CS2105 Introduction to Computer Networks

Lecture 11
Physical Layer

5 November 2018

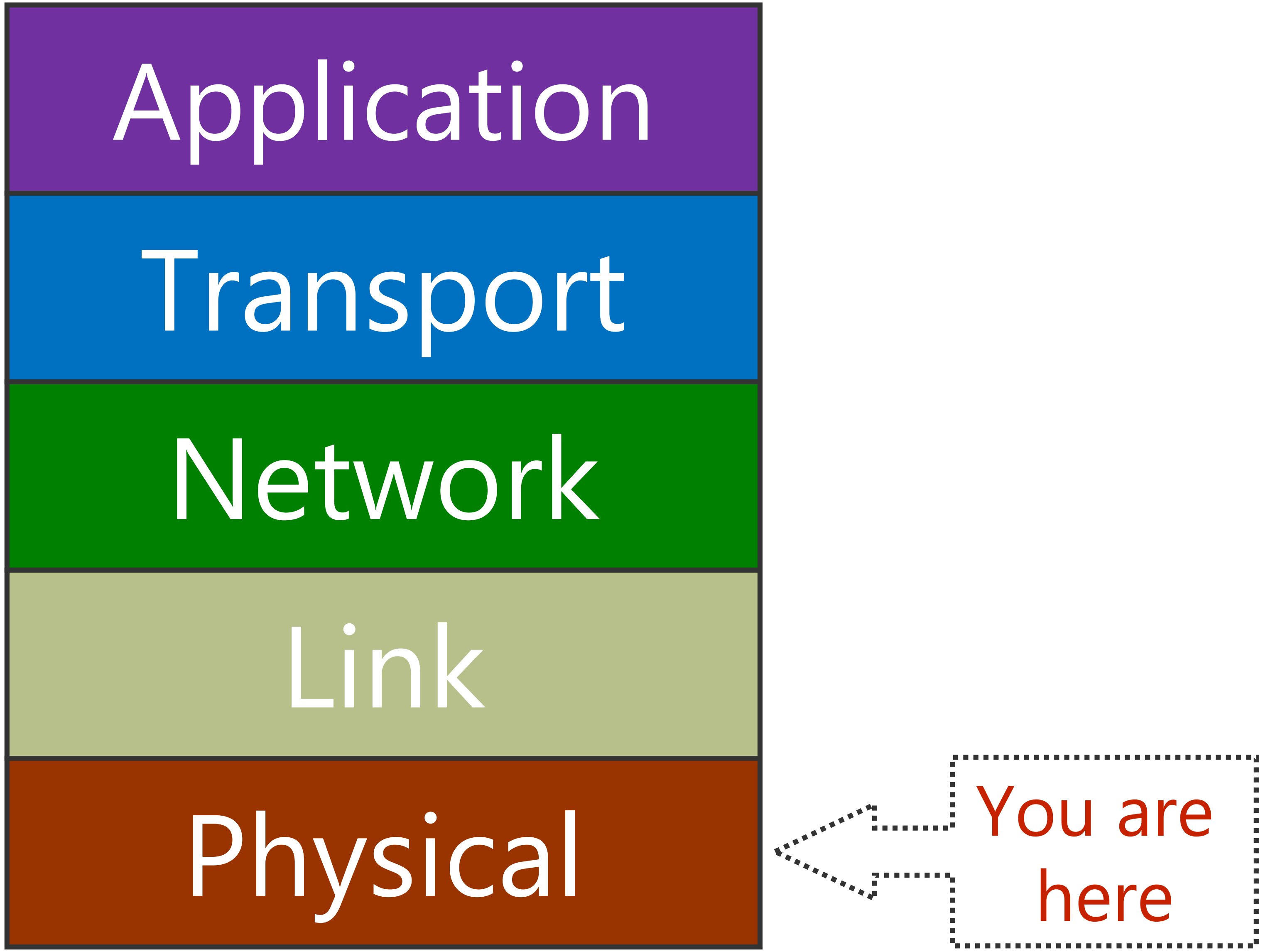
Local Area Network

- Every adapter (NIC) has a unique MAC address
    - Permanent; 48-bits; Hardware-assigned
- ARP is used to discover MAC addresses of other nodes
    - Must be in the same subnet
- Ethernet: CSMA/CD with binary (exponential) back-off
- Switch: self-learns the topology of a subnet

Learning Outcomes

After this class, you are expected to know:

- different methods of digital transmission
  - NRZ, RZ, Manchester, and DM
- different methods of analog transmission
  - Frequency, Amplitude, and Phase modulation
  - QAM and constellation diagram
  - Frequency domain and signal multiplexing
- bandwidth and theoretical capacity of a medium
  - Nyquist’s and Shannon’s formula

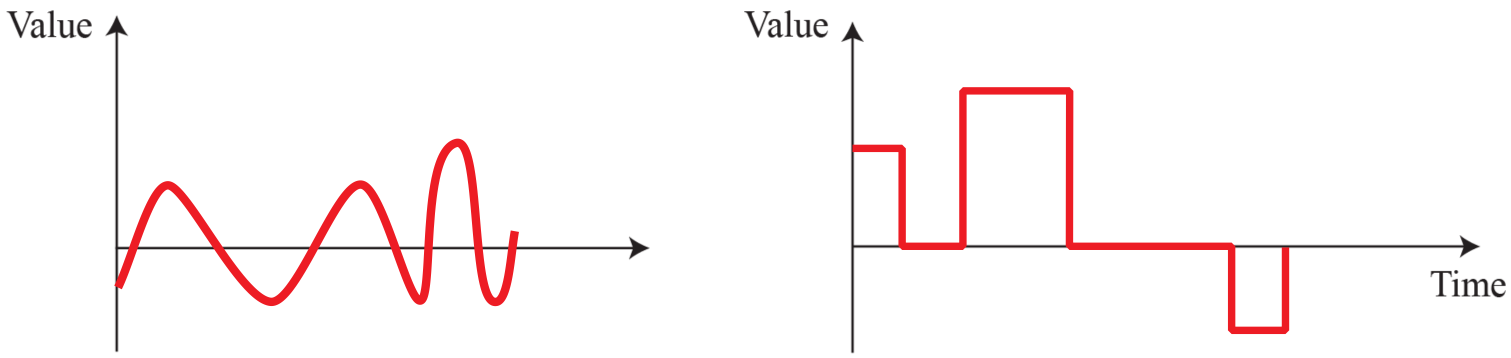

Application
Transport
Network
Link
Physical
You are
here

Lecture 11 Roadmap

1. Introduction to Signal
2. Digital Transmission
3. Analog Transmission

Signals

- Physical layer moves data in the form of electro-magnetic signals across transmission (physical) medium
  - In computers, data is encoded as 0s and 1s
- 0s and 1s can be transmitted as either analog or digital signal
  - Analog signal is continuous: *infinitely many levels*
    - Wi-Fi
  - Digital signal is discrete: *limited defined values*
    - Ethernet; USB



a. Analog signal

b. Digital signal

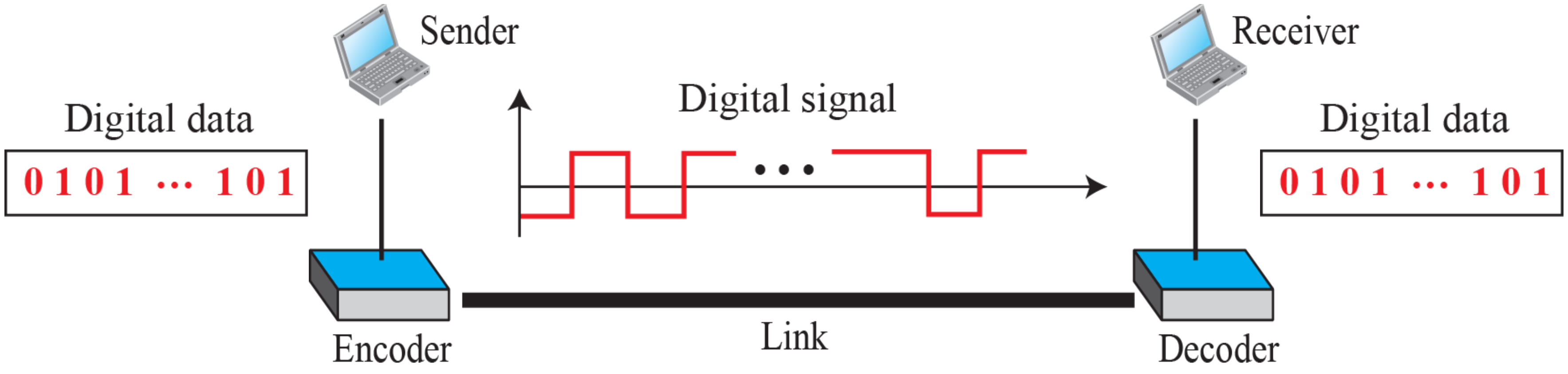
Lecture 11 Roadmap

1. Introduction to Signal
2. Digital Transmission
3. Analog Transmission

Digital Signal

Properties:

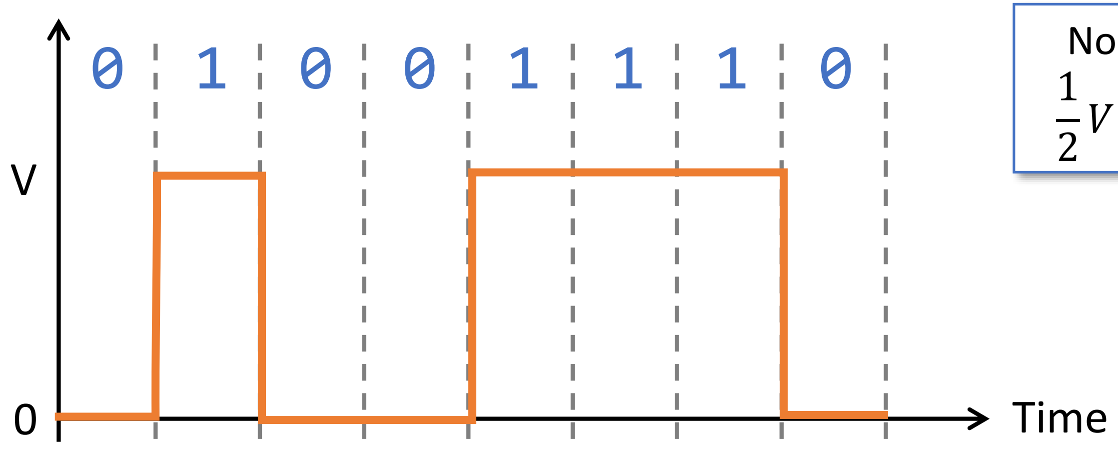
- Voltage determines the value of digital signal
  - Encode 0s and 1s with different voltages
  - Unipolar: uses voltage on only one side
  - Polar: uses two levels `(-1,1)`
  - Bipolar: uses three levels `(-1,0,1)`



Unipolar Scheme

Non-Return to Zero (NRZ)

- All signal levels are on one side



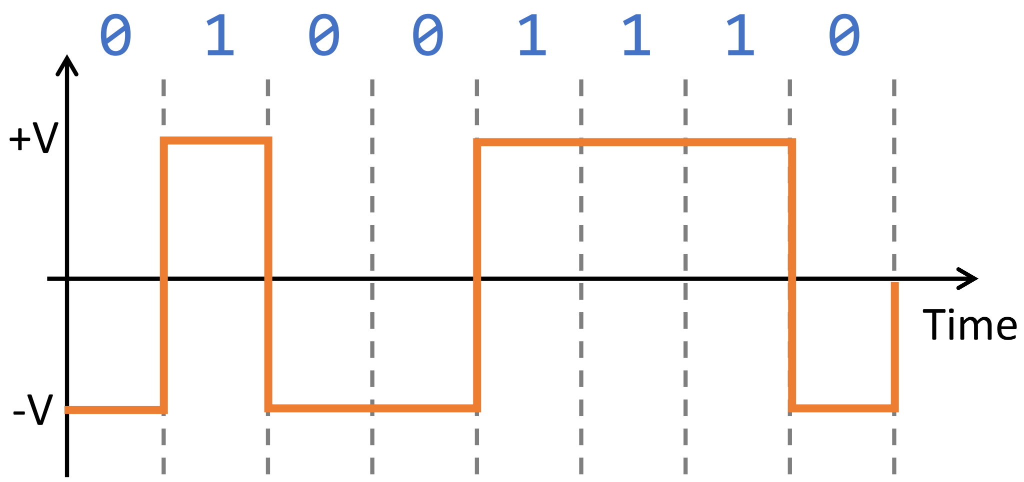
Normalized power

$$\frac{1}{2}V^2 + \frac{1}{2}0^2 = \frac{1}{2}V^2$$

Polar Scheme

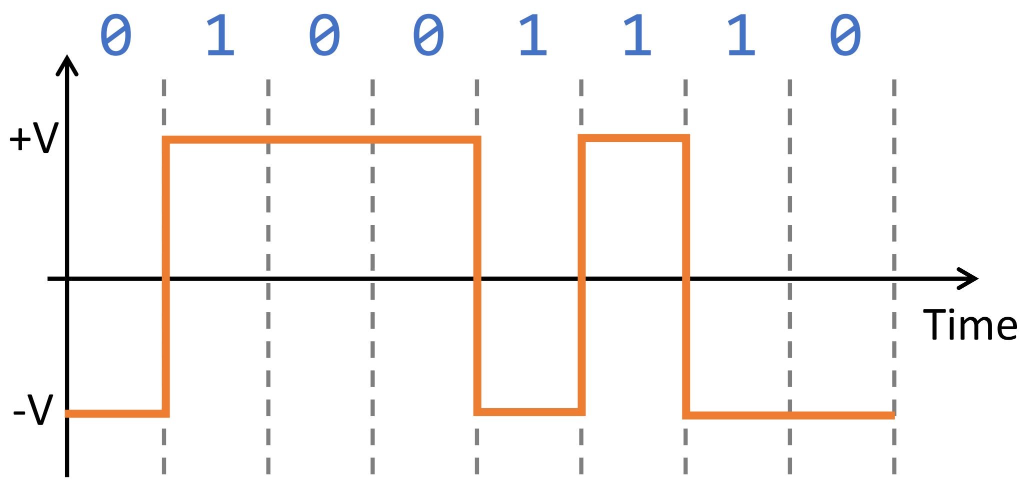
Non-Return to Zero-Level (NRZ-L)

- Bit 0: -V voltage
- Bit 1: +V voltage



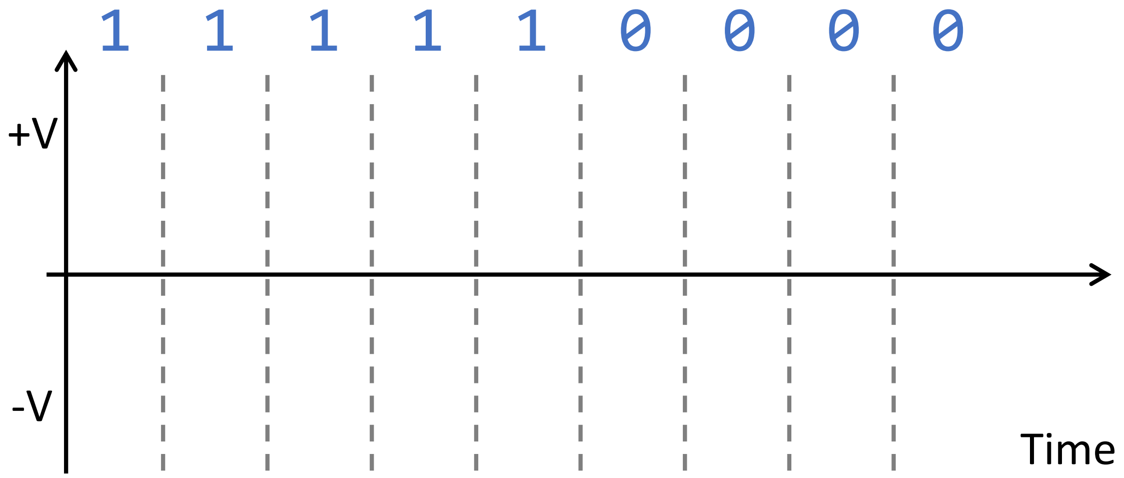
Non-Return to Zero-Invert (NRZ-I)

- Bit 0: no inversion
- Bit 1: inversion



Bit-Slip

- Suppose you have a sequence of 0s or 1s

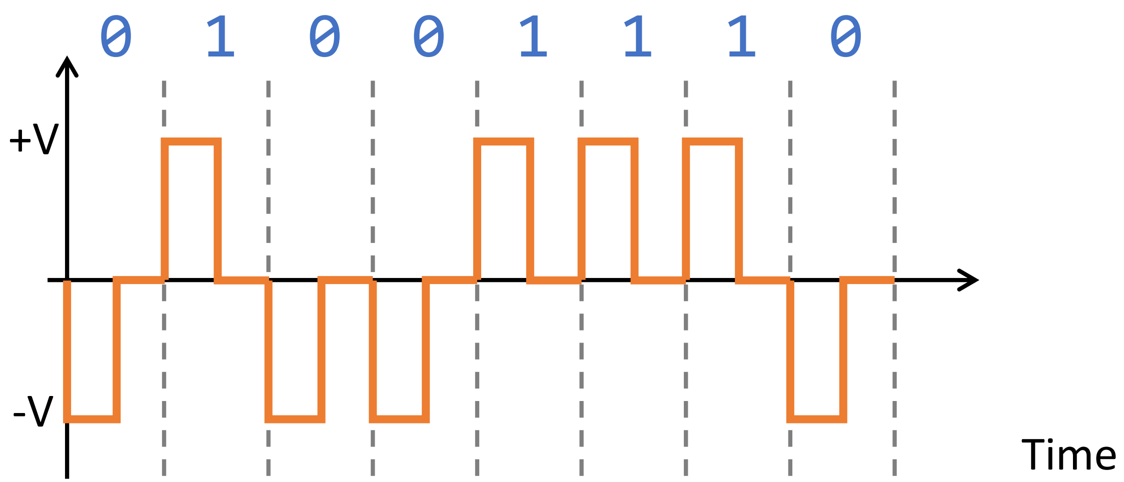


Bipolar Scheme

Return-to-Zero (RZ)

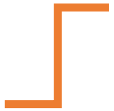
- Voltage returns to zero in the middle

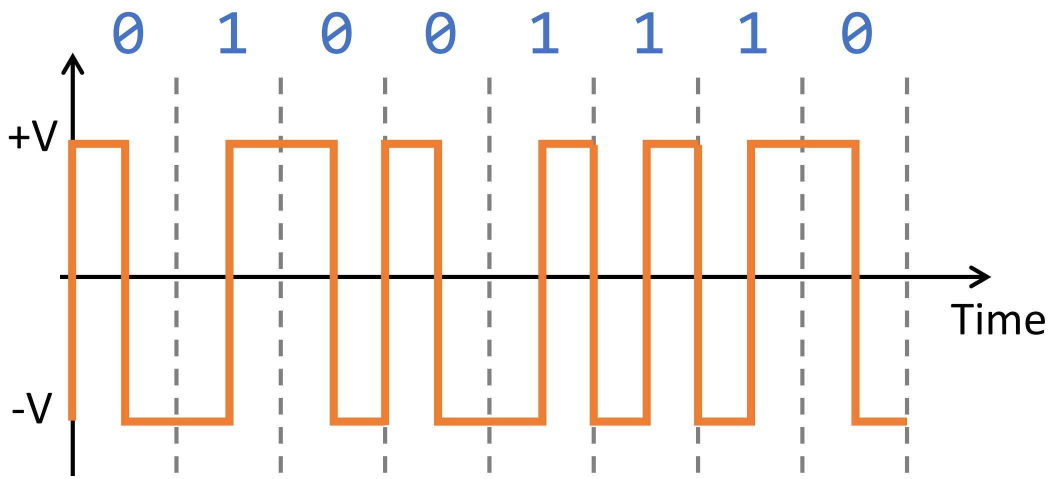
- Drawbacks:
    - 3 levels of voltage
    - Higher bandwidth required



Self-Clocking Scheme

Manchester

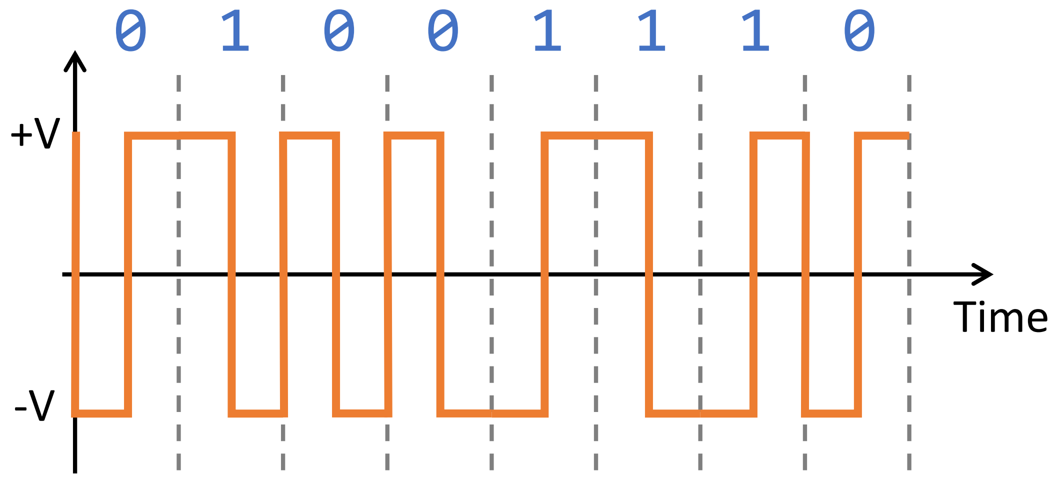
- Bit 0: 
- Bit 1: 



- Susceptible to polarity flips

Differential Manchester

- Bit 0: inversion
- Bit 1: no inversion



- Detecting transition easier

Summary of Digital Encoding

- Unipolar NRZ
- NRZ-L
- NRZ-I
- RZ
- Manchester
- Differential Manchester

Lecture 11 Roadmap

1. Introduction to Signal
2. Digital Transmission
3. Analog Transmission

Analog Signal

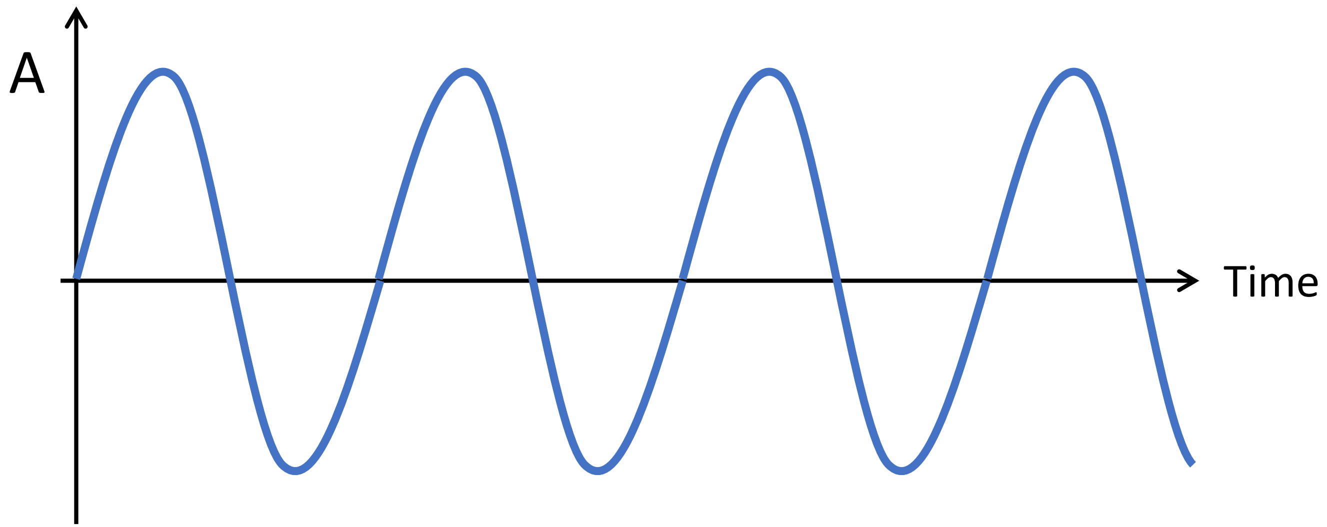
- The most basic analog signal is a sine wave

$$\boldsymbol{A}\sin(2\pi \boldsymbol{f} t + \boldsymbol{\varphi})$$

peak amplitude　　frequency　　phase

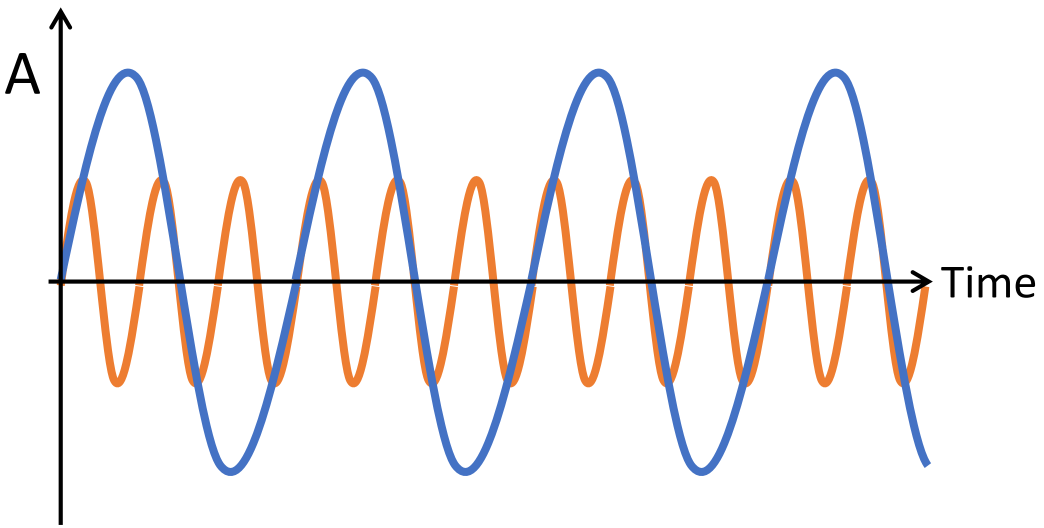
T: Period

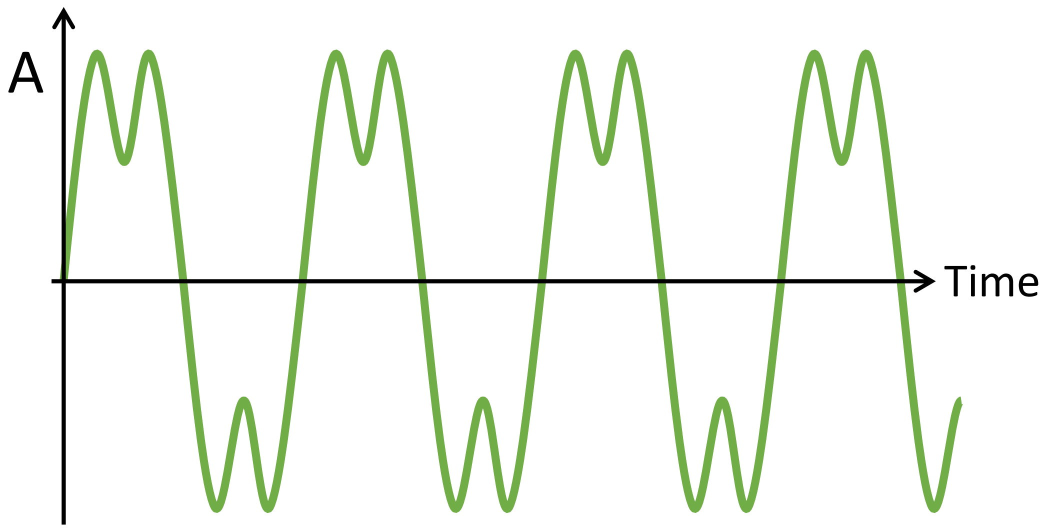
$T = \frac{1}{f}$



Analog Signal

- Analog signal can be composed into composite signal
  - Composite signal can also be decomposed to multiple sine waves
  - Useful to visualize a composite signal in frequency domain instead of time domain

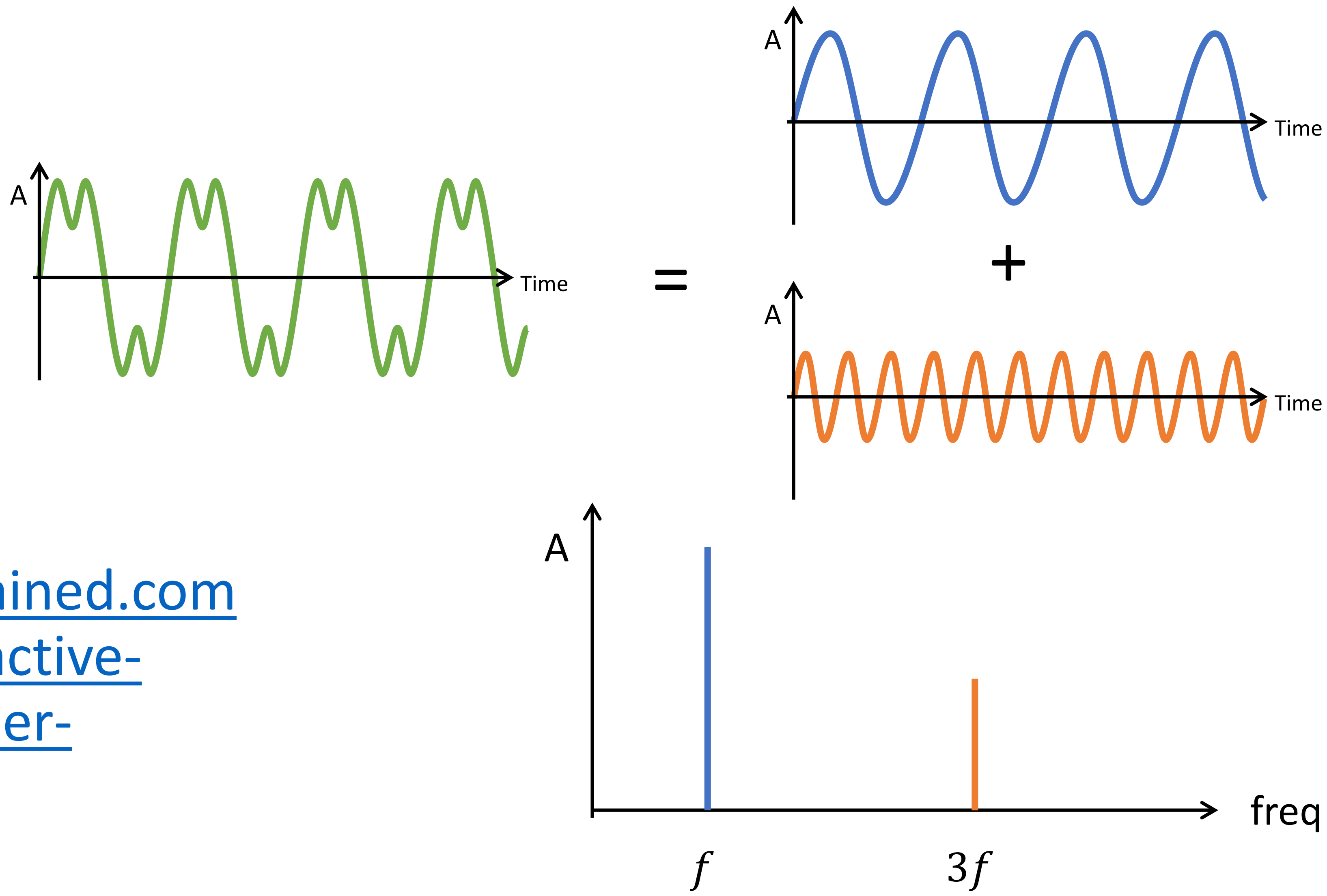




Jean-Baptiste Joseph Fourier

$$x(\omega) = \int_{-\infty}^{\infty} x(t) \cdot e^{-j\omega \cdot t} dt$$

Fourier Transform

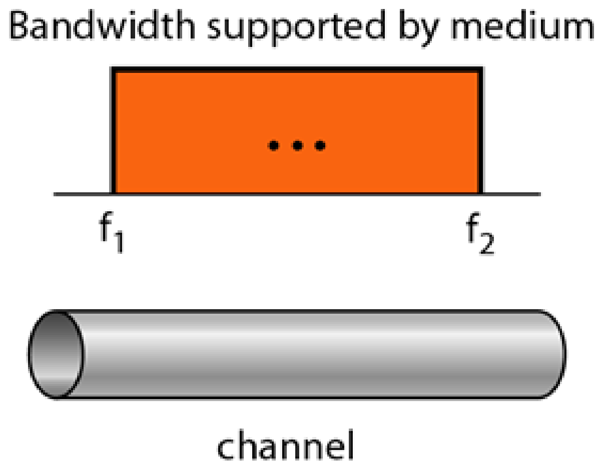


http://betterexplained.com/articles/an-interactive-guide-to-the-fourier-transform/

Bandwidth

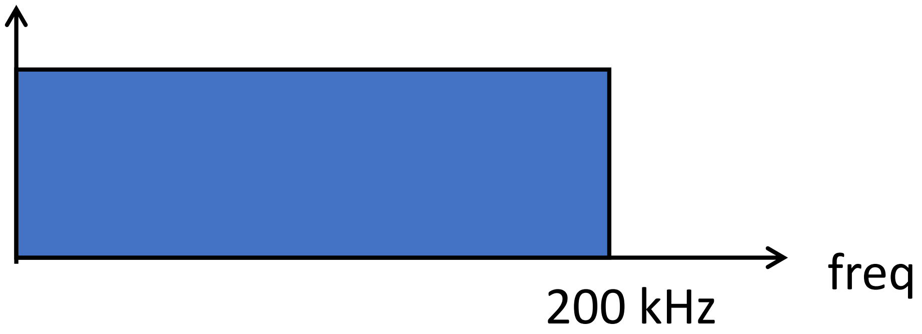
- A signal can be decomposed into different frequency
  - It has minimum and maximum frequency
  - The difference is bandwidth of the signal

- A transmission channel only allows certain frequency to pass
  - It has minimum and maximum frequency
  - The difference is bandwidth of the medium

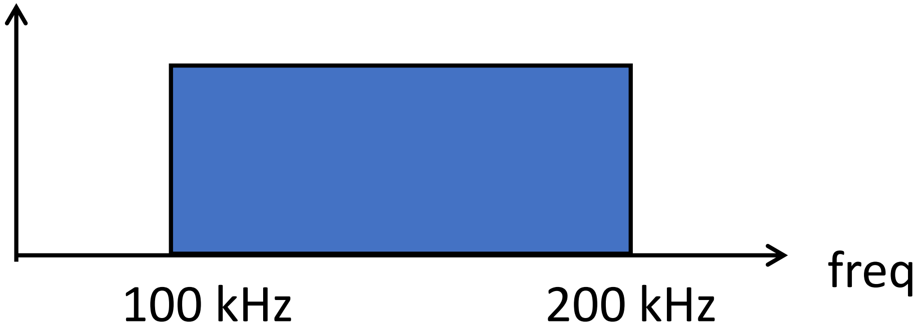


Bandwidth

- Baseband Channel
  - Very low frequencies, near 0



- Bandpass Channel
  - Only allows frequencies between a range



- How does a channel bandwidth relate to bit-rate?

Nyquist Bit-Rate Formula

- Assumption:
  - Ideal noise-less channel
- Theoretical maximum bit-rate is

$$2B \times \log_2 L$$

Where

- B is the channel bandwidth
- L is the number of signal levels

Nyquist Bit-Rate Formula

Example

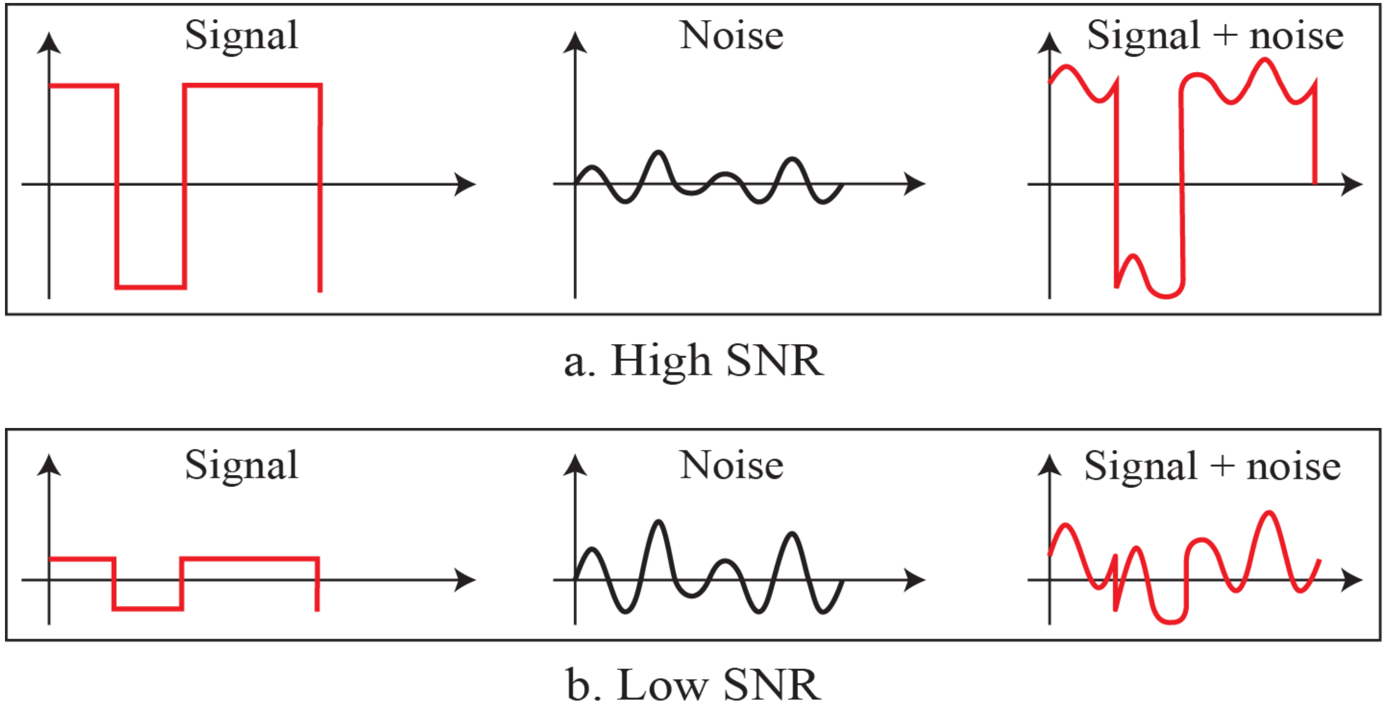
- Manchester coding
  - 2 signal levels
- Noiseless 1 MHz channel
- Theoretical maximum data rate

$$2B \times \log_2 L = 2 \times 10^6 \times \log_2 2 = 2 \times 10^6$$

  - **2 Mbps**

Signal-to-Noise Ratio

- A transmission channel introduces noise that distorts signal
  - SNR is the measure of the strength of signal over noise



Shannon Channel Capacity

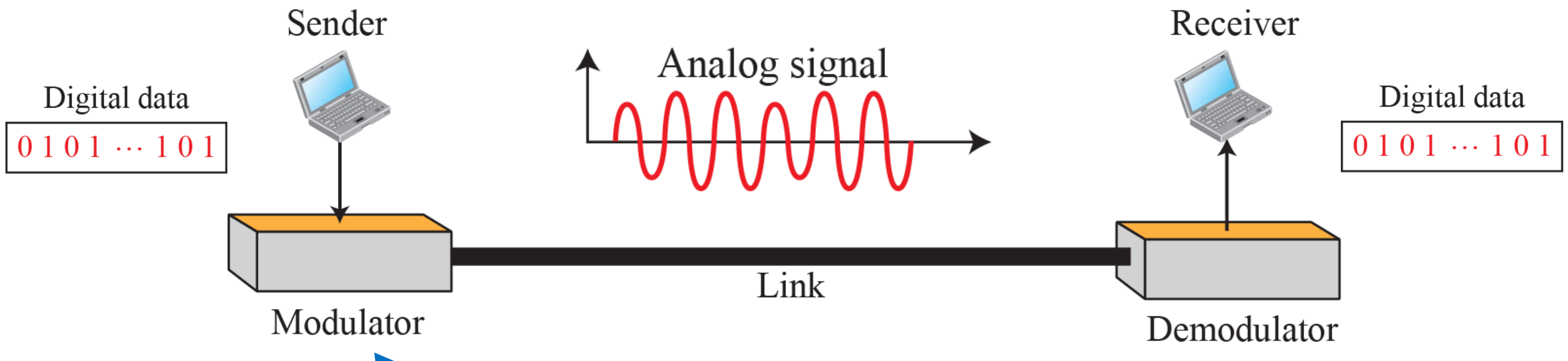
- Assumption:
  - Noisy channel (but SNR is known)
- Theoretical maximum bit-rate is

$$B \times \log_2(1 + SNR)$$

Example:

- A phone line with channel bandwidth of 3,000 Hz
- Signal-to-noise ratio of 3,162
- Capacity of the channel is 34,881 bps

Analog Transmission



modulat + demodulato

Analog Encoding

- Recap: $\boldsymbol{A}\sin(2\pi \boldsymbol{f} t + \boldsymbol{\varphi})$
  - We can change A, f, and φ to encode 0s and 1s

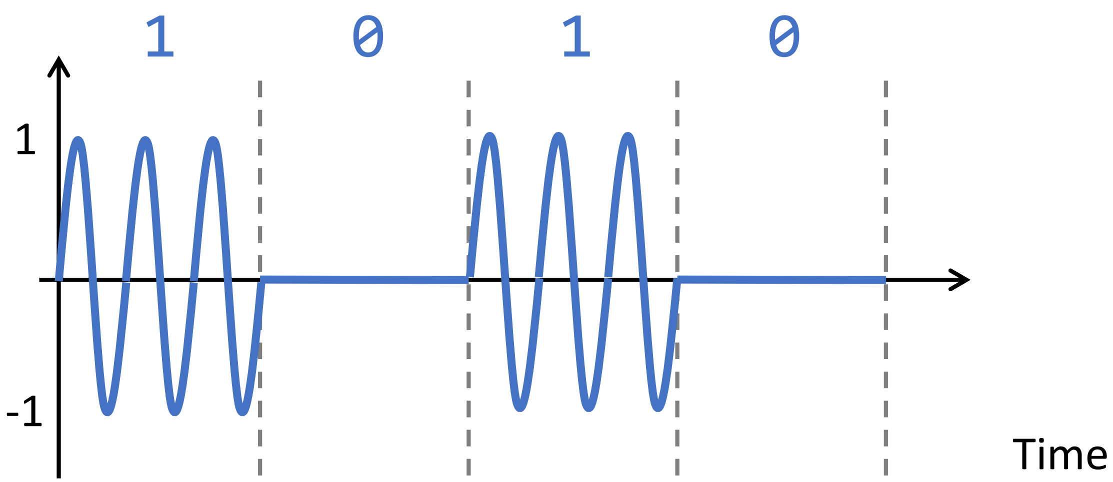
- Amplitude Shift Keying (ASK)
  - Changes the peak amplitude (A)
- Frequency Shift Keying (FSK)
  - Changes the frequency (f)
- Phase Shift Keying (PSK)
  - Changes the phase (φ)

Amplitude Shift Keying (ASK)

Use different amplitude for 0s and 1s

- Bit 1: $1 \times \sin(2\pi \boldsymbol{f} t + \boldsymbol{\varphi}) = \sin(2\pi \boldsymbol{f} t + \boldsymbol{\varphi})$
- Bit 0: $0 \times \sin(2\pi \boldsymbol{f} t + \boldsymbol{\varphi}) = 0$

- Drawback:
  - Susceptible to noise and attenuation



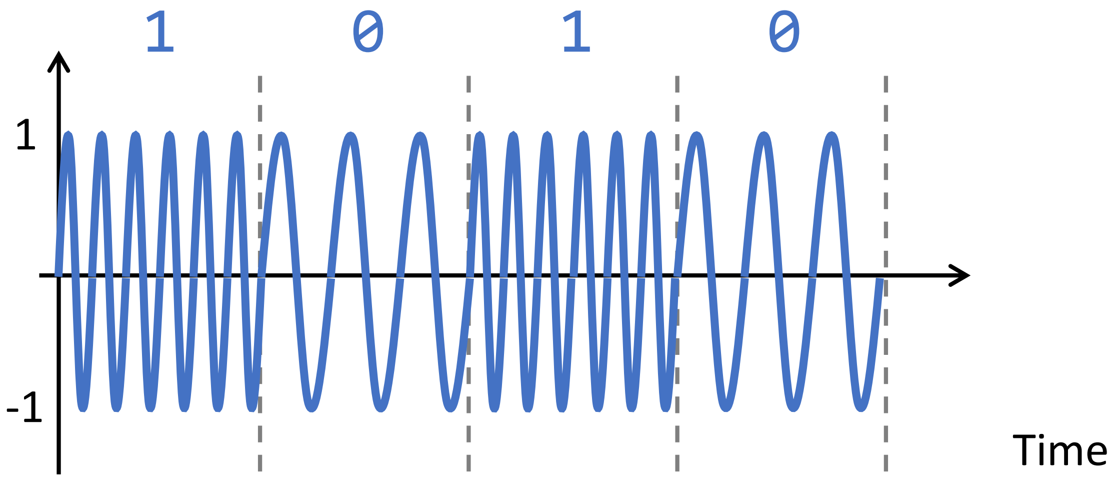
Frequency Shift Keying (ASK)

Use different frequency for 0s and 1s

- Bit 1: $\boldsymbol{A} \sin(2\pi \boldsymbol{f_1} t + \boldsymbol{\varphi})$
- Bit 0: $\boldsymbol{B} \sin(2\pi \boldsymbol{f_0} t + \boldsymbol{\varphi})$

- Amplitude & phase constant

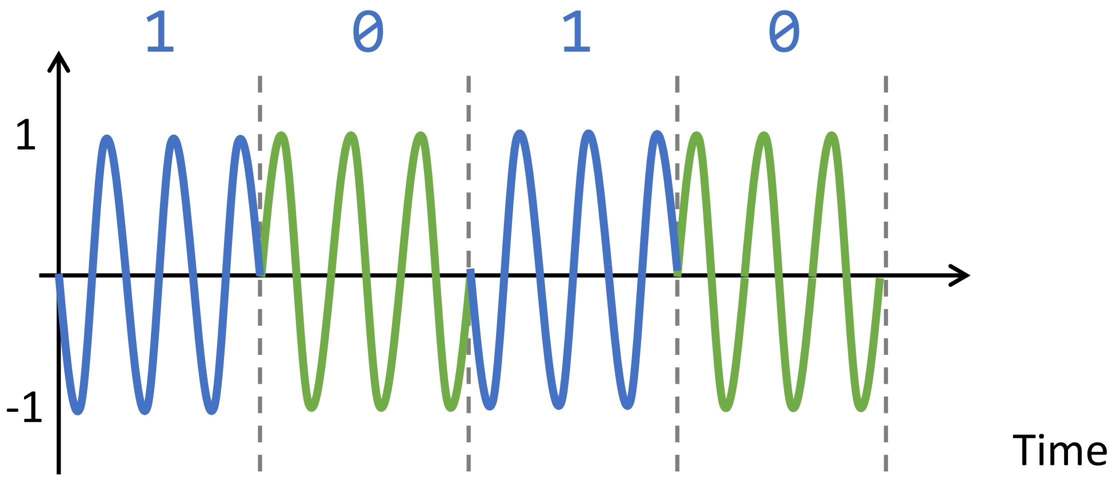
- Drawback:
    - Limited by bandwidth



Phase Shift Keying (PSK)

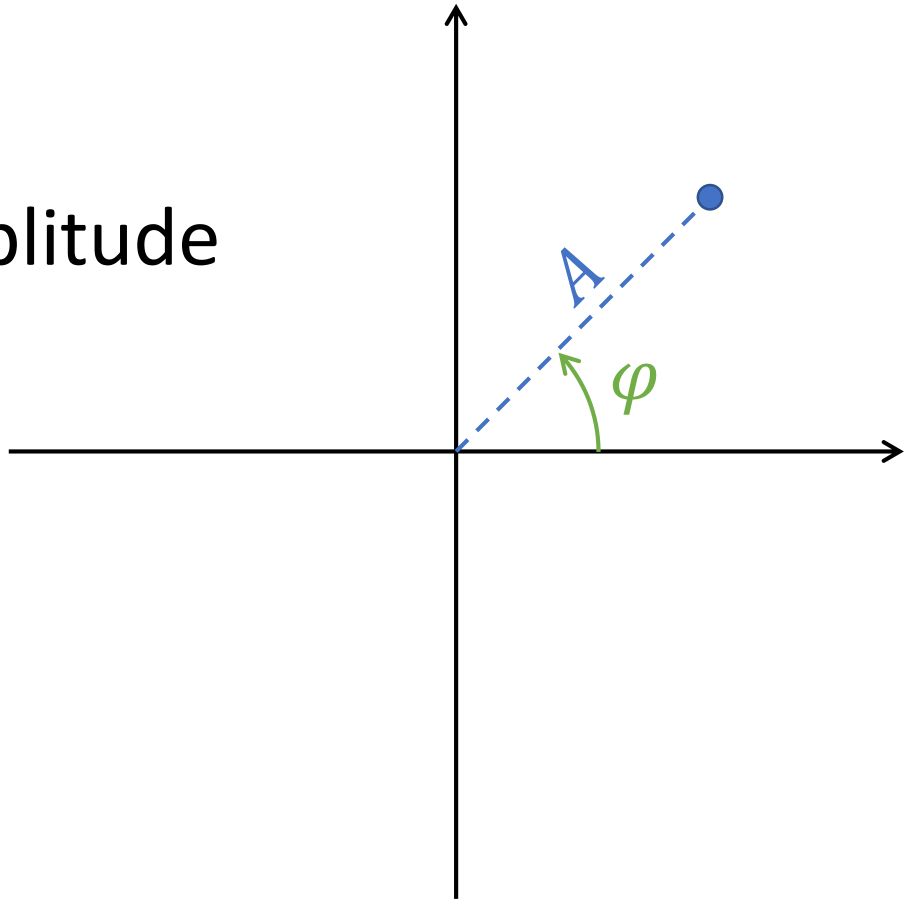
Use different phase for 0s and 1s

- Bit 1: $\boldsymbol{A}\sin(2\pi \boldsymbol{f_1} t + \pi)$
- Bit 0: $\boldsymbol{B}\sin(2\pi \boldsymbol{f_2} t + 0)$

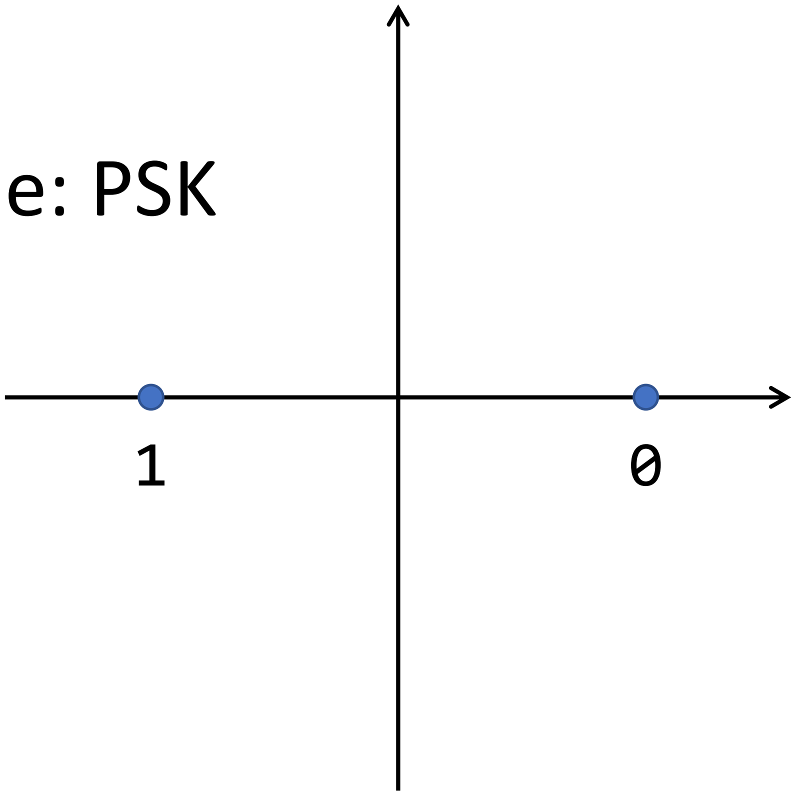


Constellation Diagram

Idea: combine phase and amplitude



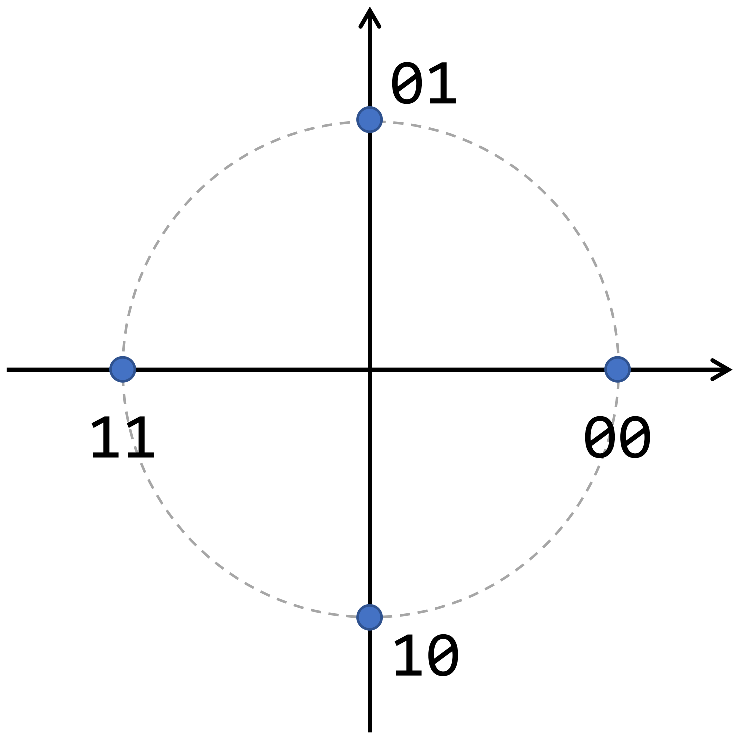
- Example: PSK



QPSK

- Can we transmit faster?
  - Phase shift to represent more bits
  - QPSK: 4 possible phases

Phase	Values represent
0^0	11
90^0	01
180^0	00
270^0	10

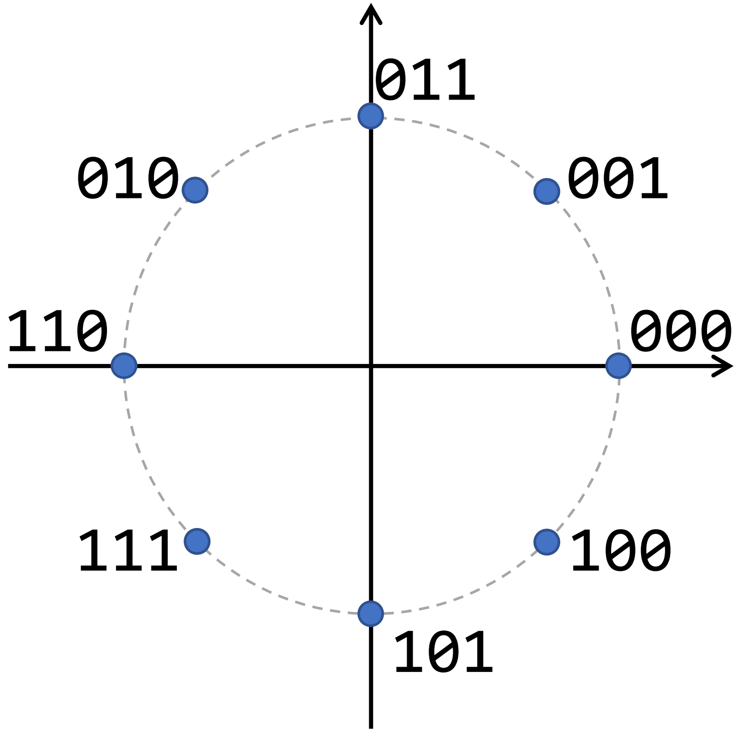


  - Every signal encode 2-bits of data

8-PSK

- Can we transmit *even* faster?
  - Phase shift to represent more bits
  - 8-PSK: 8 possible phases

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



- Every signal encode 3-bits of data

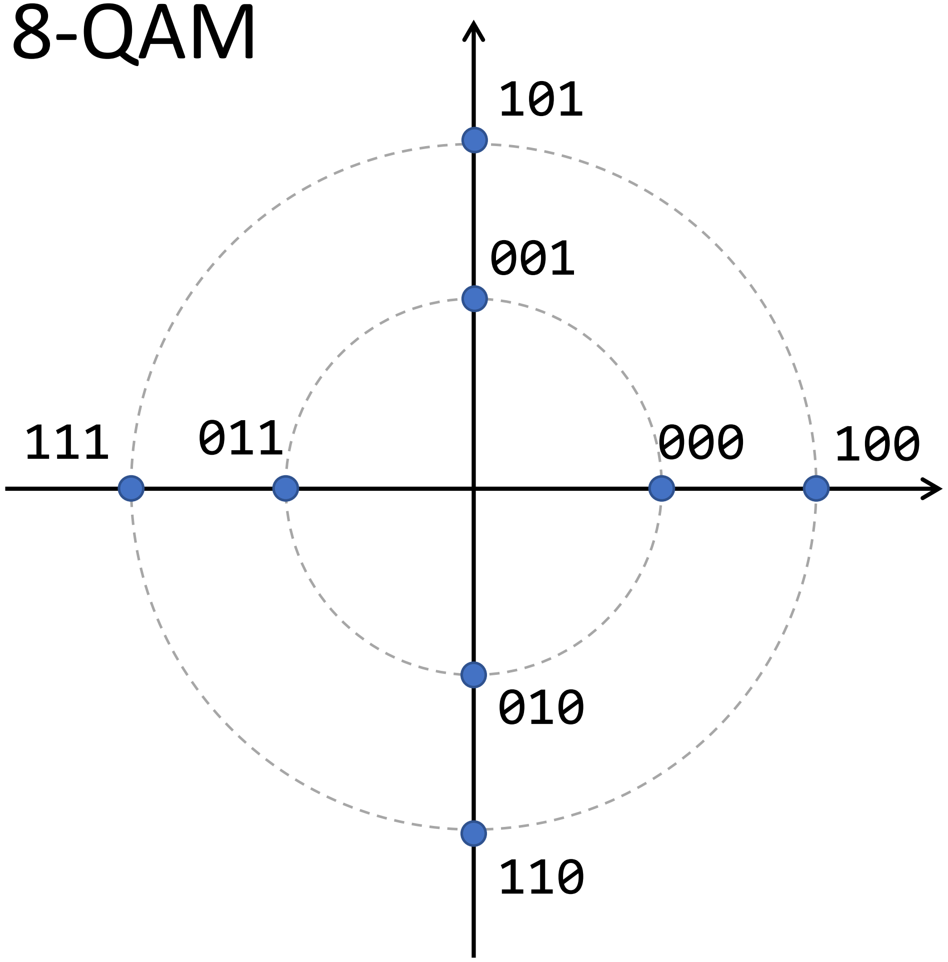
QAM

Quadrature Amplitude Modulation

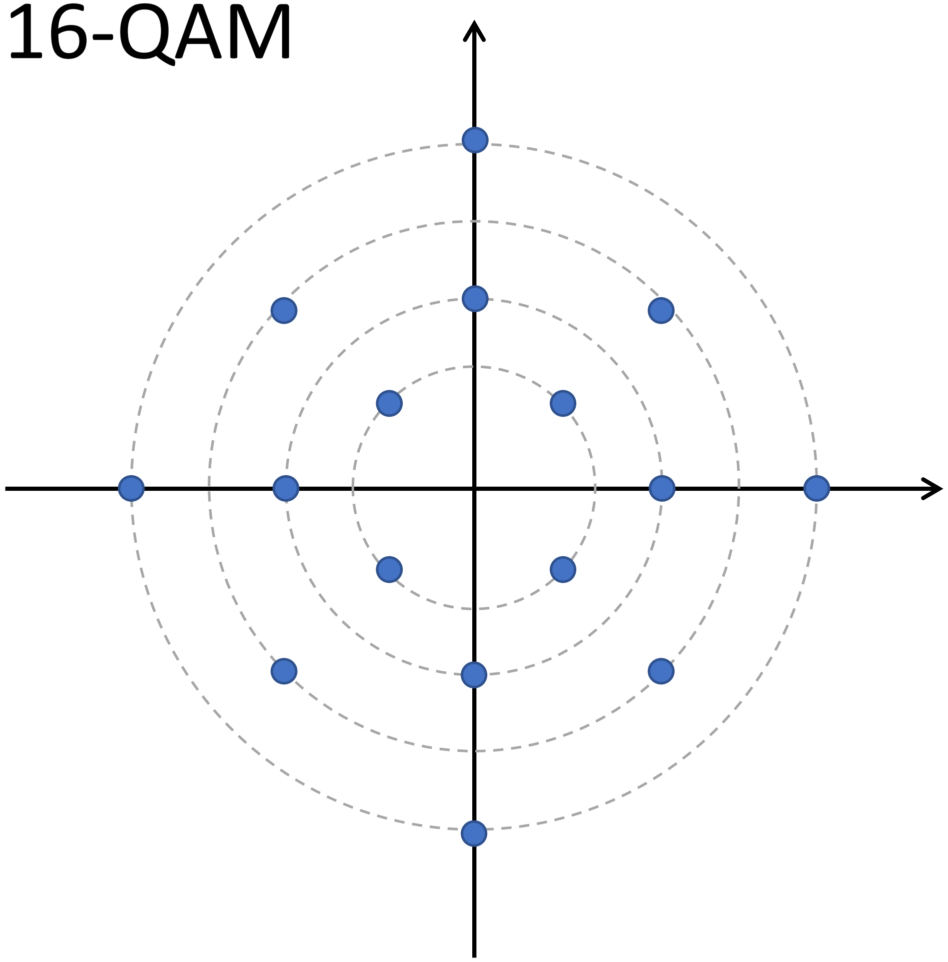
- Can we transmit *even* faster?
  - Combines ASK and PSK
  - Many combinations are possible
- A signal unit in a 2^k-QAM scheme is a combination of amplitude and phase that represents k bits
  - Baud rate (Bd) is the number of signal units per second
  - Bit rate is the number of bits per second

QAM

8-QAM

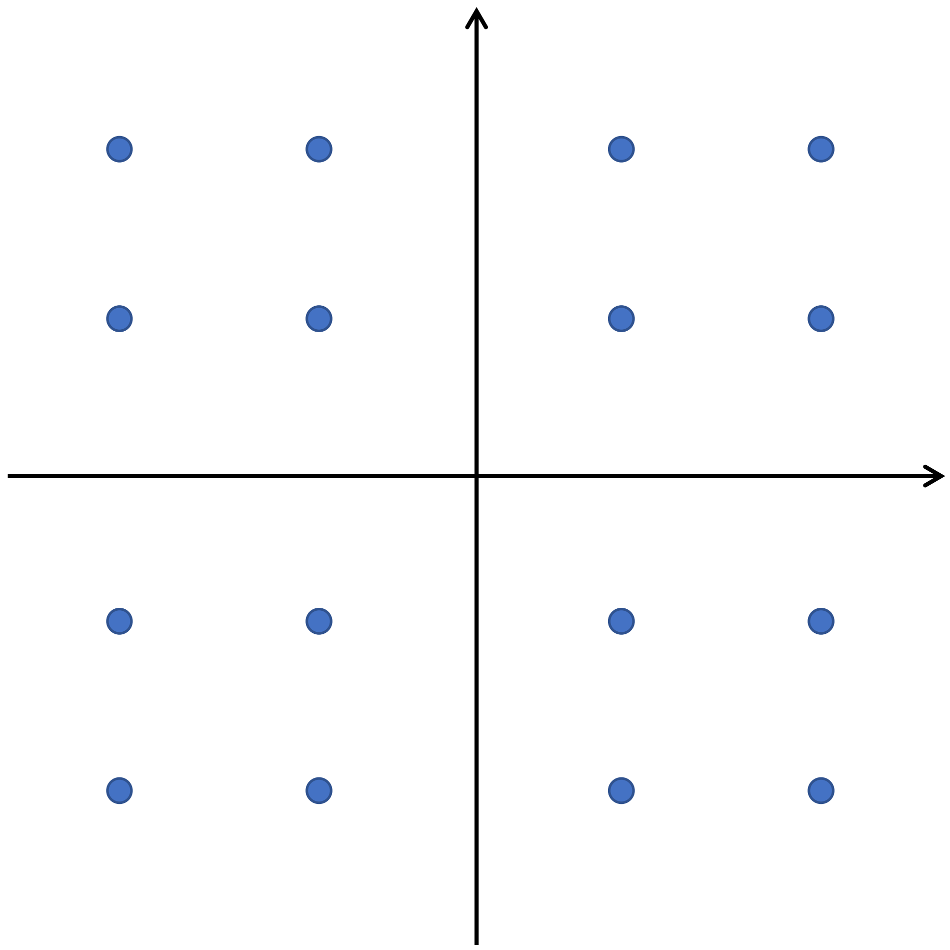


16-QAM

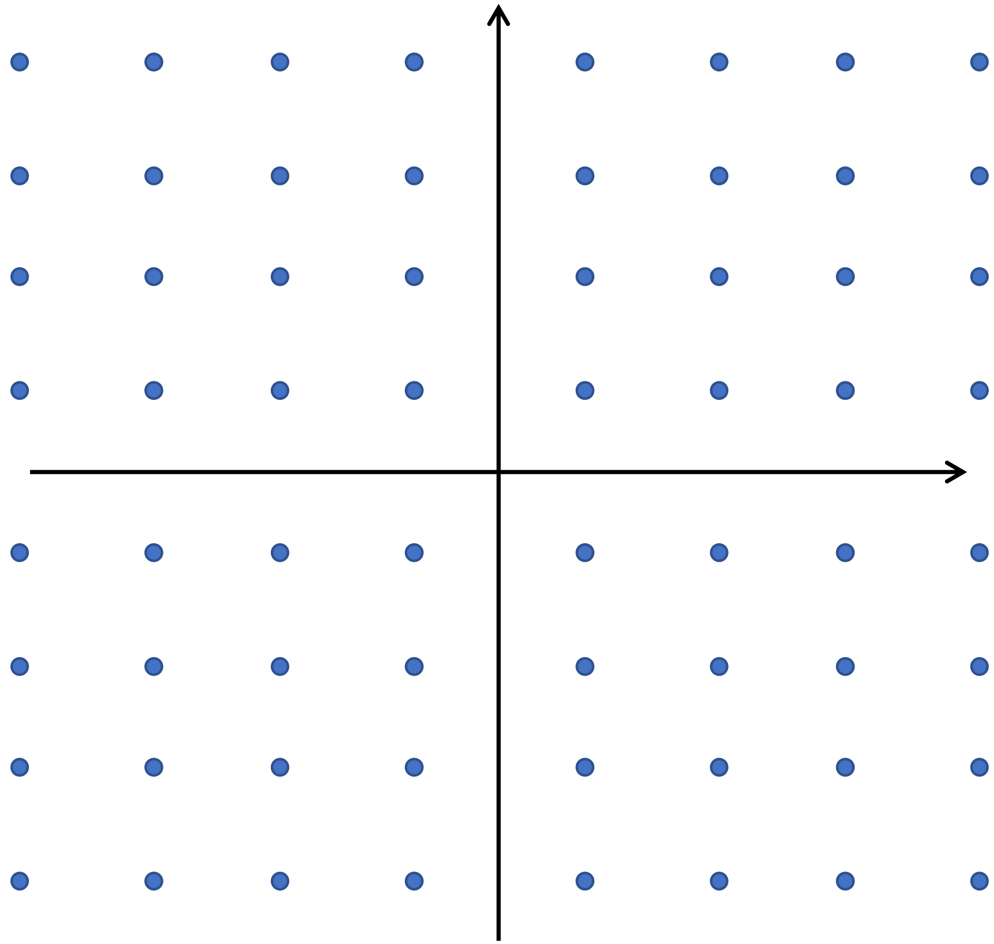


QAM

16-QAM



64-QAM



- Pros and Cons?

Real World Application

- Singapore TV broadcast uses DVB-T
  - QPSK, 16-QAM, or 64-QAM
- 802.11a/b/g/n
  - QPSK, 16-QAM, or 64-QAM
- 802.11ac
  - 256-QAM
- Ethernet, RFID, and NFC
  - Manchester Coding
- USB
  - NRZ-I

Summary

- Analog vs Digital Signals
- Digital Encoding
  - Unipolar: NRZ
  - Polar: NRZ-I, NRZ-L
  - Bipolar: RZ
  - Self-Clocking: Manchester, Differential Manchester
- Analog Encoding
  - Composite Signals
  - Bandwidth
  - ASK, FSK, PSK, QAM, and more
  - Constellation Diagram