CS2105 Lecture 11
Physical Layer

7 April, 2014

After this class, you are expected to be able to understand:

- how NRZ, RZ, Manchester, and DM, are used to encode 0s and 1s, and their pros and cons.
- how A, f and ϕ can be used to encode 0s and 1s, and their pros and cons.
- the term bandwidth and the theoretical capacabity of a medium using Nyquist's and Shannon's formula.
- how a signal can be viewed in frequency domain and how frequency can be shifted to multiplex multiple signals.
- how QAM works and its representation as a constellation.

Application

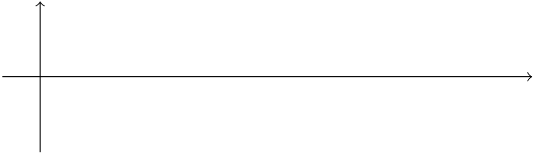
Transport

Network

Link

Physical

- 0s and 1s can be transmitted either as digital signal or analog signal over a medium.
- WiFi uses analog signal. Ethernet uses digital signal.

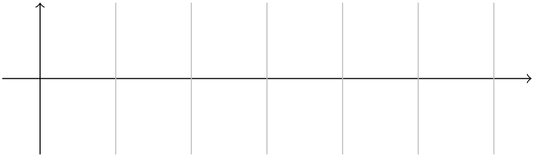


Digital Encoding

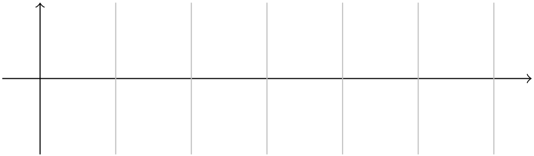
- A digital signal has a limited number of defined values (e.g., -1, 0, and 1 only)
- The value of a digital signal is determined by the voltage sent over the wire.
- Polar encoding uses two levels: -1 and 1.
- Bipolar encoding uses three levels: -1, 0, and 1.

- 0s and 1s can be encoded into digital signals in different ways.
- **NRZ** encoding is a polar encoding scheme.
- Two variants: **NRZ-L** encodes the bit value using the level of the signal; **NRZ-I** inverts the signal if bit 1 is encountered.

NRZ-L

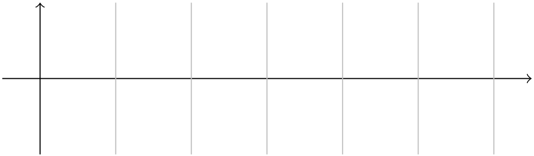


NRZ-I



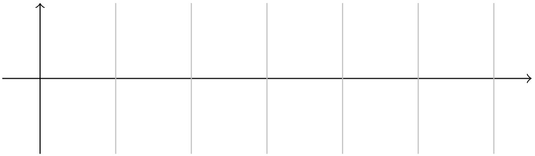
- **RZ** is a bi-polar encoding scheme, always returning the signal to zero halfway through the bit interval.
- It allows synchronization of clock at the sender and receiver, without which clock drift could lead to bit errors.
- E.g., if the sender is sending 111111..., the receiver may lost track of how many 1s have been received. This is known as a **bit slip**.

RZ

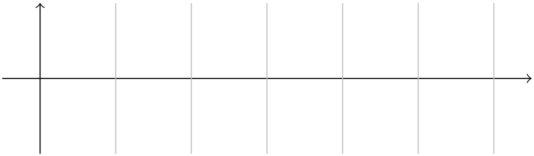


- **Machester** coding inverts the signal in the middle of a bit. A -ve to +ve trasition represents 1. A +ve to -ve trasition represents 0.
- **Differential Manchester (DM)** uses the presence of absence of a transition at the beginning of the interval to identify a bit. A transition means 0. No transition means 1.

Manchester



Differential Manchester



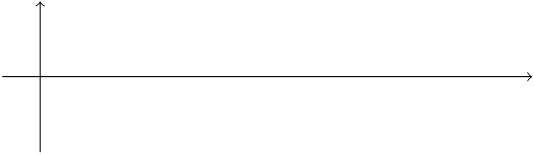
- Detecting transition is less error prone than comparing against a threshold.
- DM works even if the signals are swapped.

Digital-to-Analog Modulation

- The most basic analog signal is a sine wave:

$$Asin(2\pi ft + \phi)$$

where *A* is the peak amplitude, *f* is the frequency and ϕ is the phase.



- We can combine sine waves to form composite signals.
- Composite signal can be decomposed to multiple sine waves.
- It is useful to visualize a composite signal using the frequency of its composition (i.e., in **frequency domain** instead of time domain).

- A transmission medium only allows a frequency range to pass through.
- The difference in highest and lowest frequency that can pass through a medium is kown as the **bandwidth of the medium**.
- The difference in the highest and lowest frequency that represent a signal is known as the **bandwidth of the signal**.

- A transmission medium also introduces noise, which distorts the signal, limiting the number of bits that can go through.
- For an ideal, noiseless channel, the **Nyquist bit rate formula** gives the theorectical maximum bit rate:

$$2B \times log_2 L$$

where *B* is the channel bandwidth (in Hz) and *L* is the number of signal levels.

If we use Machester coding on a noiseless 1 MHz channel, the maximum data rate is 2 Mbps.

- For a noisy channel, characterized by a signal-to-noise ratio *SNR*, the theoretical maximum is given by **Shannon Capacity**

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

Phone line has a bandwidth of 3000 Hz and SNR of 3162. The capacity of the channel is 34860 bps.

- Let's revisit how FDM works on a medium with large enough bandwidth to support multiple signals.
- The signals' frequencies are shifted, added together, and transmitted.
- At the receiver, we filter out different frequency range, and shift the signal back to their original frequency.

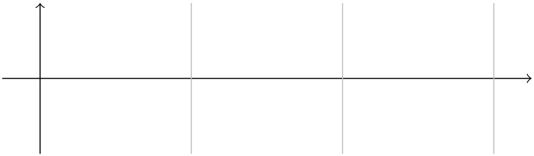
Frequency-Division Multiplexing

4-8kHz
8-12kHz
12-16kHz
16-20kHz

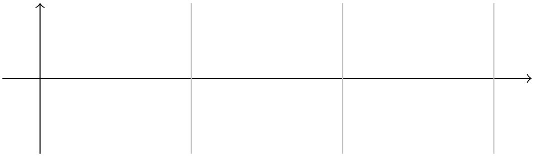
FDM

- To transmit 0s and 1s with an analog signal, we can change either A, f, or ϕ.
- Amplitude Shift Keying (ASK) changes peak amplitude to represent 0s and 1s.
- Frequency Shift Keying (FSK) changes frequency to represent 0s and 1s.
- Phase Shift Keying (PSK) changes phase to represent 0s and 1s.

ASK

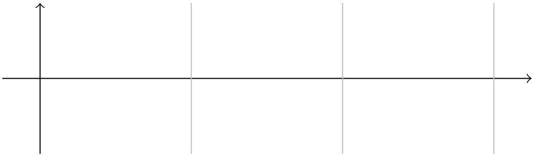


FSK

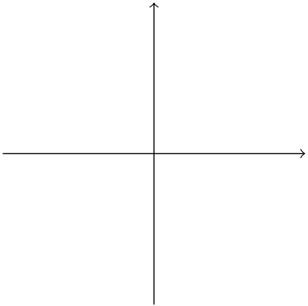


- ASK is vulnerable to noise.
- FSK is limited by bandwidth

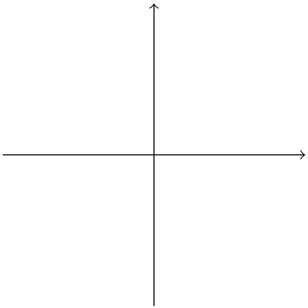
PSK



PSK constellation

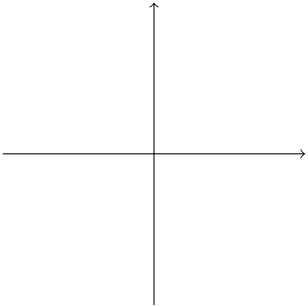


QPSK constellation

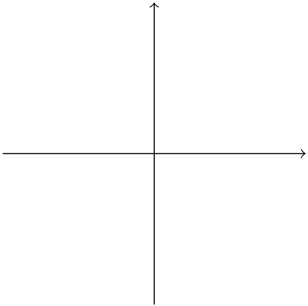


- Quadrature Amplitude Modulation (QAM) combines ASK and PSK. Many combinations are possible.
- A signal unit in a 2^k-QAM scheme is a combination of amplitude and phase that represents *k* bits.
- Baud rate is the number of signal units per second (unit is Bd).

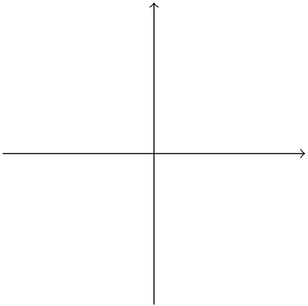
QPSK constellation



4-QAM



8-QAM



- Singapore TV broadcast uses DVB-T, which uses QPSK, 16-QAM, or 64-QAM.
- 802.11a uses BPSK, QPSK, 16-QAM or 64-QAM.
- Ethernet, RFID, and NFC use Machester coding.
- USB uses NRZ-I.