EE450 Discussion #6

- Shannon's Theorem
- Modulations
- Multiplexing

Shannon's Theorem

- $C = B \log_2(1 + SNR)$
- Theoretical Maximum Capacity that can be obtained on a line
- Sets an Upper Bound on the capacity given the conditions
  - Used for Calculating the
    - Signal to Noise Ratio – Given the Bandwidth and capacity of the channel
    - Bandwidth - Given the SNR and Channel Capacity
    - Capacity - Given the SNR and the Bandwidth

Problem #1

- What SNR is needed to put a T-1 carrier on a 50 khz line?
  - What do we know?
    - T-1 Capacity = 1.544 Mbps
    - Bandwidth = 50 KHz
  - Move them around and Solve:
    - 1,544,000 = 50,000 log 2 (1+SNR)
    - 2^30.88 –1 = SNR

Continued

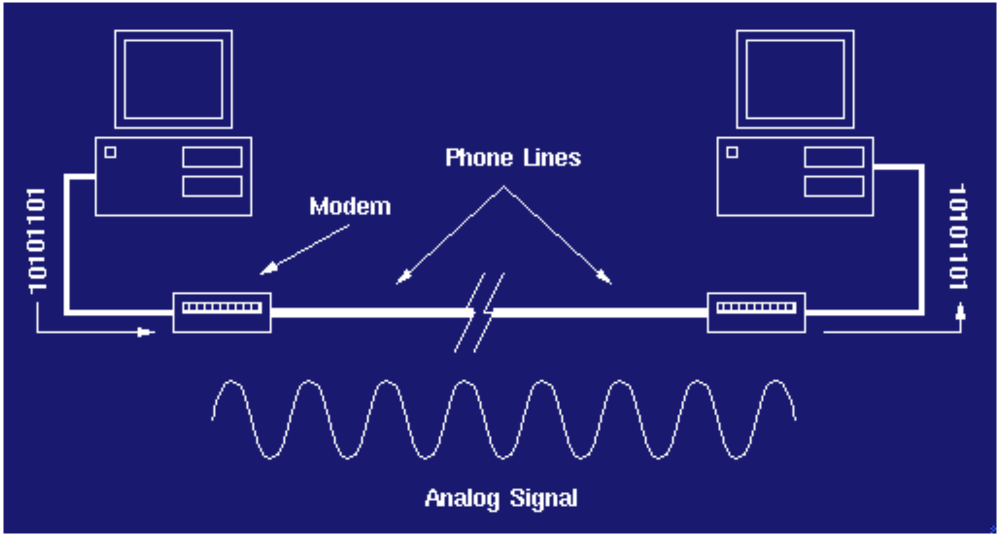
- So SNR = 1976087931
  - SNR is typically measured in DB
    - Use SNR dB = 10 $\log_{10}$ (SNR)
  - In this case
    - SNR dB = 10 $\log_{10}$ (1976087931)
    - SNR aprox. 92.9 dB
  - However you must NOT plug SNR into Shannon's theorem in dB format

Problem #2

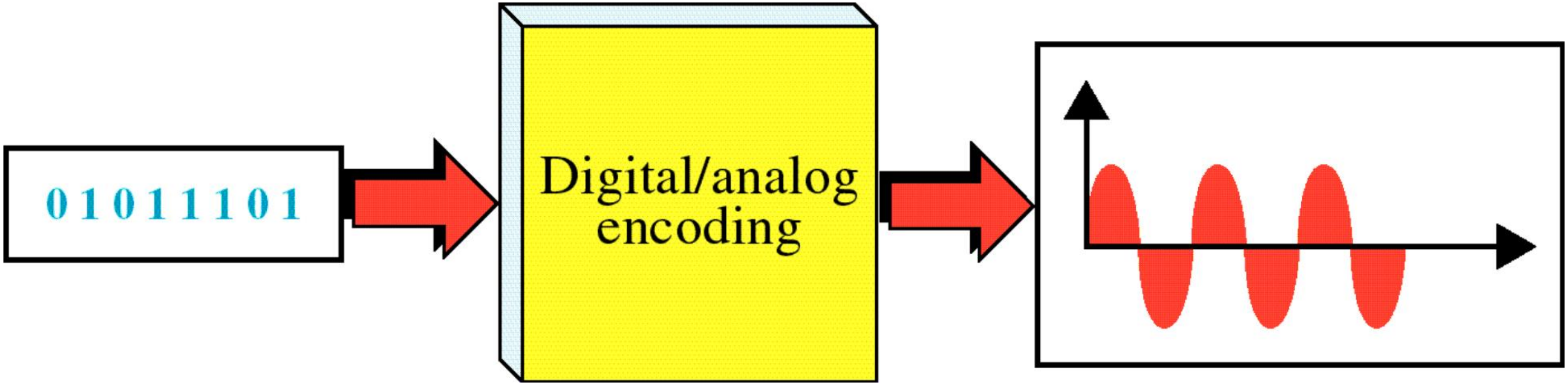
- Calculate the maximum rate supported by a telephone line with BW of 4 KHz. When the signal is 10 volts, the noise is 5 milivolts.
- SNR=Signal power/Noise Power
- Power is proportional to square of the voltage
- $S/N = (10^2)/(0.005^2) = 4000000$
- $B = 4000$ Hz
- $C = B \log_2 (1+S/N)$
  - Reminder: $\log_2 x = \ln x / \ln 2$
- $C = 4000 \log_2 (1+4000000)= 87726$ bps

Review on Modems

- Modem Stands for
  - MOdulator / DEModulator
- Uses Sine wave As the carrier Signal



Digital to Analog Encoding

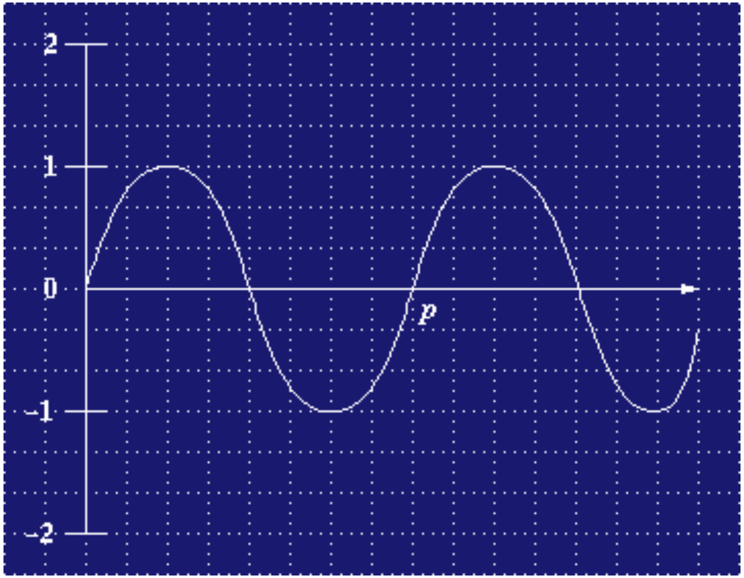


Modulation

- Need to Encode Digital Data in an Analog Signal
- In modem transmission we use different techniques for modulation
  - Amplitude Modulation
  - Frequency Modulation
  - Phase Shift

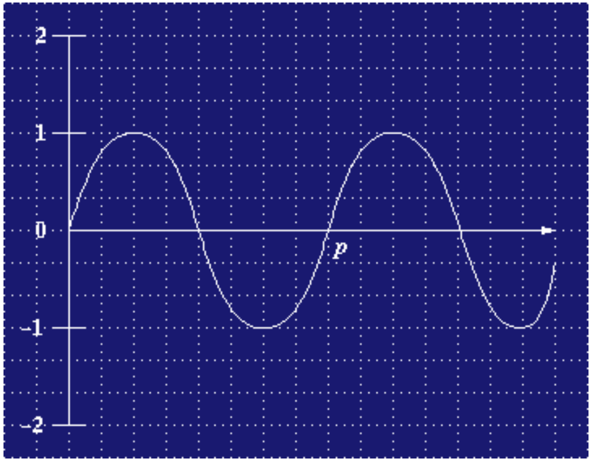
Amplitude Modulation

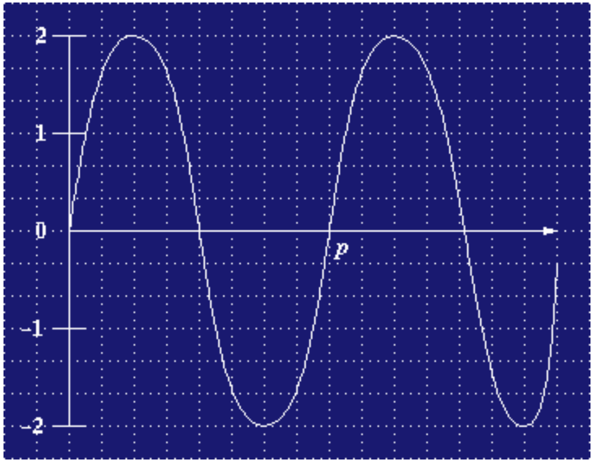
- Varies the Amplitude of the Signal



Amplitude Modulation

- Same Signal Greater Amplitude

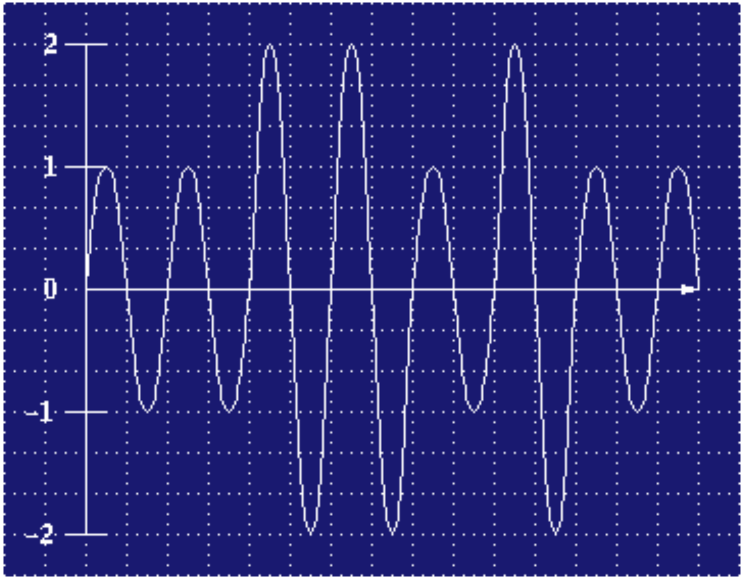




Amplitude = 1

Amplitude = 2

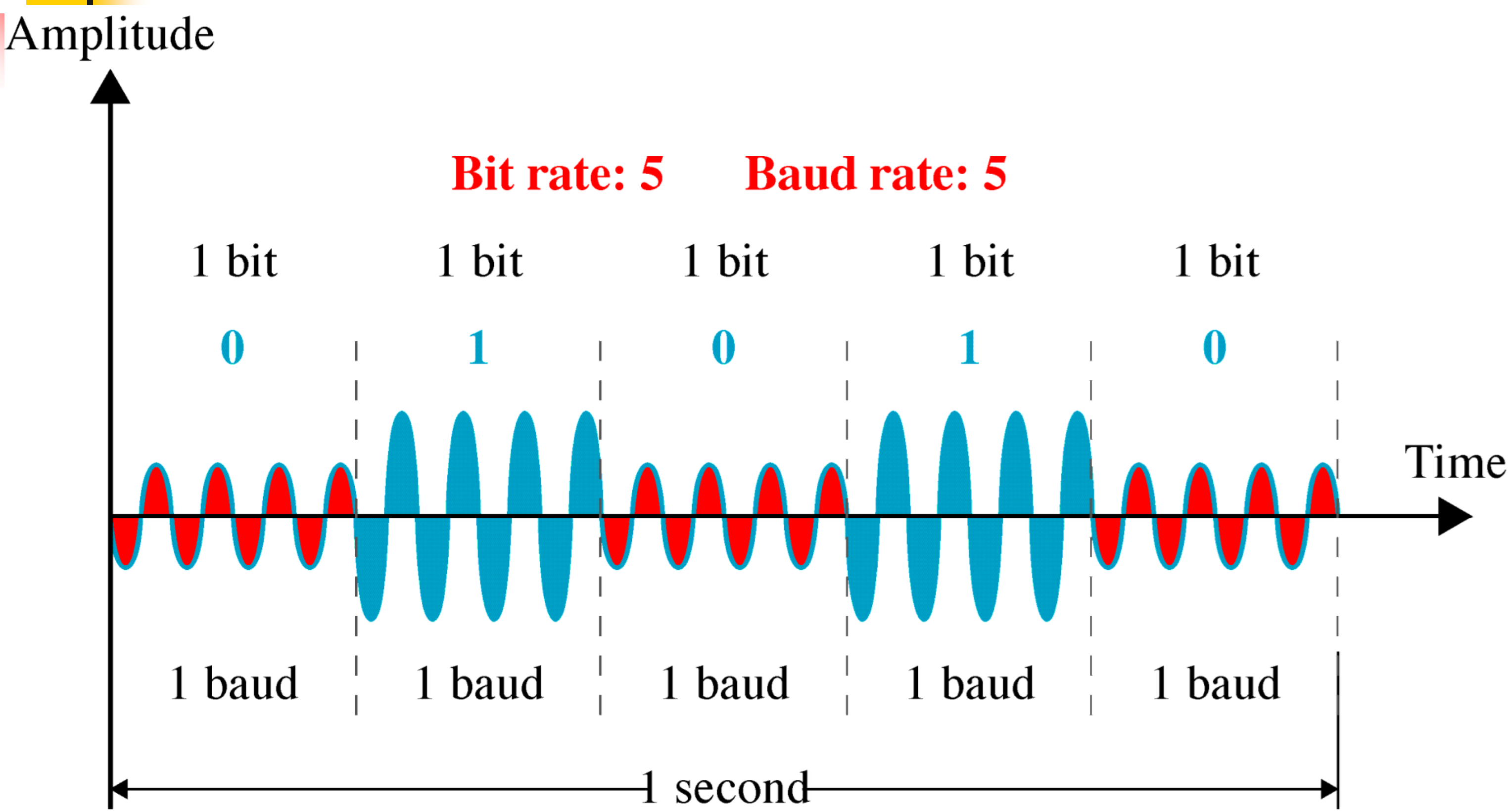
Amplitude Modulation



- Amplitude 2 = 1
- Amplitude 1 = 0

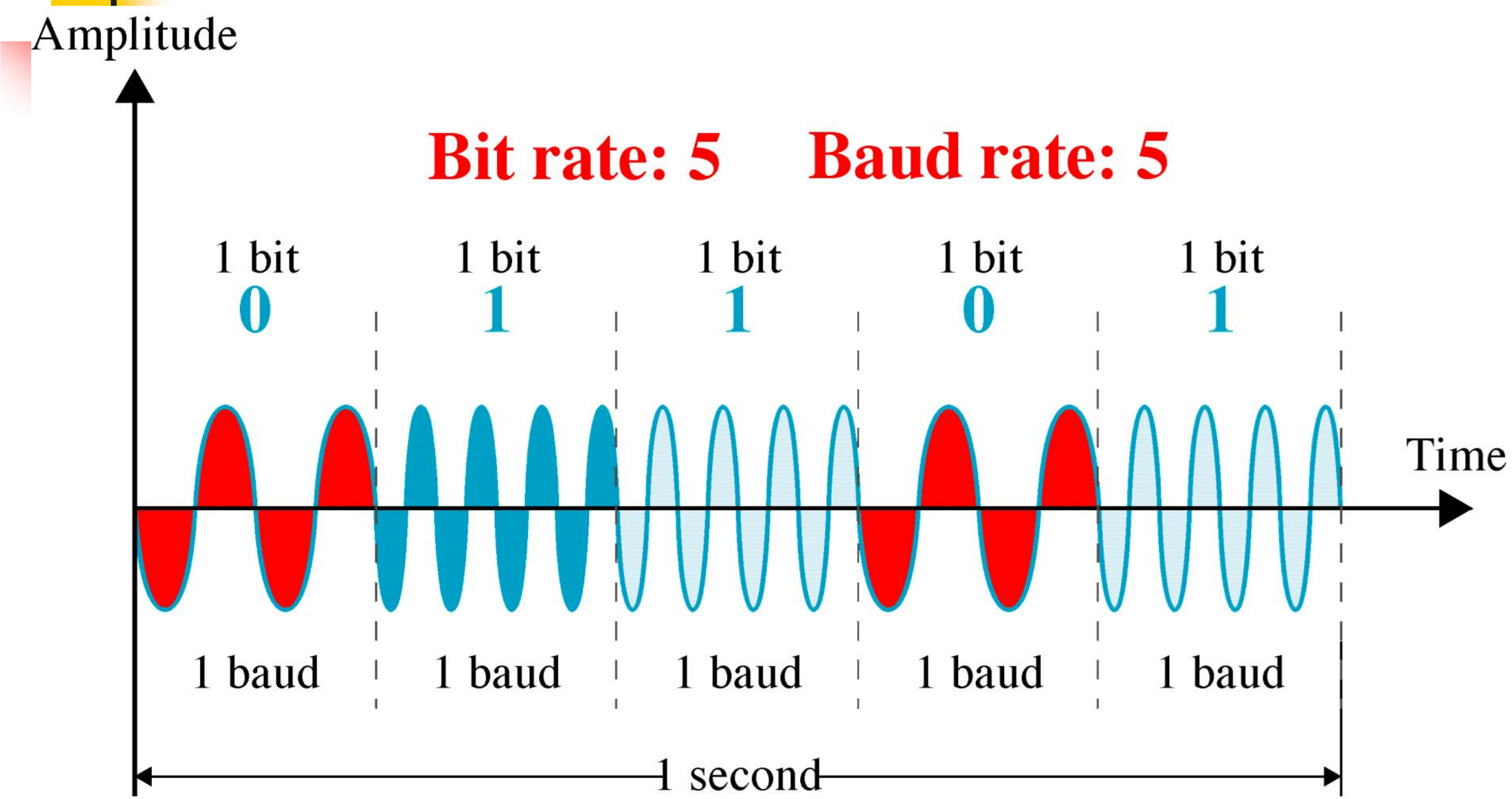
- This signal Represents:
  - 0011010

ASK



Amplitude
Bit rate: 5
Baud rate: 5
1 bit
1 bit
1 bit
1 bit
1 bit
0
1
0
1
0
Time
1 baud
1 baud
1 baud
1 baud
1 baud
1 second

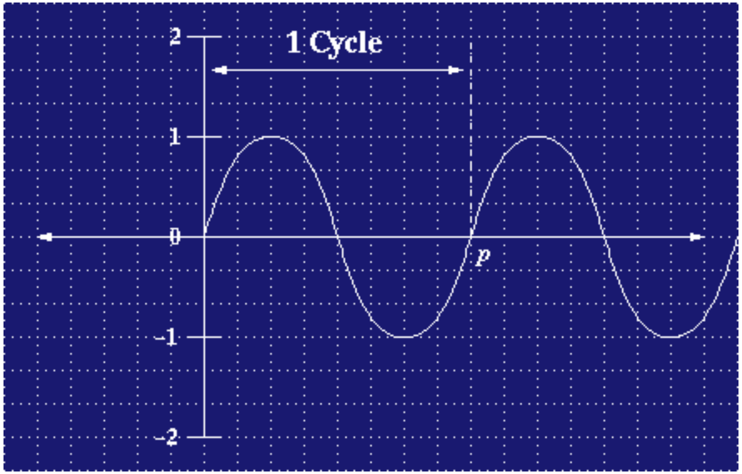
FSK



Amplitude
Bit rate: 5
Baud rate: 5
1 bit
0
1 bit
1
1 bit
1
1 bit
0
1 bit
1
Time
1 baud
1 baud
1 baud
1 baud
1 baud
1 second

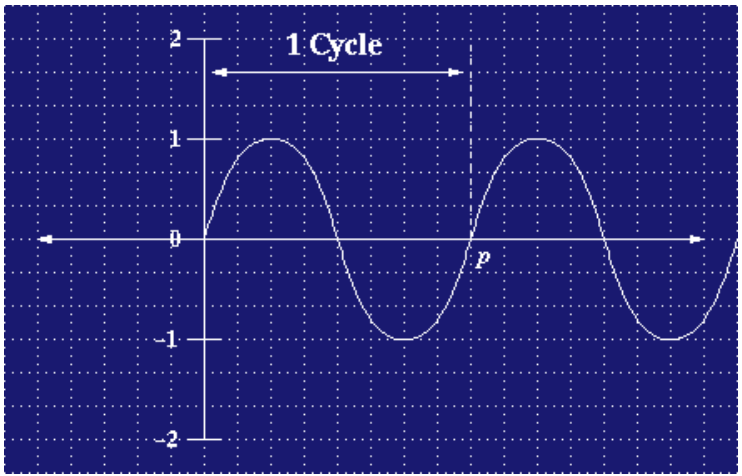
Phase-Shift Modulation

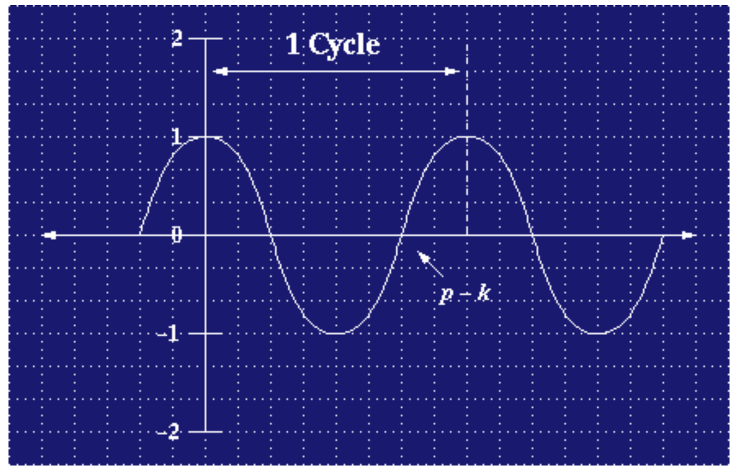
- Start with our normal sine wave
- The sine wave has a period of P
  - P may be denoted as T instead in the equations



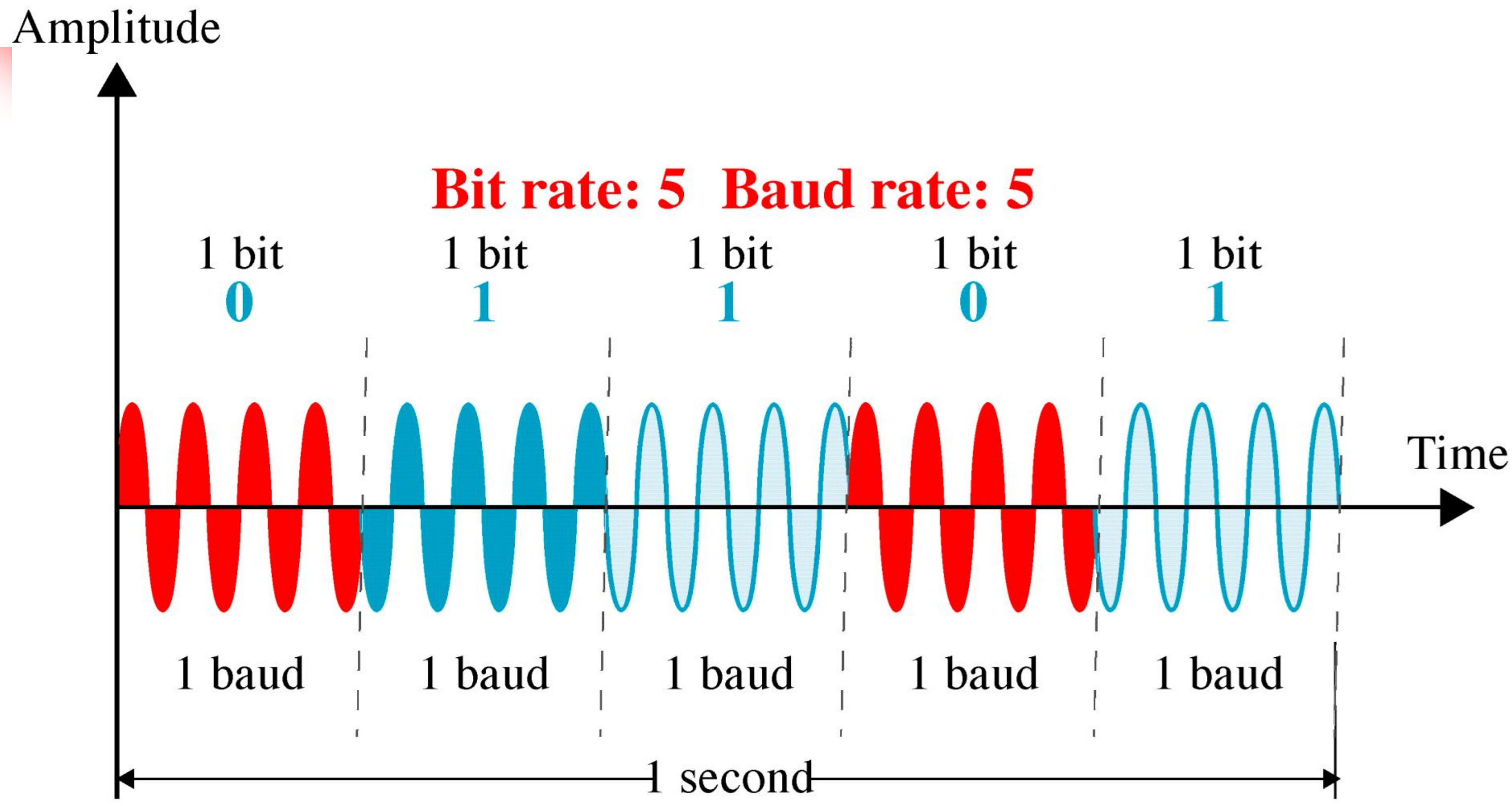
Phase-Shift Modulation

- Shift the Phase of the Sine Wave
- Shifted diagram shows that the cycle starting at 1 vs. starting at 0





PSK

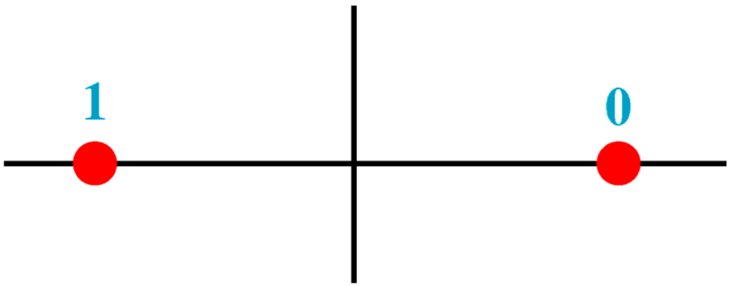


Amplitude
Bit rate: 5 Baud rate: 5
1 bit
0
1 bit
1
1 bit
1
1 bit
0
1 bit
1
Time
1 baud
1 baud
1 baud
1 baud
1 baud
1 second

PSK Constellation

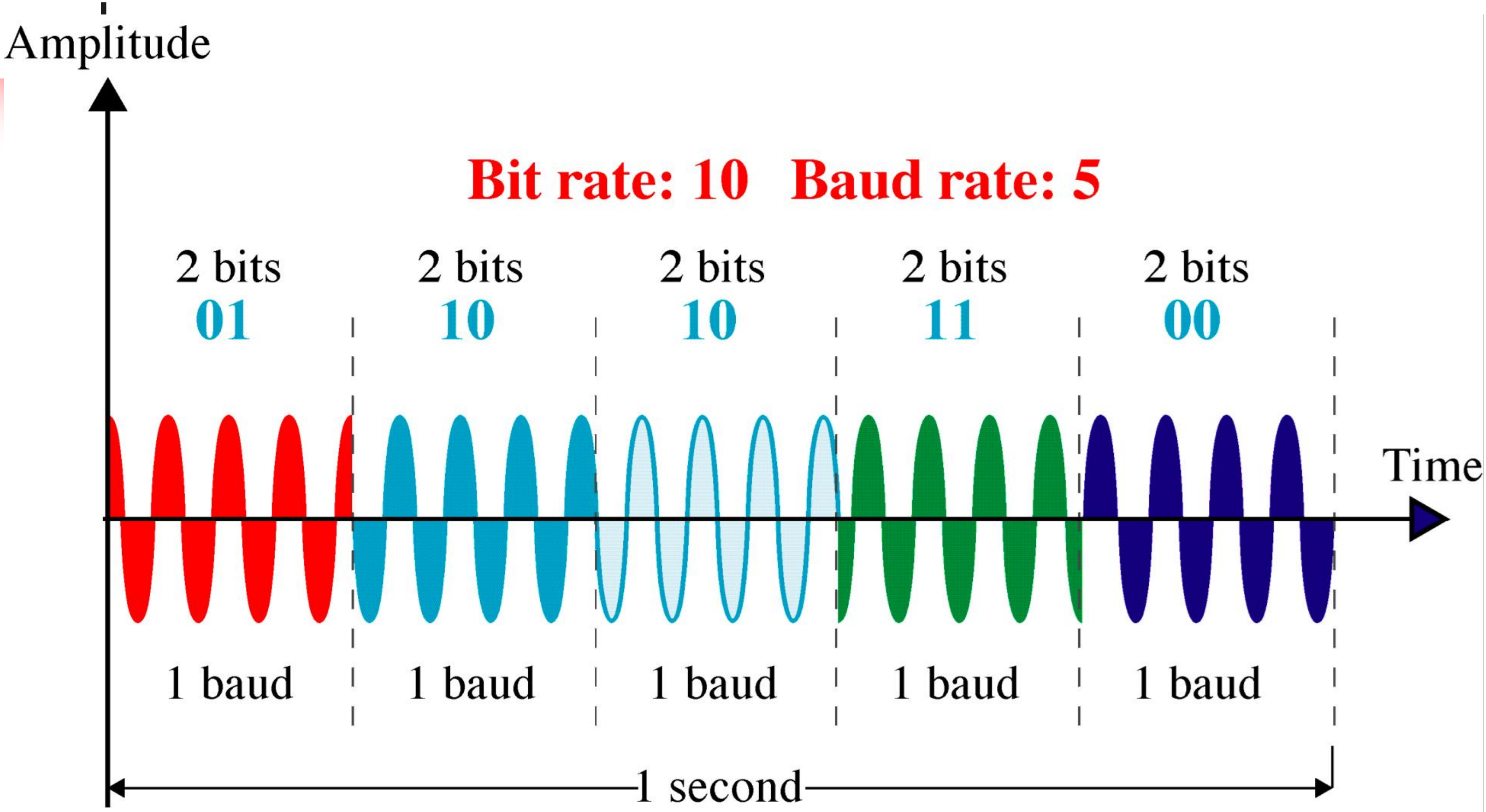
Bit	Phase
0	0
1	180

Bits



Constellation diagram

4-PSK

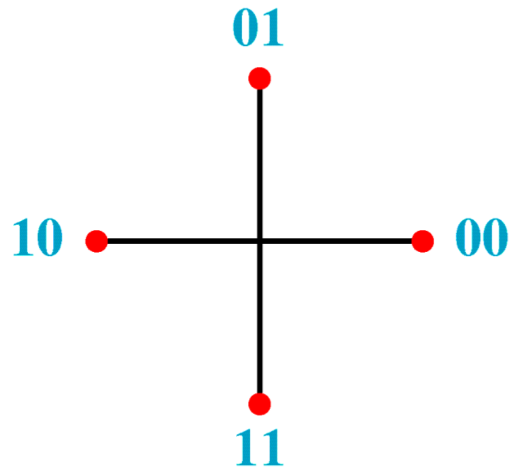


Amplitude
Bit rate: 10 Baud rate: 5
2 bits
01
2 bits
10
2 bits
10
2 bits
11
2 bits
00
Time
1 baud
1 baud
1 baud
1 baud
1 baud
1 second

4-PSK Constellation

Dibit	Phase
00	0
01	90
10	180
11	270

Dibit
(2 bits)

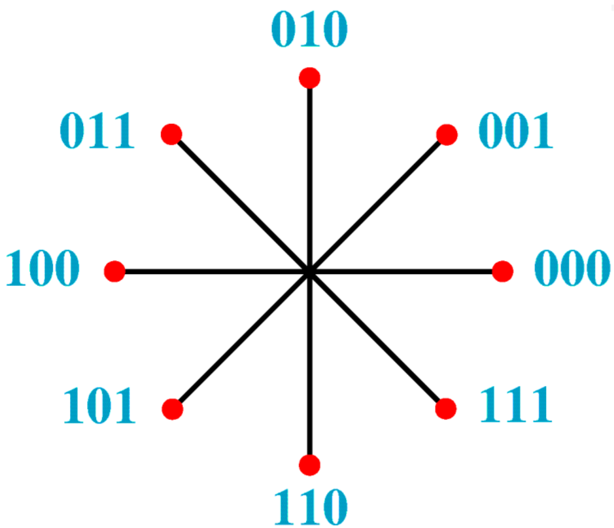


Constellation diagram

8-PSK Constellation

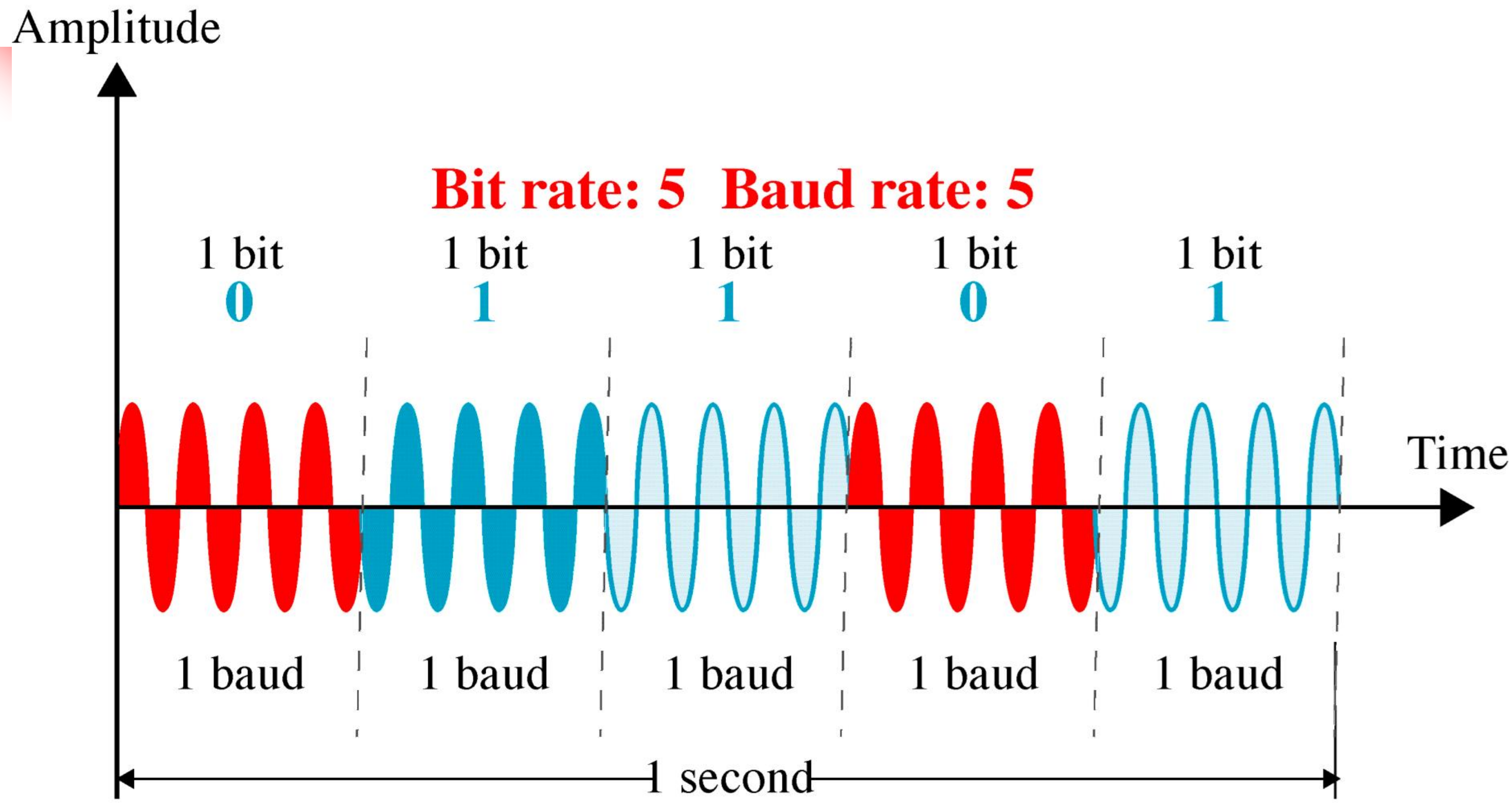
Tribit	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

Tribits
(3 bits)



Constellation diagram

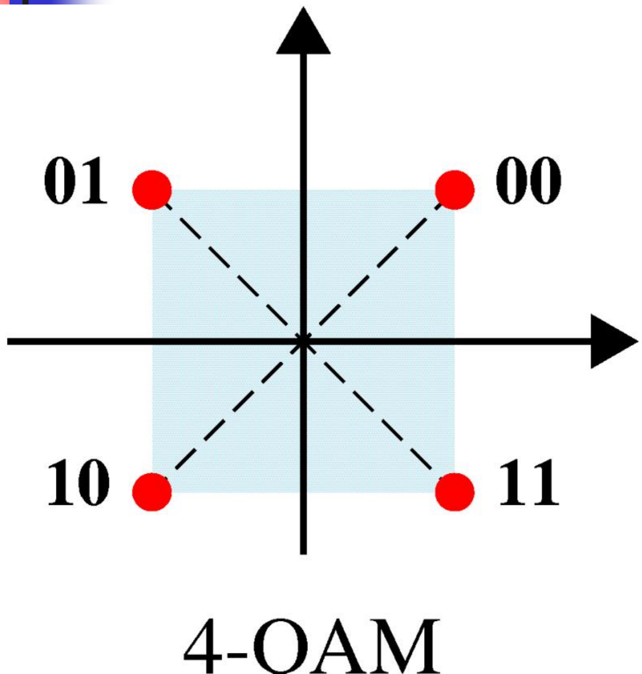
PSK

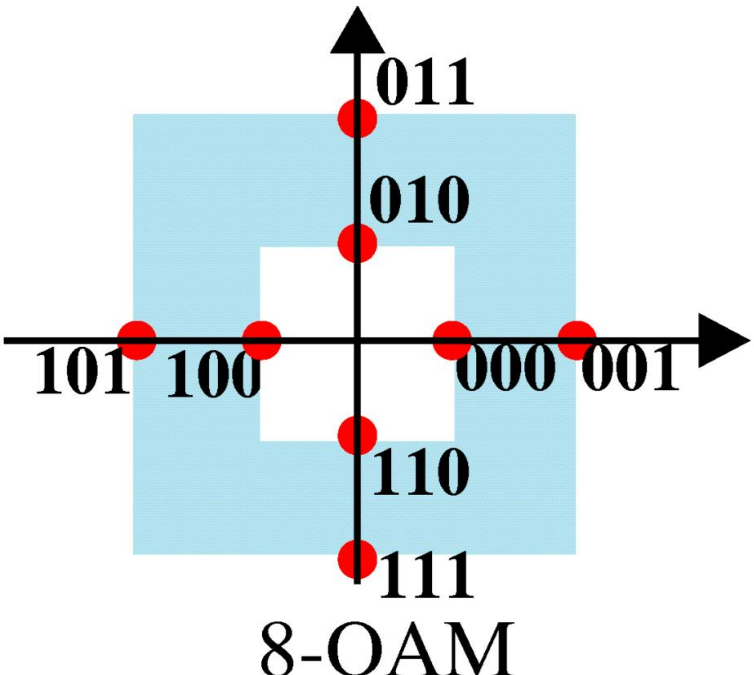

Amplitude
Bit rate: 5 Baud rate: 5
1 bit
0
1 bit
1
1 bit
1
1 bit
0
1 bit
1
Time
1 baud
1 baud
1 baud
1 baud
1 baud
1 second

Combining Both

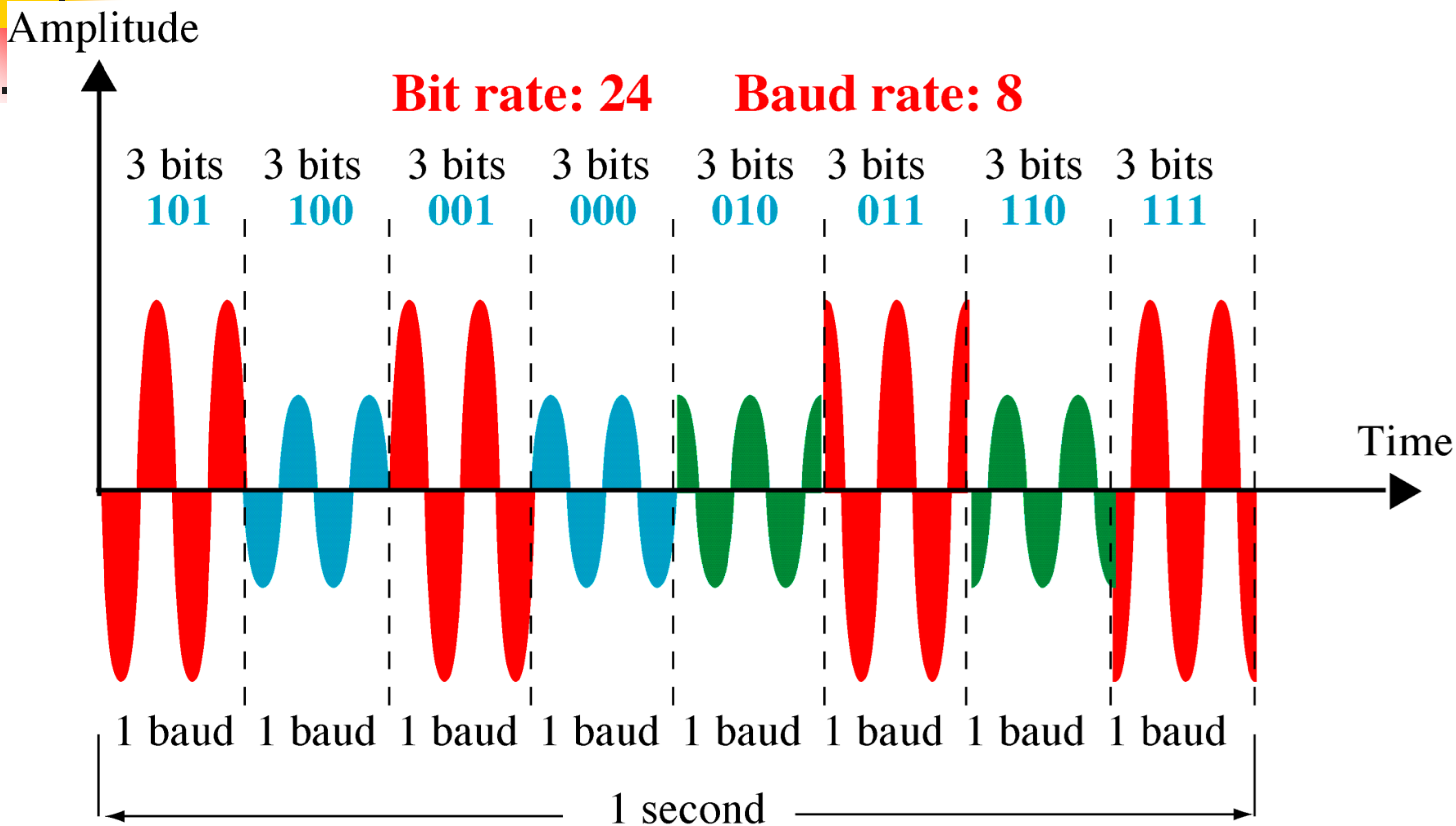
- Modulation used in Modern Modems
  - Uses:
    - Amplitude Modulation
    - Phase Shift Keying
- QAM
  - Quadrature Amplitude Modulation
    - Big Name – Simple Concept

4-QAM and 8-QAM Constellation



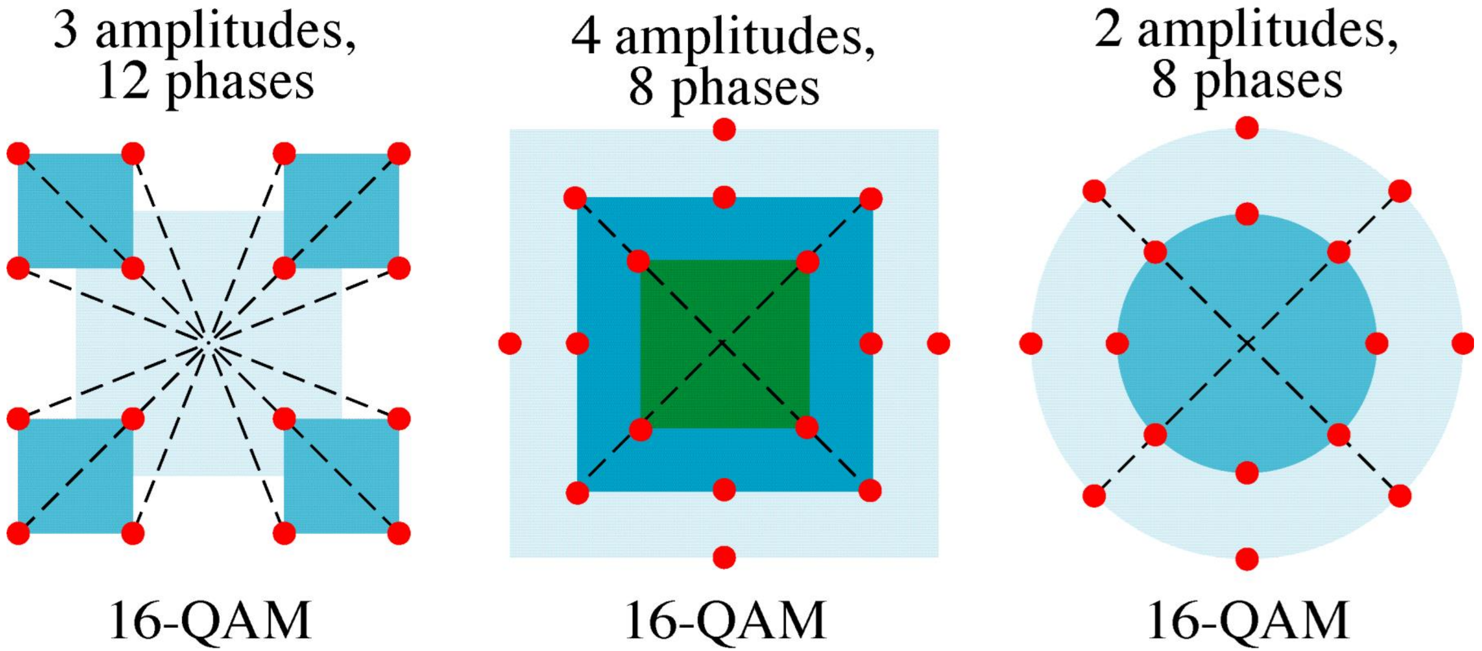


8-QAM Signal

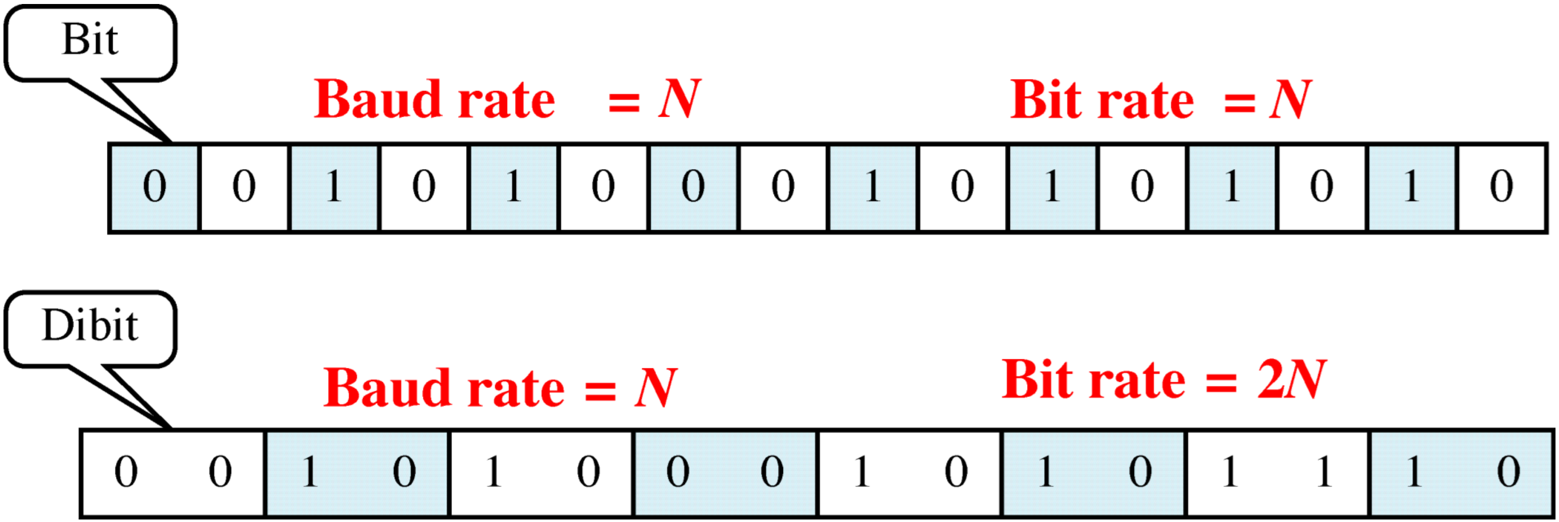


Amplitude
Bit rate: 24
Baud rate: 8
3 bits
101
3 bits
100
3 bits
001
3 bits
000
3 bits
010
3 bits
011
3 bits
110
3 bits
111
Time
1 baud
1 baud
1 baud
1 baud
1 baud
1 baud
1 baud
1 baud
1 second

16-QAM Constellation



Bit Rate and Baud Rate



Problem #3

- A modem uses an 8-PSK modulation scheme supporting data rate of 4800 bps. What is the signaling rate (aka baud rate)?
- 8 PSK – (Phase Shift Keying)
  - 8 different encoding levels
  - Each encoding has $\log_2 8 = 3$ bits
  - 4800 / 3 = 1600 Baud Rate

Statistical TDM Parameters

- I = Number of Input Sources
- R = Data rate of each source (bps)
- α (Alpha) = mean fraction of time each source is transmitting
- M = Effective capacity of multiplexed line
- $K = M / (I \times R)$ = Ratio of multiplexed line capacity to total input rate
- λ (lambda) = $\alpha \times I \times R$ = Average Arrival rate
- $T_s = 1 / M$ = Service time in seconds

ρ : Line Utilization

- ρ = Fraction of total link capacity being used
- Many different forms to express line utilization
  - $\rho = \lambda T_s$
  - $\rho = (\alpha \times I \times R) / M$
  - $\rho = \alpha / K$
  - $\rho = \lambda / M$

Sample Problem #5

- Ten 9600 bps lines are multiplexed using TDM. Ignoring overhead bits what is the total capacity required for Synchronous TDM?
  - Simple: 10 X 9600 = 96 kbps (96,000)

Sample Problem #6

- Ten 9600 bps lines are multiplexed using TDM. Assuming that we limit line utilization to 0.8 and each line is busy 50 % of the time. What is the capacity required for Statistical TDM?
  - What do we know?
    - Line utilization – $\rho = .8$
    - Fraction of time transmitting - $\alpha = .5$
    - R Data Rate of each input source = 9600 bps
    - I number of Input Sources = 10

Continued

- The Equation:
- $\rho = \alpha \times I \times R \times /M$
  - Where M is the capacity of the multiplexed line
- Rearrange for M
  - $M = \alpha \times I \times R / \rho$
- Plug in the given parameters
  - $M = 0.5 \times 10 \times 9600 / 0.8$
  - M = 60 kbps

Four 1 Kbps devices are to be multiplexed using synchronous TDM. The multiplexor will take one bit from each source during each cycle. Find

a) The duration of the bit before multiplexing
b) The duration of the bit after multiplexing
c) The duration of the multiplexed frame
d) The multiplexer bit rate
e) The multiplexer frame rate.

Duration of bit before MUX = 1/1K = 1 msec
Multiplexer bit rate is 4x1K = 4Kbps and hence the bit duration at output of MUX is 1/4K = 0.25 msec
Duration of multiplexed frame is 4x0.25msec = 1msec
Frame rate is 1/1msec = 1000 frames/sec
