- Higher data rate are more vulnerable to ISI.



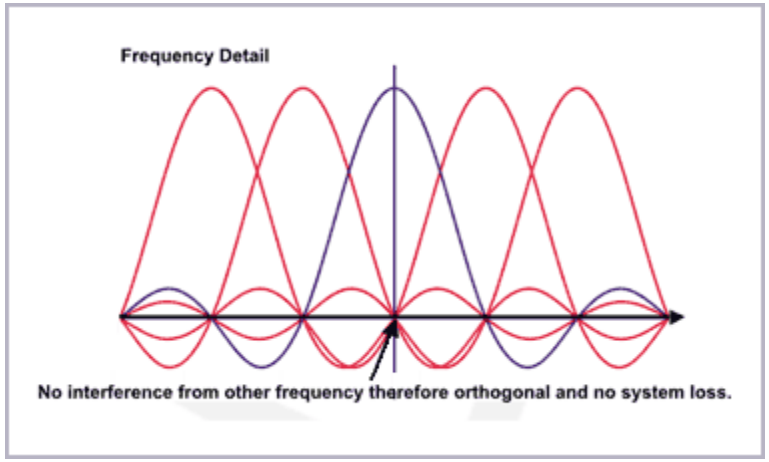
Multi-carrier modulation (MCM)

- Split the high data rate stream to many low data rate streams, each being sent through an independent carrier frequency.
- Orthogonal frequency division multiplexing (OFDM): the maximum of one subcarrier frequency appears exactly at a frequency where all the others subcarriers are zero.



Multi-carrier modulation (MCM)

- One type of frequency division multiplexing.
- Frequency selective fading only influences one subcarriers and not the whole signal.



Summary

- Modulation
  - Amplitude modulation
  - Frequency modulation
  - Phase modulation
- Advanced modulation
  - Advanced frequency shift keying
  - Advanced phase shift keying
  - Quadrature amplitude modulation
  - Multi-carrier modulation
- Cellular systems