COMPUTER ENGINEERING

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ADVANCED DIGITAL SIGNAL PROCESSING

Chapter 3: Modulation/Demodulation

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Content

- PSK
  - BPSK
  - QPSK (4-QAM)
- ASK
  - BASK
  - 4-ASK
- QAM
  - 16-QAM
  - Mapper
  - De-Mapper
    - Hard De-Mapper
    - Soft De-Mapper

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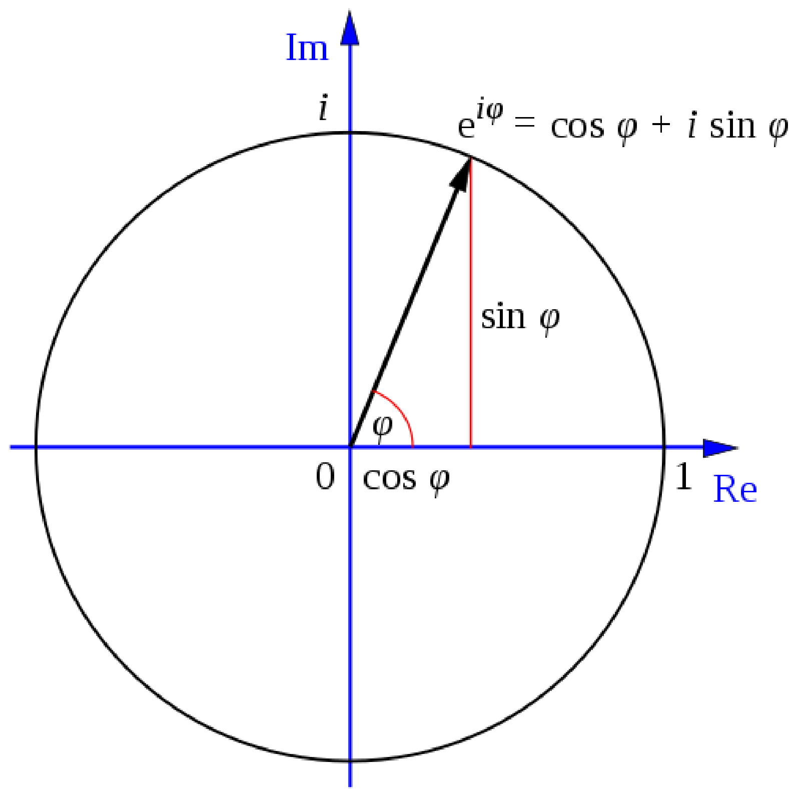
Modulation

■ Remind

$$e^{i\varphi} = cos\varphi + i\ sin\varphi$$



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Phase Shift Keying (PSK)

- In PSK, the modulation signal set is

$$s_i(t) = A\cos\big(2\pi f_c t + \emptyset_i(t)\big), i = 1, \ldots M; 0 \leq t \leq T_s$$

- T_s is symbol period, A is carrier amplitude (constant), "phase" $\emptyset_i(t)$ carries symbol information, and $\log_2 M$ bits per symbol
- BPSK: 1 bit per symbol - minimum phase separation 180^o
- QPSK: 2 bits per symbol - minimum phase separation 90^o
- 8-PSK: 3 bits per symbol - minimum phase separation 45^o
- Etc…

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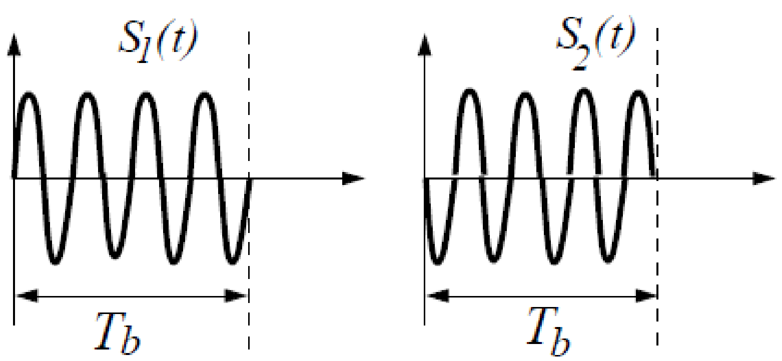
Binary Phase Shift Keying (BPSK)

- BPSK: M = 2. It is convention to use $m_1 = 1$ for bit 0, and $m_2 = -1$ for bit 1

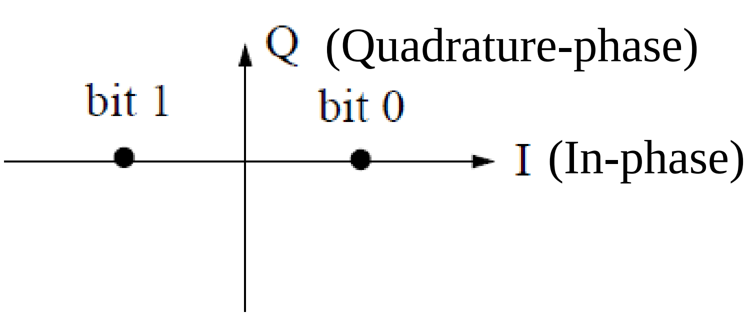
$$s_i(t) = A\cos(2\pi f_c t + (i-1)\pi + \theta_c), i = 1,2; 0 \le t \le T_b$$

  - T_b: bit period
  - $T_s = T_b$
  - θ_c: an initial phase
  - $A = \sqrt{\frac{2E_b}{T_b}}$
  - E_b: Energy per bit

Phase separation: π (90^o)



BPSK constellation diagram



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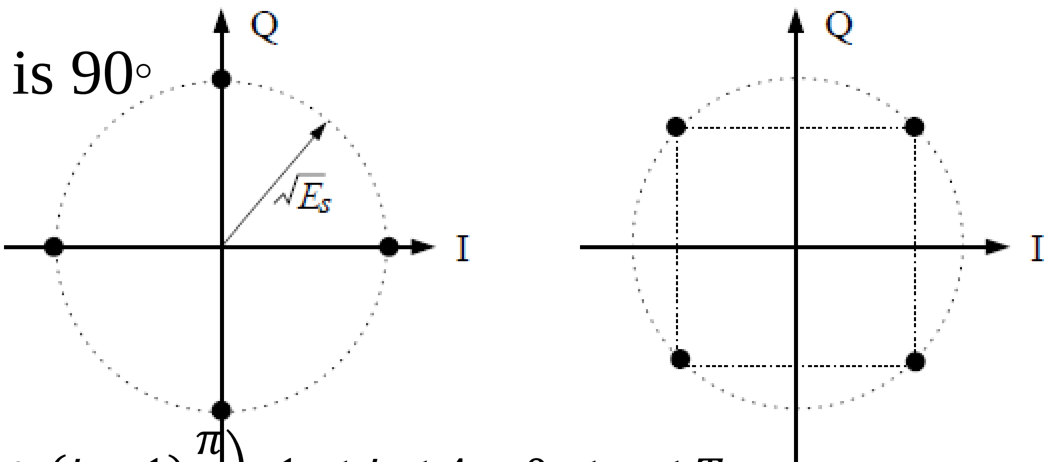
Quadrature Phase Shift Keying (QPSK)

- QPSK: M = 4, 2 bits per symbol, symbol period $T_s = 2T_b$, energy per symbol $E_s = 2E_b$
- QPSK signal constellation:
- Minimum phase separation is 90°



- QPSK signal set:

$$s_i(t) = \sqrt{\frac{2E_s}{T_s}} cos\left(2\pi f_c t + (i-1)\frac{\pi}{2}\right), 1 \le i \le 4; \quad 0 \le t \le T_s$$

- The transmitted QPSK RF signal can also be written as:

$$s_i(t) = \sqrt{\frac{2E_s}{T_s}} cos\left((i-1)\frac{\pi}{2}\right) cos(2\pi f_c t) - \sqrt{\frac{2E_s}{T_s}} sin\left((i-1)\frac{\pi}{2}\right) sin(2\pi f_c t)$$

$$0 \le t \le T_s$$

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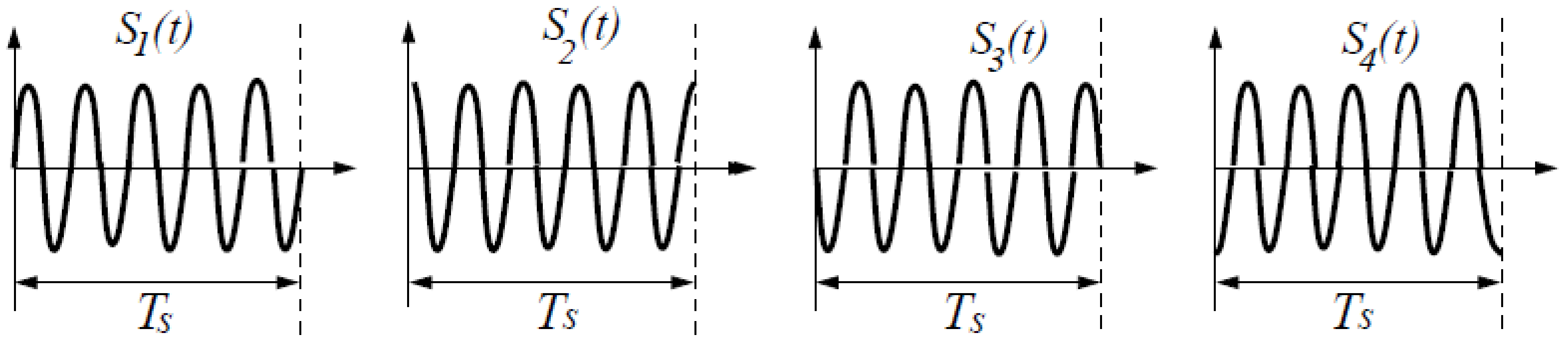
Quadrature Phase Shift Keying (QPSK)

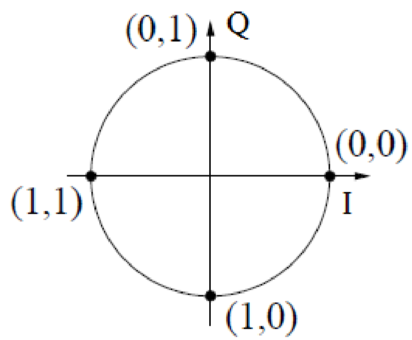
- QPSK signal set:

$$s_i(t) = \sqrt{\frac{2E_s}{T_s}} cos(2\pi f_c t + \emptyset_i), 1 \le i \le 4; 0 \le t \le T_s; \emptyset_i = (i-1)\frac{\pi}{2}$$



bit (0,0): $\phi_1 = 0$ bit (0,1): $\phi_2 = \frac{\pi}{2}$ bit (1,1): $\phi_3 = \pi$ bit (1,0): $\phi_4 = \frac{3\pi}{2}$

- QPSK constellation diagram



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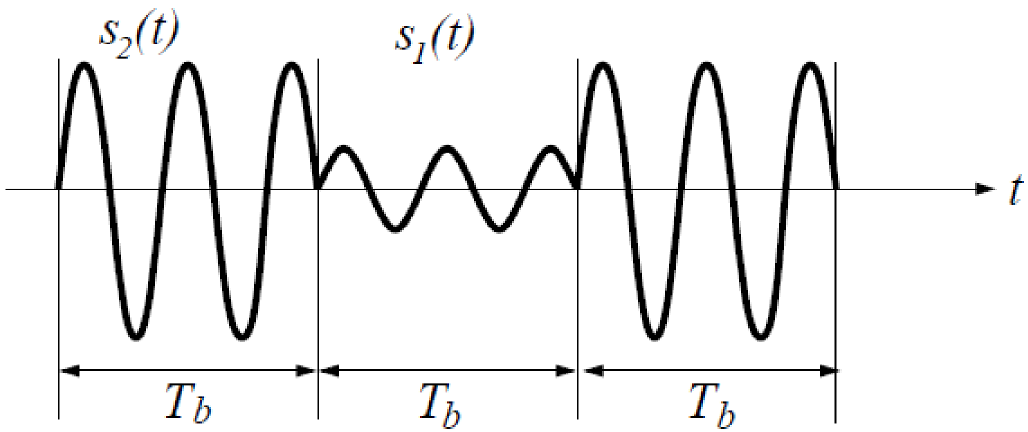
Binary Amplitude Shift Keying (BASK)

- ASK: Carrier amplitude A_i carries symbol information

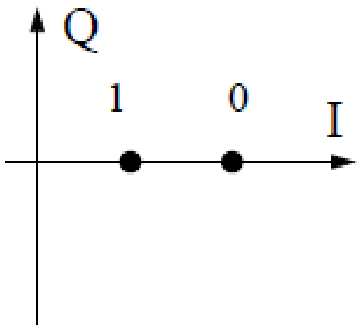
$$s_i(t) = A_i cos(2\pi f_c t + \theta), \qquad 1 \leq i \leq M; 0 \leq t \leq T_s$$

- BASK: M = 2, bit 0: A_1 = A, bit 1: A_2 = 3A

$$s_1(t) = Acos(2\pi f_c t + \theta)$$
$$s_2(t) = 3Acos(2\pi f_c t + \theta)$$



BASK constellation diagram



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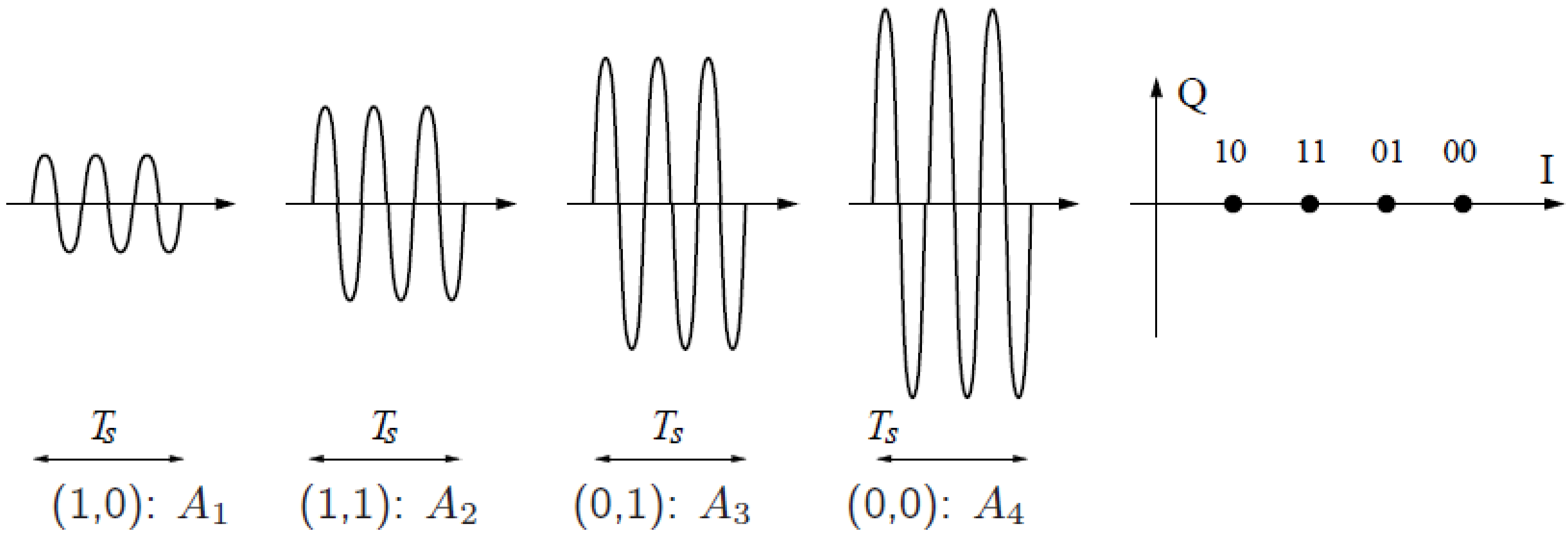
4-Amplitude Shift Keying (4-ASK)

- 4-ASK: M = 4
- Signal set:

$$s_i(t) = A_i cos(2\pi f_c t + \theta), \qquad 1 \le i \le 4; 0 \le t \le T_s$$

4-ASK constellation diagram



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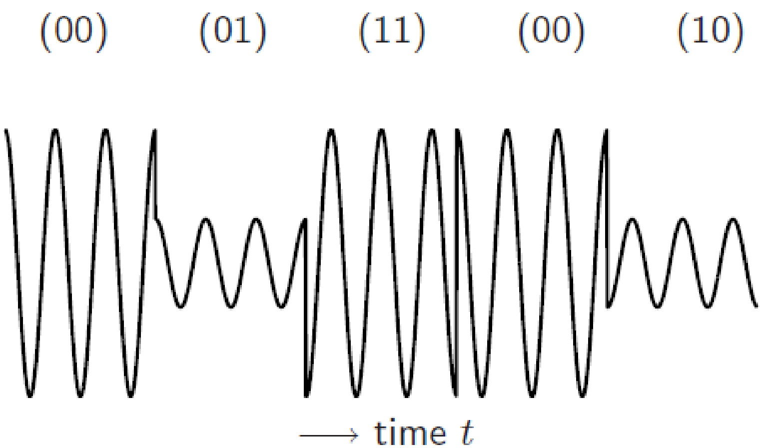
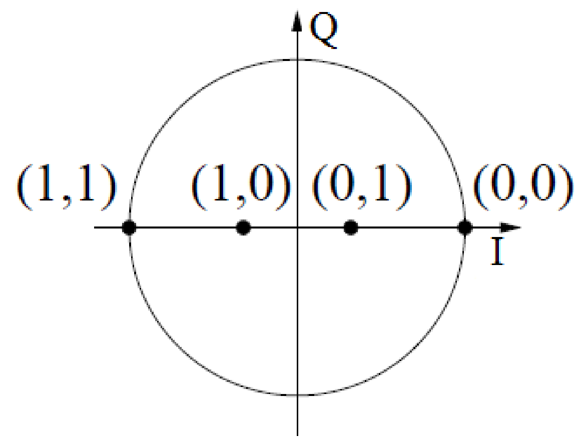
Combined ASK/PSK

- PSK and ASK can be combined.
- Here is an example of 4-ary or 4-PAM (pulse amplitude modulation) of 2 amplitude levels and phase shift of are combined to represent 4-ary symbols

Transmitted signal s(t)



Constellation diagram



- Note in $\sqrt{M}$-ary or $\sqrt{M}$ -PAM, quadrature component is not used, a more generic scheme of combining PSK/ASK is QAM, which uses both I and Q branches

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Quadrature Amplitude Modulation

- QAM: combines features of PSK and ASK, uses both I and Q components, and is bandwidth very efficient

$$s_i(t) = A_i cos\big(2\pi f_c t + \emptyset_i(t)\big), 0 \le t \le T_s, 1 \le i \le M$$

- T_s being symbol period, as both amplitude and phase are used to carry symbol information, it is very bandwidth efficient
- symbol set size M: $2^1 \times 2^1 = 4$, $2^2 \times 2^2 = 16$, $2^3 \times 2^3 = 64$, etc → 4QAM, 16QAM, 64QAM, etc
- The larger M is, the better bandwidth efficiency but lower robustness against noise and fading

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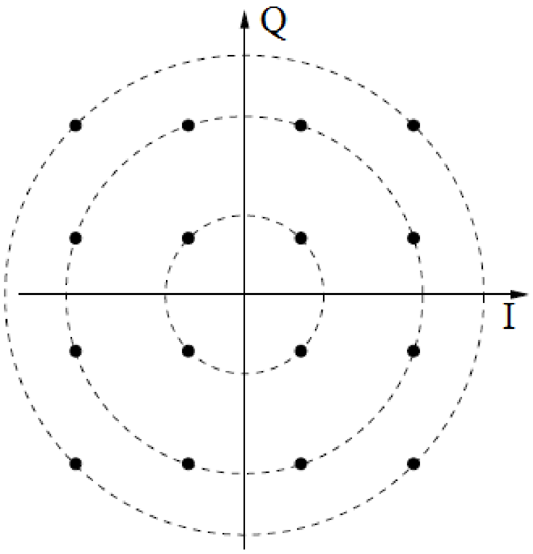
Quadrature Amplitude Modulation (QAM)

- An example of (squared) 16-QAM:



- Note for squared M-QAM, I and Q branches are both pM-ary (of previous slide)
- Depending on the channel quality, 64-QAM, 128-QAM, or 256-QAM are possible
- Why high-order QAM particularly bandwidth efficient? and what is penalty paid?

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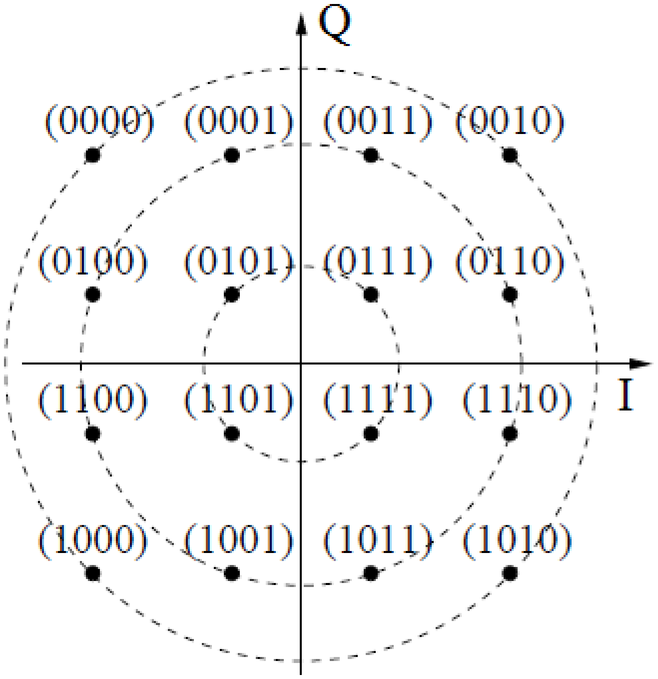
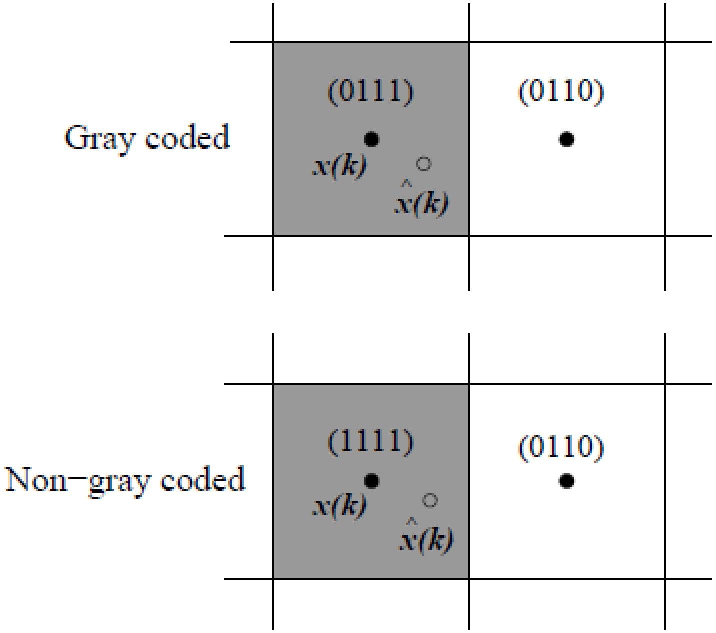
Quadrature Amplitude Modulation (QAM)

- Gray Mapping: adjacent constellation points only differ in a single bit (minimum Hamming distance)





Transmitted symbol $x(k)$ was sent, but received symbol $\hat{x}(k)$ in neighbor region due to noise.

- If noise or distortions cause misclassification in the receiver, Gray coding can minimize the bit error rate

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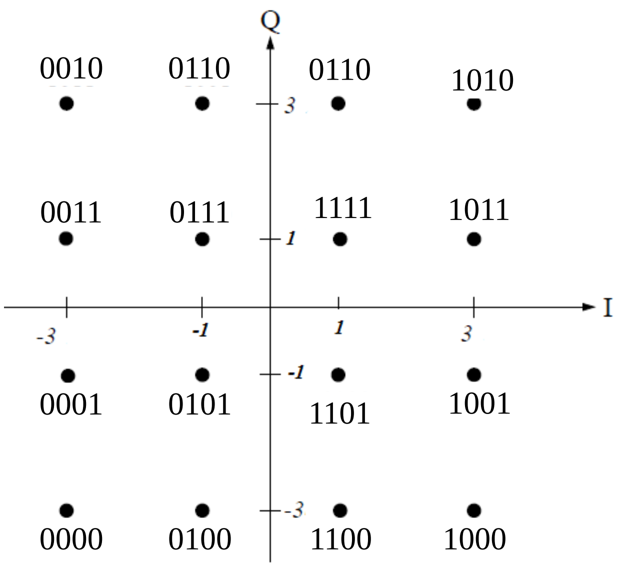
Mapper

- 16-QAM Mapper



Input	I + jQ
0000	-3-3j
0001	-3-j
0010	-3+3j
0011	-3+j
0100	-1-3j
0101	-1-j
0110	-1+3j
0111	-1+j

Input	I + jQ
1000	3-3j
1001	3-j
1010	3+3j
1011	3+j
1100	1-3j
1101	1-j
1110	1+3j
1111	1+j

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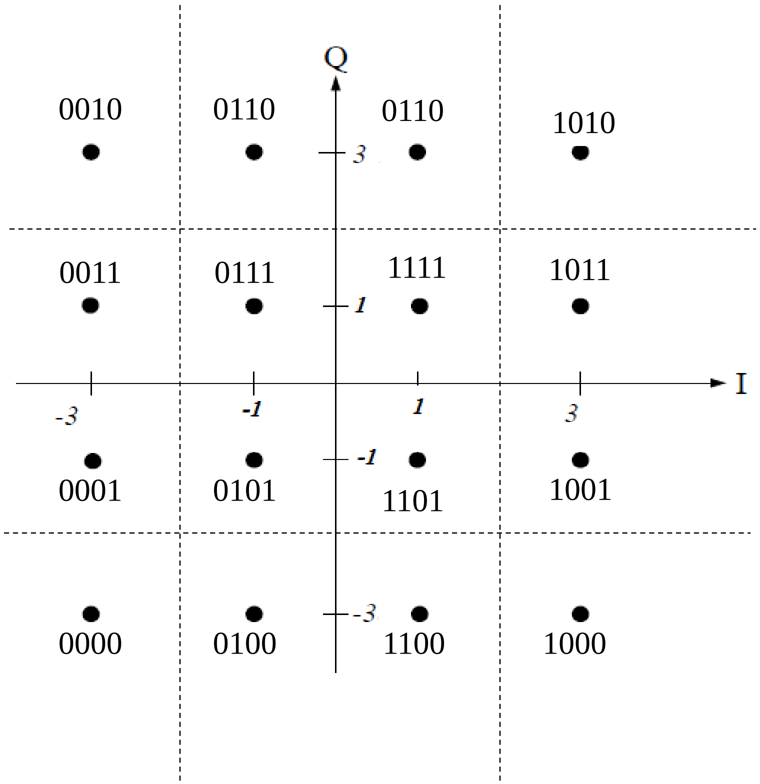
De-Mapper

- Hard-Decision



Input (I, Q)	Output
-2 >= I && -2 >= Q	0000
	0001
	0010
	0011
	0100
	0101
	0110
	0111

Input	Output
	1000
	1001
	1010
	1011
	1100
	1101
	1110
	1111

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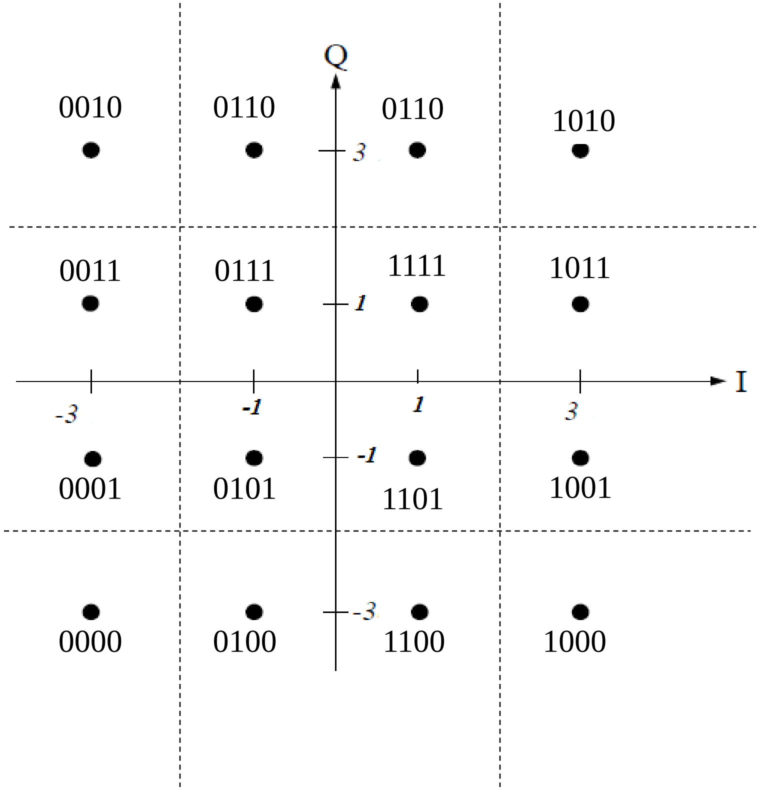
De-Mapper

- Soft-Decision

http://www.dsplog.com/2009/07/05/softbit-16qam/

b0b1b2b3



$$sb(b0) = \begin{cases} 2(Y_{re}+1) & Y_{re} < -2 \\ Y_{re} & -2 \le Y_{re} < 2 \\ 2(Y_{re}-1) & Y_{re} > 2 \end{cases}$$

$$sb(b1) = -|Y_{re}| + 2 \quad for\ all \quad Y_{re}$$

$$sb(b2) = \begin{cases} 2(Y_{im}+1) & Y_{im} < -2 \\ Y_{im} & -2 \le Y_{im} < 2 \\ 2(Y_{im}-1) & Y_{im} > 2 \end{cases}$$

$$sb(b3) = -|Y_{im}| + 2 \quad for\ all \quad Y_{im}$$

DeMap Bit = (sign(sb)+1)/2

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END

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