

Encoding Information

As we have seen earlier:

Information: Digital $\leftrightarrow$ Analog

In the same way:

Medium: Digital $\leftrightarrow$ Analog

- Digital: Twisted pair, coax
- Analog: Fiber, wireless (and these days also twisted pair and coax)

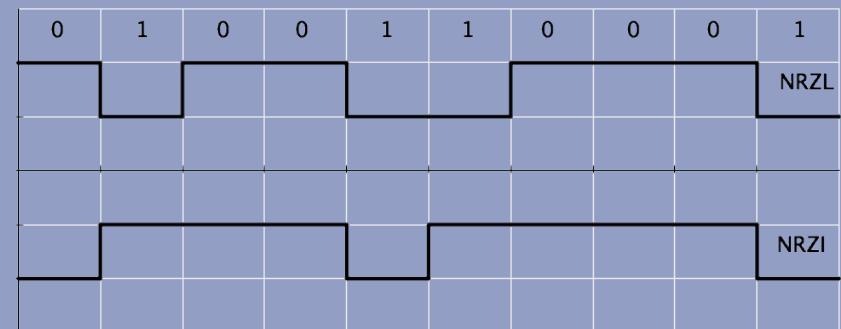
Encoding Information

- This results in 4 cases:

Information \ Medium	Digital	Analog
	Digital	Analog
Digital	1	2
Analog	3	4

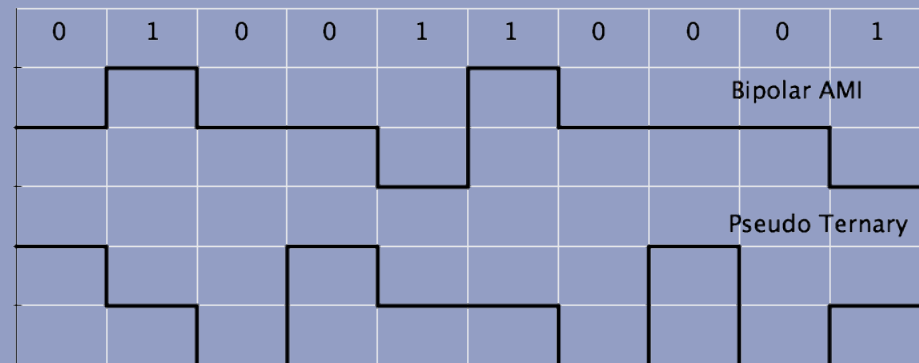
Case I: NRZL

- Non Return to Zero Level (NRZL)
- Transition of $0 \rightarrow 1$ and $1 \rightarrow 0$
- Non Return to Zero Invert
- Transition on “ones”



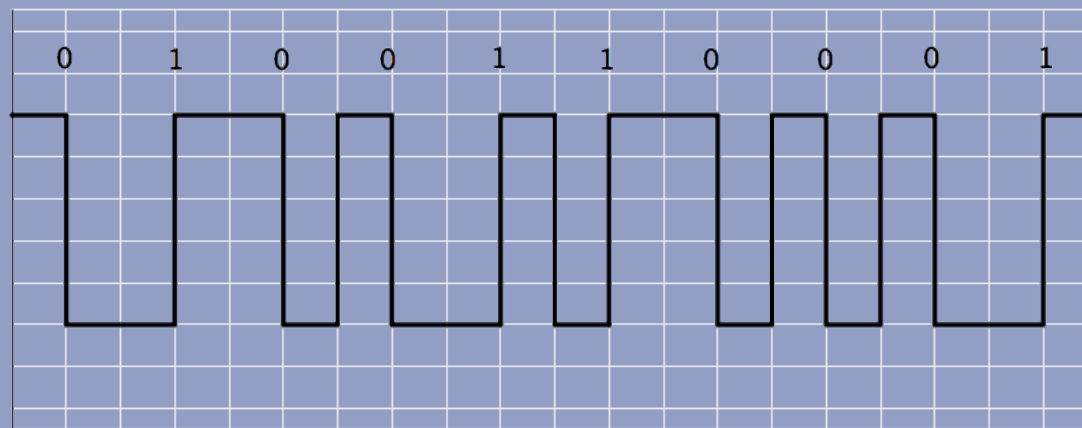
Case I: Bipolar AMI and Pseudo ternary

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



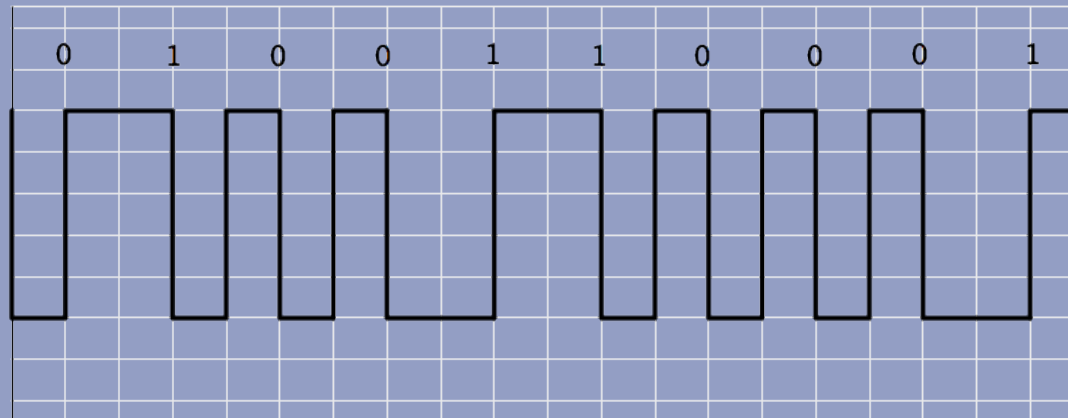
Case I: Manchester

- Manchester: Transit in middle.
 - 1: L $\rightarrow$ H
 - 0: H $\rightarrow$ L



Case I: Differential Manchester

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



Synchronization

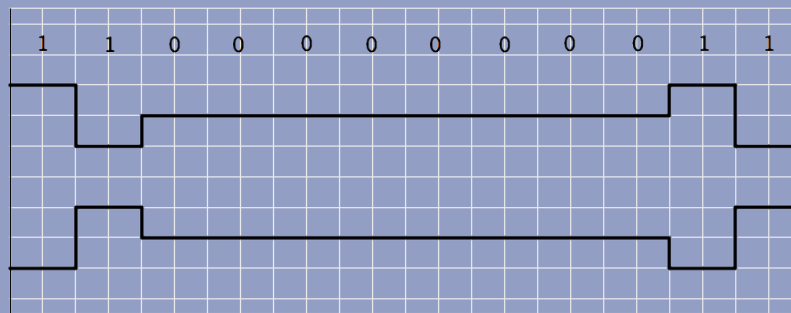
- Problem: Synchronisation! How to agree on when clock ticks occur for sender and receiver?
- Avoiding clock skew.

Synchronization

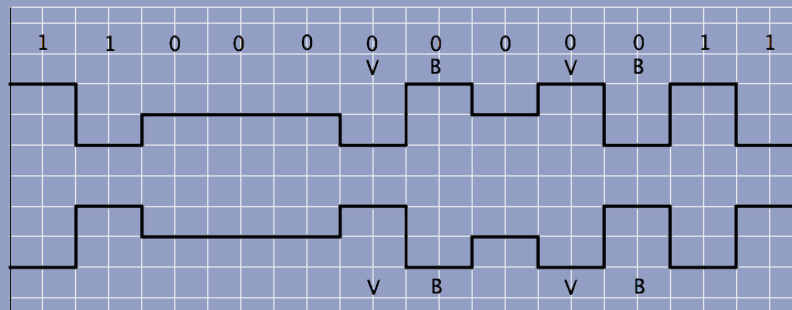
- Synchronisation:
 - NRZL: At long sequences of 0 or long sequences of 1.
 - NRZI: At long sequences of 0
 - Bipolar AMI: At long sequences of 0
 - Pseudo Ternary: At long sequences of 1

Scrambling

- For bipolar AML the signal is scrambled



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

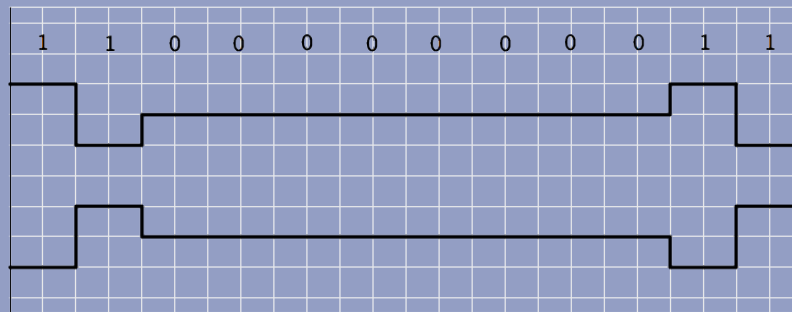


V: Violation

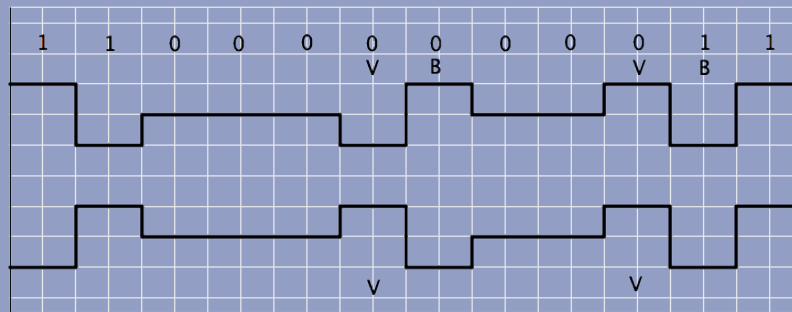
B: Balancing

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

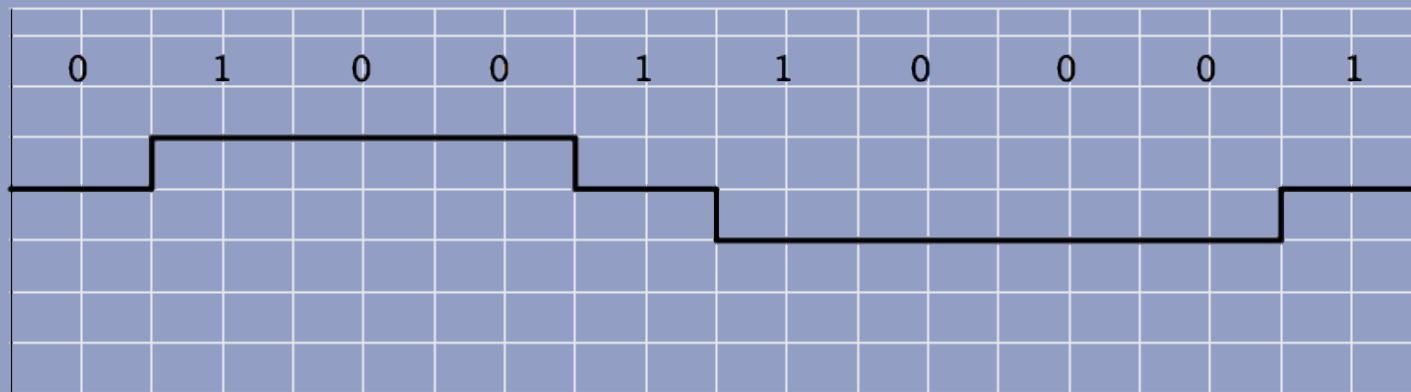
- Scrambling not possible on NRZL and NRZI.
- Manchester and differential manchester is self clocked but cost twice the bandwidth.

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
- Each group represents 2 bits giving 4 valid three bit combinations
- 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 change during transmission (preventing DC current)

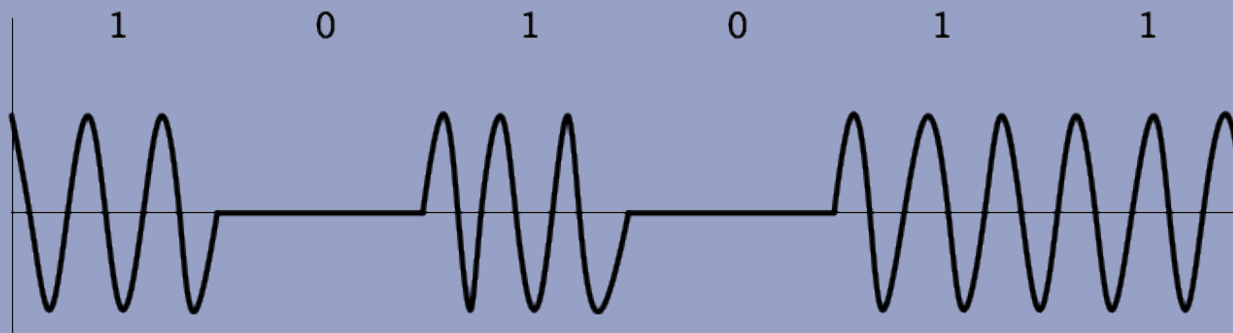
PAM-5 technique (Pulse Amplitude Modulation)

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

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



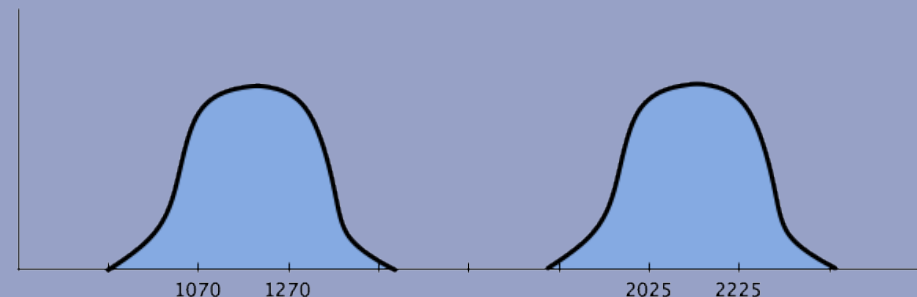
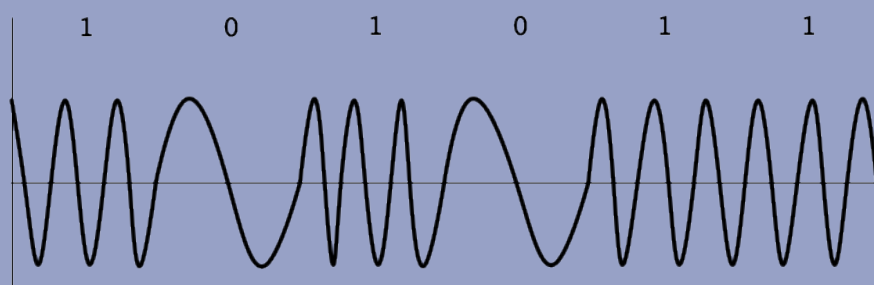
< 1200 bps on telephone lines

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



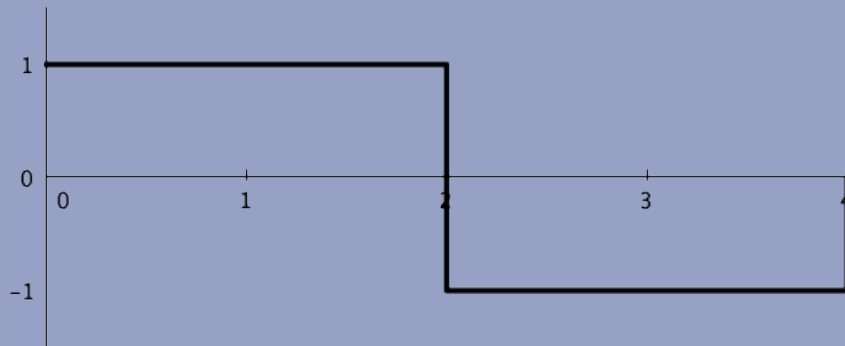
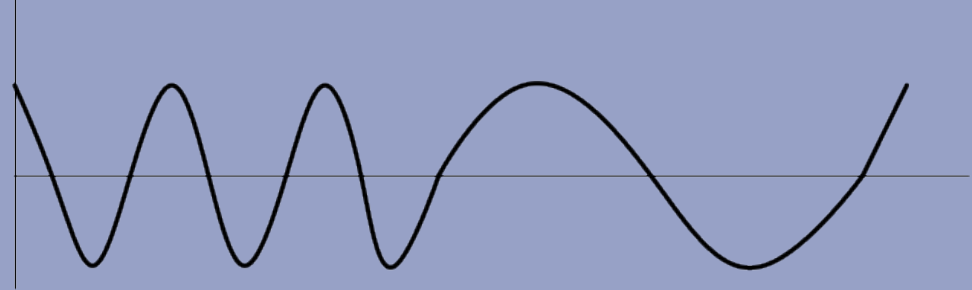
Spectrum

PSK

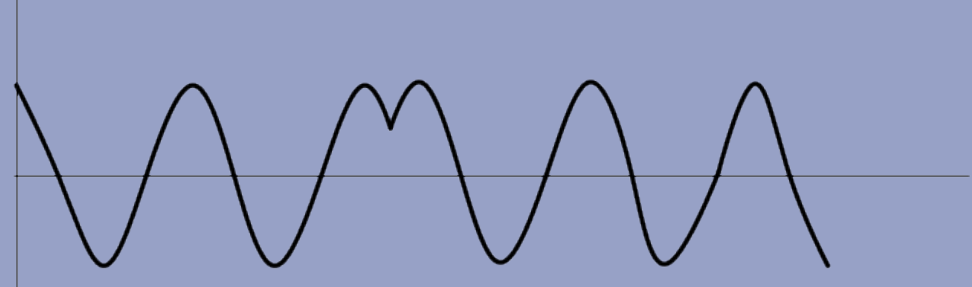
$$s(t) = \begin{cases} A \cos(2\pi f_c t + \pi) & 1 \\ A \cos(2\pi f_c t) & 0 \end{cases}$$

FSK & PSK example (1/3)

FSK



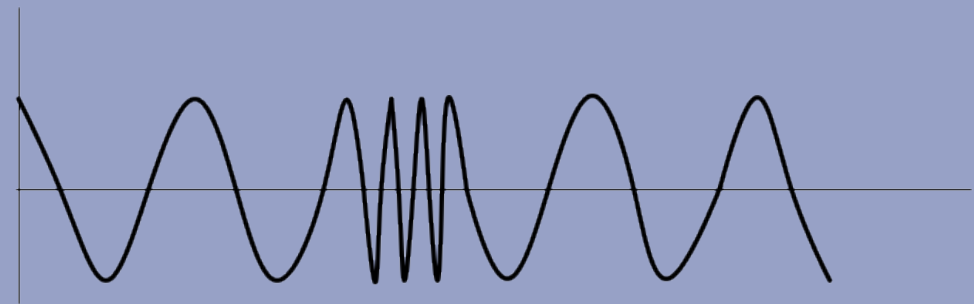
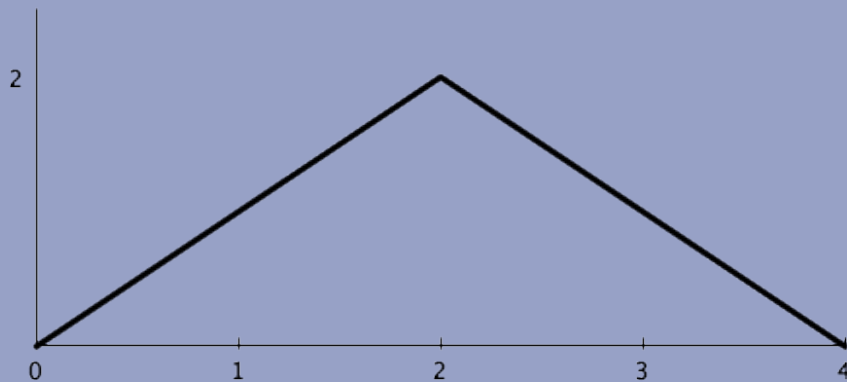
PSK



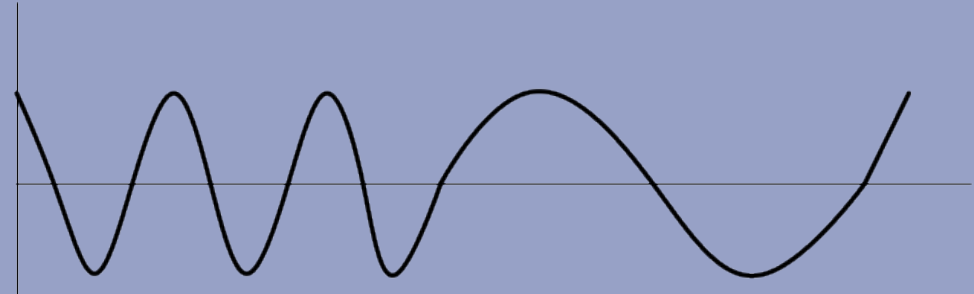
FSK & PSK example

(2/3)

FSK

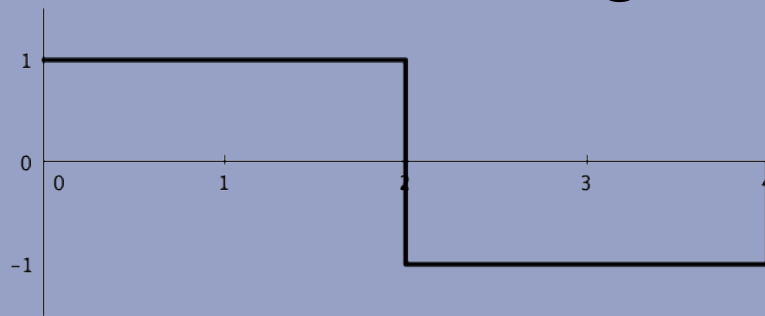


PSK

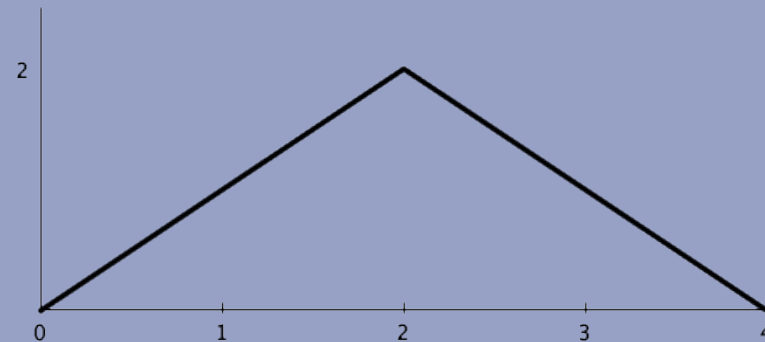
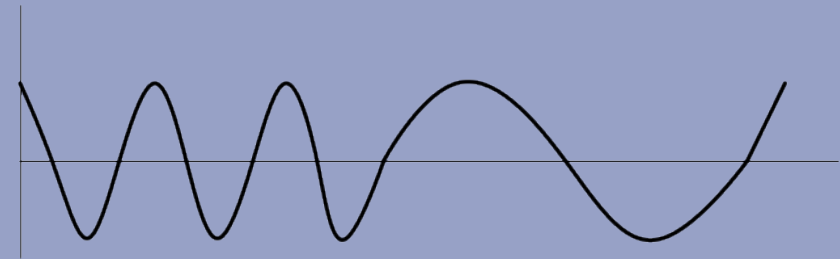


FSK & PSK example (3/3)

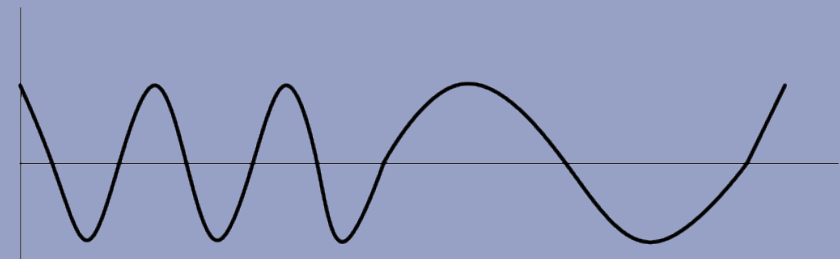
Note the following:



FSK



PSK



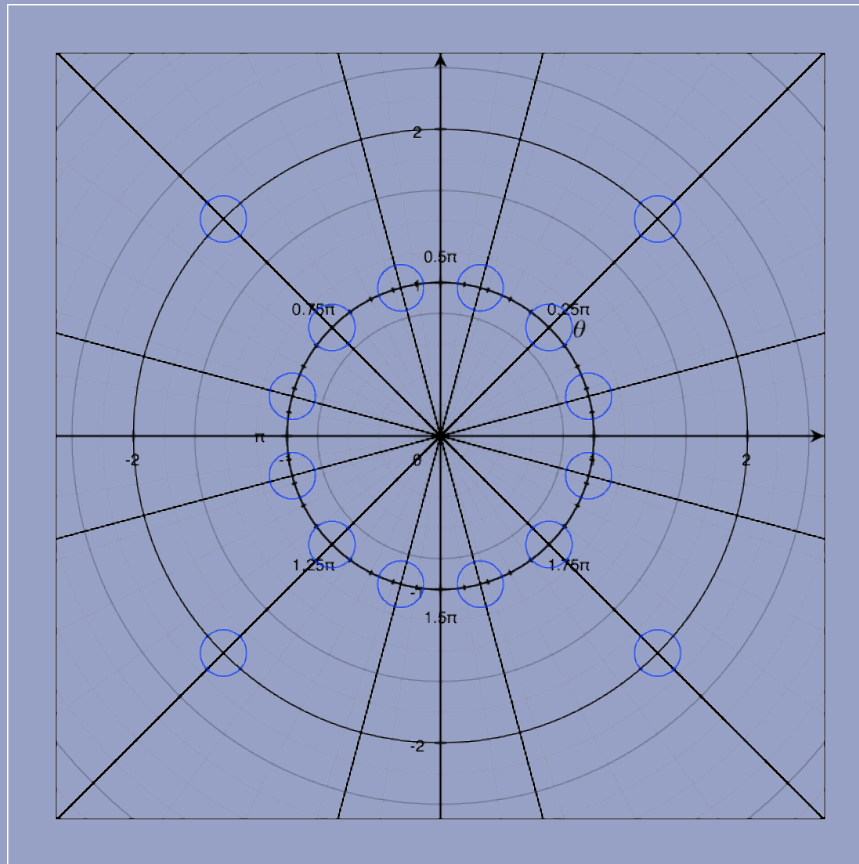
QPSK

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

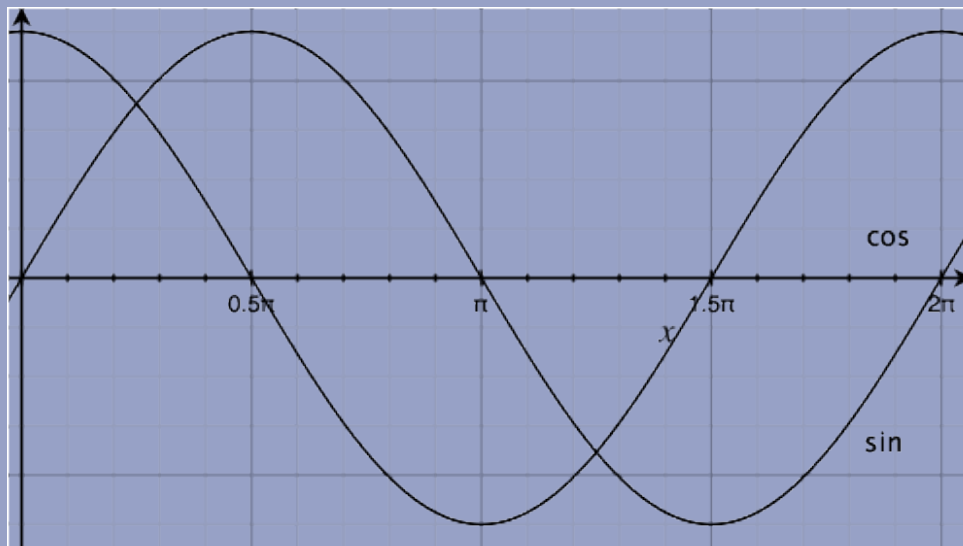


Total of 16 points = 4 bits

QAM (I)

QAM (quadrature amplitude modulation)
Higher bit rates possible

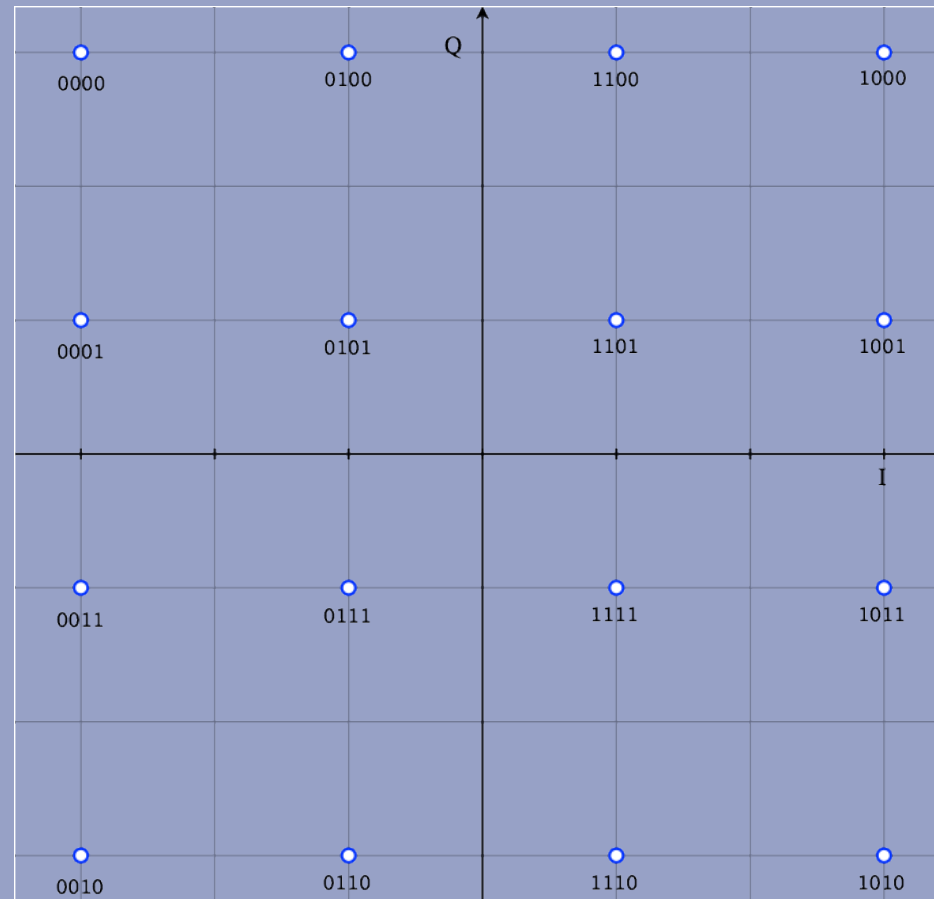
$$s(t) = I(t) \cos(2 \pi f_c t) + Q(t) \sin(2 \pi f_c t)$$



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

QAM (2)

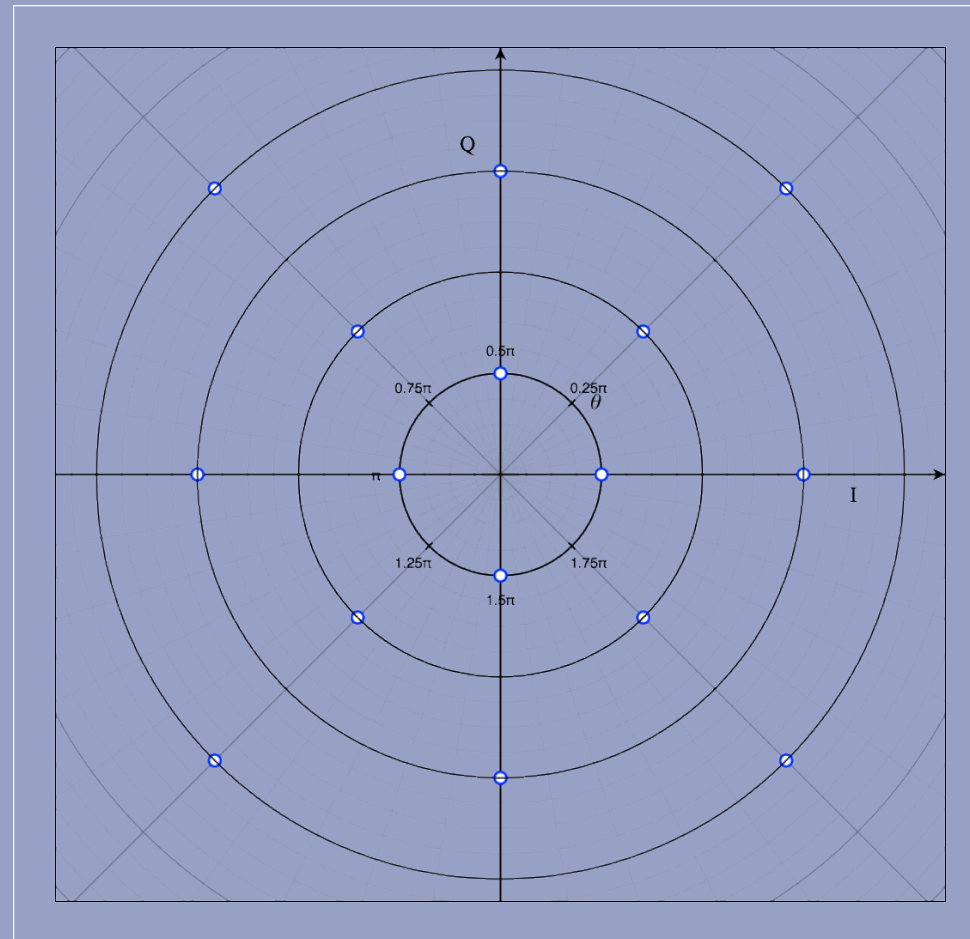
16-QAM



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

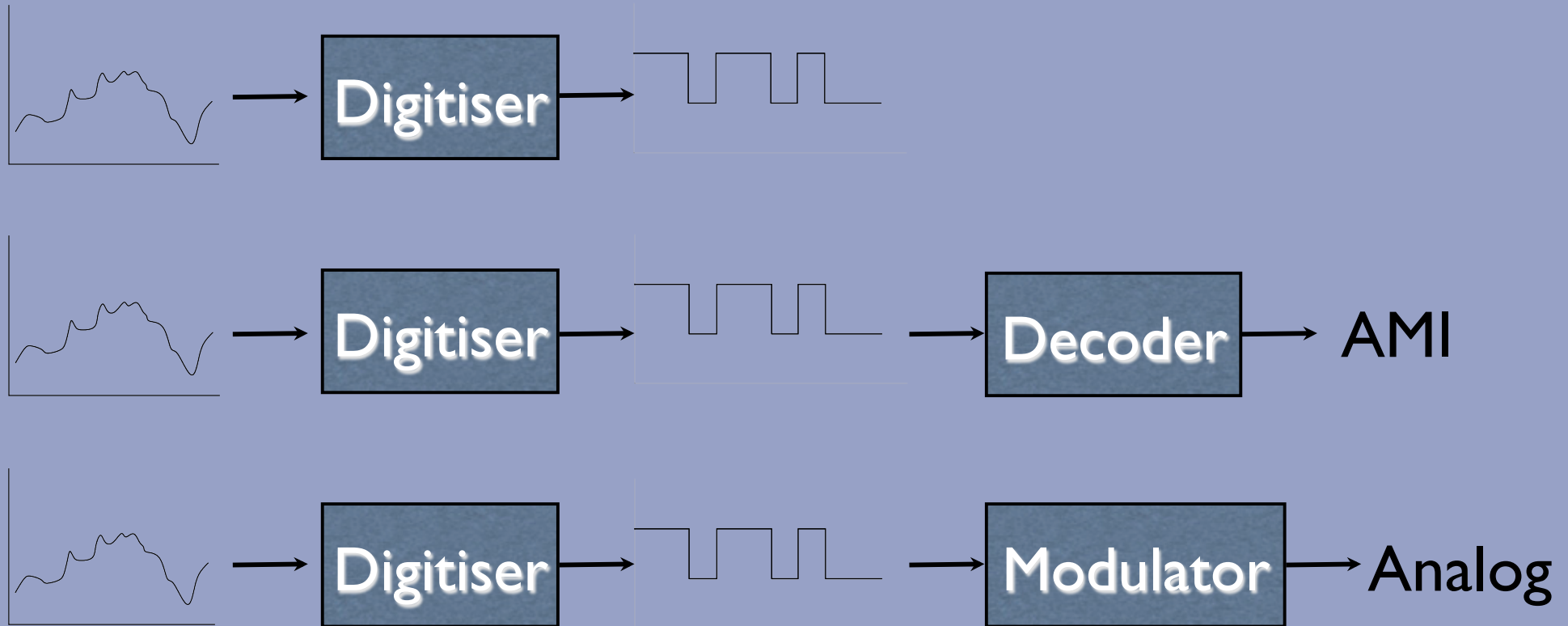
Two reasons

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

Case 3: Analog Data over Digital Medium

Analog

NRZ-L

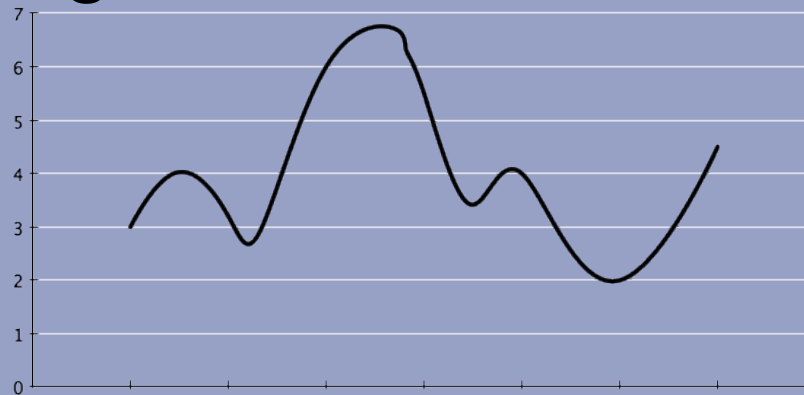


Digitisers

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

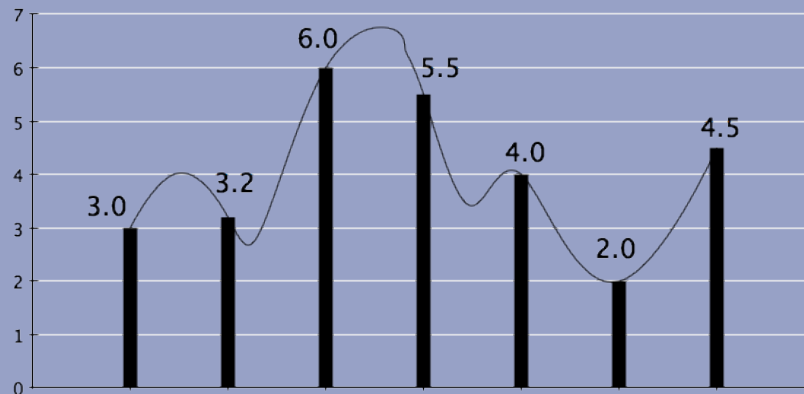
PCM (1/2)

Signal



Bandwidth: B

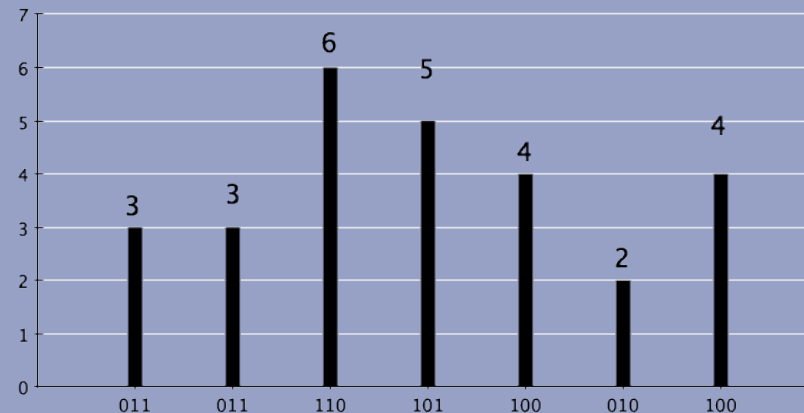
Pulse Amplitude Modulation



Sampling Rate: $2B$

PCM (2/2)

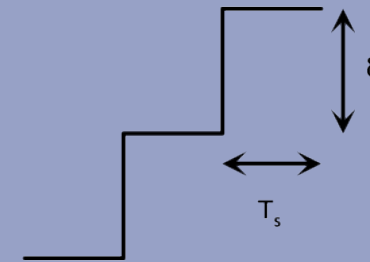
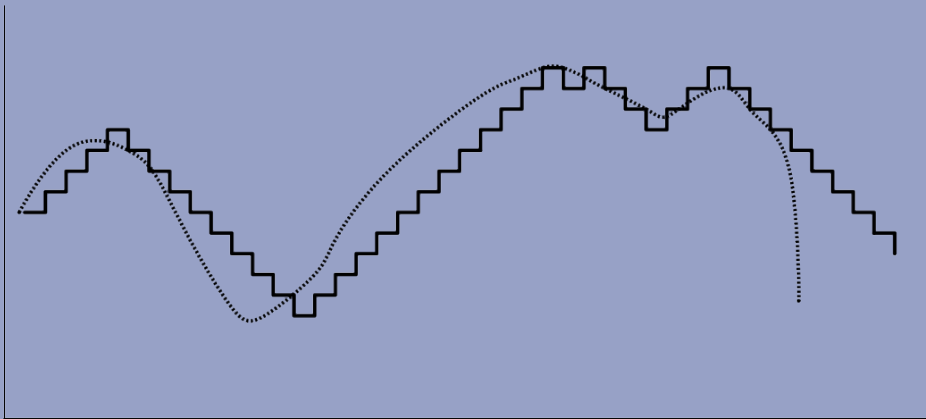
Approximate amplitude with n bits (e.g. n = 3)



Output: 0 | 1 0 | 1 | 1 | 1 0 | 0 | 1 0 0 0 | 0 | 1 0 0 ...

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)

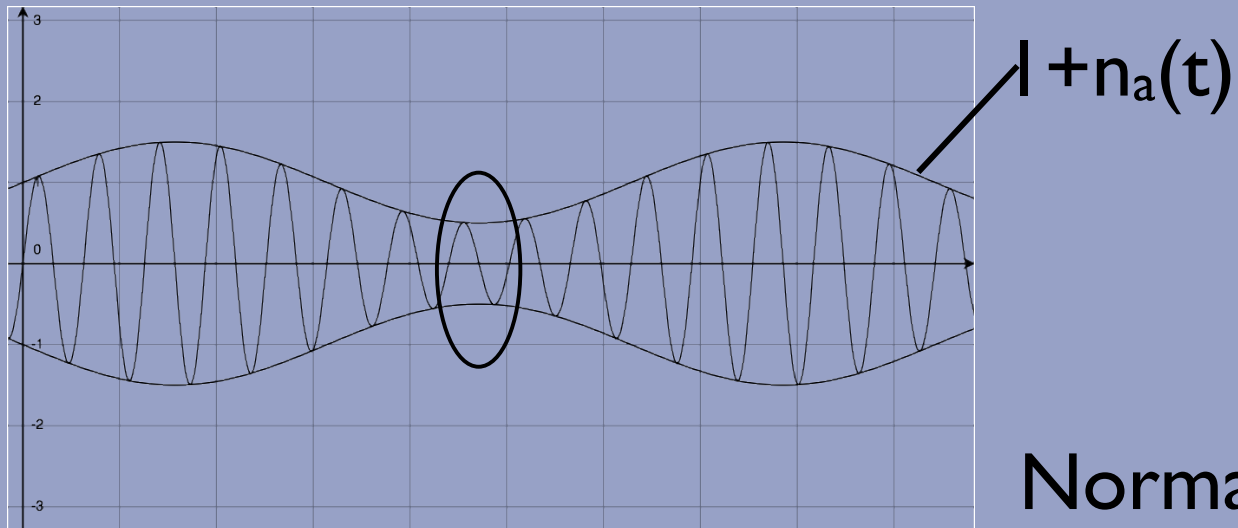
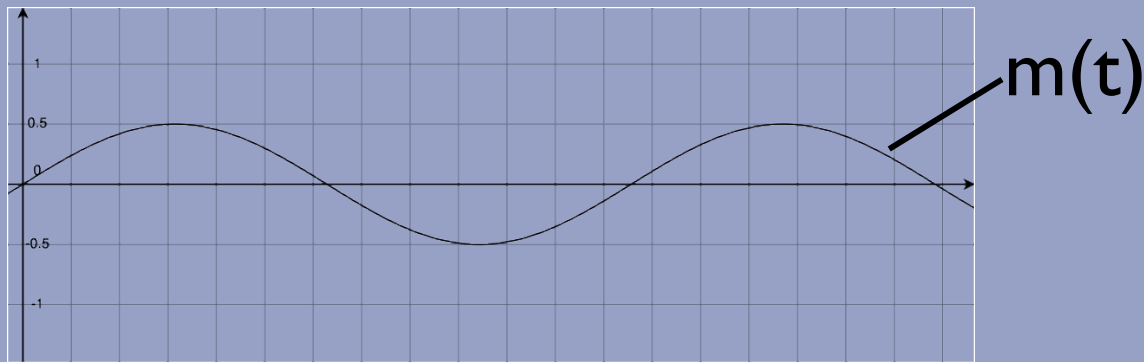
$$s(t) = [1 + n_a x(t)] \cos(2\pi f_c t)$$

$x(t)$: the signal

$m(t) = n_a x(t)$: normalized $x(t)$ so that:

$$|n_a x(t)| < 1, \quad \forall t$$

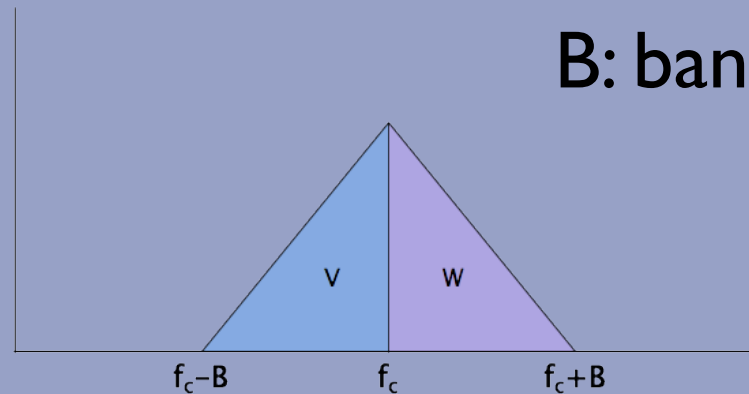
AM



Normalisation needed

AM

Spectrum:



B : bandwidth of $x(t)$

$V \equiv W$, 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: $\phi'(t) = n_f \times m(t)$

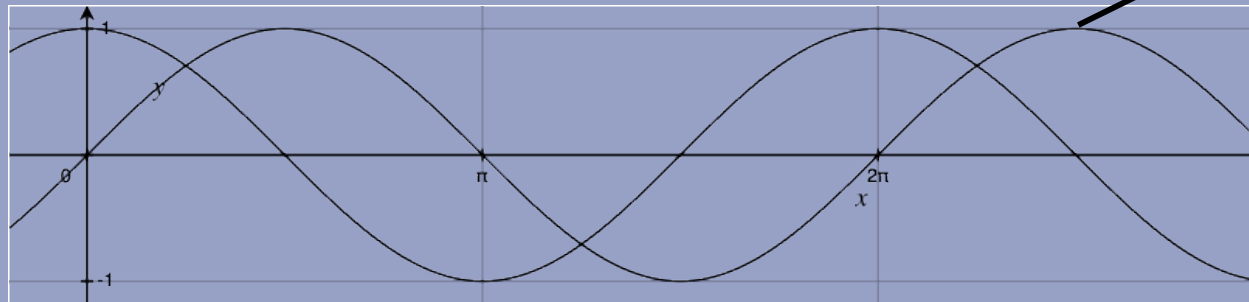
Thus with PM, the phase change in $s(t)$ is proportional with the change in $m(t)$ ($x(t)$), for FM, $m(t)$ is proportional with the frequency change.

FM & PM

Change in frequency of $s(t)$:

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

For:

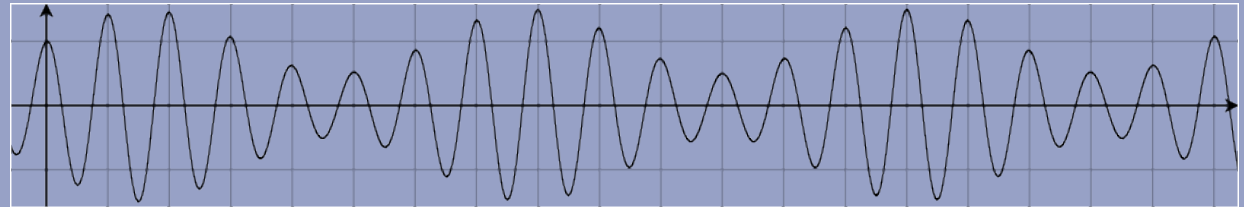


$m(t) = \sin(t)$

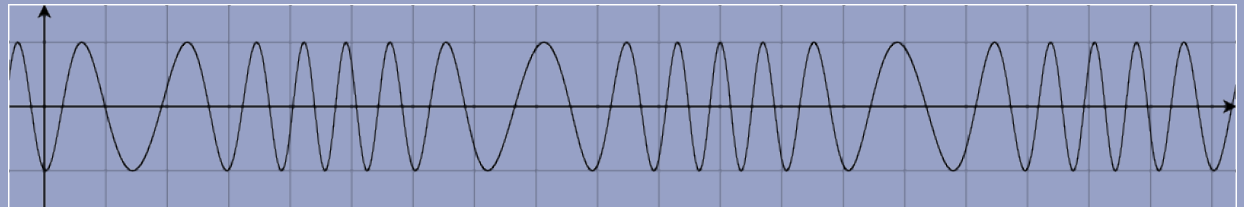
$$\begin{aligned} \text{PM: } \phi(t) &= \dots \sin(t) & \frac{d}{dt} \cos(t) &= \sin(t) \\ \text{FM: } \phi(t) &= \dots \cos(t) \end{aligned}$$

FM & PM

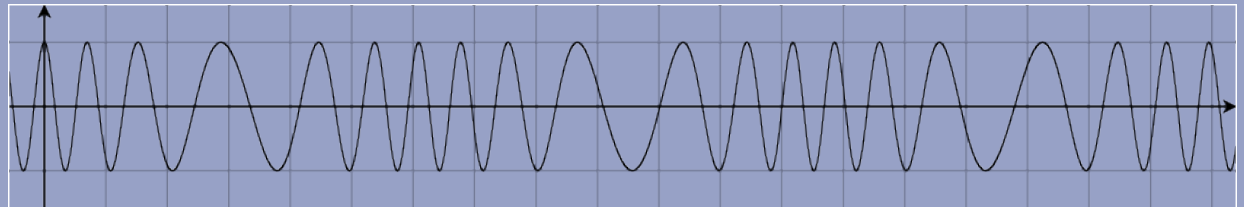
AM



FM



PM



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