Communication Engineering Systems

Bandpass Modulation (10)

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"All things are difficult before they are easy"

Example- Why Bandpass Modulation?

- Given the the bandpass signal with center of frequency f_0 at 3000 Hz, find the antenna size. Repeat the same computation for f_0 = 900 MHz

Answer: $f_0 = 3$ kHz, $L = \lambda/4 = c/4f_0 \sim 25$ km

$f_0 = 900$ MHz, $L = \lambda/4 = c/4f_0 \sim 8$ cm

- Modulation onto carriers allow for smaller antenna size !

Bandpass Modulation

Consider the carrier wave

$$s(t) = A(t) \cdot \cos[\theta(t)]$$

$$\theta(t) = \omega_0 t + \phi(t)$$

where $A(t)$ is the amplitude

ω_0 is the radian frequency of the carrier

$\phi(t)$ is the phase

Modify the *amplitude*, *frequency*, or *phase* according to transmitted symbols

Types of bandpass modulation

- Amplitude shift keying (ASK)
  - Modulates $A(t)$
- Phase shift keying (PSK)
  - Modulates $\phi(t)$
  - Standards for satellite communications
- Frequency shift keying (FSK)
  - Modulates frequency
  - Popular for low data rate applications

Types of bandpass modulation

- Quadrature amplitude modulation (QAM)
  - Modulates amplitude and phase
- Other types
  - Differential PSK (DPSK)
  - Continuous-phase FSK (CPFSK)
  - Minimum shift keying (MSK)
    - Gaussian minimum shift keying (GMSK)

Detection/Demodulation

- Coherent detection
  - Know the carrier phase
- Noncoherent detection
  - Do not know the carrier phase
    - Degrade the performance, i.e., reduced BER, P_B

Phase Shift Keying (PSK)

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos\left(\omega_0 t + \phi_i(t)\right) \qquad \text{for } i = 1, 2, \ldots, M$$

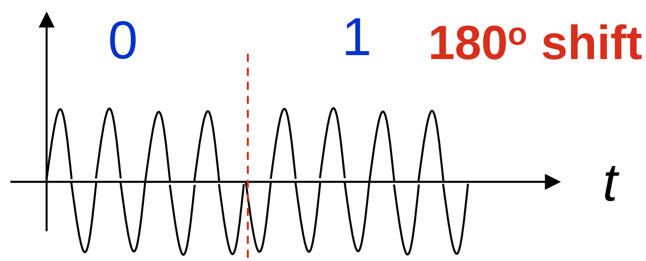
where $\phi_i = \dfrac{2\pi i}{M}$ is the phase of the i-th symbol, E is the symbol energy

Example – binary phase shift keying (BPSK), M = 2

$\phi_1 = 2\pi/2 = \pi$ and $\phi_2 = 2\pi(2)/2 = 2\pi$ or 0

Antipodal sets:

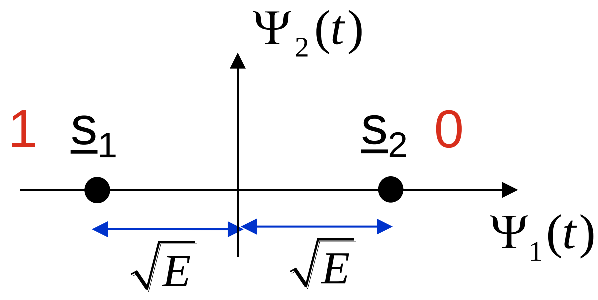
$$s_1(t) = -\sqrt{\frac{2E}{T}} \cos[\omega_0 t], \quad s_2(t) = \sqrt{\frac{2E}{T}} \cos[\omega_0 t]$$



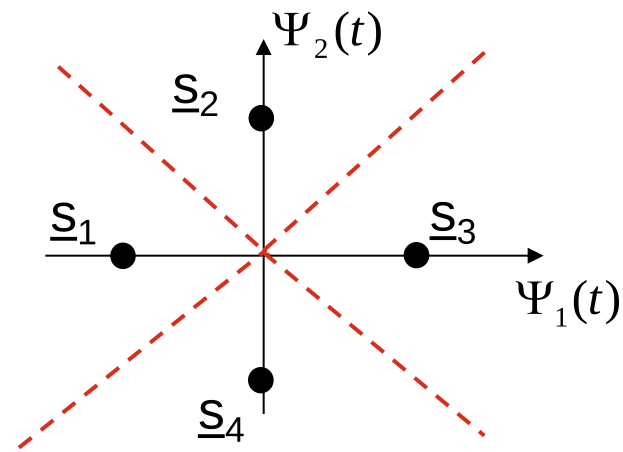
Example

Equal Energy

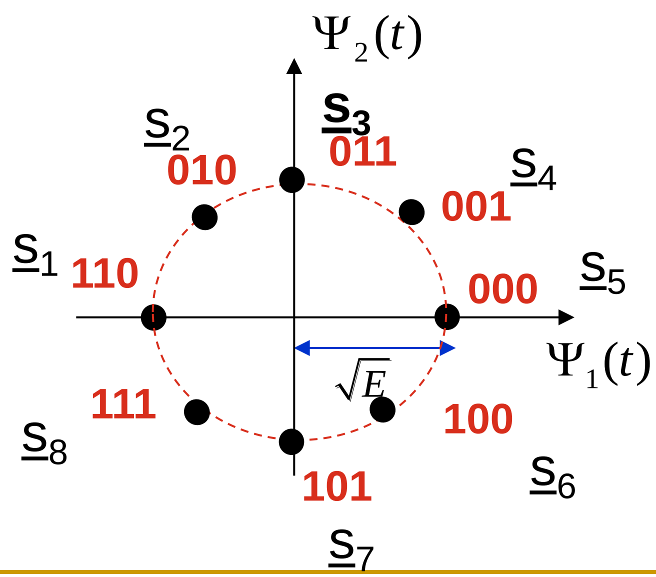
M = 2
BPSK



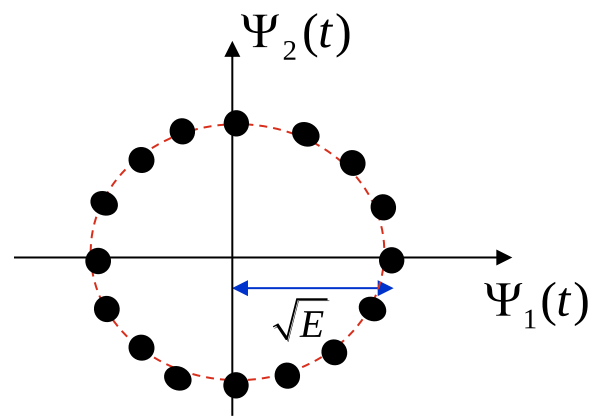
M = 4
QPSK



M = 8
8PSK



M = 16
16PSK



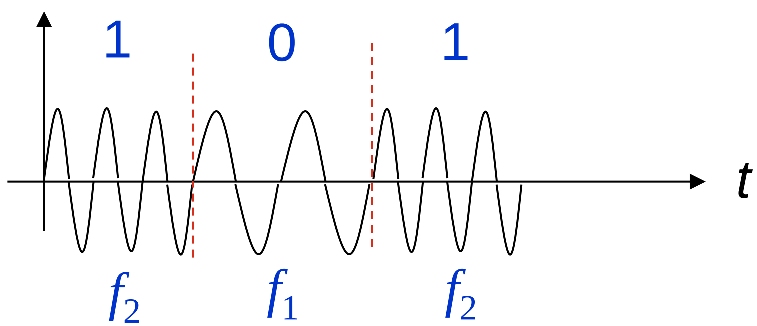
Frequency Shift Keying (FSK)

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos(\omega_i t + \phi) \qquad \text{for } i = 1, 2, \ldots, M$$

where ω_i is the frequency of the i-th symbol, E is the symbol energy

Example – binary frequency shift keying (BFSK), M = 2

with $\omega_1 = 2\pi f_1$, $\omega_2 = 2\pi f_2$



$$s_1(t) = A\cos(\omega_1 t)$$
$$s_2(t) = A\cos(\omega_2 t)$$

M-dimensional signal space

Amplitude Shift Keying (ASK)

$$s_i(t) = \underbrace{\sqrt{\frac{2E_i(t)}{T}}}_{A_i} \cos(\omega_0 t + \phi) \qquad \text{for } i = 1, 2, \ldots, \mathrm{M}$$

where A_i is the amplitude of the i-th symbol, E is the symbol energy

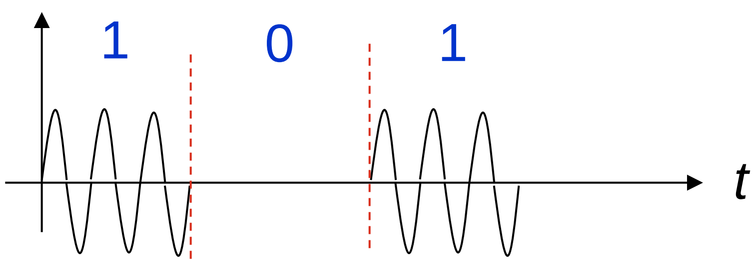
Example – binary amplitude shift keying (BASK), M = 2

with $A_1 = 0$, $A_2 = A$

On-off keying:

$$s_1(t) = 0$$

$$s_2(t) = A\cos(\omega_0 t)$$



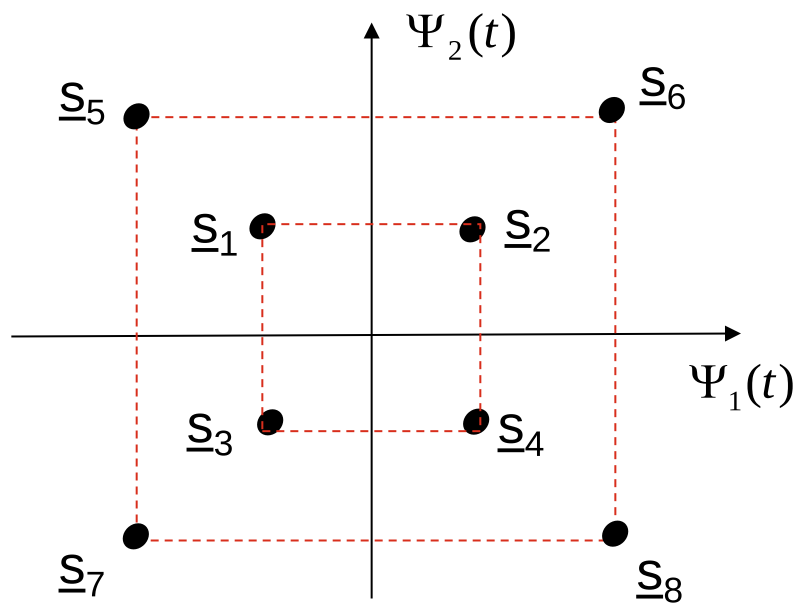
Amplitude Phase Keying (APK)

$$s_i(t) = \sqrt{\frac{2E_i(t)}{T}} \cos[\omega_0 t + \phi_i(t)]; \quad 0 \le t \le T, i = 1, \ldots, M$$

2 dimensional case =

Quadrature Amplitude Modulation

(QAM)



M = 8

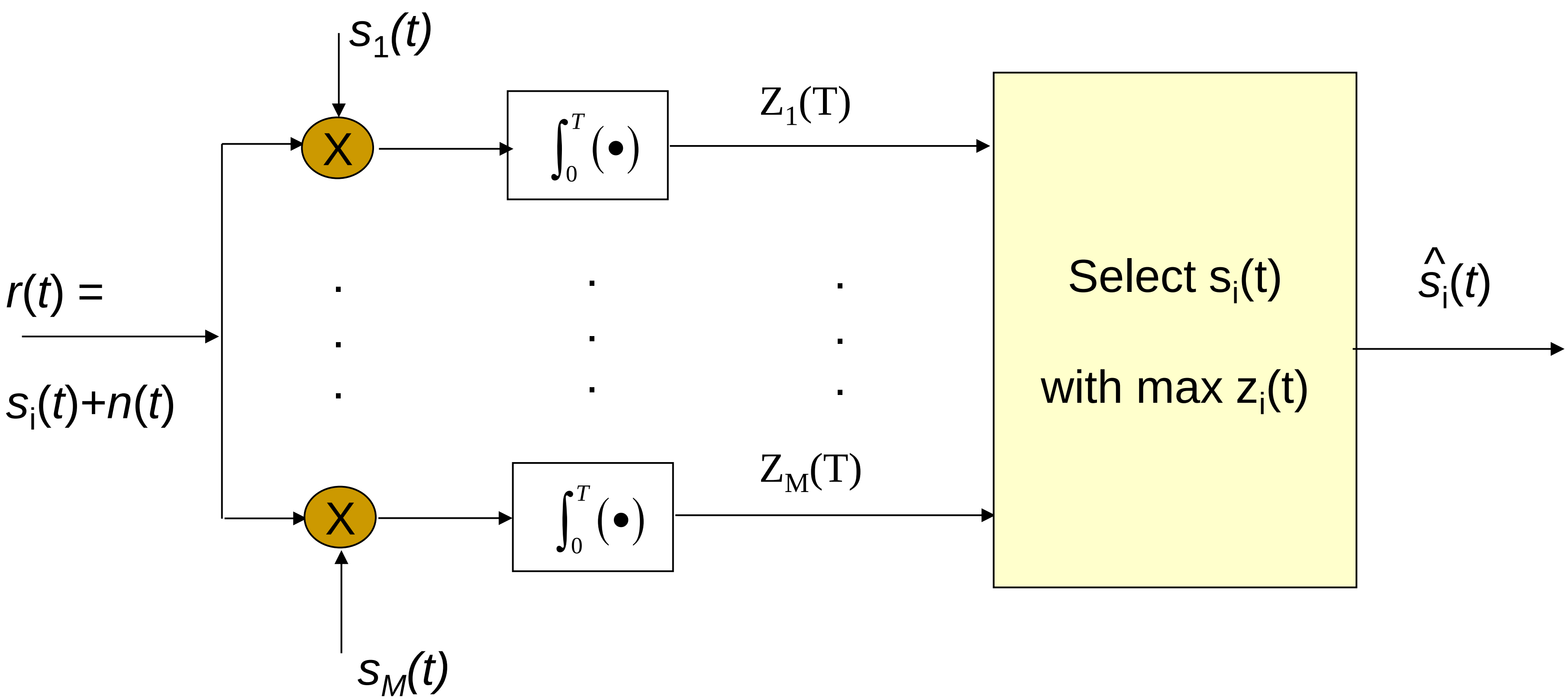
Detection of Bandpass Signal

- Generally a bandpass signal is first transformed down to a baseband signal, then demodulate and make a decision

Two *equivalent* ways:

1) Detection at the bandpass level
2) Converting to a baseband level, make a decision

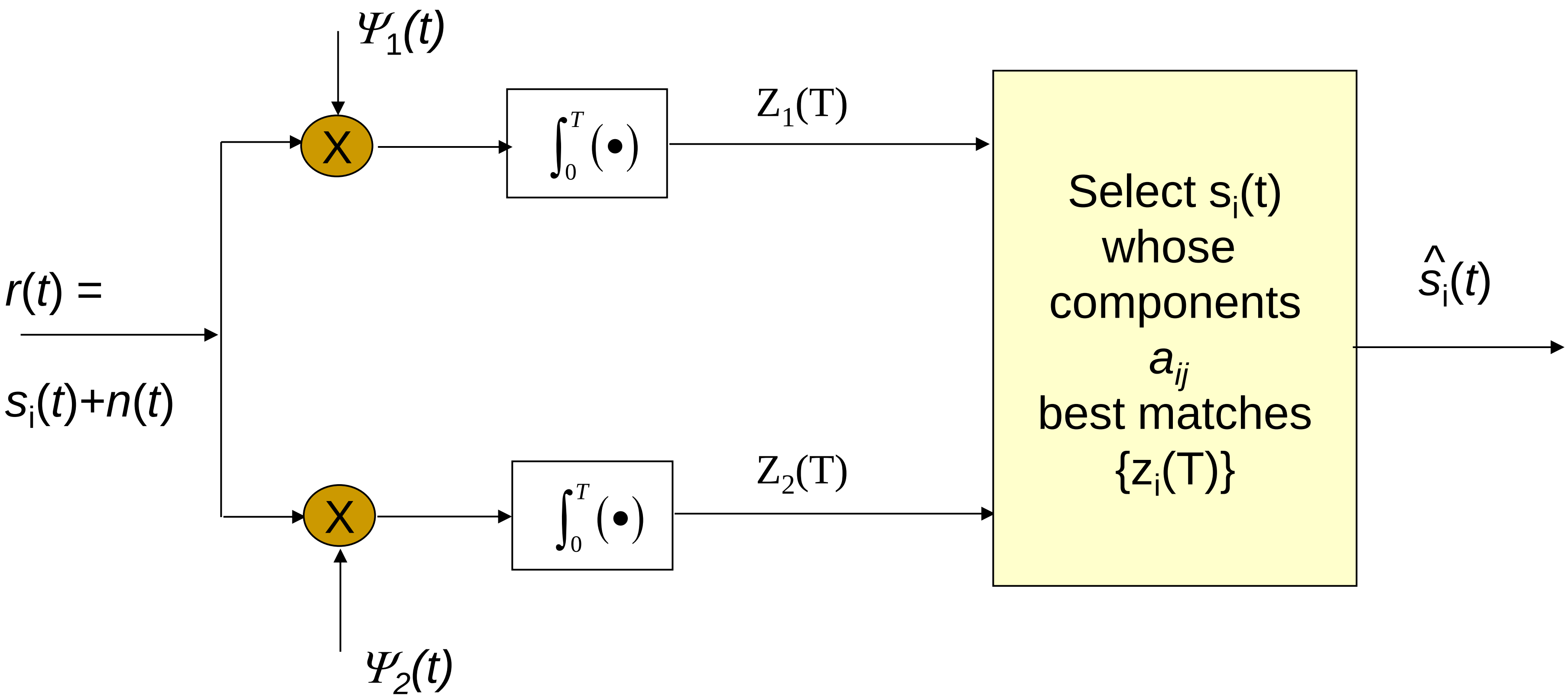
Correlator Receiver with $\{s_i(t)\}$



Applies for PSK, FSK, ASK, QAM, etc.

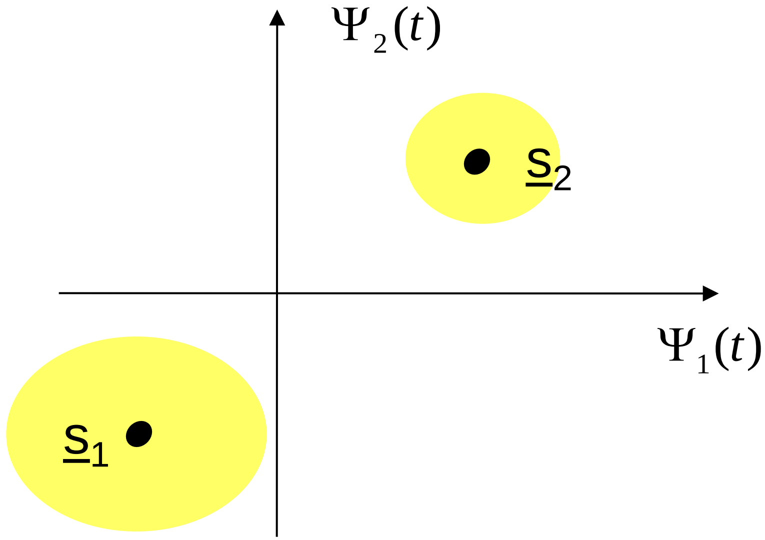
For 2-Dimensional Signal Space

- In-phase, Quadrature phase components



Minimum Distance Detector

- Given that $\mathbf{s_1} + \mathbf{n}$ and $\mathbf{s_2} + \mathbf{n}$



n ~ zero-mean random noise

r ~ random vectors with mean $\mathbf{s_1}$ or $\mathbf{s_2}$

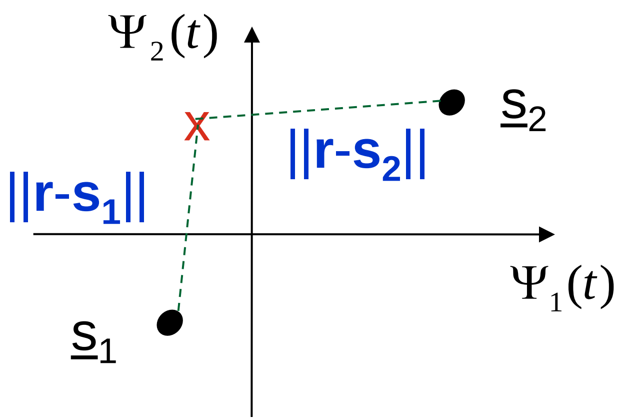
- The detector decides if s_1 or s_2 is transmitted
- Make decision with the goal of reducing P(E)

Minimum Distance Detector

- When $P(\mathbf{s_1}) = P(\mathbf{s_2})$,
  maximum likelihood (ML) detector

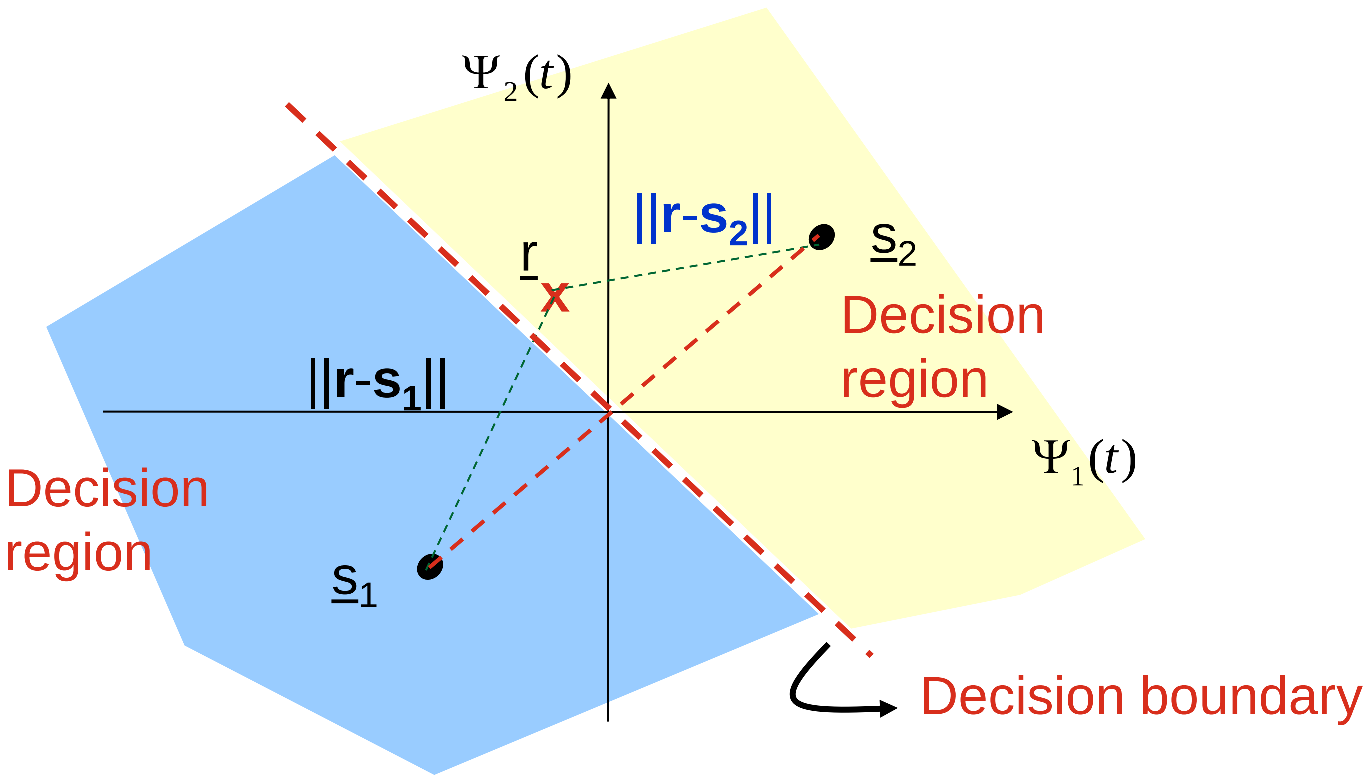
  ⇩

  minimum distance (MD) detector



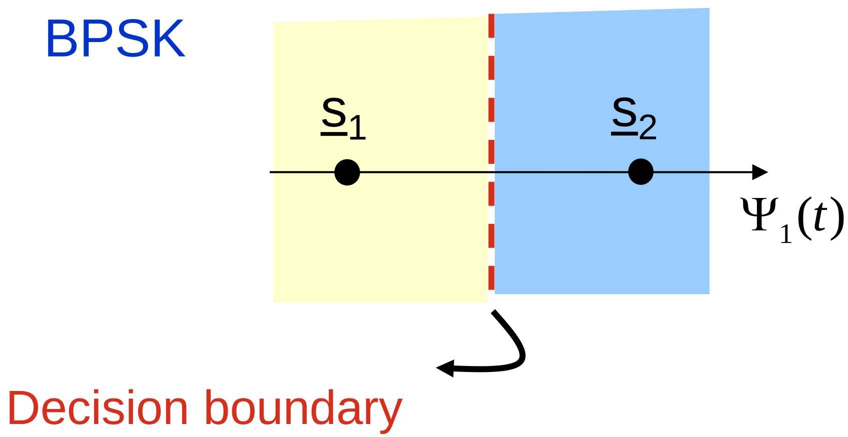
Decision Regions

- Geometric view of decision making

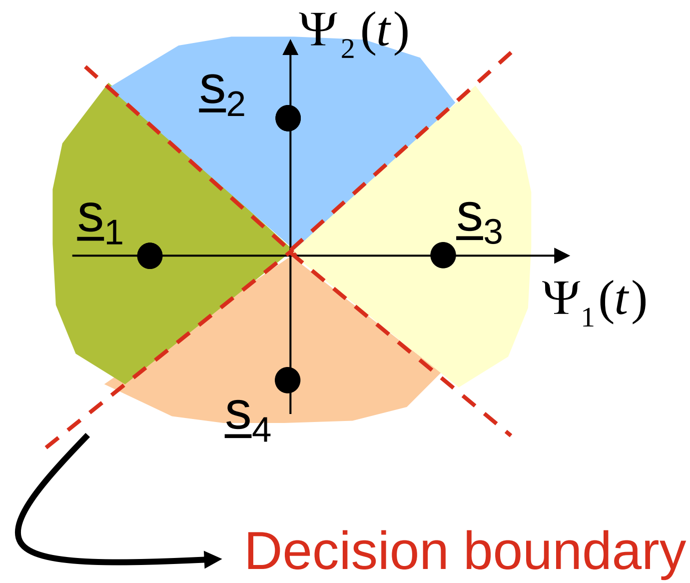


Equal Energy

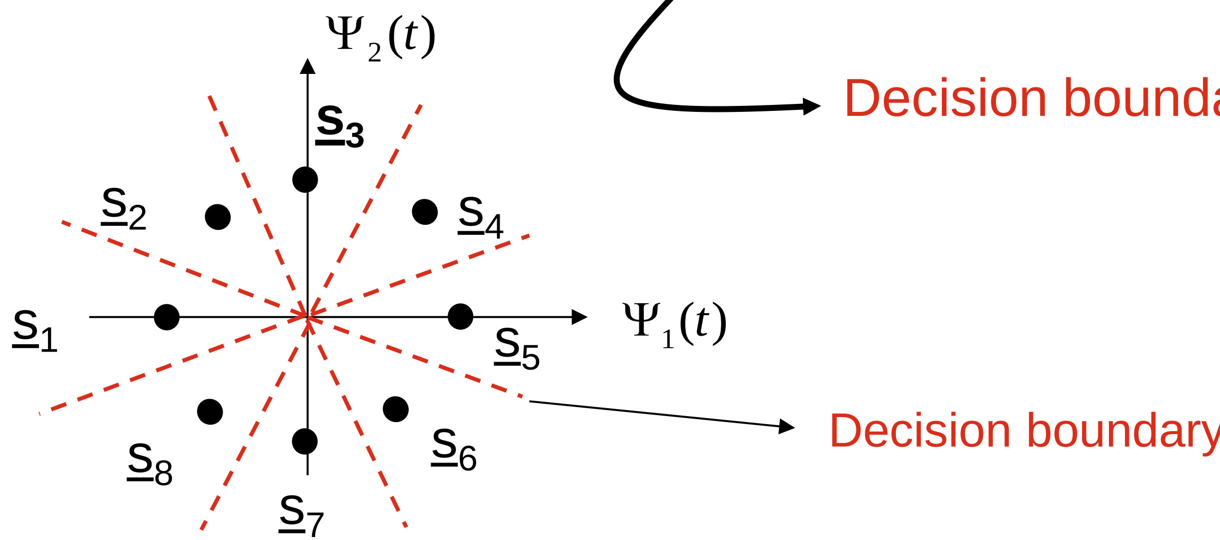
M = 2
BPSK

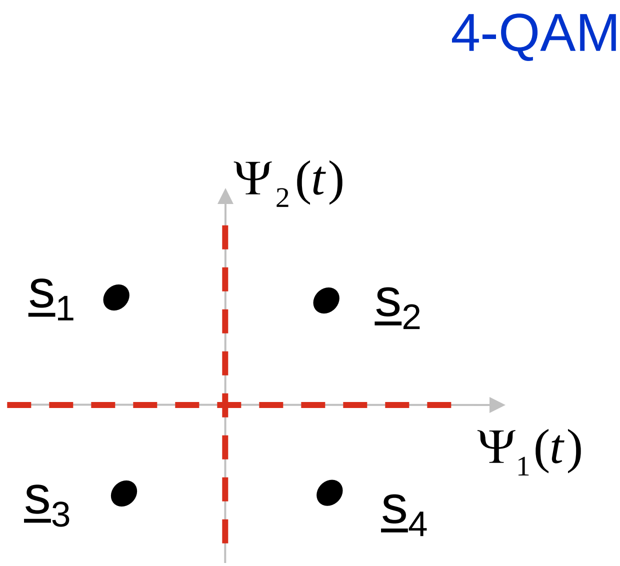


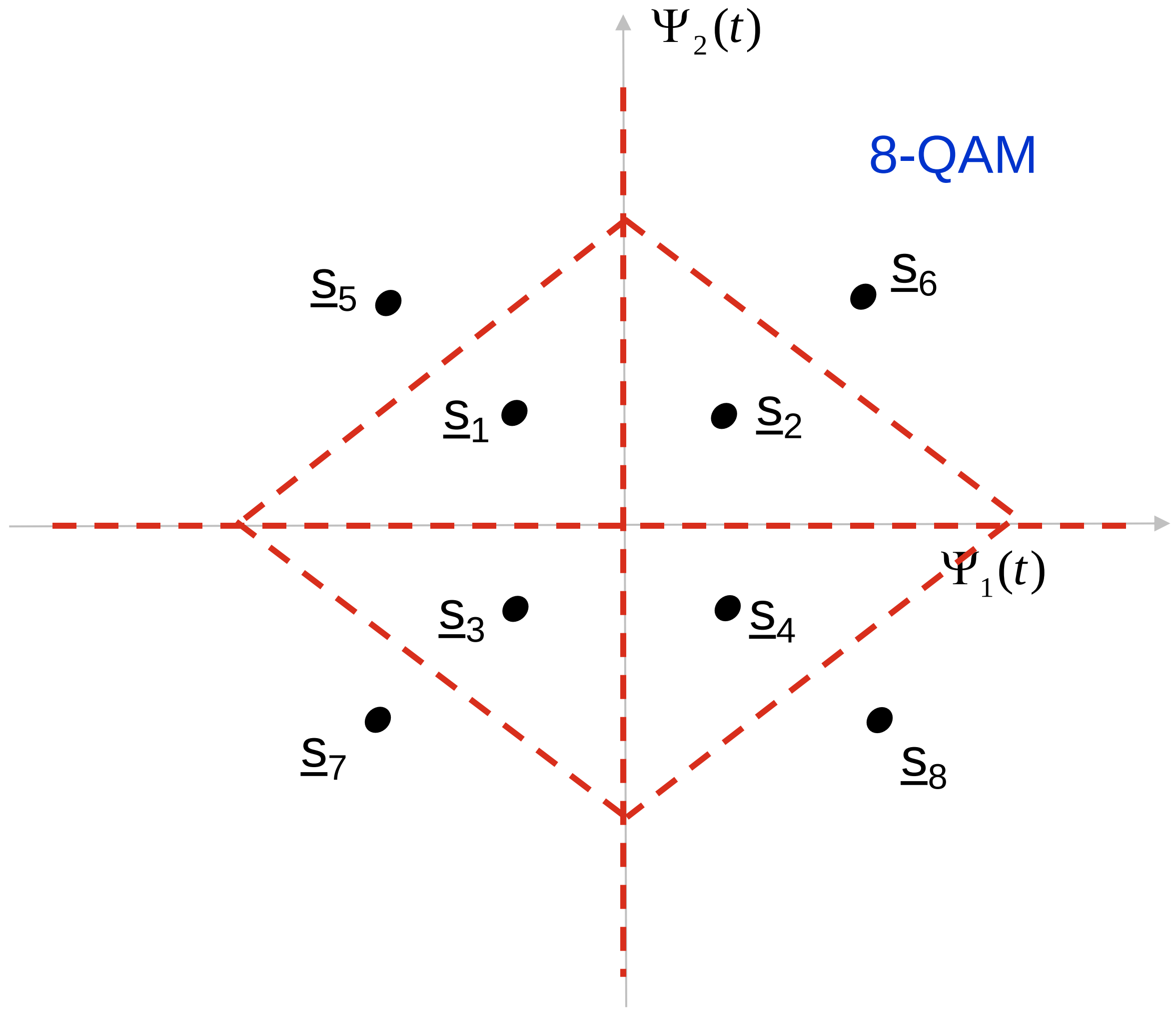
M = 4
QPSK



M = 8
8PSK




4-QAM
Ψ2(t)
Ψ1(t)
s1
s2
s3
s4


8-QAM
Ψ2(t)
Ψ1(t)
s1
s2
s3
s4
s5
s6
s7
s8