HY-330

fall semester 2024

Introduction to telecommunication systems theory

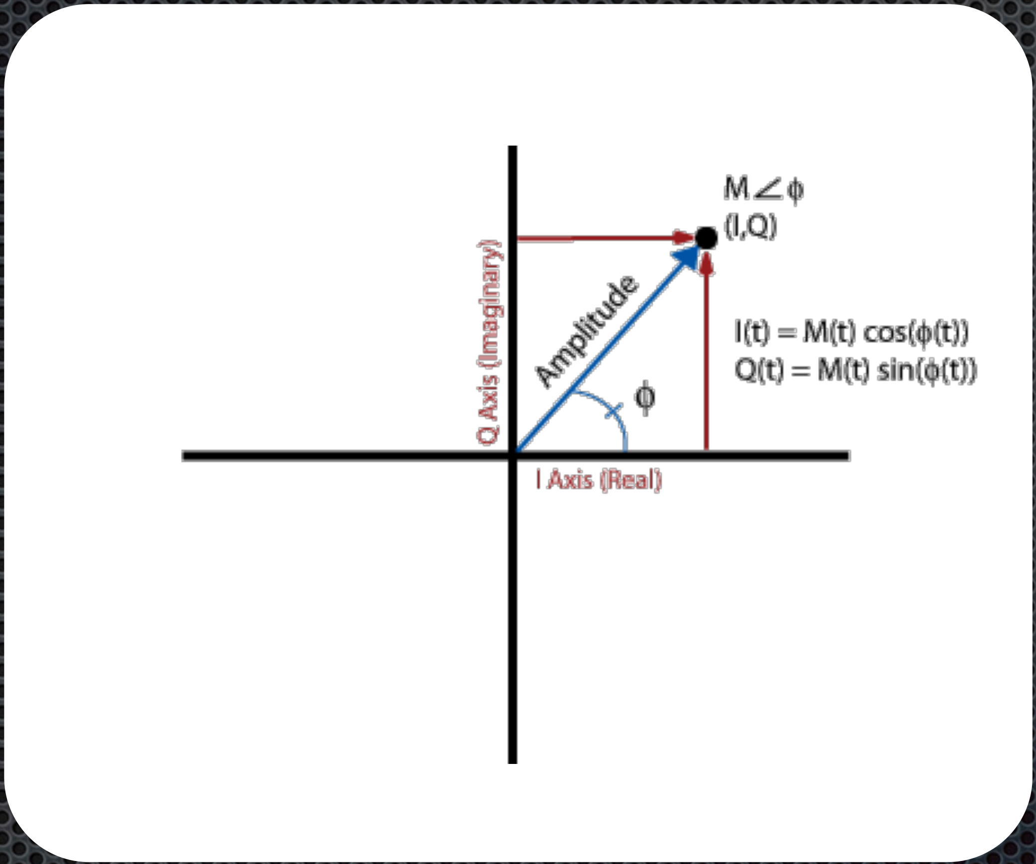
University of Crete
Computer Science Department

Stefanos Papadakis

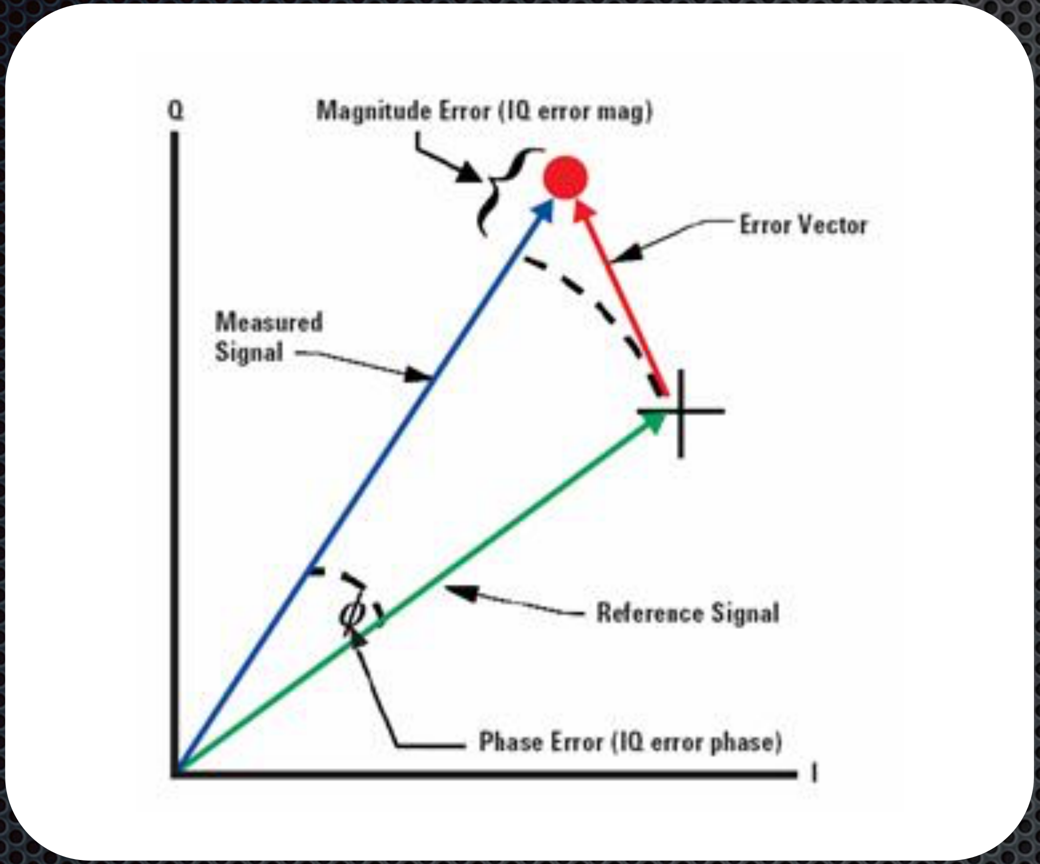
Digital Modulations

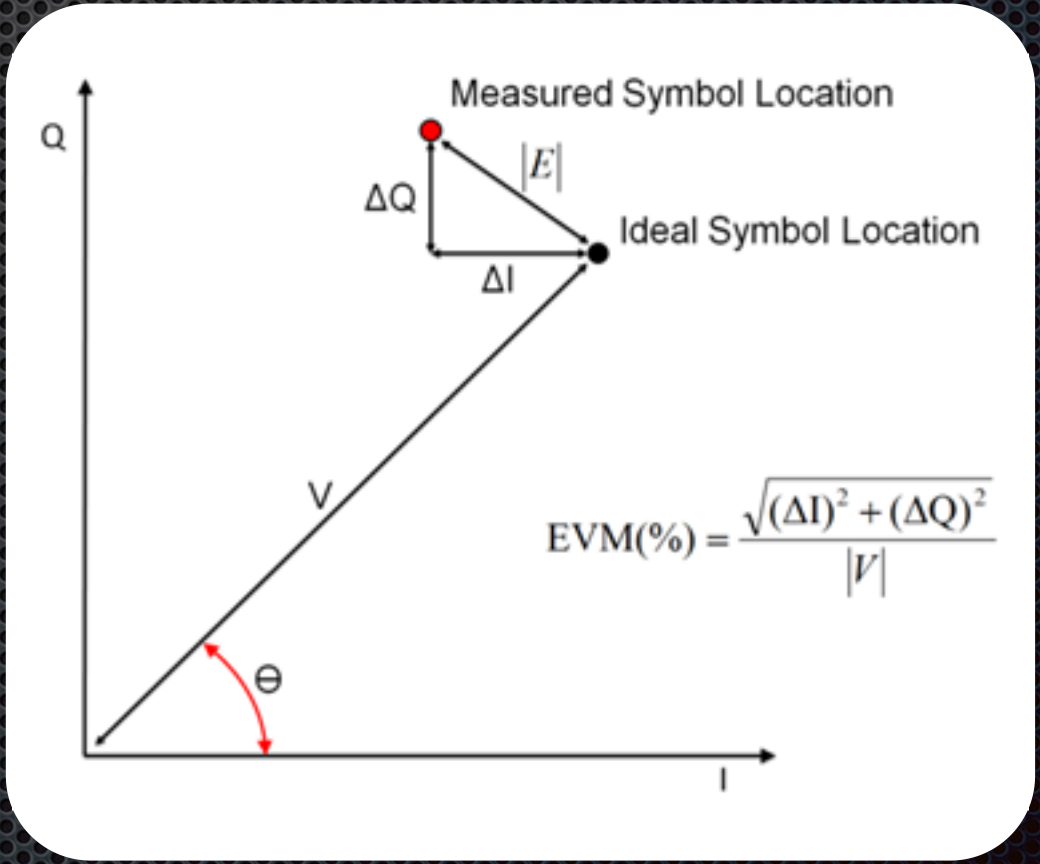
- EVM
- Efficiency

Quadrature Amplitude Modulation



Error Vector Magnitude





Error Vector Magnitude

- EVM

$$EVM(\%) = \sqrt{\frac{P_{error}}{P_{reference}}} \cdot 100\%$$

$$EVM(dB) = 10\log_{10}\frac{P_{error}}{P_{reference}}$$

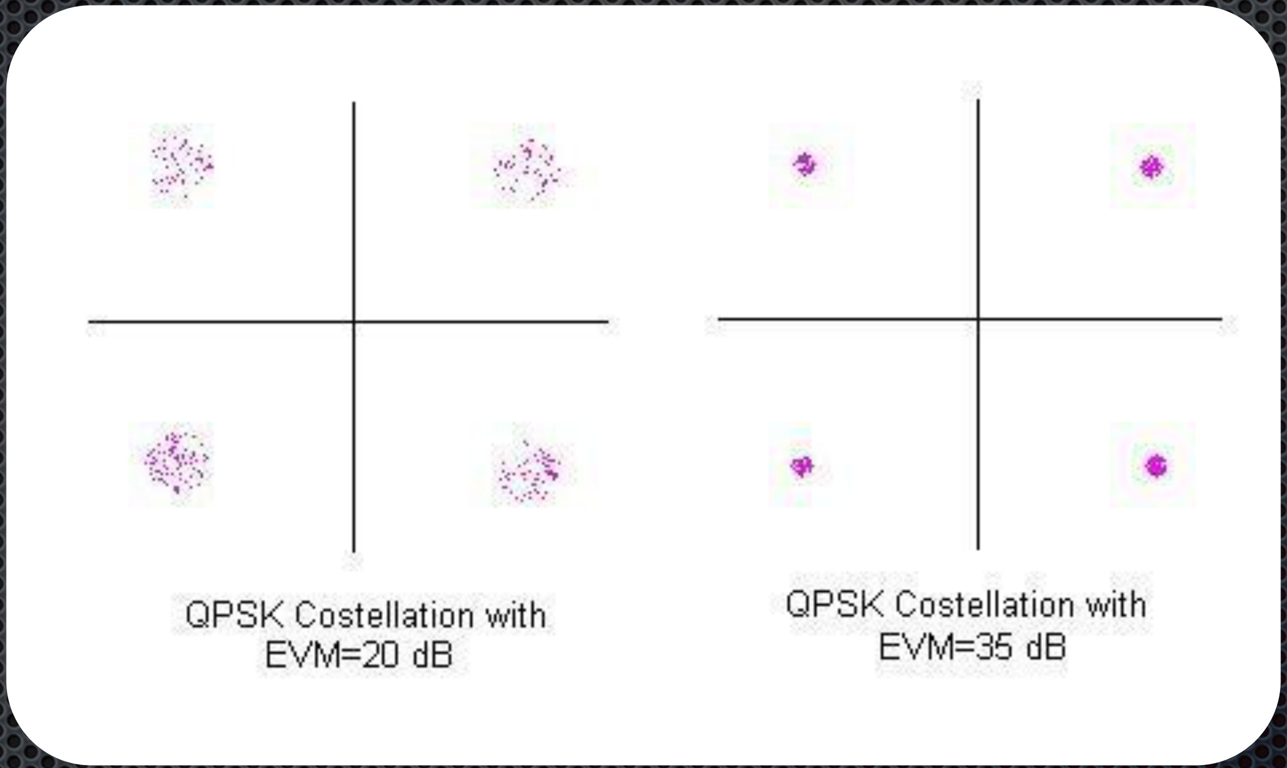
Error Vector Magnitude

- EVM vs SNR

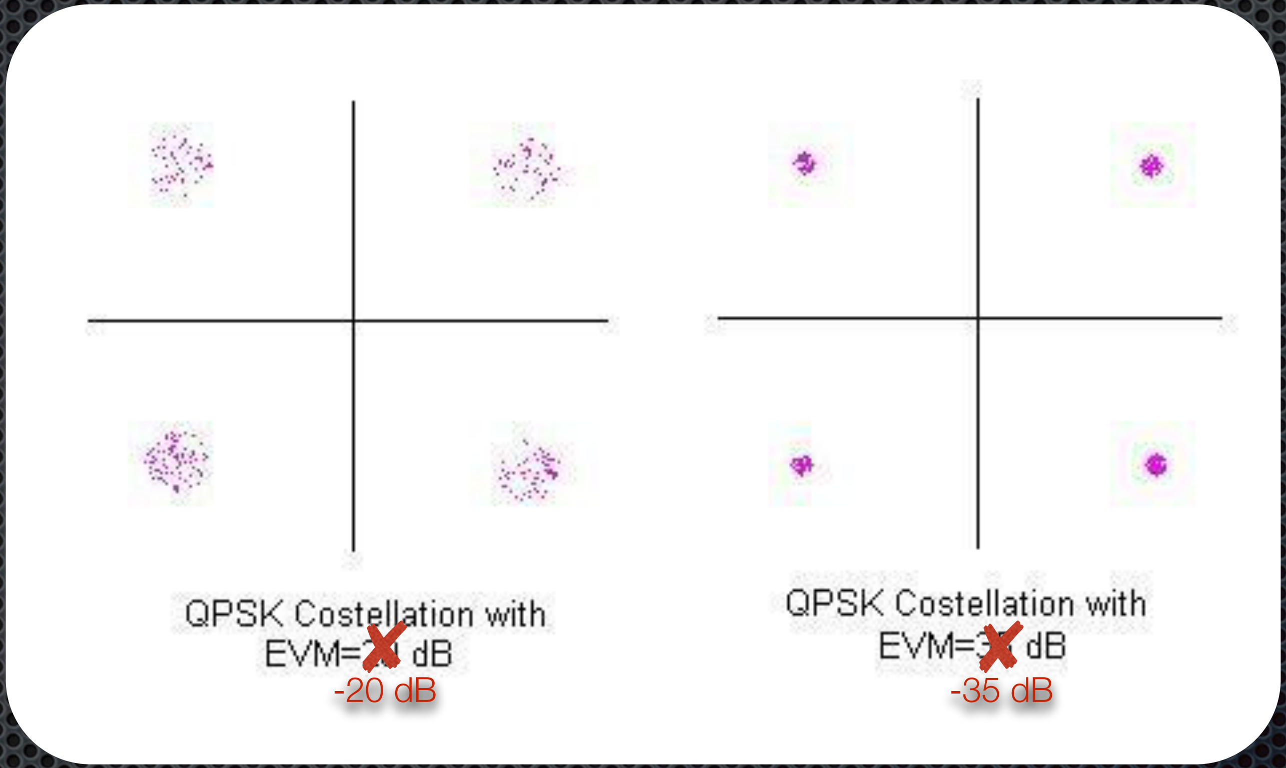
$$EVM_{RMS} \approx \sqrt{\frac{1}{SNR}}$$

$$SNR[dB] = -20 \cdot \log(EVM/100\%)$$

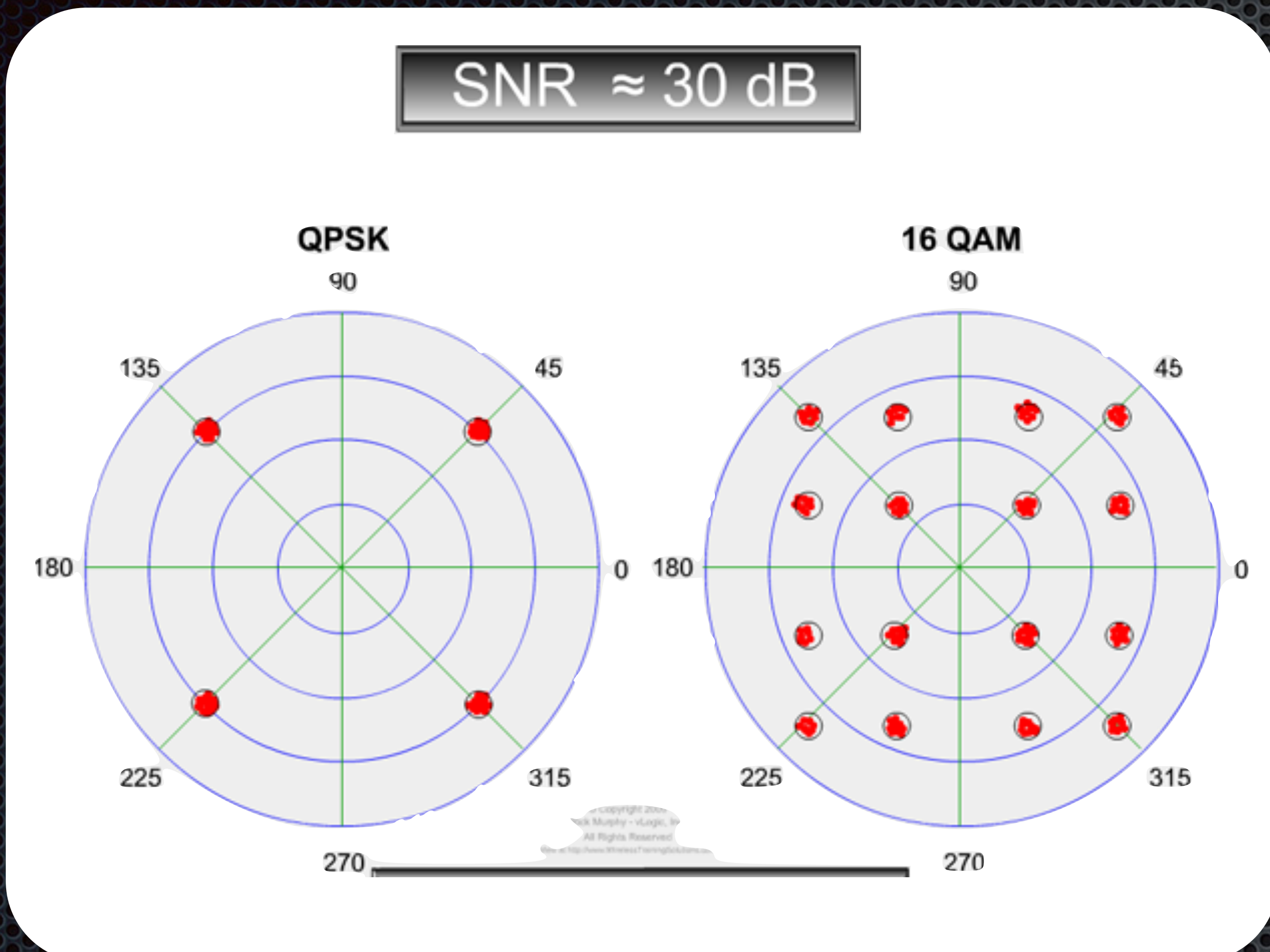
Error Vector Magnitude



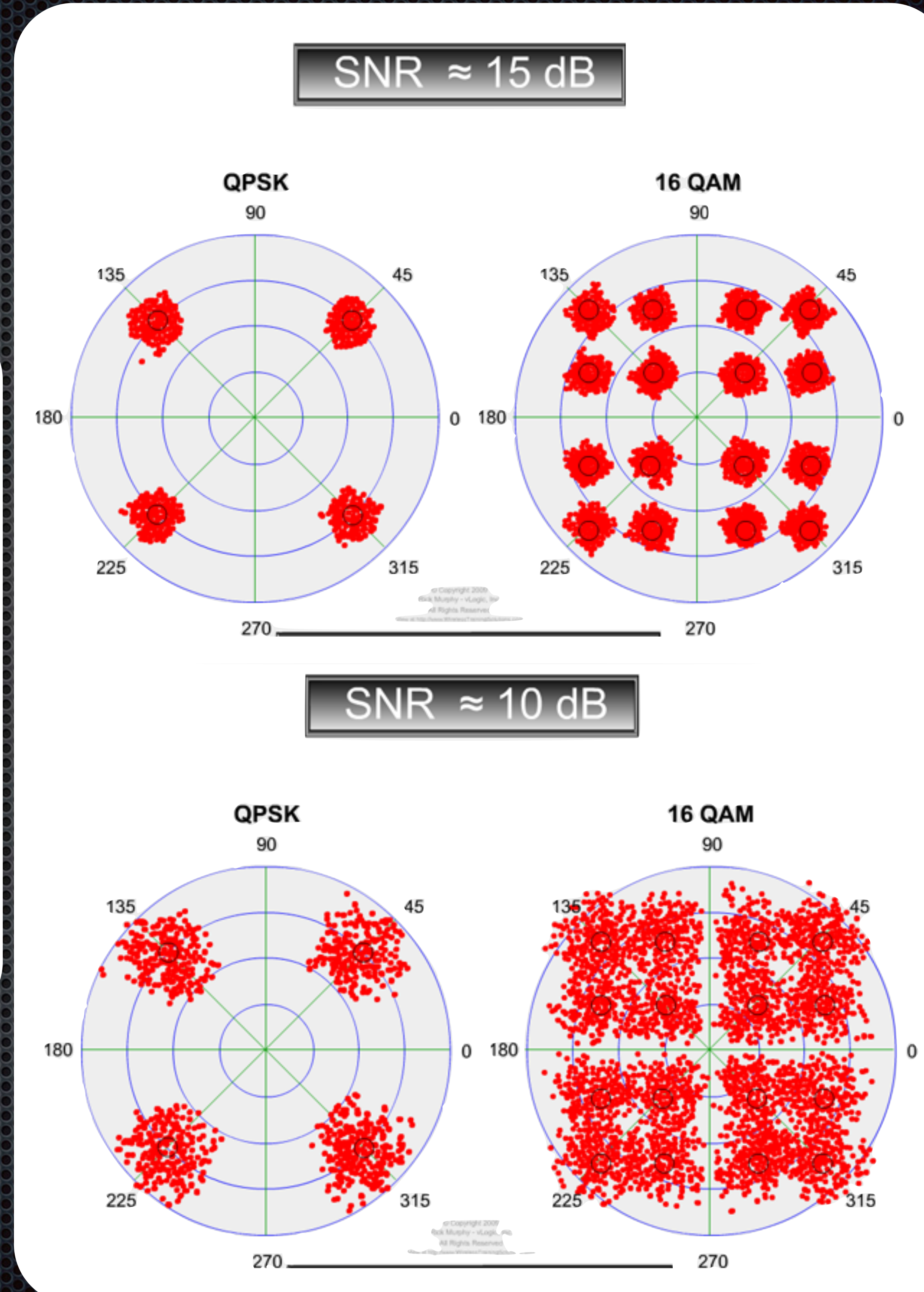
Error Vector Magnitude



SNR~EVM

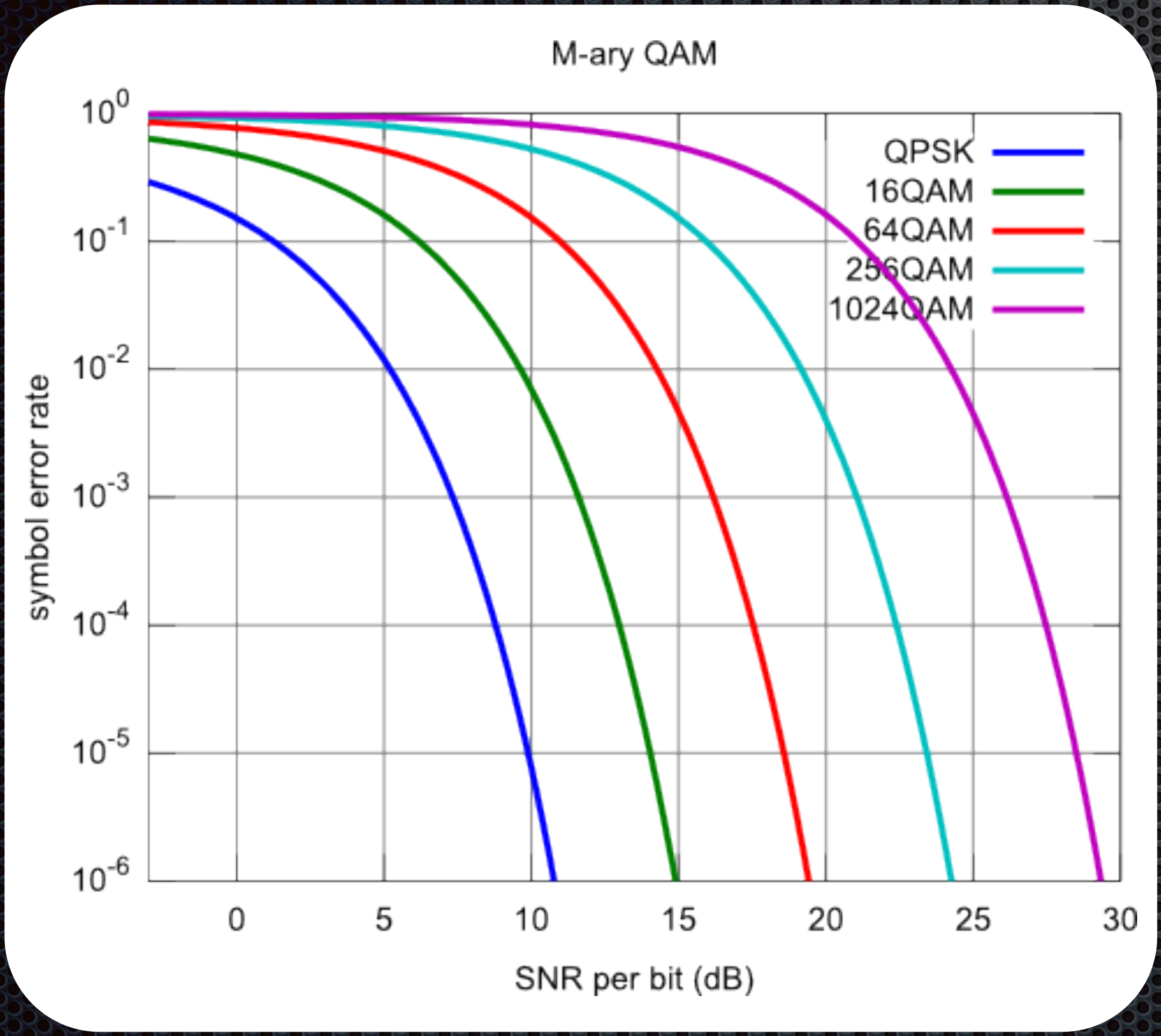


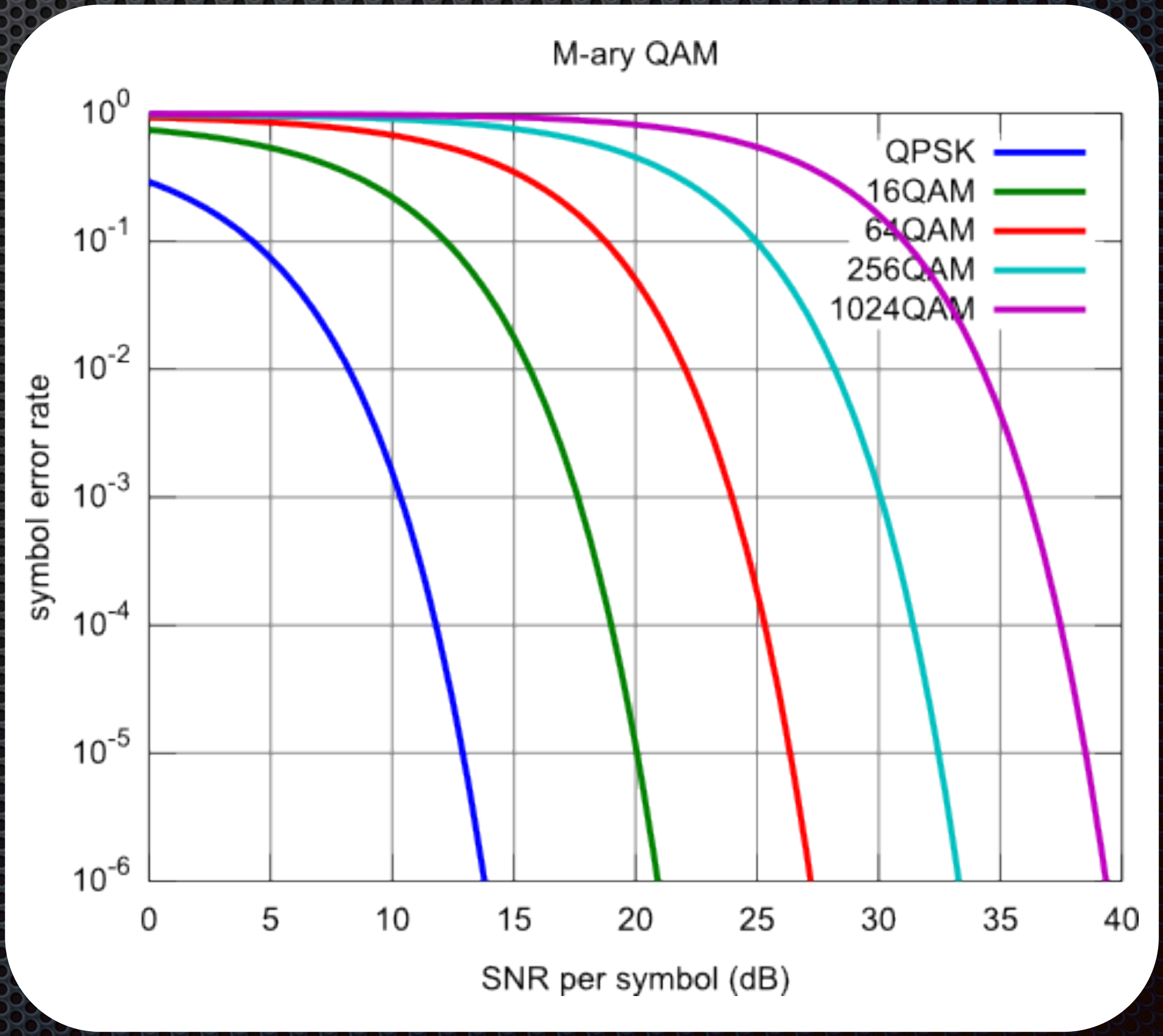
SNR ≈ 30 dB
QPSK
16 QAM
90
135
45
180
0
225
315
270



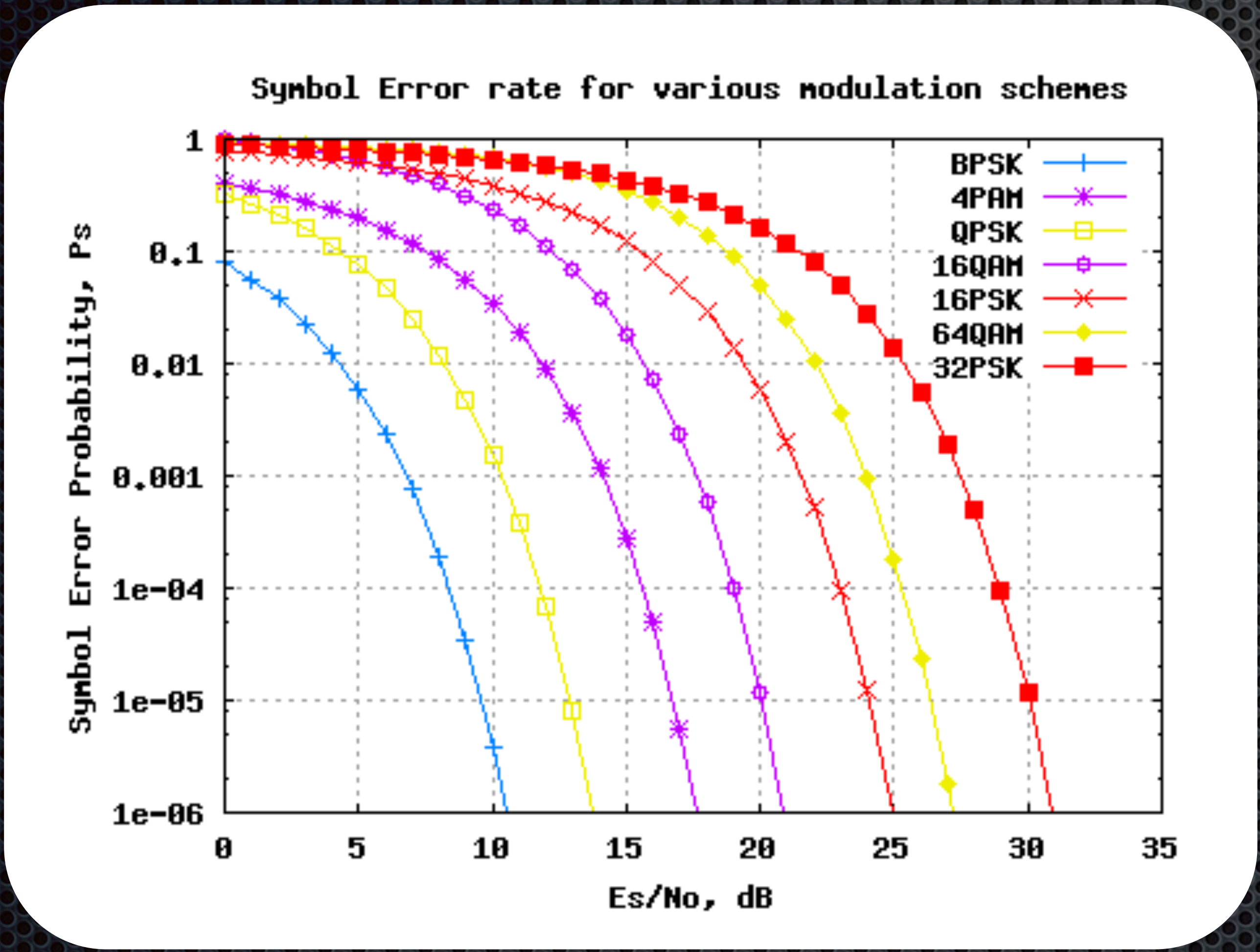
SNR ≈ 15 dB
QPSK
16 QAM
SNR ≈ 10 dB
90
135
45
180
0
225
315
270

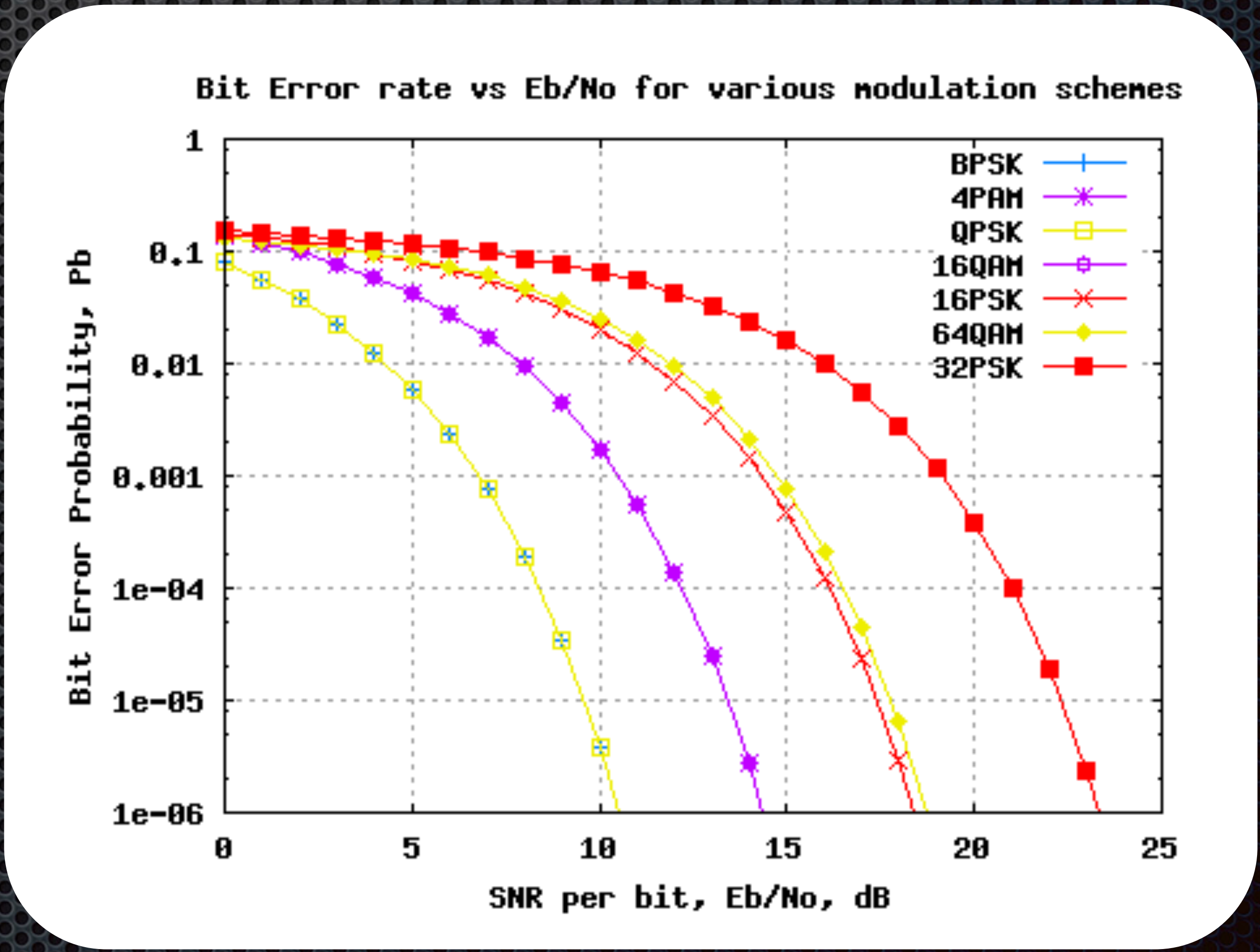
Performance of QAM

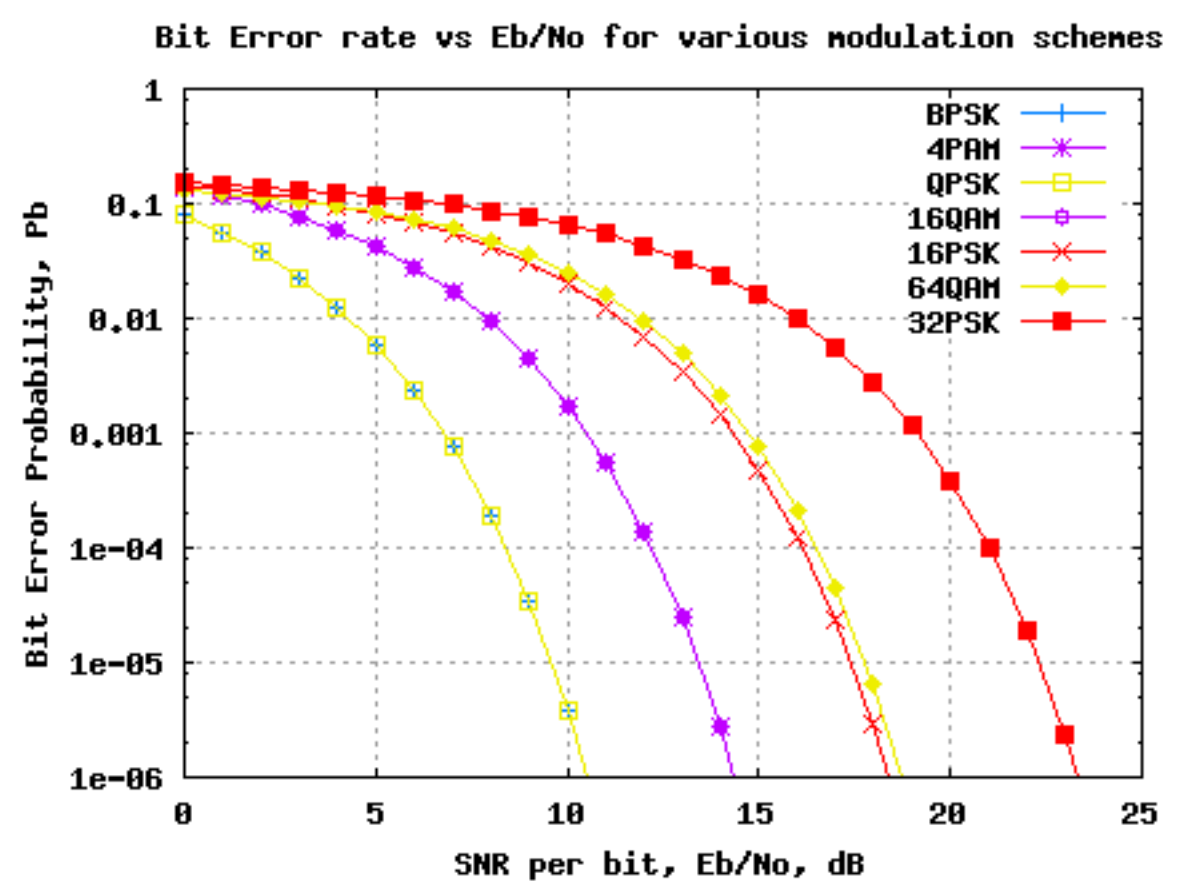


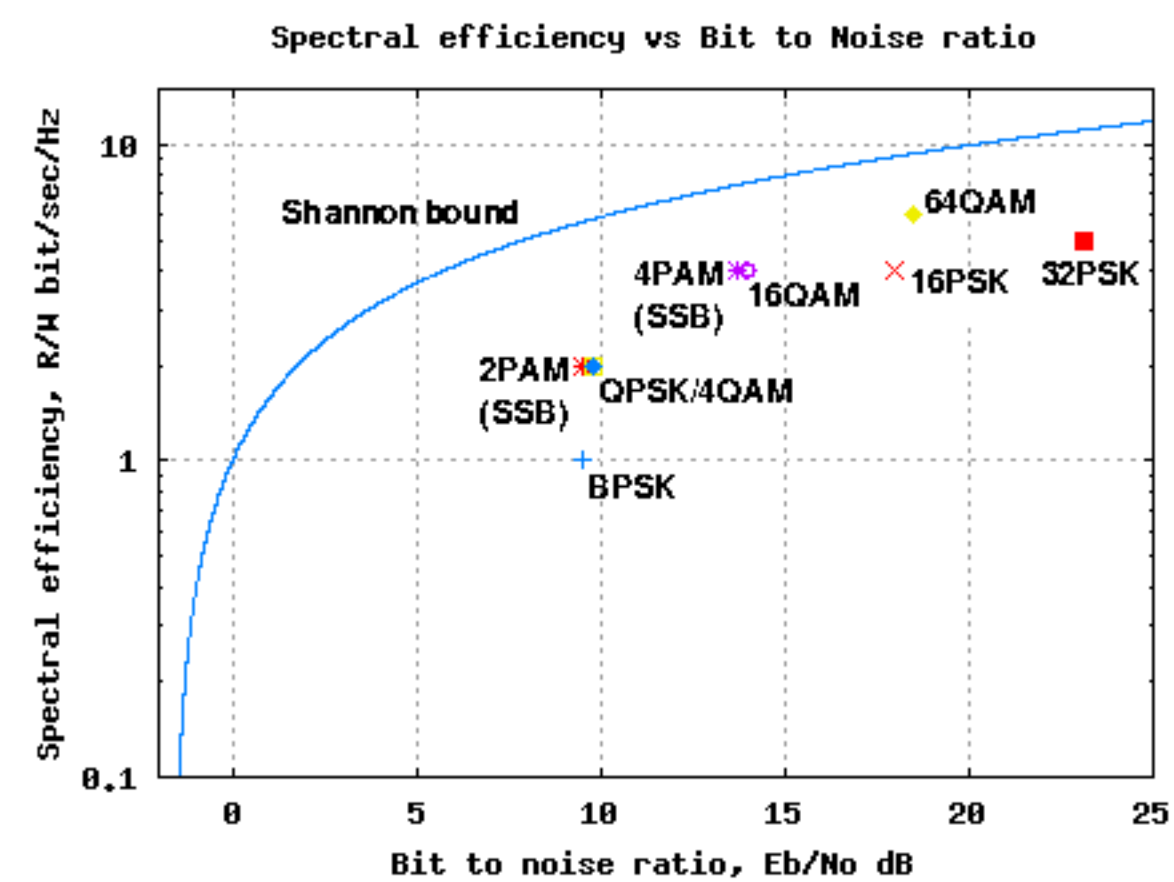


Performance of Modulations






Bit Error rate vs Eb/No for various modulation schemes
Bit Error Probability, Pb
SNR per bit, Eb/No, dB
BPSK
4PAM
QPSK
16QAM
16PSK
64QAM
32PSK
1
0.1
0.01
0.001
1e-04
1e-05
1e-06
0
5
10
15
20
25


Spectral efficiency vs Bit to Noise ratio
Spectral efficiency, R/W bit/sec/Hz
Bit to noise ratio, Eb/No dB
Shannon bound
64QAM
4PAM
(SSB)
16QAM
16PSK
32PSK
2PAM
(SSB)
QPSK/4QAM
BPSK
10
1
0.1
0
5
10
15
20
25

Performance of Modulations

Digital Modulation scheme	Symbol time, second	Bit Rate, bits/second	Bandwidth, Hz	Capacity, (bits/ second/ Hz)	Eb/No, dB required for Ps = 10^-5
BPSK	T	1/T	1/T	1	9.5
2-PAM (SSB BPSK)	T	1/T	1/2T	2	9.5
QPSK	T	2/T	1/T	2	9.8
4-QAM	T	2/T	1/T	2	9.8
4-PAM (SSB)	T	2/T	1/2T	4	13.7
16-QAM	T	4/T	1/T	4	14
16-PSK	T	4/T	1/T	4	18
32-PSK	T	5/T	1/T	5	23.1
64-QAM	T	6/T	1/T	6	18.5