

X

Receiver For M-ary QAM

$$y(t) = x(t) + n(t)$$

$$y(t) = a_1 p_1(t) + a_2 p_2(t) + n(t)$$

$n(t)$ is AWGN

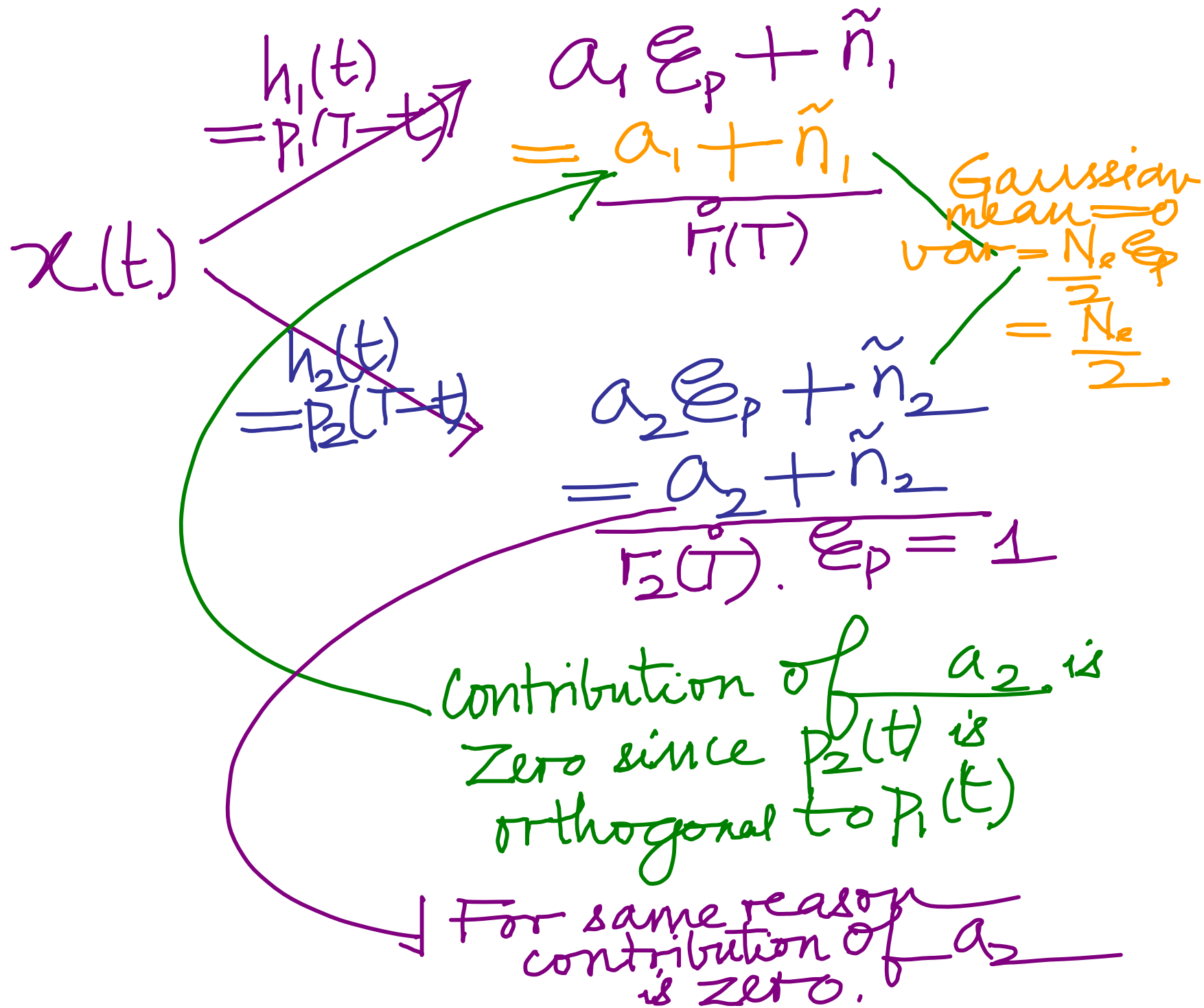
$$P_n(\tau) = \frac{N_0}{2} \delta(\tau)$$

Mean = 0

Similar to QPSK
Separately Matched
Filter with $h_1(t)$

$$= p_1(T-t)$$

$$\& h_2(t) = p_2(T-t).$$

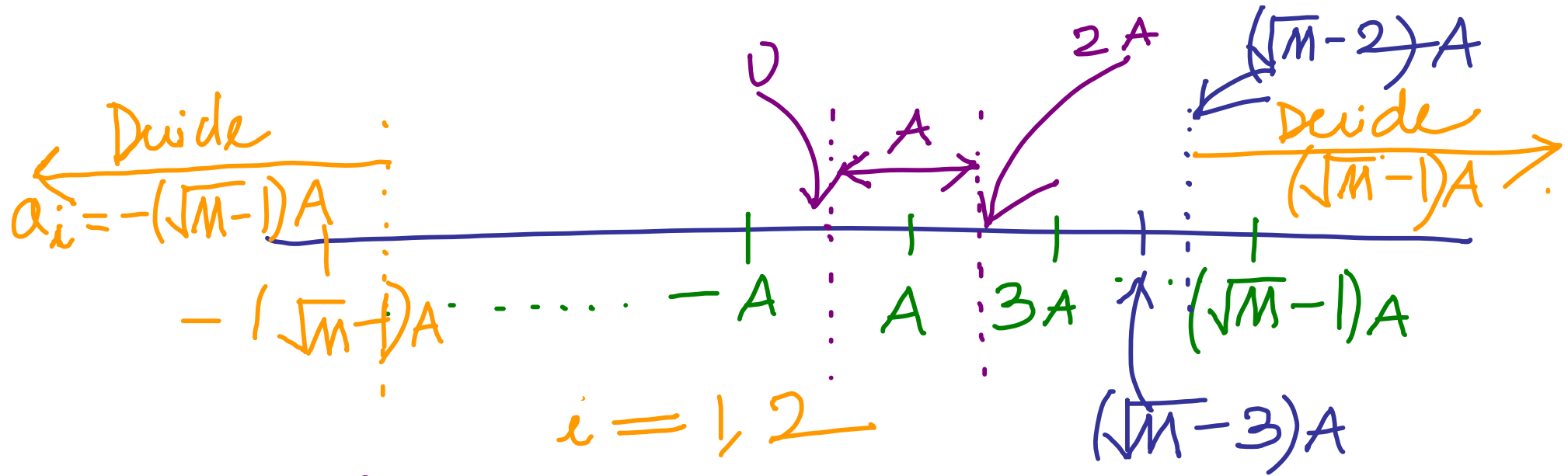


$\tilde{n}_1, \tilde{n}_2$ — Gaussian
mean = 0
var = $\frac{N_0}{2}$

Decision Rule

Decide a_1 from $r_1(T)$
Decide a_2 from $r_2(T)$

These are independent
PAM symbols $\Rightarrow$ Decision
is similar to PAM, But
 $\sqrt{M}$ PAM.



If $0 \leq r_i(T) < 2A$

Decide $a_i = A$

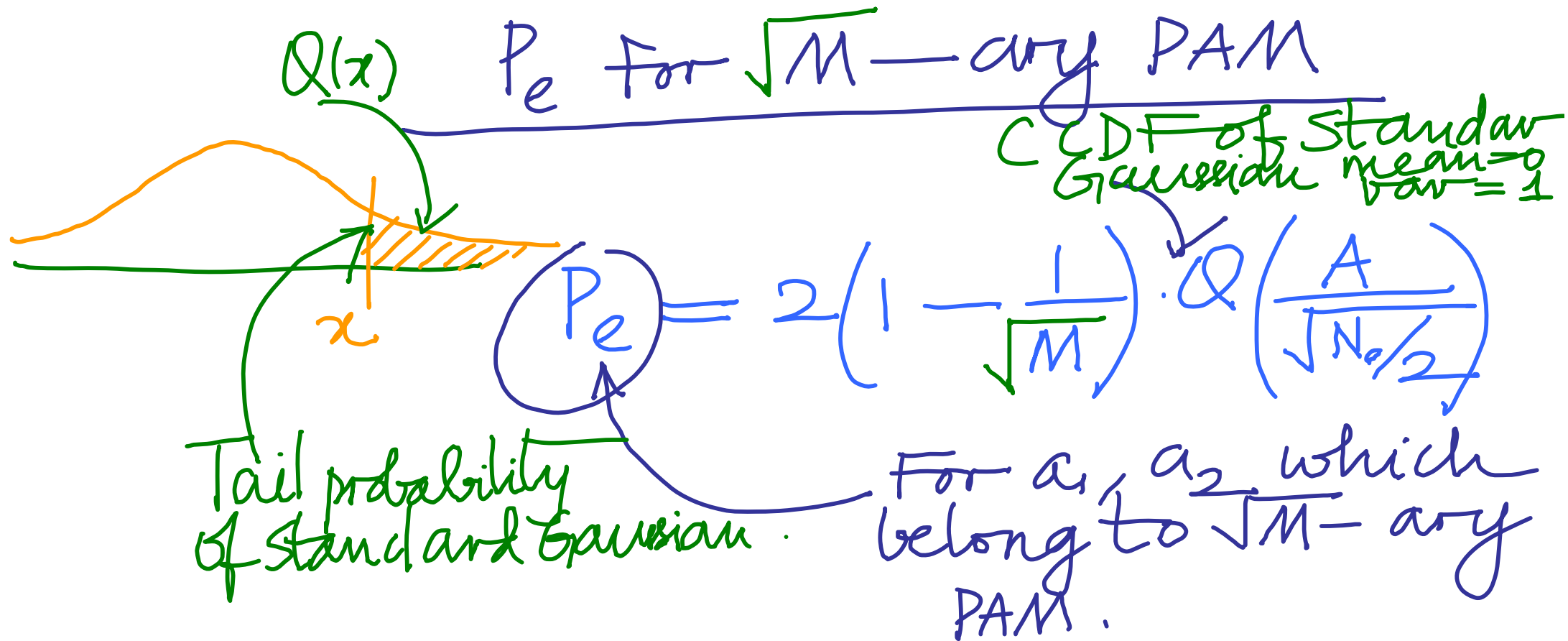
End points

If $r_i(T) \geq (\sqrt{M-2})A$

Decide $a_i = (\sqrt{M-1})A$

Similarly one can formulate the rest of the cases.

Choose $a_i =$ closest constellation point in $\sqrt{M}$ -ary PAM to $r_i(T)$.



M-ary QAM:

Given symbol Energy E_s .
Each individual M-ary
PAM has average
energy $\frac{E_s}{2}$.

$$A = \sqrt{\frac{3E_s}{2(M-1)}}$$

Ensures average
symbol Energy E_s
for each M-ary PAM
Average energy E_s
for overall M-ary QAM.

$$P_e = 2 \left(1 - \frac{1}{\sqrt{M}} \right) Q \left(\sqrt{\frac{3E_s}{2(M-1)N_b}} \right)$$

$$P_e = 2 \left(1 - \frac{1}{\sqrt{M}} \right) Q \left(\sqrt{\frac{3E_s}{N_b(M-1)}} \right)$$

Average symbol Error rate for each constituent $\sqrt{M}$ -ary PAM.

$P_{e,QAM} \approx 2P_e$ as shown below

Error rate for overall M-ary QAM constellation is,

$$\begin{aligned} P_{e,QAM} &= 1 - (1 - P_{e,PAM})^2 \\ &= 1 - (1 + P_{e,PAM}^2 - 2P_{e,PAM}) \\ &= 2P_{e,PAM} - \underbrace{P_{e,PAM}^2}_{\text{At high SNR very small in comparison to } P_{e,PAM}} \\ &\approx \underline{2P_{e,PAM}} \end{aligned}$$

At high SNR
very small in
comparison to $P_{e,PAM}$

$$P_{e,QAM} = 4 \left(1 - \frac{1}{\sqrt{M}} \right) Q \left(\sqrt{\frac{3E_s}{N_0(M-1)}} \right)$$

Error rate for overall
M-ary QAM.

CONSTELLATION DIAGRAM

M-ary QAM

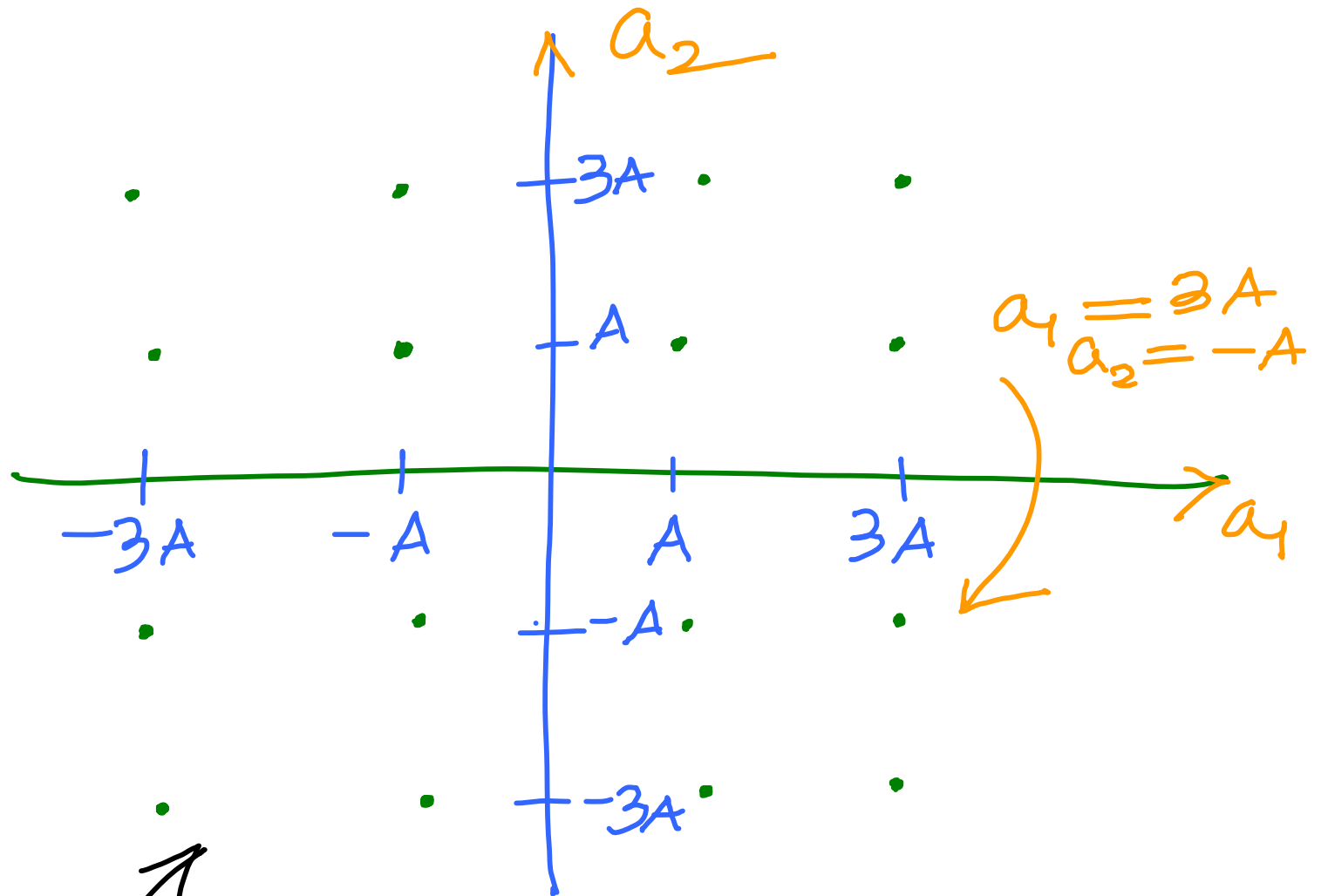
$$M = 16$$

$$a_1, a_2 \in \sqrt{M} = 4\text{-PAM}$$

$$a_1 \in \{-3A, -A, A, 3A\}$$

$$a_2 \in \{-3A, -A, A, 3A\}$$

Levels of $\sqrt{16} = 4\text{ PAM}$



QAM is a
SQUARE constellation

Total of 16 points
in 16-QAM
constellation.

$$\# \text{ bits/symbol} = \log_2 M.$$

$$M = 16$$

$$\# \text{ bits} = \log_2 16.$$

$$= 4 \text{ bits}$$

QPSK

2 bits on each
constituent PAM
QAM

M	$=$	4, 16, 64, 256, 1024, 4096
$\# \text{ bits}$	$=$	2, 4, 6, 8, 10, 12

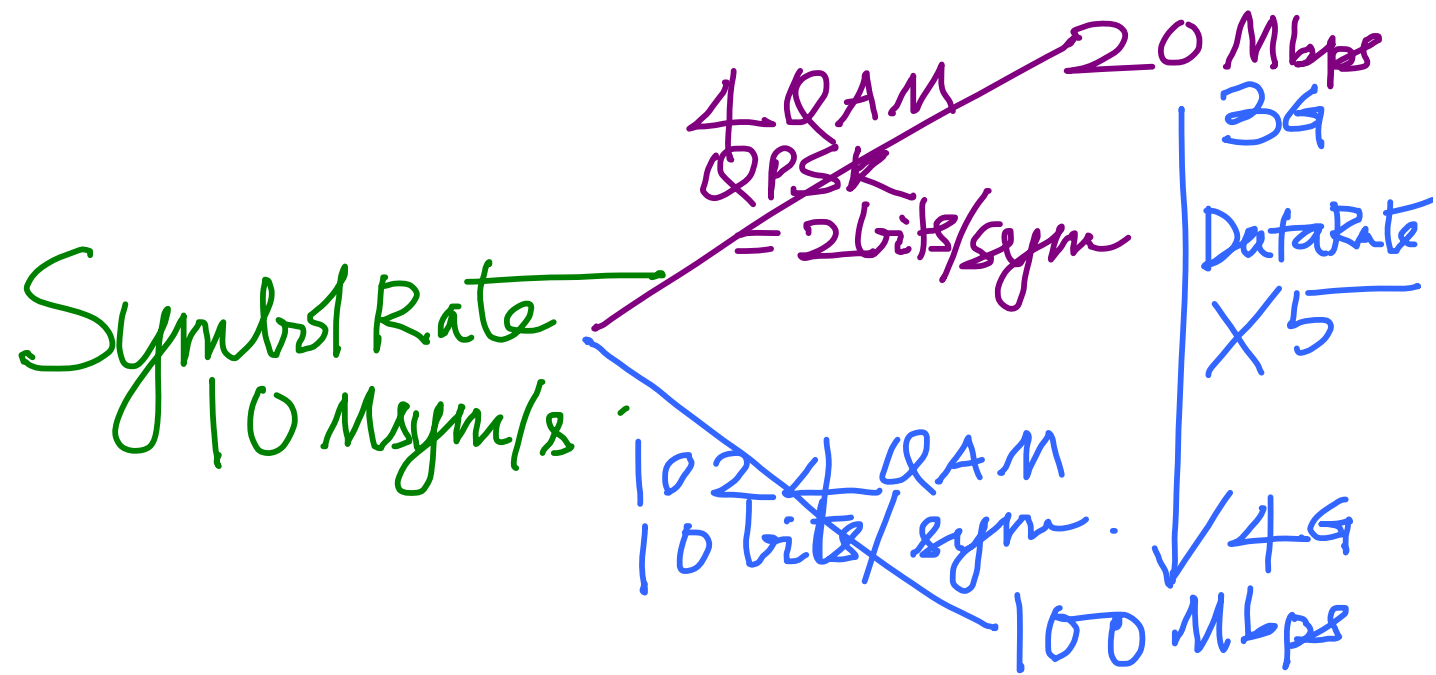
bits increases
Higher order modulation

Modulation can be
chosen adaptively to
meet rate requirements

Adaptive Modulation

Higher order modulation
+
Adaptive modulation

important to achieve
higher data rates in
3G, 4G, 5G, systems.



QAM — widely used modulation Schemes
