University of Pittsburgh

ECE 1150: Computer Networks

Physical Layer – Modulation

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Objectives of This Unit

- Analog signals for analog data and digital data
- Explain why modulation is needed
- Describe the difference between AM, FM, PM
- Analyze ASK, FSK, PSK

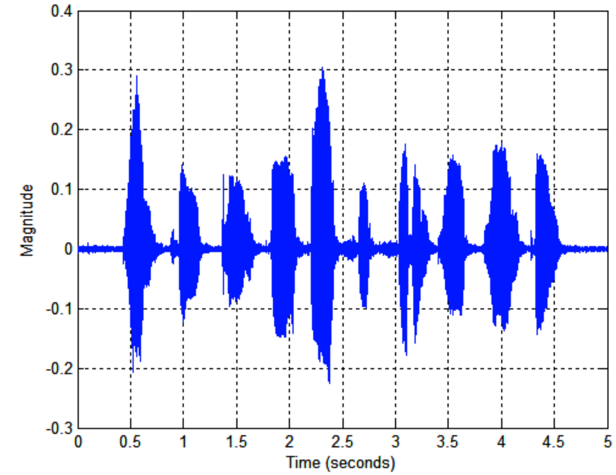
Transmission Approaches

- Two primary transmission approaches
  - Baseband: supports frequency = 0
  - Passband: does not support frequency = 0

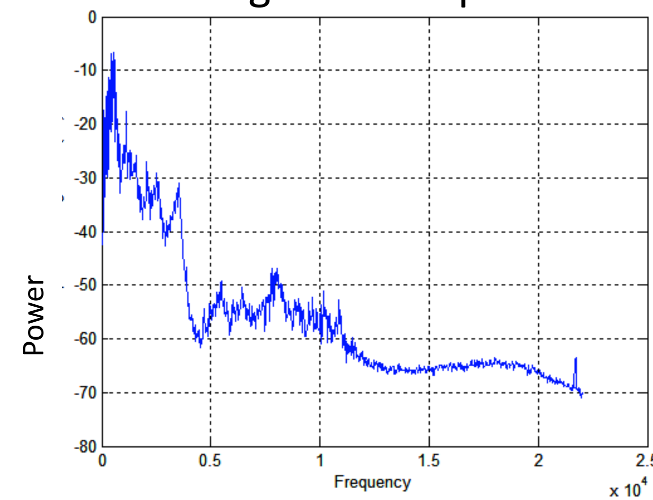
Baseband Systems

- Baseband system: Send signals without frequency shifting (modulation)
  - Baseband analog or digital
    - Voice on copper cable in landlines
    - Ethernet

Audio signal in time domain

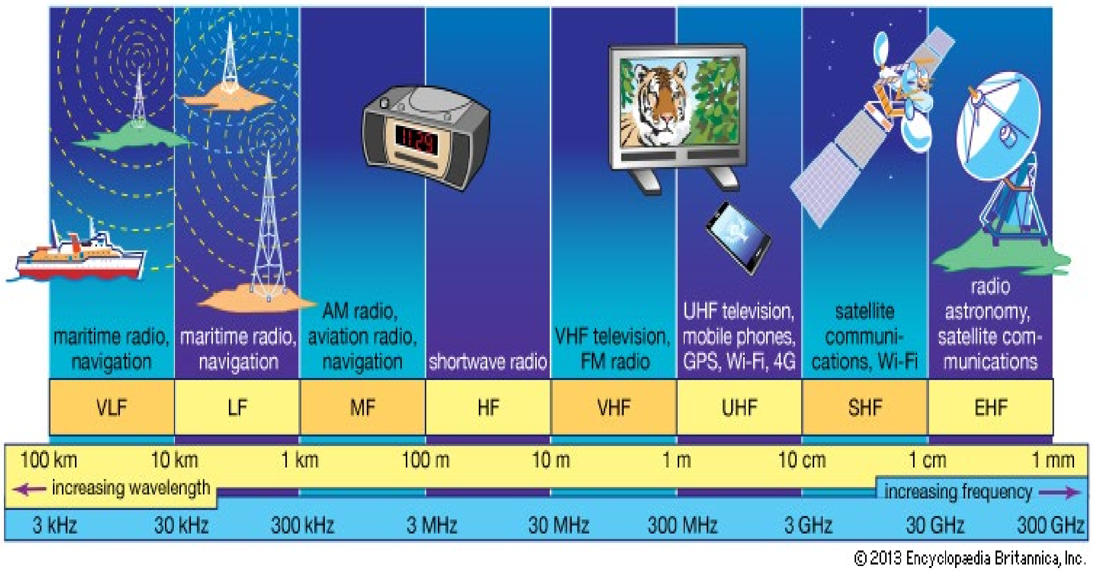


Audio signal in freq. domain



Passband Systems

- Passband system: Shift signal to a higher frequency to transmit it
  - AM/FM radio, Cellular Telephone Signals, Satellite



Passband Transmission

- We need **modulation** to shift the frequency components of signals
- Why?
  - **Medium characteristics**
    - Different medium support different frequencies
  - **Wireless radio wave transmissions**
    - Antenna sizes are smaller as f_c increases
  - **Multiplexing**
    - **Support different applications over the same medium**

Modulation

- **Modulation** is the **process of shifting the frequency** to higher frequency band
  - By carrying the signal over a **carrier**
  - Carrier has **higher frequency** & can be transmitted over medium
- The output (modulated) signal is a **passband analog signal**
  - Analog signals for analog data (e.g. radio broadcast)
  - Analog signals for of digital data (e.g. DSL)
- Receiver demodulates the signal: from analog signal, get back the data

Carrier Signal

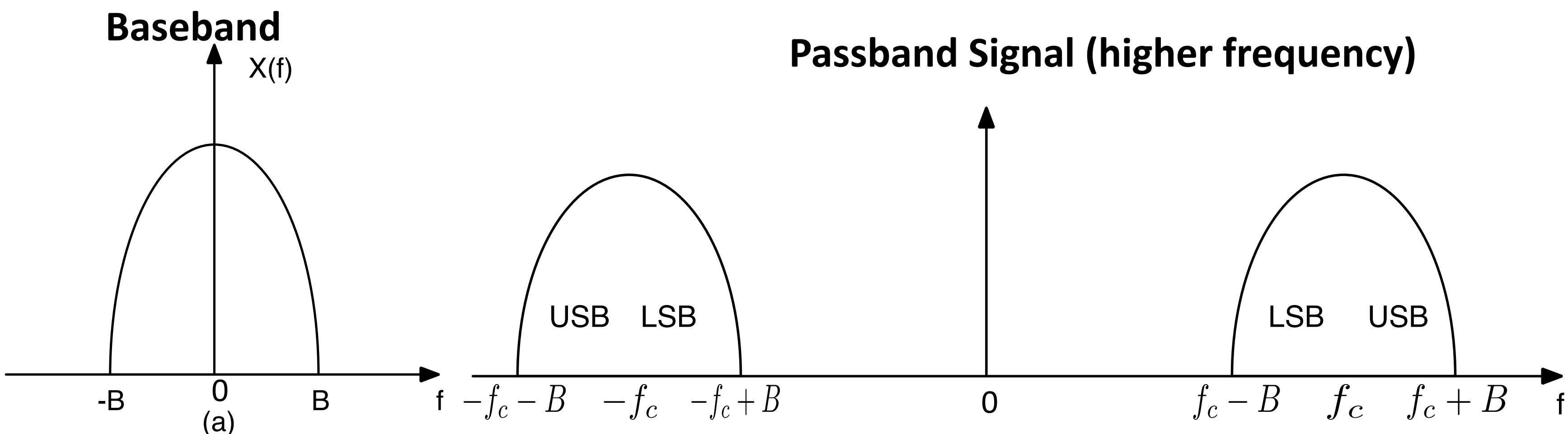
- Carrier signal is a sinusoidal signal

$$A \cos(2\pi f_c t + \varphi)$$

1. **Amplitude (A) :** height of wave
2. **Frequency (f_c):** repetitions per second (Hertz)
   - **Wavelength** proportional to the inverse of frequency
3. **Phase (φ):** wave direction (degrees) or the point at which the wave begins

Modulation

- Impressing data on a carrier wave (sinusoid)
- The original data signal is called the **baseband** signal
- Modulation moves the spectrum (frequency contents) of the signal to a region around f_c
  - We say that the modulated signal is a **passband** signal



LSB = Lower Side Band,
USB= Upper Side Band

Analog & Digital Modulation

- Analog modulation: when the data is analog
- Digital modulation: when the data is digital
- In both cases, the output of the modulation is **analog** passpand signal

Analog Modulation

- Analog Modulation: means that the data to be modulated is analog (e.g radio broadcast signal)

- **Modulation**: The amplitude, frequency or phase of the carrier changes as a function of the baseband analog data

Analog Modulation Schemes

- Amplitude modulation (AM)
  - Amplitude of the signal is changed based on the data
  - Low bandwidth requirement
  - Susceptible to noise
- Frequency modulation (FM)
  - Amplitude is fixed
  - Frequency of the carrier wave varies according to the data
  - High bandwidth requirement
  - Insensitive to noise
- Phase modulation (PM)
  - Phase varies according to the data, can achieve low BER
  - Like frequency modulation
  - Receivers more expensive

Example: Amplitude Modulation (1/2)

- Let the analog data be m (t)
- Let carrier signal be c(t) = $\cos(2\pi f_c t)$
- The modulated signal is:

  $m(t)\,c(t) = m\,(t)\cos(2\pi f_c t)$

Note that the **amplitude** of the **modulated signal** is function of the analog data (message)

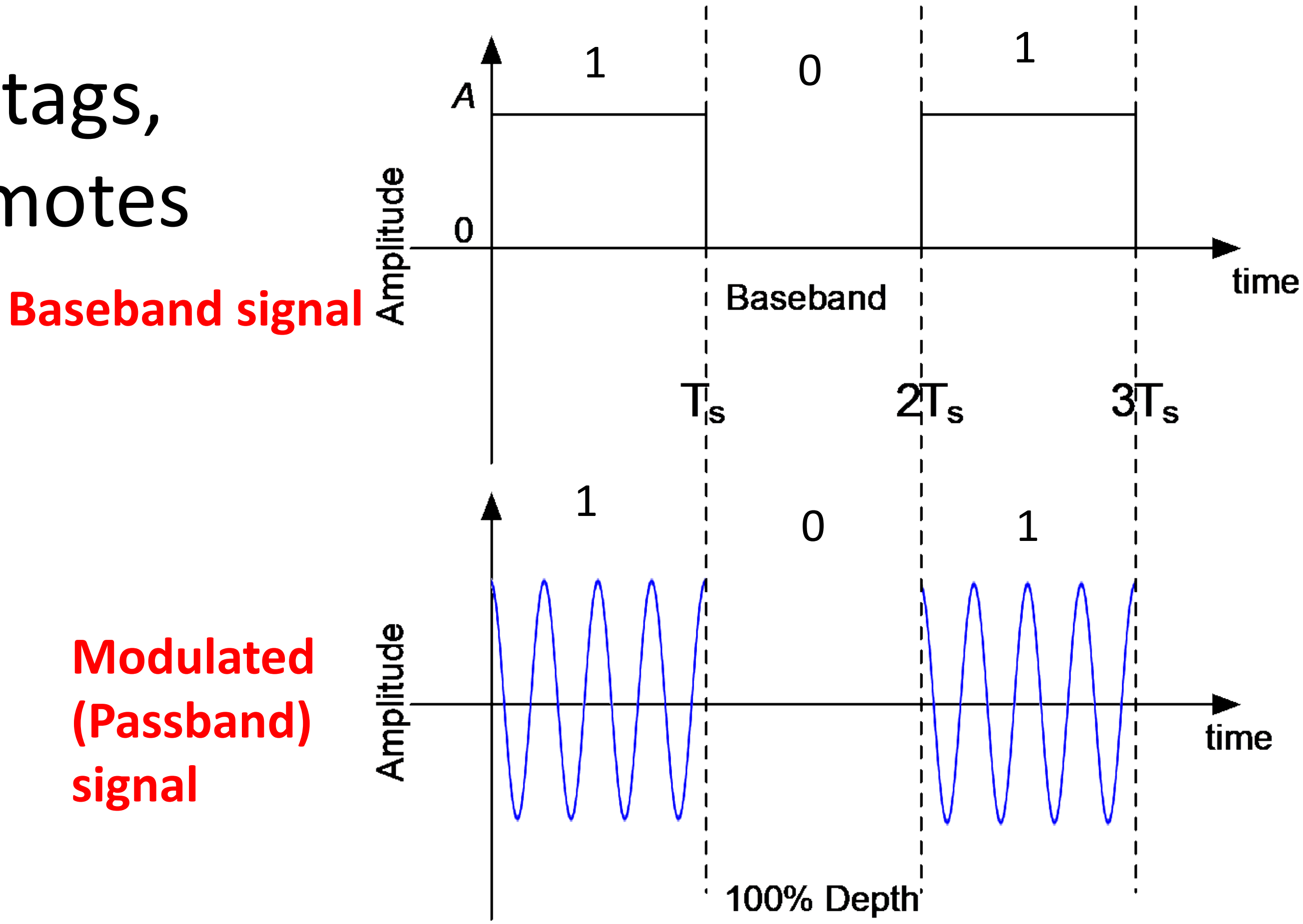
– Therefore, this is **amplitude modulation**

Digital Modulation

- Analog transmission of a digital data (bits)
- **Modem** (modulation/demodulation): Devices used to transmit a **digital data over an analog channel**
- **<u>Digital Modulation Schemes:</u>**
  - **Amplitude Shift Keying (ASK)**
    - The carrier's amplitude changes following the digital baseband data
  - **Frequency Shift Keying (FSK)**
    - The carrier's frequency changes following the digital baseband data
  - **Phase Shift Keying (PSK)**
    - The carrier's phase changes following the digital baseband data
- Output of modulation at transmitter is a passband signal

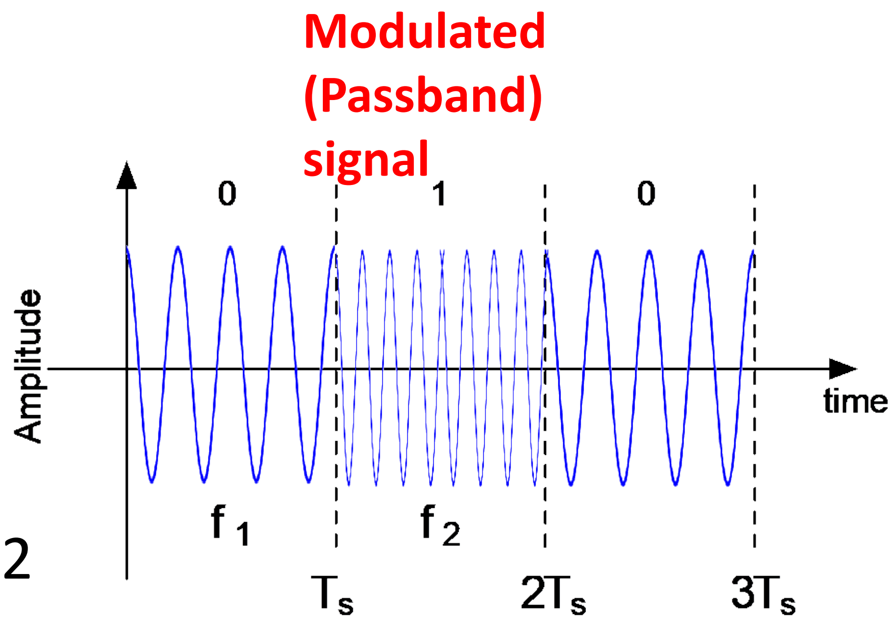
Binary ASK or On-Off Keying

- Today: RF-ID tags, television remotes



BFSK: Binary Frequency Shift Keying

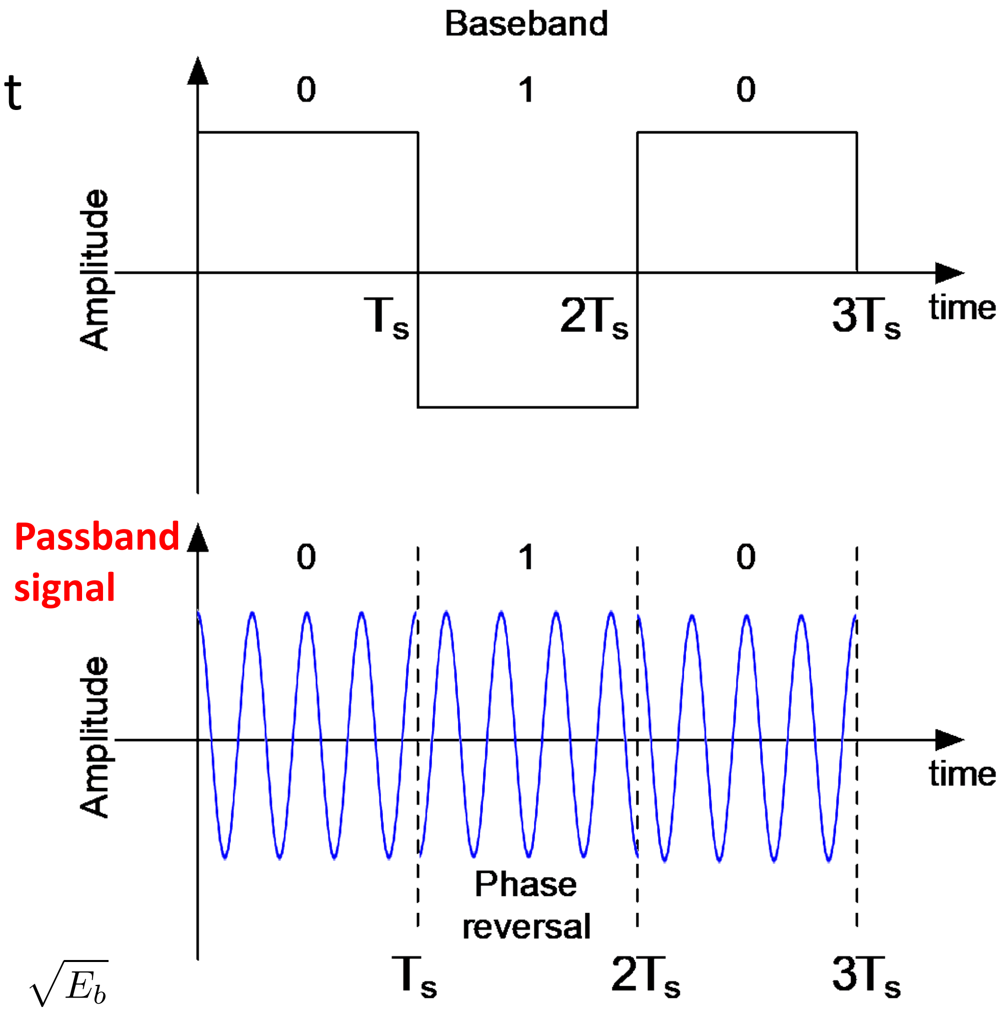
- Binary means: ‘1’ or ‘0’
- FSK means: frequency change based on the data
  - Use two different frequencies to represent “0” and “1”

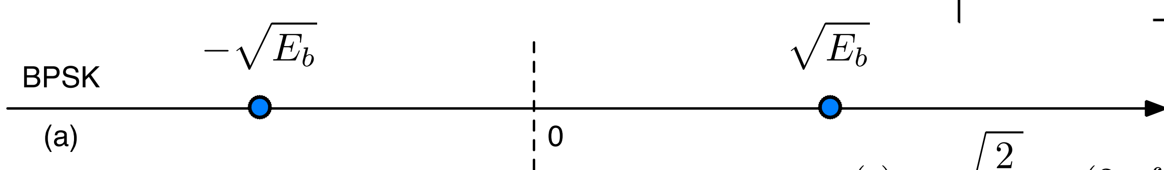


- Signals (symbols) are given by:
  - $s_i(t)=A\cos(2\pi f_i t)$, $0 \le t \le T_s$ for $i=1,2$
  - Send $s_1(t)$ if the bit is zero, send $s_2(t)$ if the bit is one
- Bluetooth

BPSK: Binary Phase Shift Keying

- PSK means: Use two different phases to represent “0” and “1”
- Signals are given by:
  - $s_i(t)=A\cos(2\pi f_c t+\varphi_i)$, $0\le t\le T_s$ for i=1,2
  - Send $s_1(t)$ if the bit is zero, send $s_2(t)$ if the bit is one
- It is common to assume that $\varphi_1 = 0$ and $\varphi_2 = \pi$





$$\varphi_1(t) = \sqrt{\frac{2}{T}}\cos(2\pi f_c t)$$

Digital Modulation

- **Output of modulation are symbols**
  - Each symbol is continuous-time signals lasting for T_s seconds ($s_i(t)$ in previous slide)
  - Symbol rate = $1/T_s$
- **Binary modulation** (binary ASK, BPSK, BPSK)**:** **One bit per symbol**
  - **Symbol rate = bit rate** = $1/T_s$
- **M-Ary modulation: *k* bits per symbol**

Question

Q_BPSK

A BPSK signal has rate of 10Ksymbols/sec. What is the bit rate?

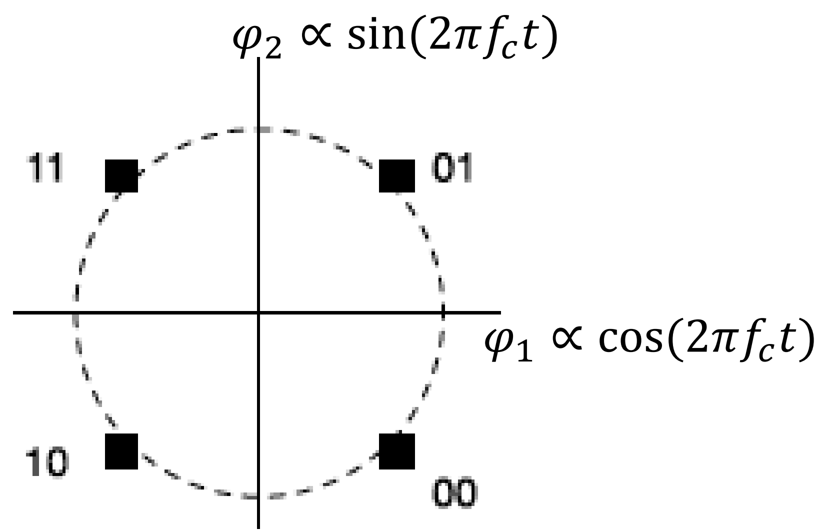
A	10kbps
B	20kbps
C	None of the above

M-Ary Modulation

- Instead of modulating bit by bit, represent multiple bits with one symbol
- **M different symbols**, each represents **$K = \log_2(M)$** bits
  - Number of different symbols is $2^k = M$
- Note in binary case, we have $M = 2$, and $K = \log_2(2) = 1$
  - Means one bit for each symbol
- Symbol rate is = bit rate / K
  - Symbol rate is also called **baud**

M-Ary Modulation: QPSK

- Quadrature phase Shift Keying (QPSK) uses **4 symbols with** **4 different phases**
  - Each symbol carries 2 bits

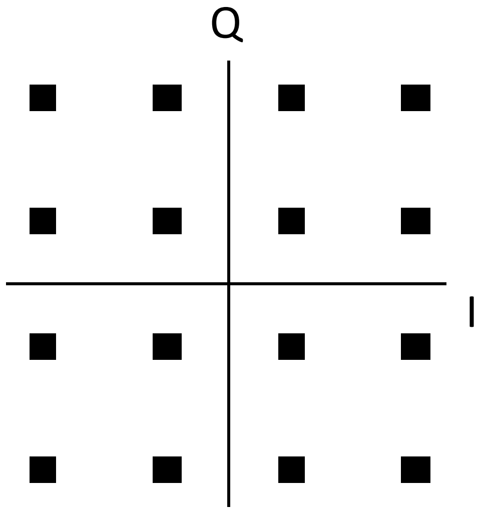


Graphical representation

cos(2 pit fc t – theta1) = cos (2pi fc t) cos (theta1) + sin(2 pi fc t) sin (theta 1)

M-Ary Modulation: QAM

- Quadrature Amplitude Modulation (**QAM**) uses both amplitude and phase of a carrier to encode information
  - Example: 16-QAM, means you have 16 different symbols
    - Each symbol represents $\log_2(16) = 4$ bits



- QPSK and QAM are common in wireless networks
  - Cable television, modems, cellular, WiFi

Question

Q_QAM

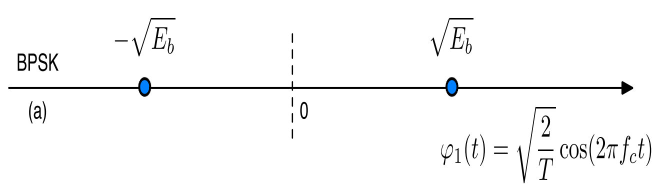
The bit rate of 16Mbps. The bits are modulated with 16-QAM. What is the baud rate (symbol rate)

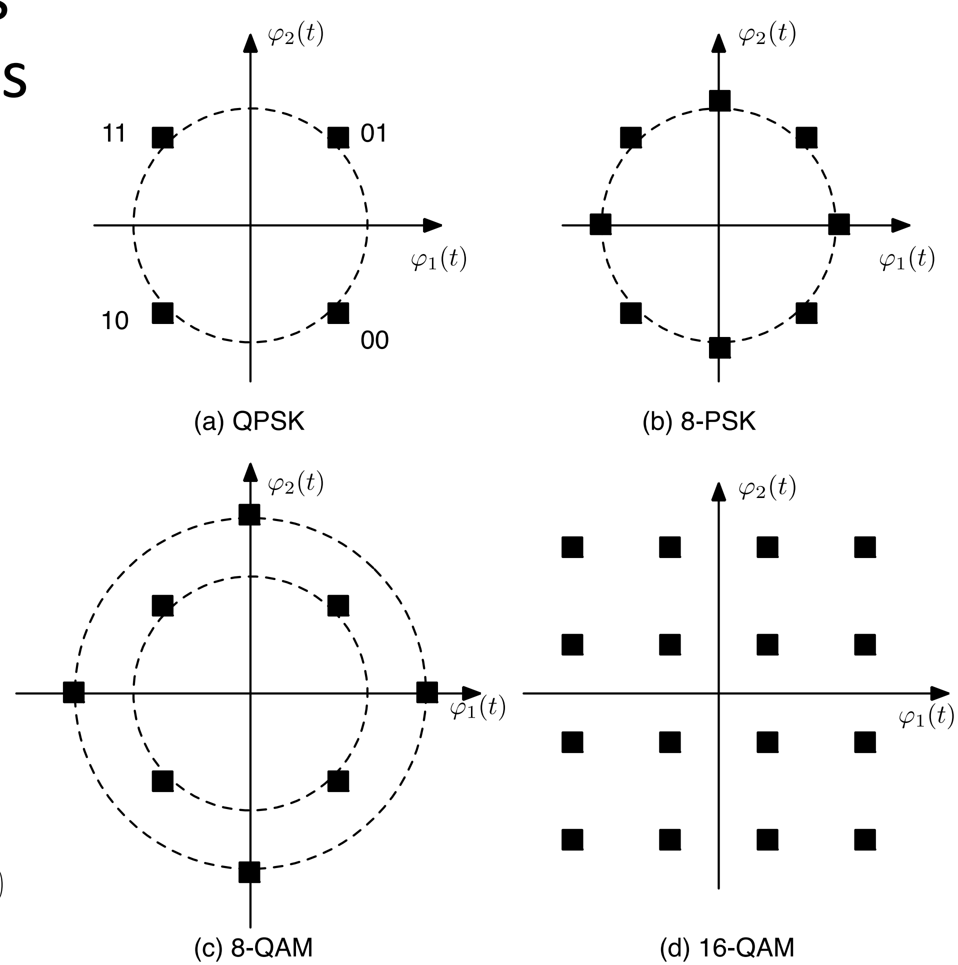
A	16Mbps
B	8Mbps
C	4Mbps

Signal Constellation

- Constellation: graphical representation of signals used for communications
- Shows the “distance” between signals
  - Larger the distance, easier it is for the receiver to distinguish between the signals

$\varphi_1(t) \propto \cos(2\pi f_c t)$
$\varphi_2(t) \propto \sin(2\pi f_c t)$





Key Takeaways

- Modulation shifts signal to higher frequency band
- Analog modulation: AM, FM, PM
- Digital modulation: ASK, FSK, PSK, QAM..