Encoding Information

- As we have seen earlier:
  - Information: Digital ↔ Analog
- In the same way:
  - Medium: Digital ↔ Analog
    - Digital: Twisted pair, coax
    - Analog: Fiber, wireless (and these days also twisted pair and coax)

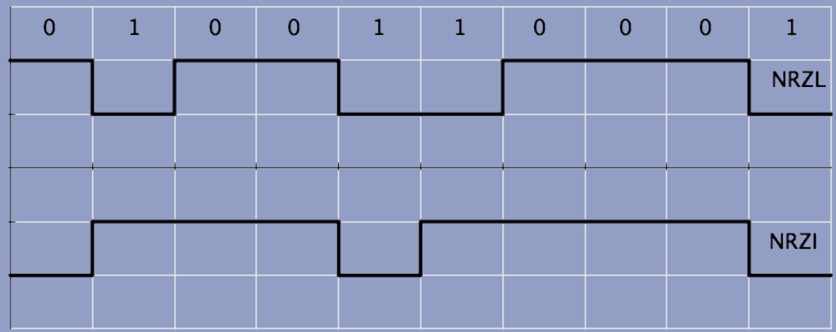
Encoding Information

- This results in 4 cases:

Information \ Medium	Digital	Analog
Digital	1	2
Analog	3	4

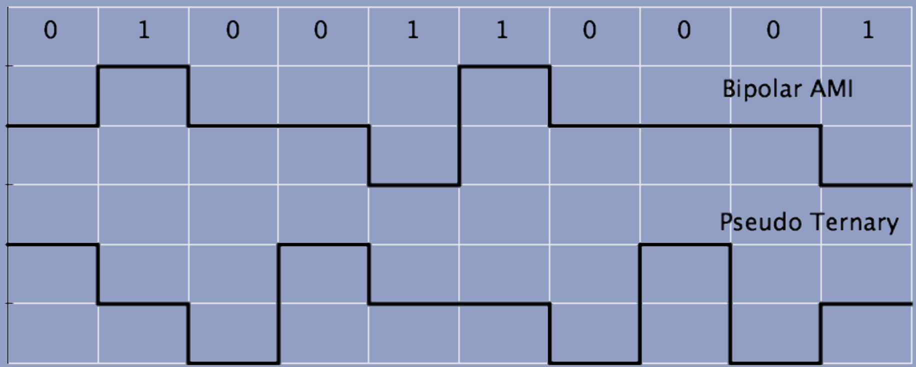
Case 1: NRZL

- Non Return to Zero Level (NRZL)
  - Transition of 0→1 and 1→0
- Non Return to Zero Invert
  - Transition on "ones"



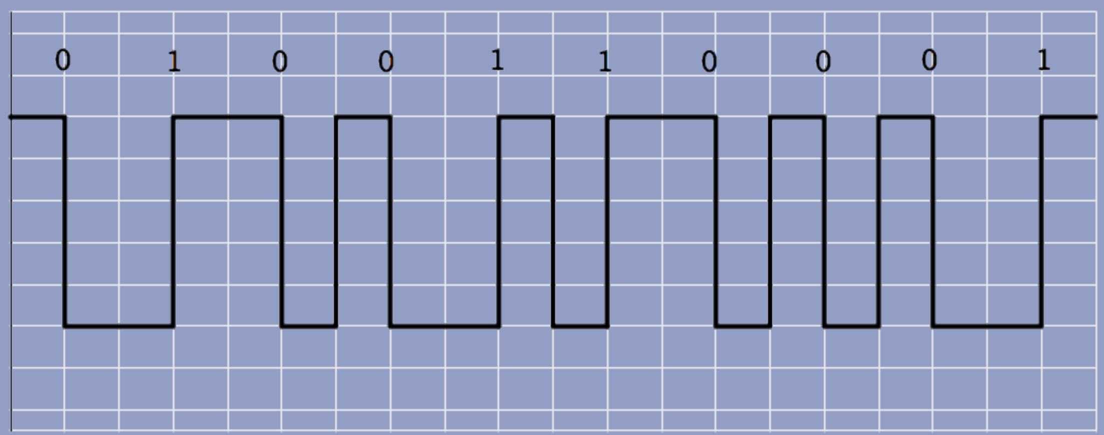
Case 1: Bipolar AMI and Pseudo ternary

- Alternate Mark Inversion
  - Bipolar AMI
    - Alternate on 1
  - Pseudo ternary
    - Alternate on 0



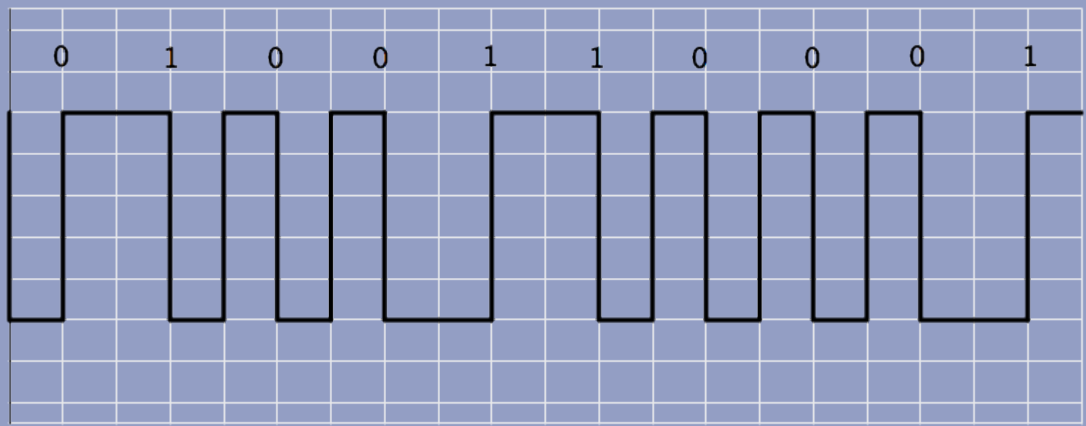
Case 1: Manchester

- Manchester: Transit in middle.
  - 1: L→H
  - 0: H→L



Case 1: Differential Manchester

- Differential Manchester
  - 0: Transition at the start
  - 1: No transition
  - Always transition in middle



Synchronization

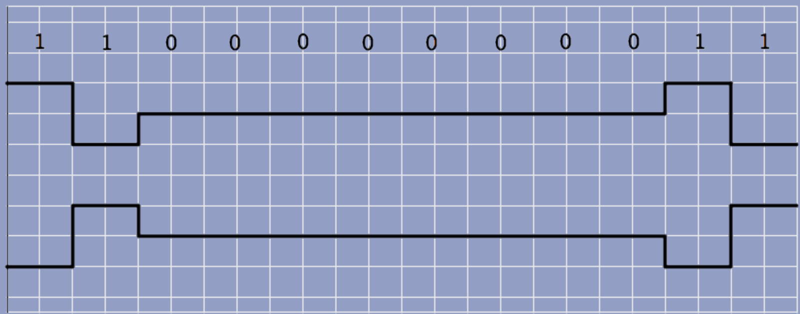
- Problem: Synchronisation! How to agree on when clock ticks occur for sender and receiver?
- Avoiding clock skew.

Synchronization

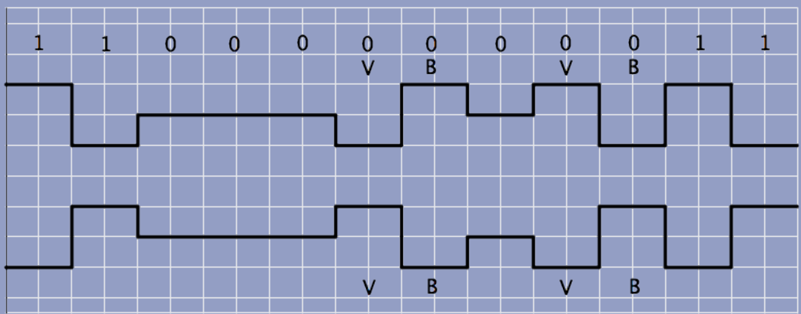
- Synchronisation:
  - NRZL: At long sequences of 0 or long sequences of 1.
  - NRZI: At long sequences of 0
  - Bipolar AMI: At long sequences of 0
  - Pseudo Ternary: At long sequences of 1

Scrambling

- For bipolar AMI the signal is scrambled



- B8ZS (bipolar 8-zero substitution): Substitute eight ‘0’ with:

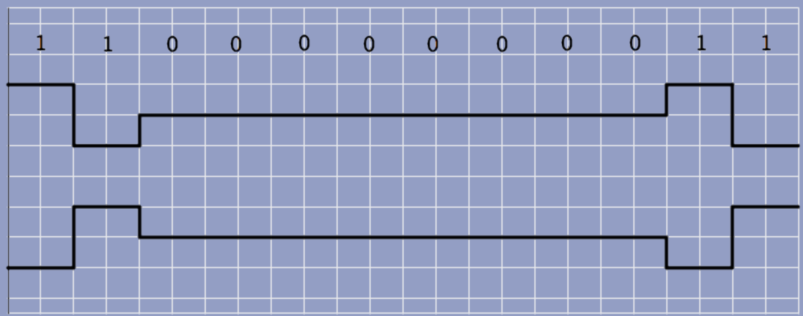


V: Violation

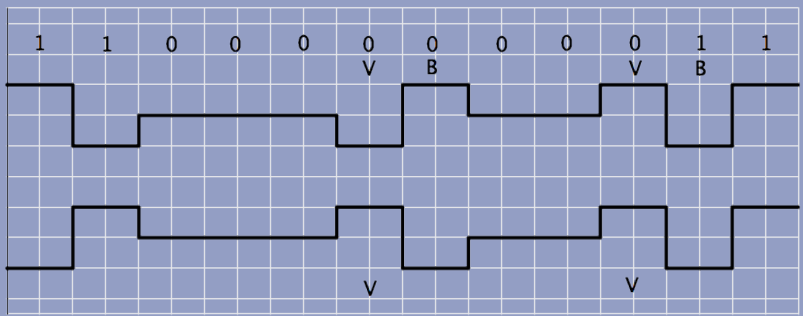
B: Balancing

Scrambling

- Bipolar AMI:



- HDB3 (High-Density Bipolar Order 3):



B8ZS and HDB3

- B8ZS: 00000000 $\rightarrow$ 000VB0VB
- HDB3: 0000 $\rightarrow$ 000V (if odd number of ones between) or B00V
- B needed to balance the current flow

Self clocked

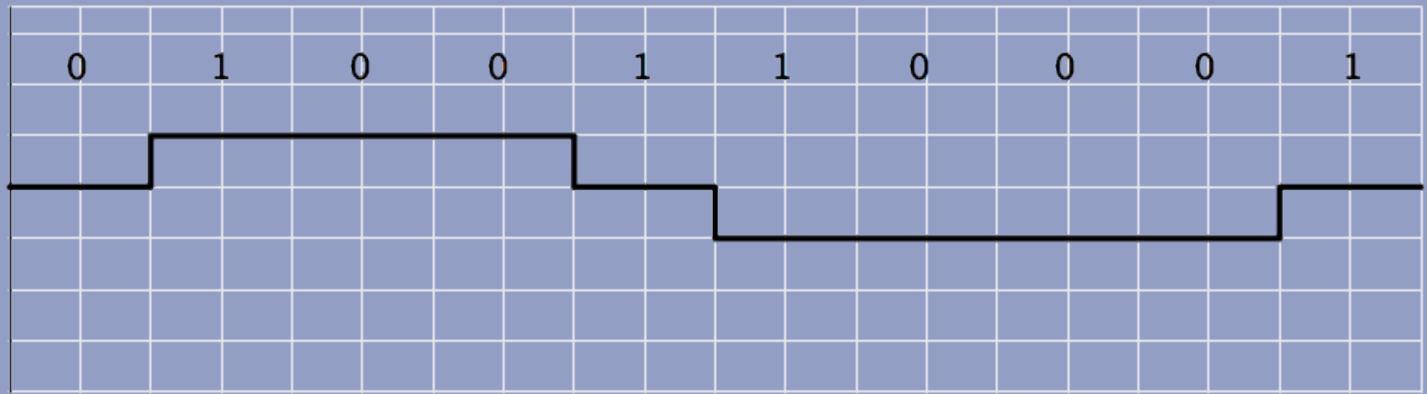
- Scrambling not possible on NRZL and NRZI.
- Manchester and differential manchester is self clocked but cost twice the bandwidth.

Fast Ethernet

- 10 Mbit/s Ethernet: Diff. Manchester.
- 100 Mbit/s Ethernet: Diff. Manchester not usable.
- STP/UTP(CAT5) $\leq 10^8$ Hz
    - Nyquist max 2×10^8 bps ~ 200 Mbit/s, but twice as many transitions needed, so max 100 Mbit/s. In practice lower!

MLT-3

- 100 Mbit/s Ethernet (100 BASE_TX) uses Multi Level Transmit, MLT-3 (NRZI-3)
- For 0, do nothing.
- For 1, transit + 0 - 0 + 0 - 0 + 0 - ...



MLT-3

- With MLT3, synchronization problem appears again.
- "Scrambling" done in different way.
  - Every group of 4 bits of data is transmitted as 5 bits so that there are at least two transitions per 5 bits.
  - Predetermined code words.

4b/5b

Data	4b/5b encoded
0000	11110
0001	01001
0010	10100
...	...
1101	11011
1110	11100
1111	11101

The 5 bit encoded data is transmitted using MLT3

Gigabit Ethernet

Basically five standards available, including 1000BASE-X for optical fiber and 1000BASE-T for twisted pair and 1000BASE-CX for Coax. More precisely:

Name	Medium	Specified distance
1000BASE-CX	Twin axial cabling	25 meters
1000BASE-KX	Copper backplane	1 meter
1000BASE-SX	Multi-mode fiber	220 to 550 meters
1000BASE-LX	Multi-mode fiber	550 meters
1000BASE-LX	Single-mode fiber	5 km
1000BASE-LX10	Single-mode fiber using 1,310 nm wavelength	10 km
1000BASE-EX	Single-mode fiber at 1,310 nm wavelength	~ 40 km
1000BASE-ZX	Single-mode fiber at 1,550 nm wavelength	~ 70 km
1000BASE-BX10	Single-mode fiber, over single-strand fiber: 1,490/1,310 nm	10 km
1000BASE-T	Twisted-pair cabling (Cat-5, Cat-5e, Cat-6, or Cat-7)	100 meters
1000BASE-TX	Twisted-pair cabling (Cat-6, Cat-7)	100 meters

10 Gigabit (10GE, 10GbE, or 10GigE) Ethernet also available but not for cat. 5e twisted pair 100m cabling

1000BASE-T

- All four copper wires are used at the same time
- Every 8 bits are split up in 4 groups of 3 bits ensuring enough transitions
- Every three bits are mapped to a voltage level, for example:

3 bits	voltage
000	0
001	+1
010	+2
011	-1
100	0
101	+1
110	-2
111	-1

- These mappings changed during transmission (preventing DC current)

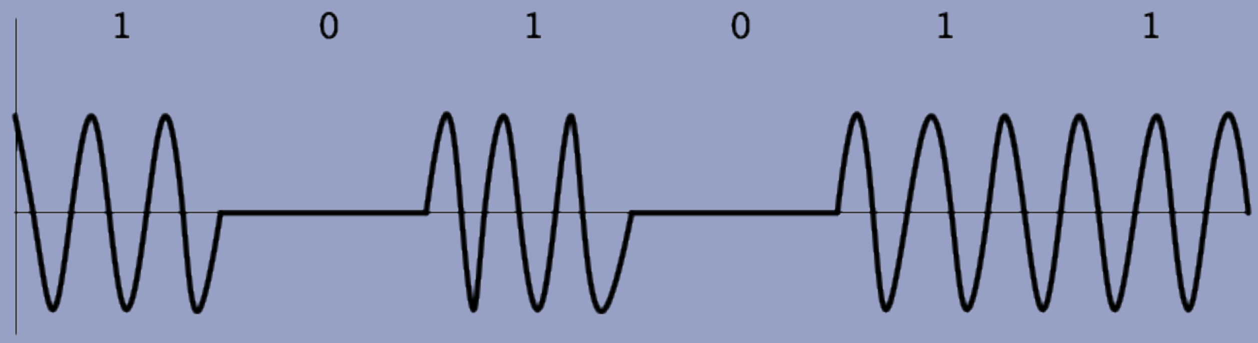
PAM-5 technique (Pulse Amplitude Modulation)

Case 2: Digital Data over Analog Medium

- Most common way to transmit digital data. Three primary techniques:
  - Amplitude shift keying (ASK)
  - Frequency shift keying (FSK)
  - Phase shift keying (PSK)
- Used when transmitting data over fiber, wireless and telephone lines.

ASK

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & 1 \\ 0 & 0 \end{cases}$$



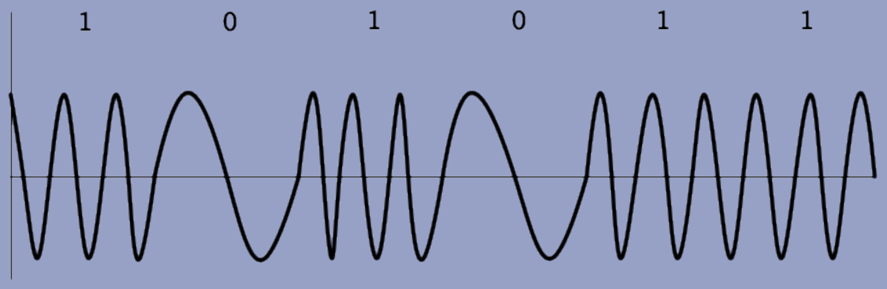
< 1200 bps on telephone lines

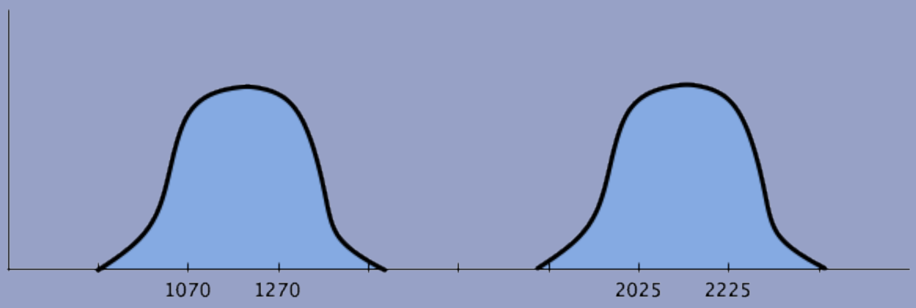
FSK

$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & 1 \\ A\cos(2\pi f_2 t) & 0 \end{cases}$$

< 1200 bps on telephone lines
full duplex possible:
→1070 & 1270 Hz
←2025 & 2225 Hz

f_1 and f_2 are offsets to a carrier



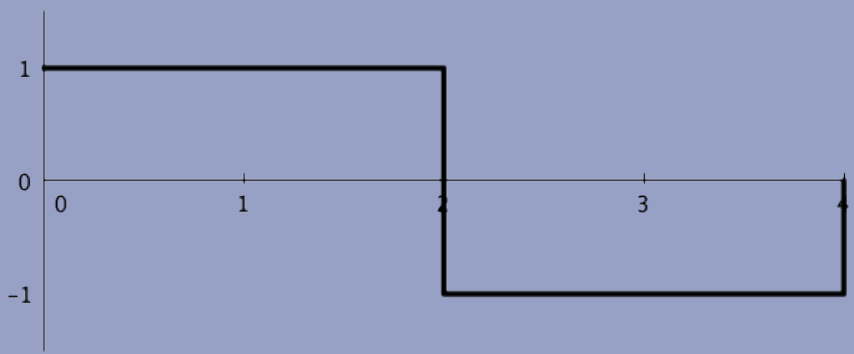


Spectrum

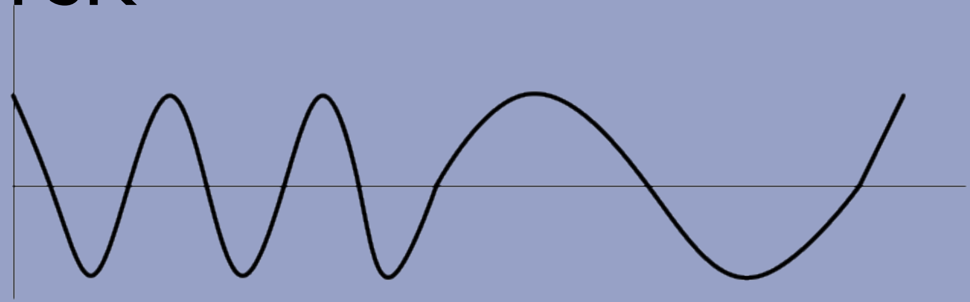
PSK

$$s(t) = \begin{cases} A\cos(2\pi f_c t + \pi) & 1 \\ A\cos(2\pi f_c t) & 0 \end{cases}$$

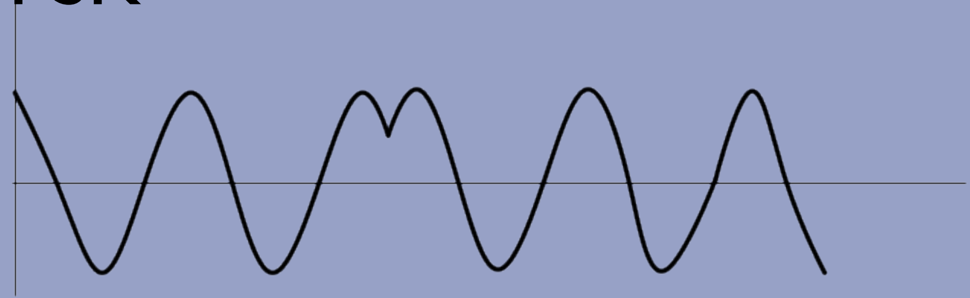
FSK & PSK example (1/3)



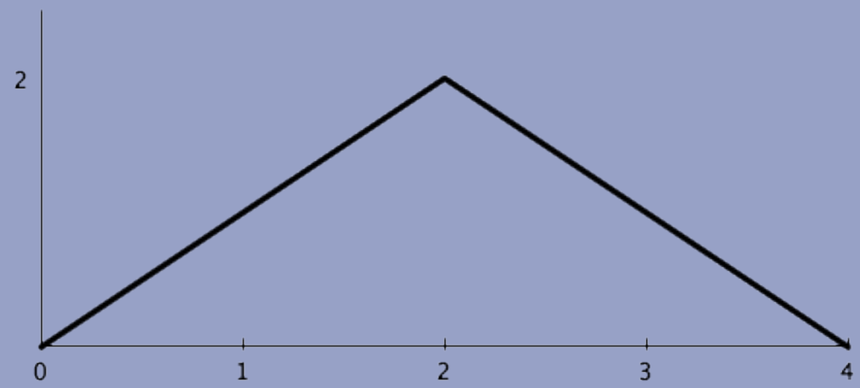
FSK



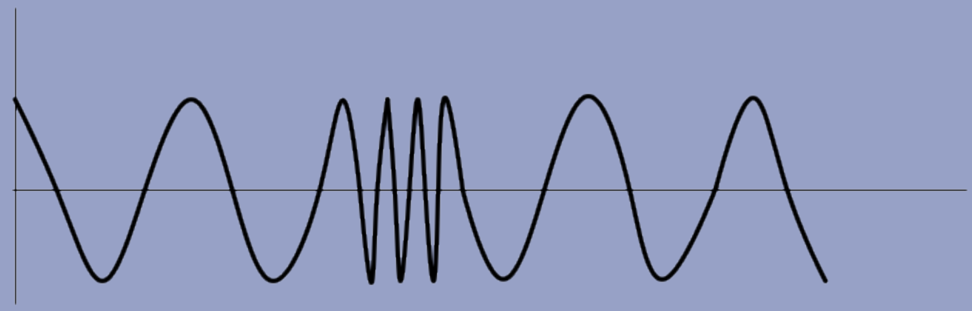
PSK



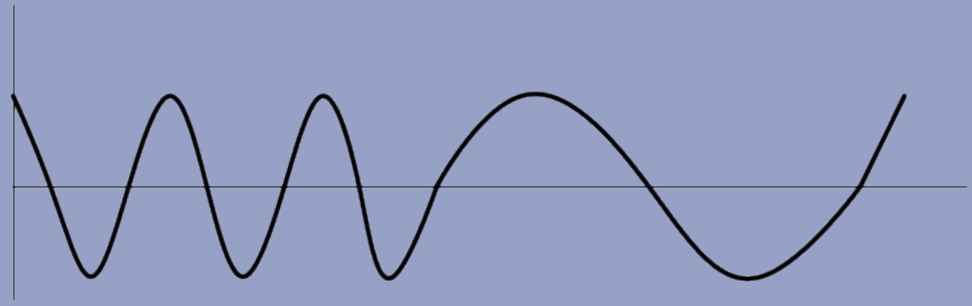
FSK & PSK example (2/3)



FSK



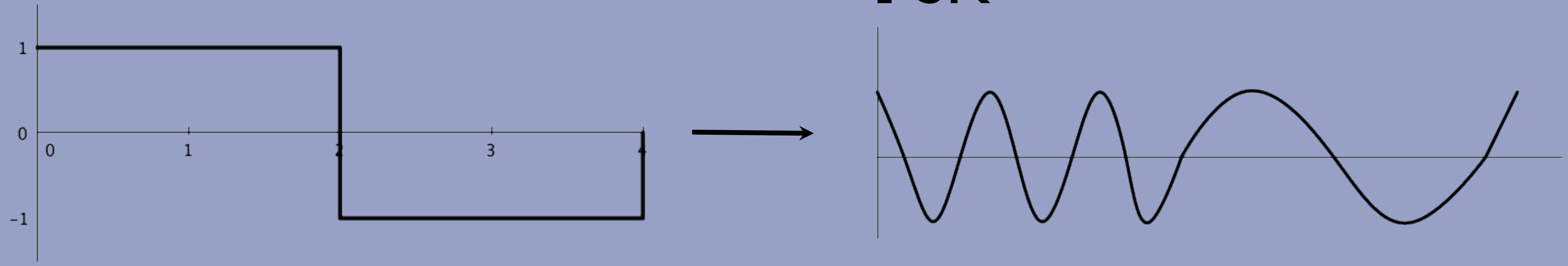
PSK



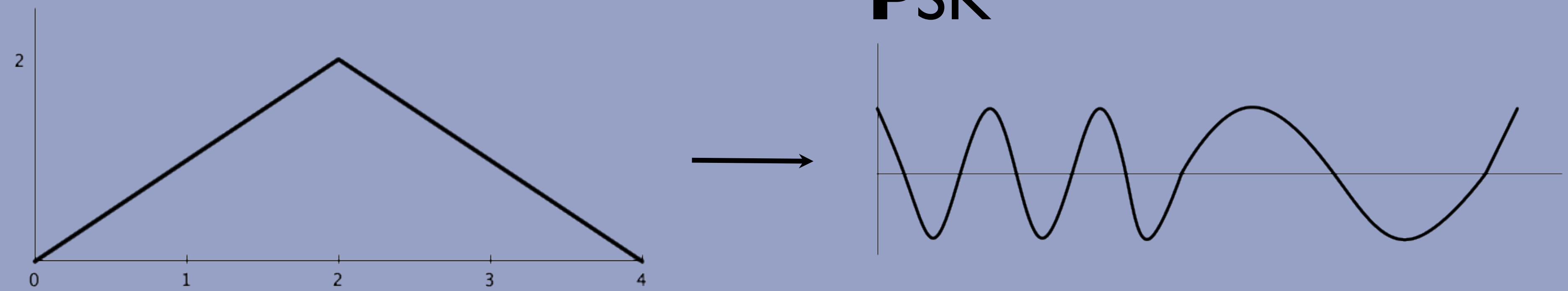
FSK & PSK example (3/3)

Note the following:

FSK



PSK



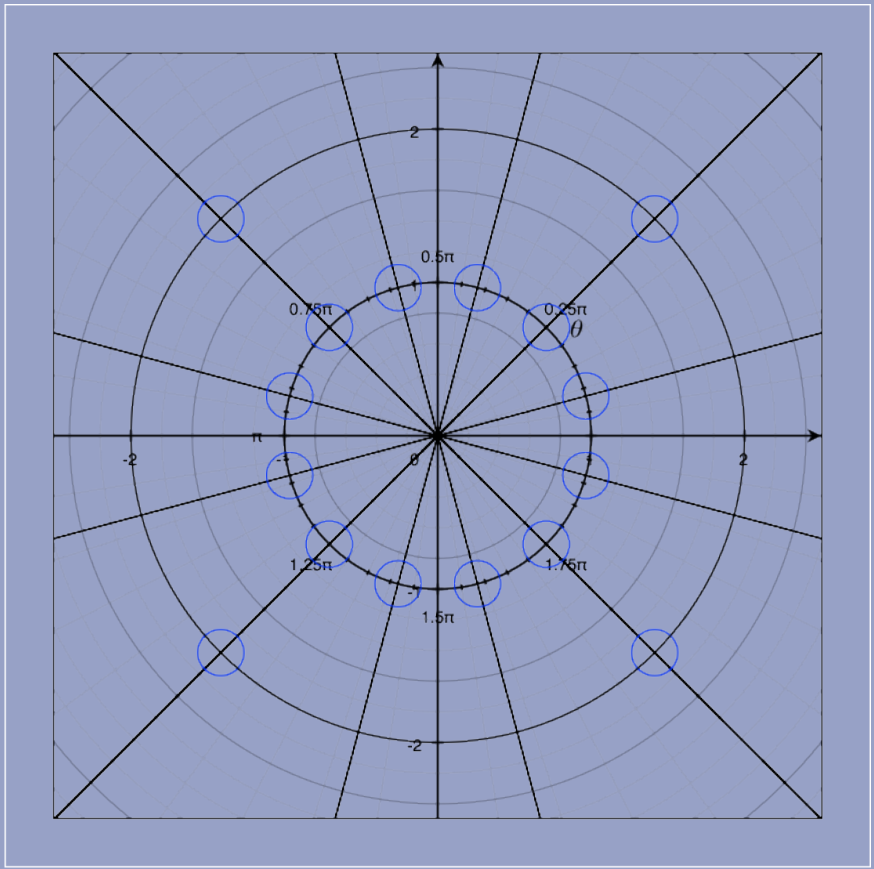
QPSK

Used for phone lines (modems and ADSL) when frequency > 1200 bps.

$$s(t) = \begin{cases} A\cos(2\pi f_c t + \pi/4) & 11 \\ A\cos(2\pi f_c t + 3\pi/4) & 10 \\ A\cos(2\pi f_c t + 5\pi/4) & 00 \\ A\cos(2\pi f_c t + 7\pi/4) & 01 \end{cases}$$

QPSK (2)

Include Amplitude Modulation

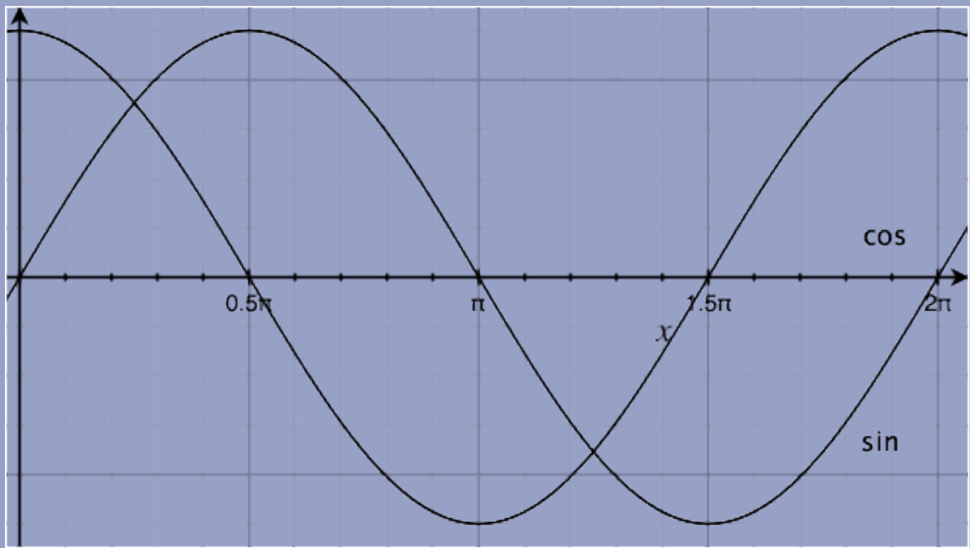


Total of 16 points = 4 bits

QAM (1)

QAM (quadratic amplitude modulation)
Higher bit rates possible

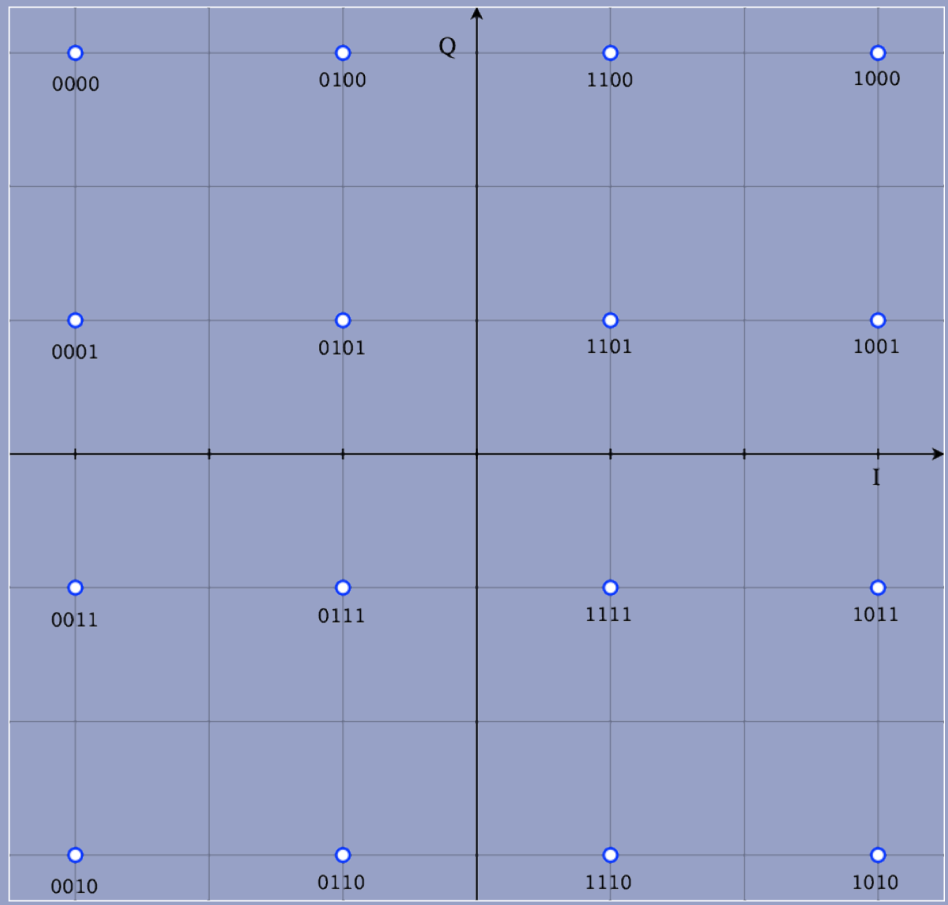
$$s(t) = I(t)\ \cos(2\pi f_c t) + Q(t)\ \sin(2\pi f_c t)$$



Sufficiently different in phase so that I(t) and Q(t) can be isolated.

QAM (2)

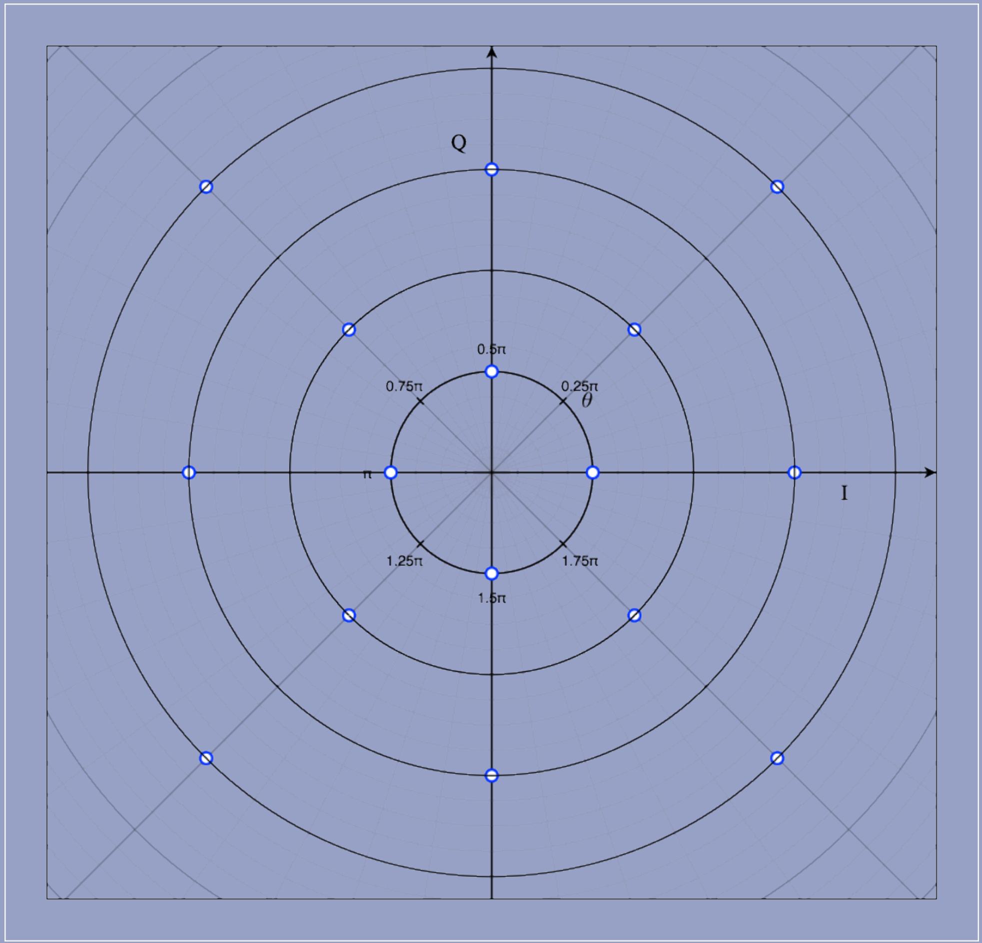
16-QAM



Rectangular constellation

QAM (3)

Circular 16-QAM



Circular constellation

QAM (3)

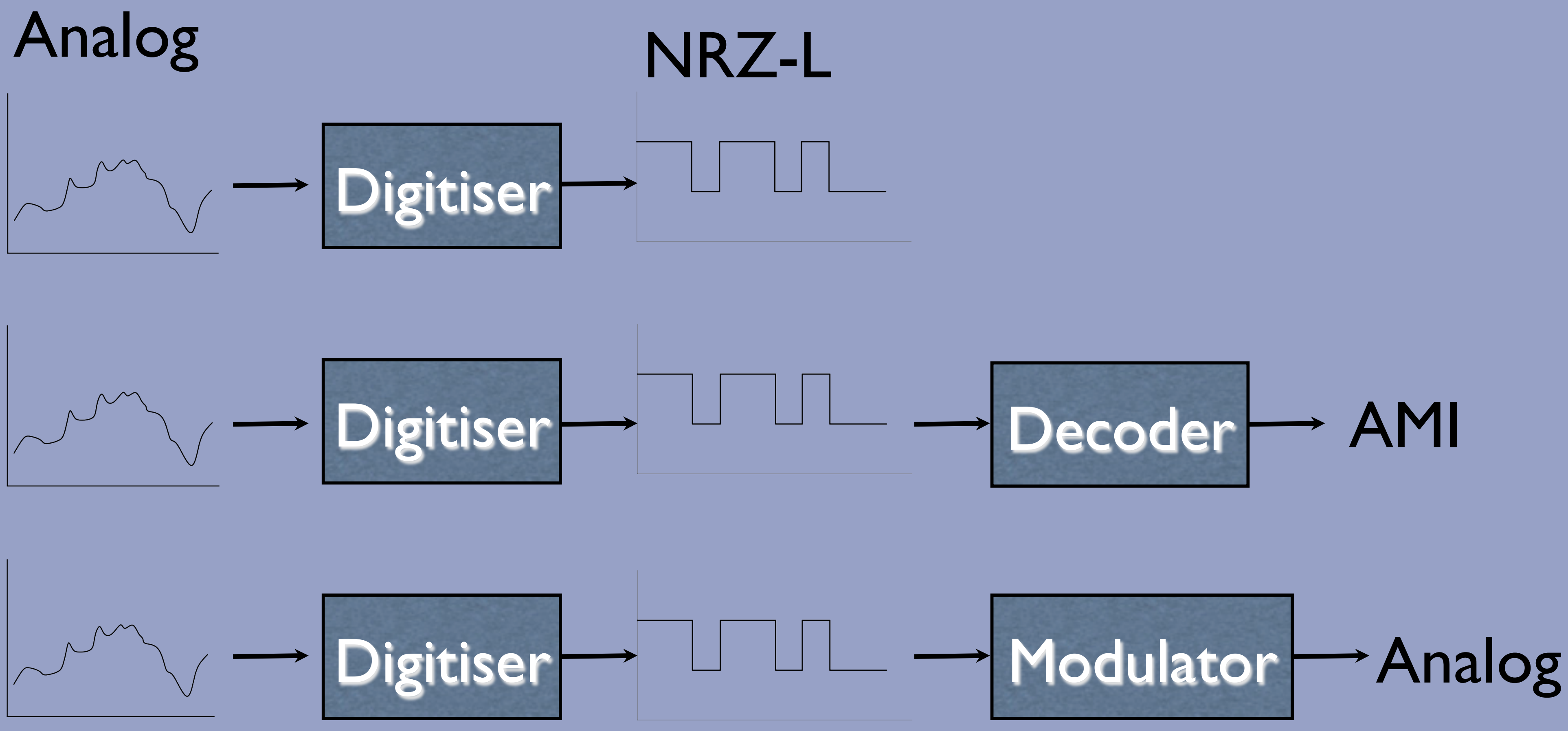
- Infinite possibilities with different characteristic
  - Error sensitivity
- Circular constellation better, but harder to modulate and demodulate, than rectangular constellation.

Case 3: Analog Data over Digital Medium

Two reasons

1. Nothing else possible, available medium is digital.
2. Preventing errors.

Case 3: Analog Data over Digital Medium

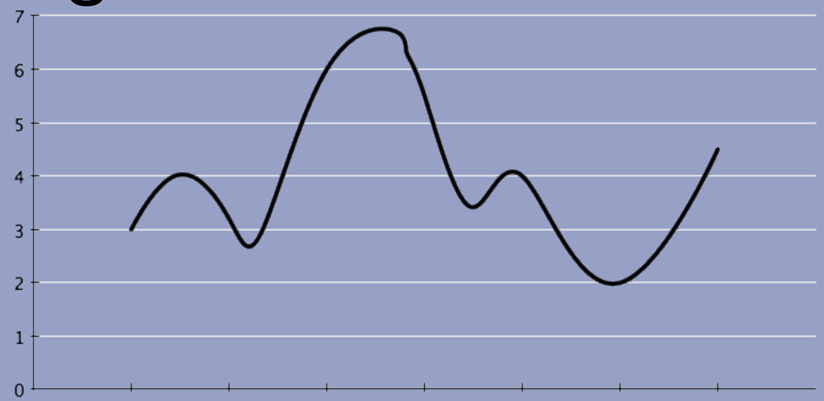


Digitisers

- Pulse Code Modulation (PCM)
- Delta Modulation (DM)

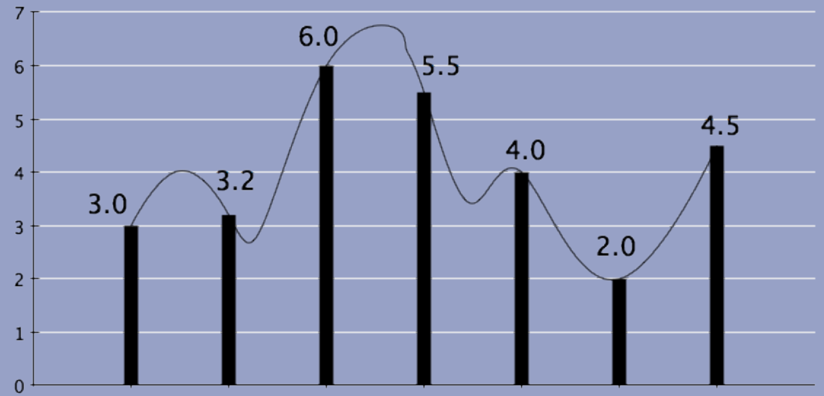
PCM (1/2)

Signal



Bandwidth: B

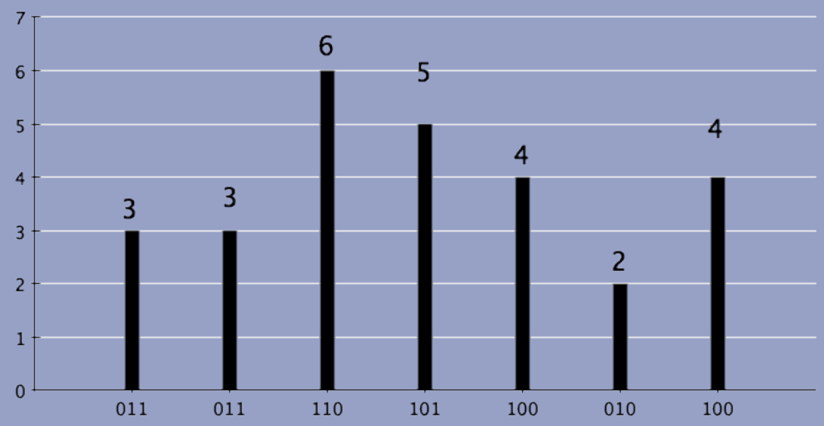
Pulse Amplitude Modulation



Sampling Rate: 2B

PCM (2/2)

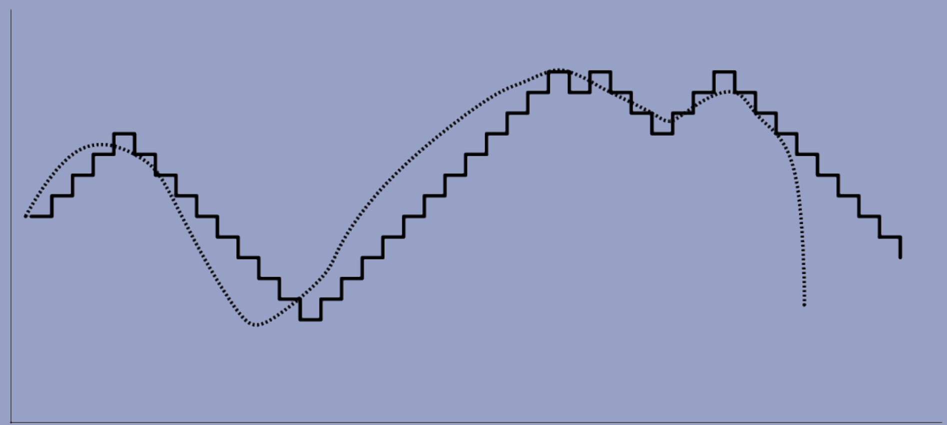
Approximate amplitude with n bits (e.g. n = 3)

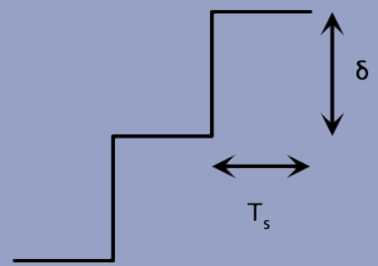


Output: 011011110101100010100...

Delta Modulation

(More efficient than PCM)





T_s: sample time

δ step up: 1
δ step down: 0

Example: Voice 4 kHz

PCM

- 8000 samples/s
- 128 quant. levels: 7 bits
- 56 kbps
- (Nyquist) 28 kHz

DM

- 8000 samples/s
- 1 bit/sample
- 8 kbps
- (Nyquist) 4 kHz

Digital Transmission

Advantages:

- Repeaters instead of amplifiers (more exact)
- Time Division Multiplexing (TDM) instead of Frequency Division Multiplexing (FDM) (less inter modular noise)
- Digital switching technology is more advanced.

Case 4: Analog Data Over Analog Medium

Using AM (Amplitude Modulation), FM (Frequency Modulation) and PM (Phase Modulation), comparable to ASK, FSK and PSK

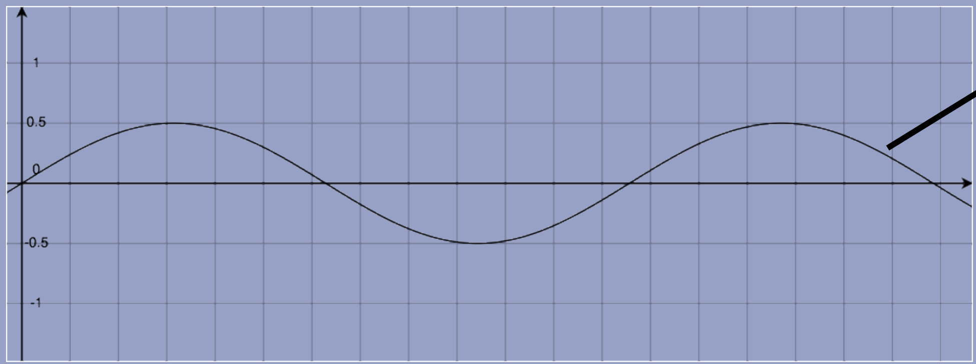
Amplitude Modulation (AM)

$s(t) = [1 + n_a\, x(t)] \cos(2\pi f_c t)$

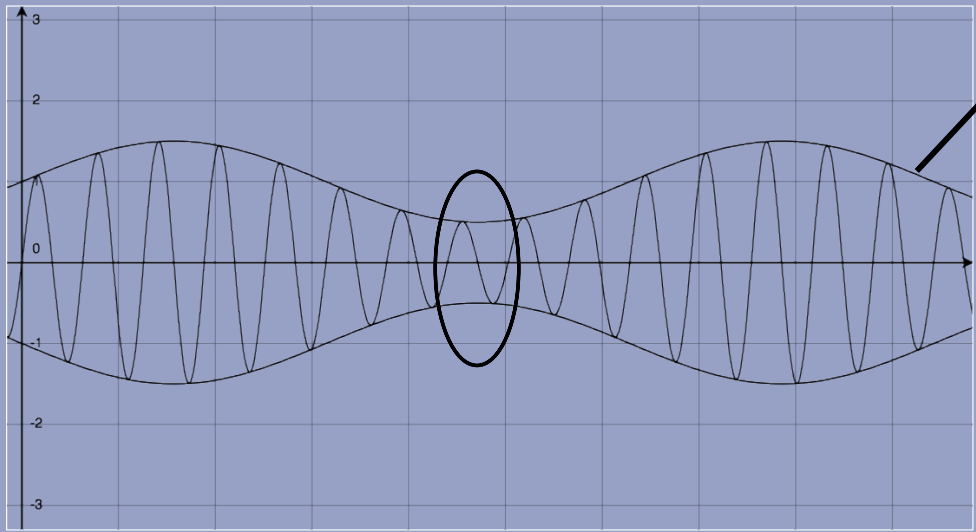
$x(t)$: the signal

$m(t) = n_a\, x(t)$: normalized $x(t)$ so that:
$|n_a\, x(t)| < 1, \ \forall t$

AM



m(t)

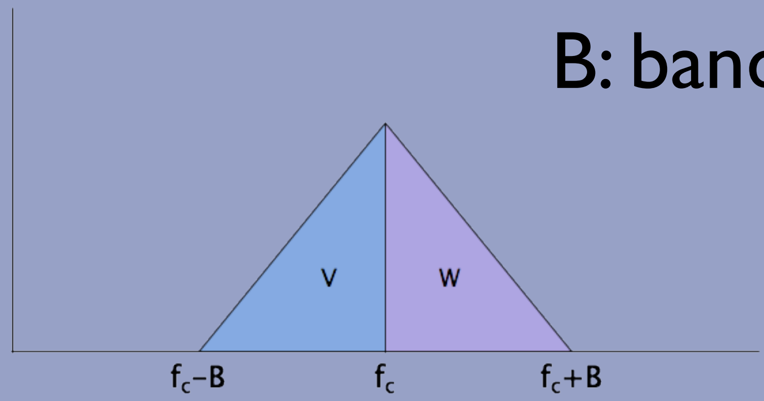


$1+n_a(t)$

Normalisation needed

AM

Spectrum:



B: bandwidth of x(t)

V≡W, so all frequencies between f_c-B and f_c can be filtered away.

Single Sided Band (SSB) instead of Double Sided Band Transmitter Carrier (DSBTC)

Frequency and Phase Modulation (FM & PM)

$s(t)=A\cos(2\pi f_c t + \phi(t))$

$\phi(t)$: angle modulation

- PM: $\phi(t) = n_p \times m(t)$
- FM: $\phi'(t) = n_f \times m(t)$

Thus with PM, the phase change in s(t) is proportional with the change in m(t) (x(t)), for FM, m(t) is proportional with the frequency change.

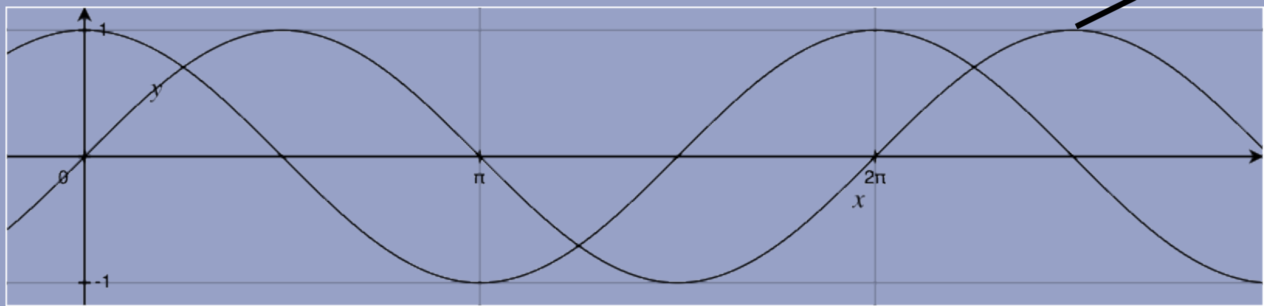
FM & PM

Change in frequency of s(t):

$$\frac{d}{dt}[2\pi f_c + \varphi(t)] = 2\pi f_c + \varphi'(t)$$

For:

m(t)=sin(t)



PM: ϕ (t) = ... sin(t)
FM: ϕ (t) = ... cos(t)

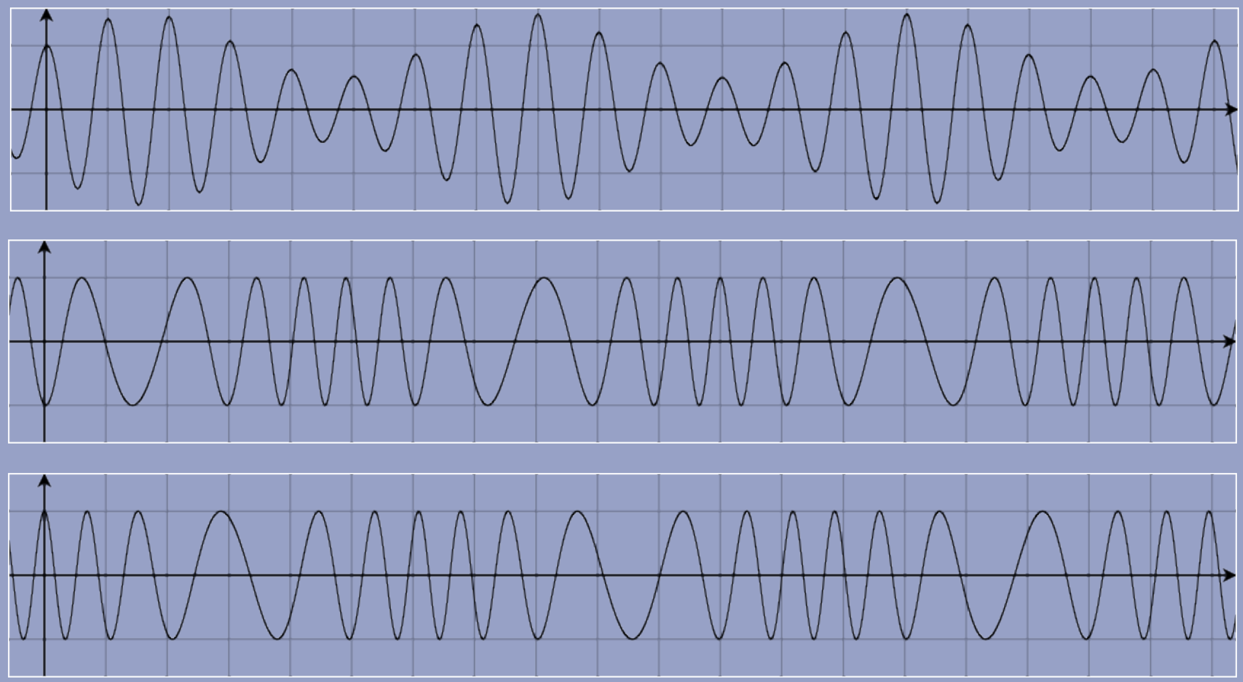
$$\frac{d}{dt}cos(t) = sin(t)$$

FM & PM

AM

FM

PM



Thus, PM is shifted FM in the case x(t) is a sine wave. See also the PSK/FSK relation.