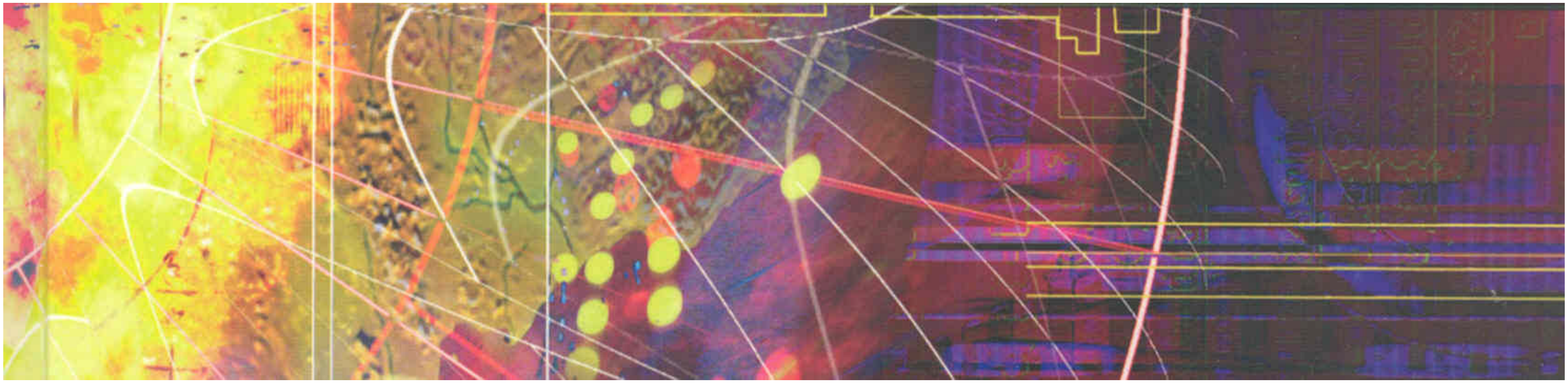
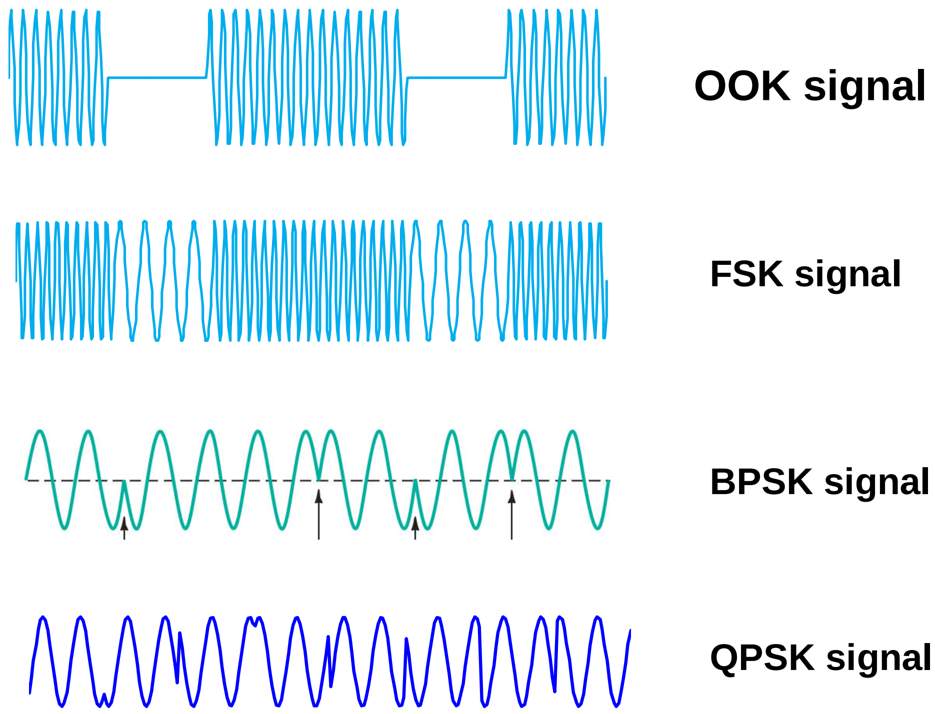


EE303 Lesson 20: Digital Modulation 2

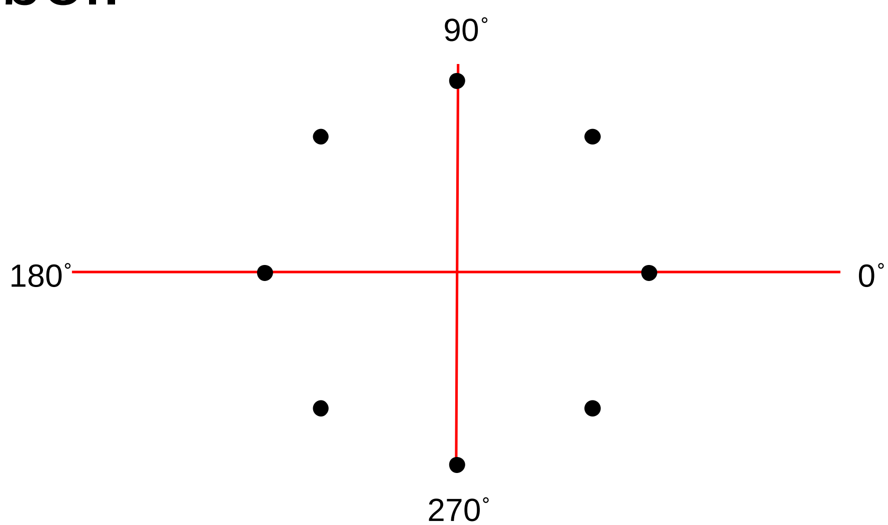
Digital modulation schemes

- We’ve discussed these types of digital modulation



M-ary PSK

- In order to increase the data rate without increasing bandwidth, we can further increase the number of bits per symbol.
- In the 8-PSK constellation below, 8 possible phase shifts allow 3 bits to be transmitted by each symbol.



0° = binary 000

45° = binary 001

90° = binary 011

135° = binary 010

180° = binary 110

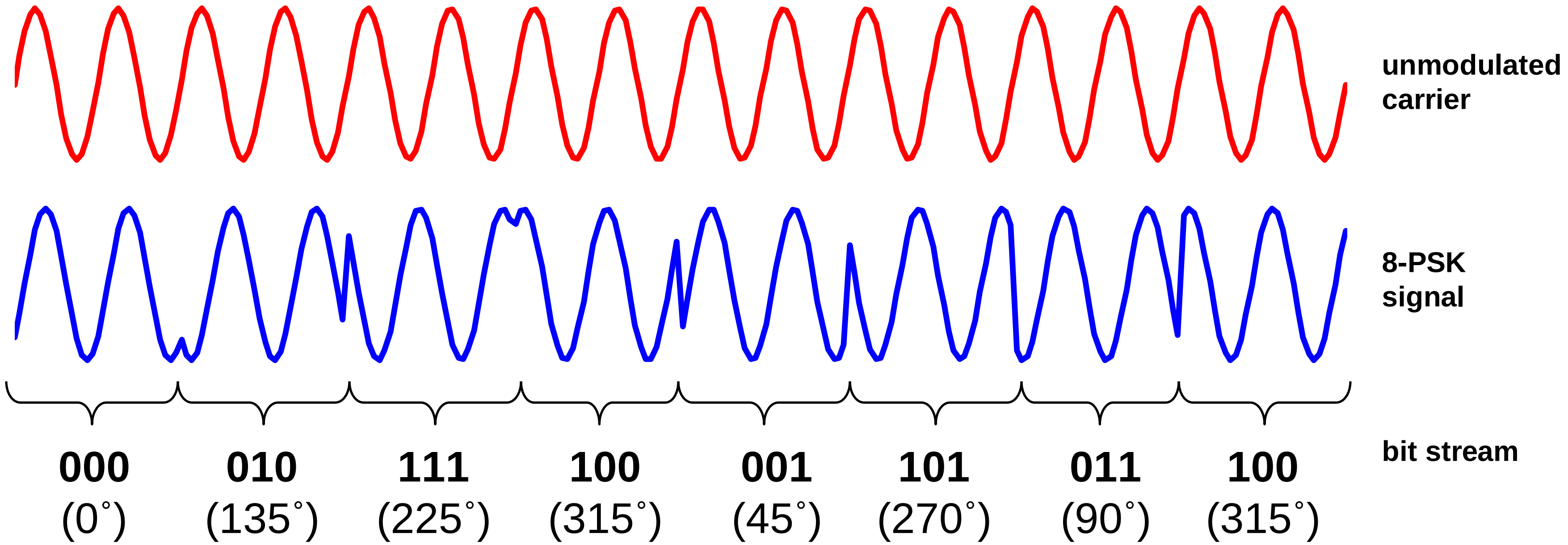
225° = binary 111

270° = binary 101

315° = binary 100

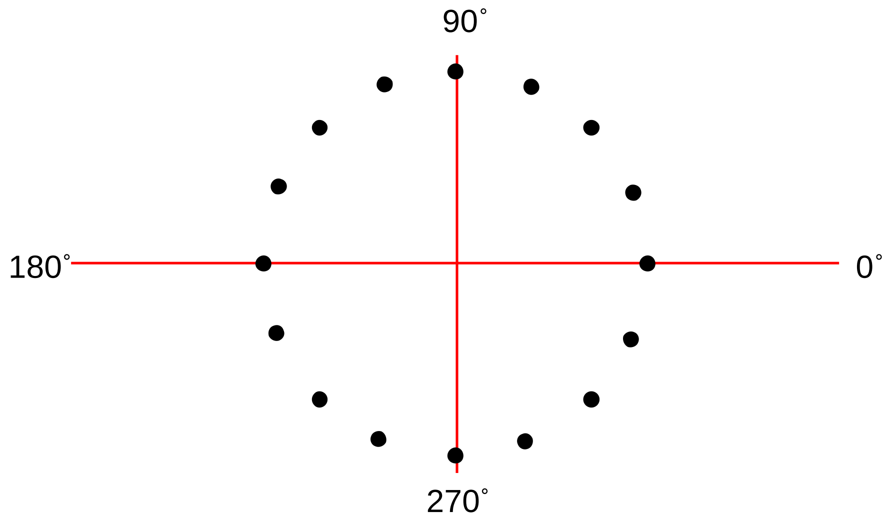
8-PSK

- Consider the bit stream below and the resulting 8-PSK signal.



16-PSK

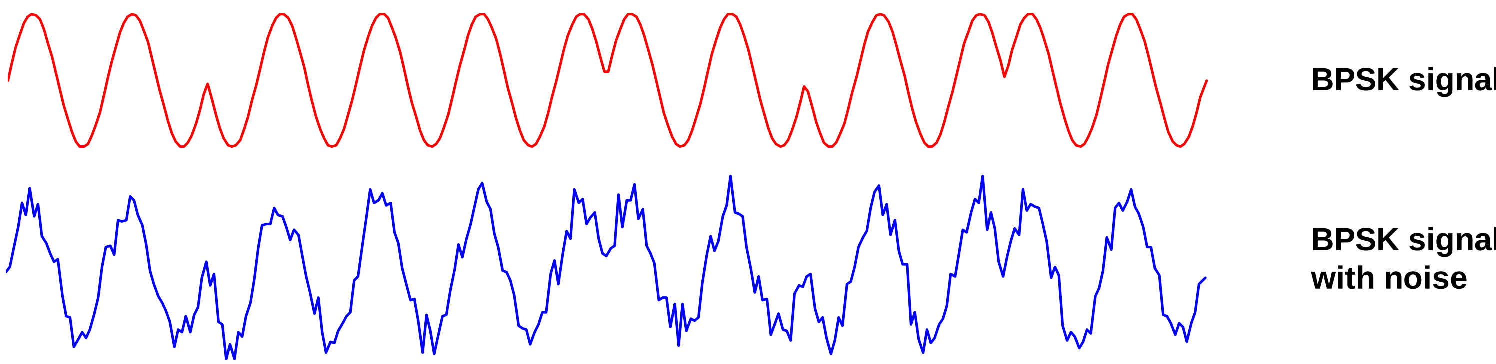
- We could further increase to 4 bits/symbol using 16-PSK.



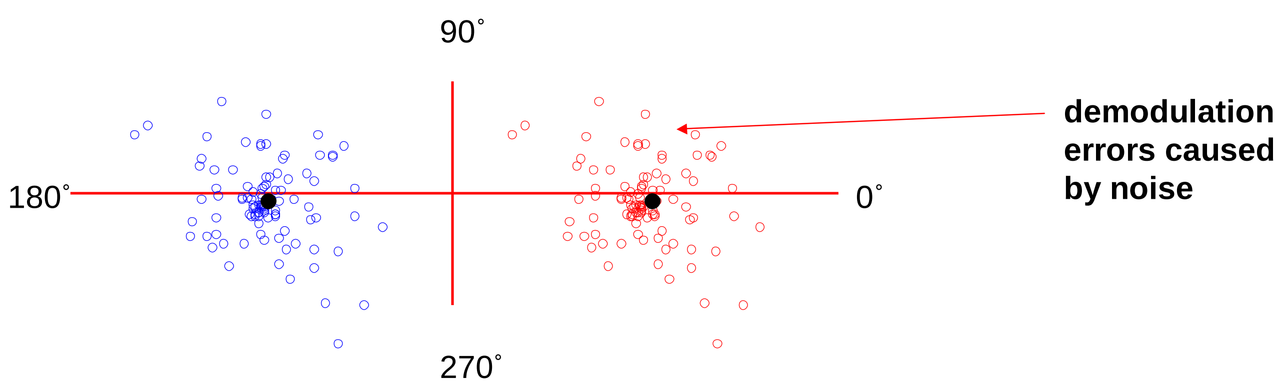
- To demodulate 16-PSK, the receiver must determine the phase within ±11.25˚.

Noise effects

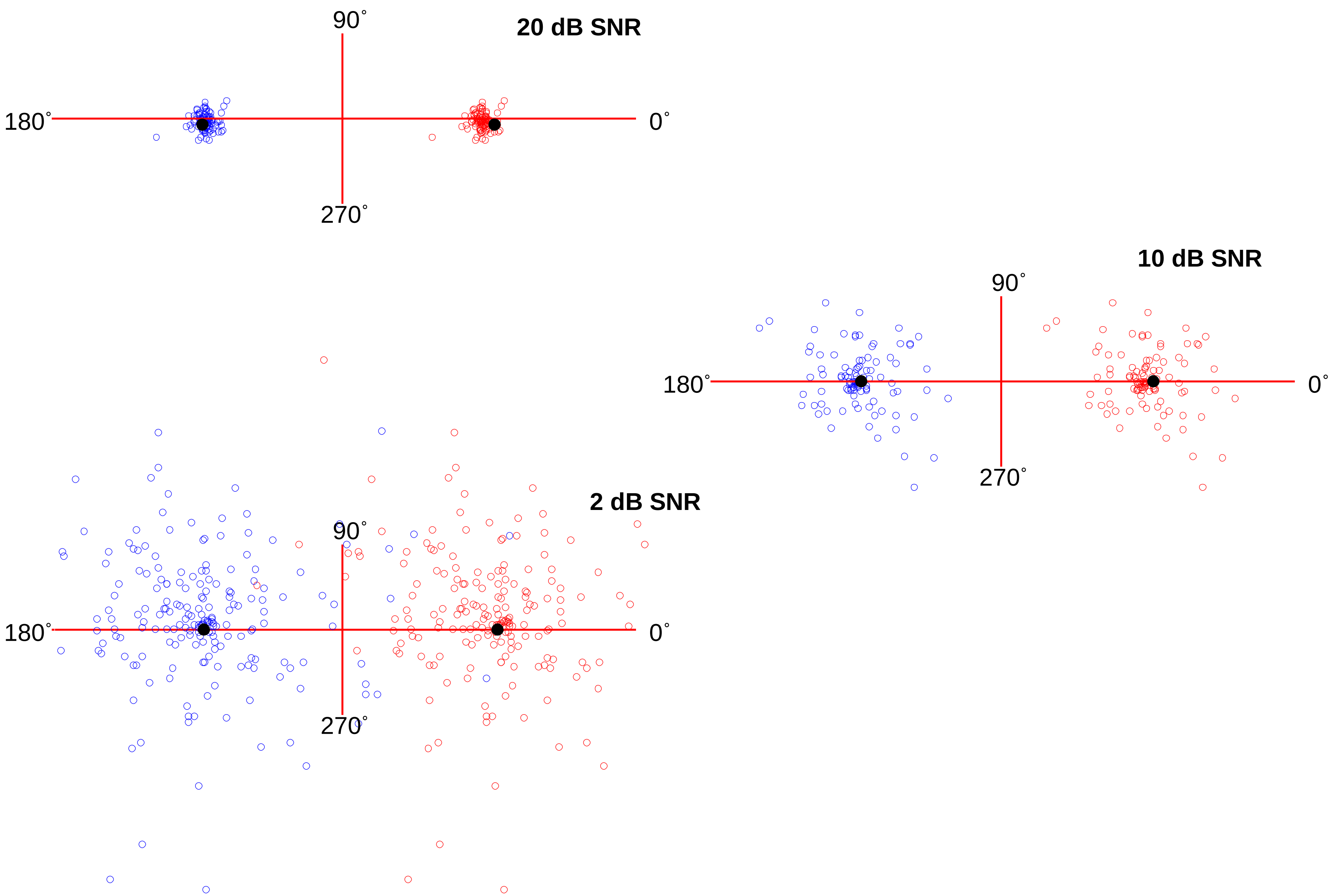
- Like all transmissions, the received signal will be degraded by noise.



- This can be depicted in the phasor domain as follows.



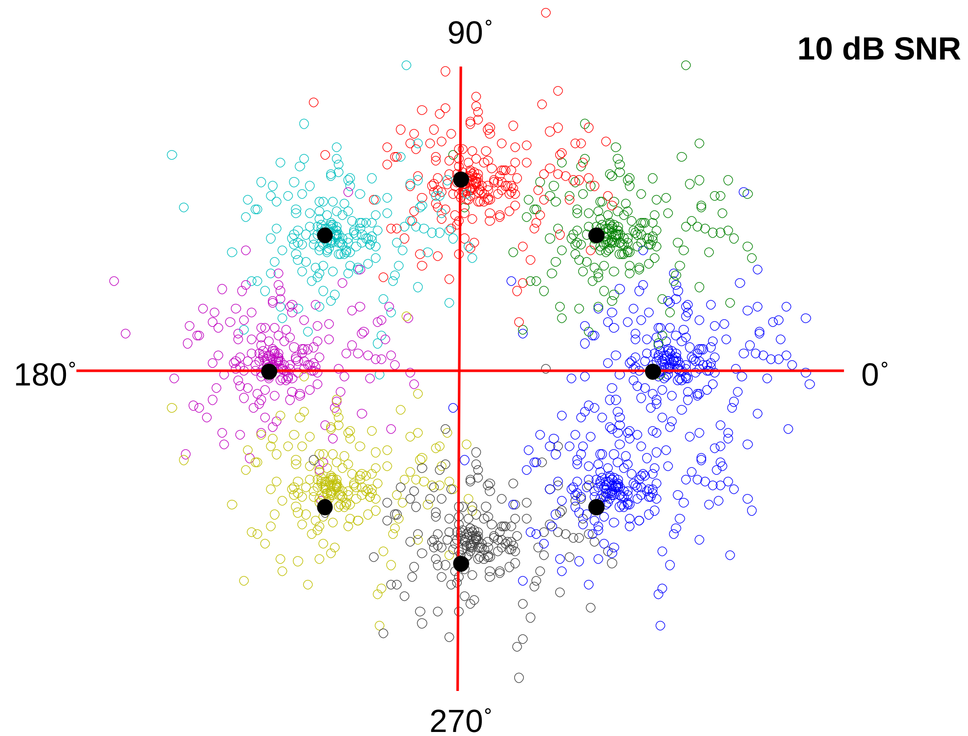
Noise effects



Noise effects

- A BPSK receiver must make a decision to determine the phase of a received signal to determine the corresponding binary signal.
- Now consider the same noise in the presence of a QPSK or 8-PSK signal.

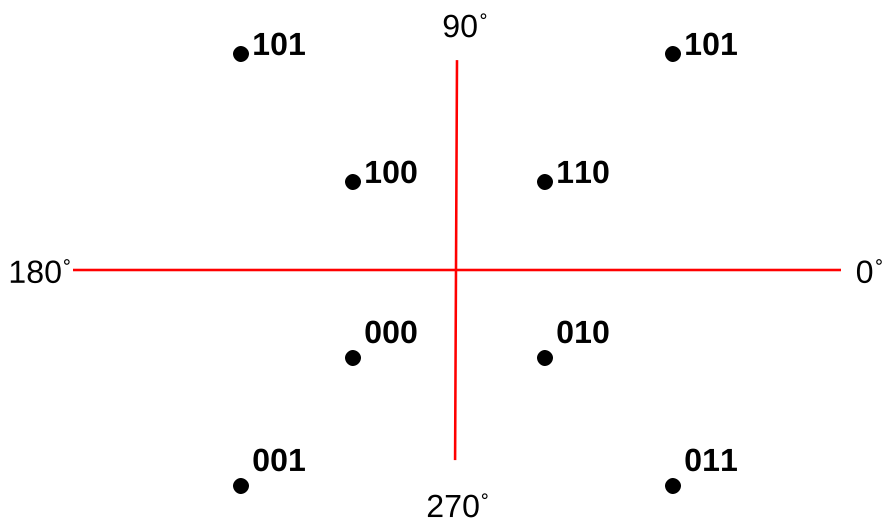
Noise effects (8-PSK)



- What is the relative likelihood of an error?

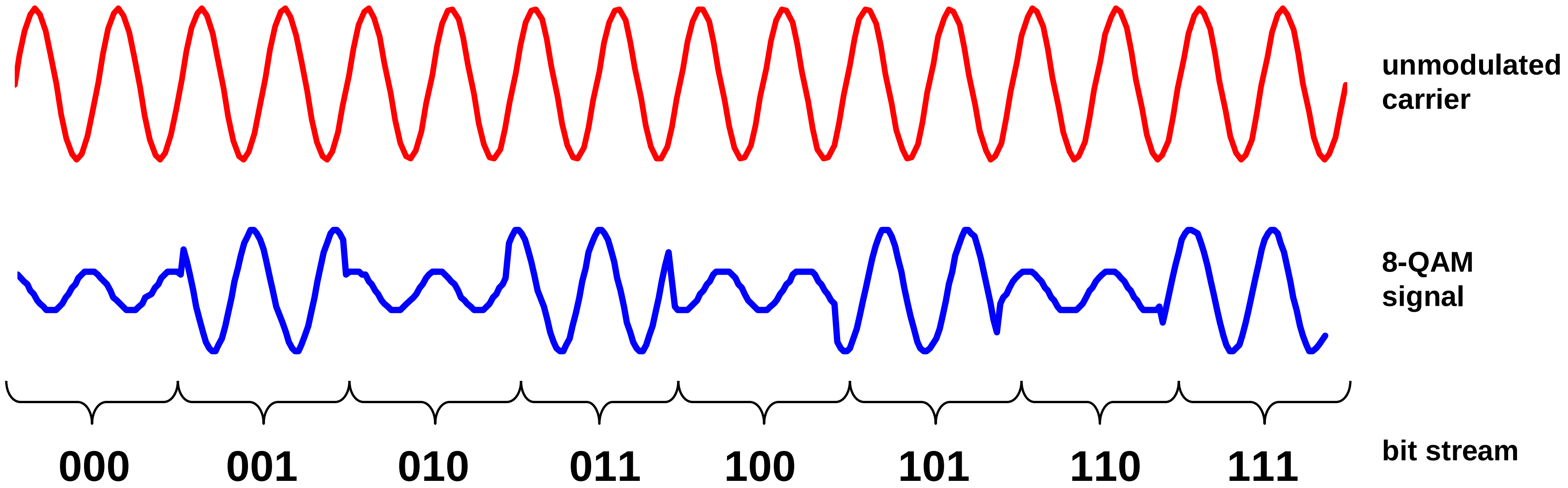
Quadrature Amplitude Modulation

- In order to increase the distance between points in the signal constellation, another option is to modulate both the amplitude and the phase.
- This is called quadrature amplitude modulation.
- Consider the 8-QAM constellation below.



8-QAM

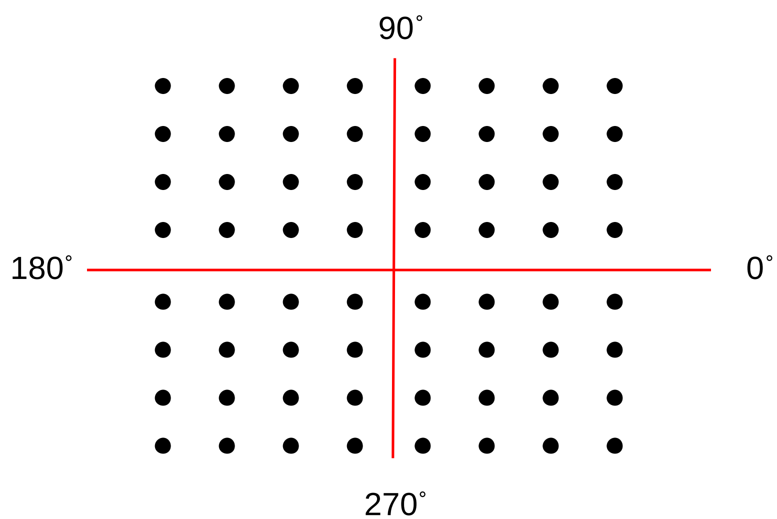
- Consider the bit stream below and the resulting 8-QAM signal.



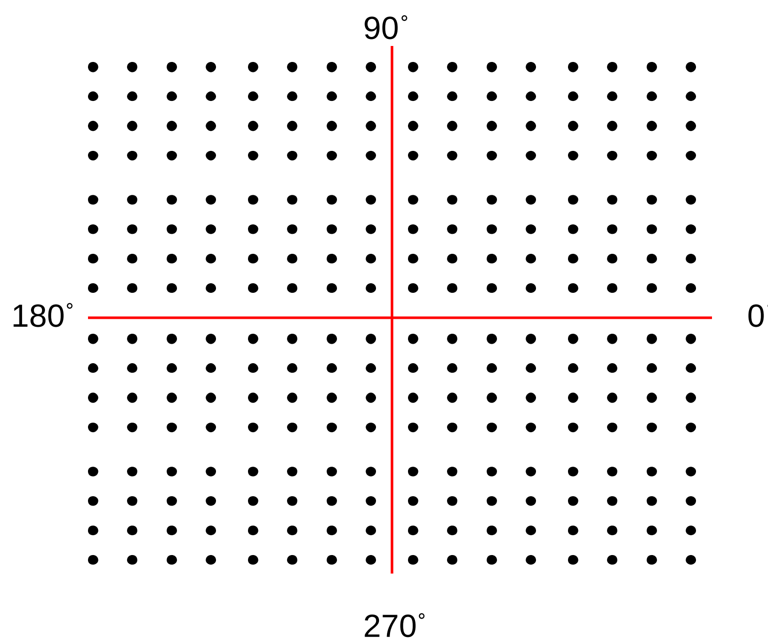
Higher level QAM signals

- QAM signals can be extended to much higher bit rates as depicted.
- 64-QAM and 256-QAM are common in cable modems, satellites, and high-speed fixed broadband wireless.

64-QAM



256-QAM



Spectral Efficiency

- Spectral efficiency is a measure of how fast data can be transmitted over a given bandwidth.
- It is measured in bits per second per hertz (bps/Hz).

Modulation	**Spectral efficiency (bps/Hz)**
FSK	<1
MSK	1.35
BPSK	1
QPSK	2
8-PSK	3
16-QAM	4

Example Problem 1

Based on the spectral efficiency of the various digital modulation schemes, what is the minimum bandwidth required to transmit at a rate of 9600 bps using:

a. MSK (or GMSK)

b. BPSK

c. 8-PSK

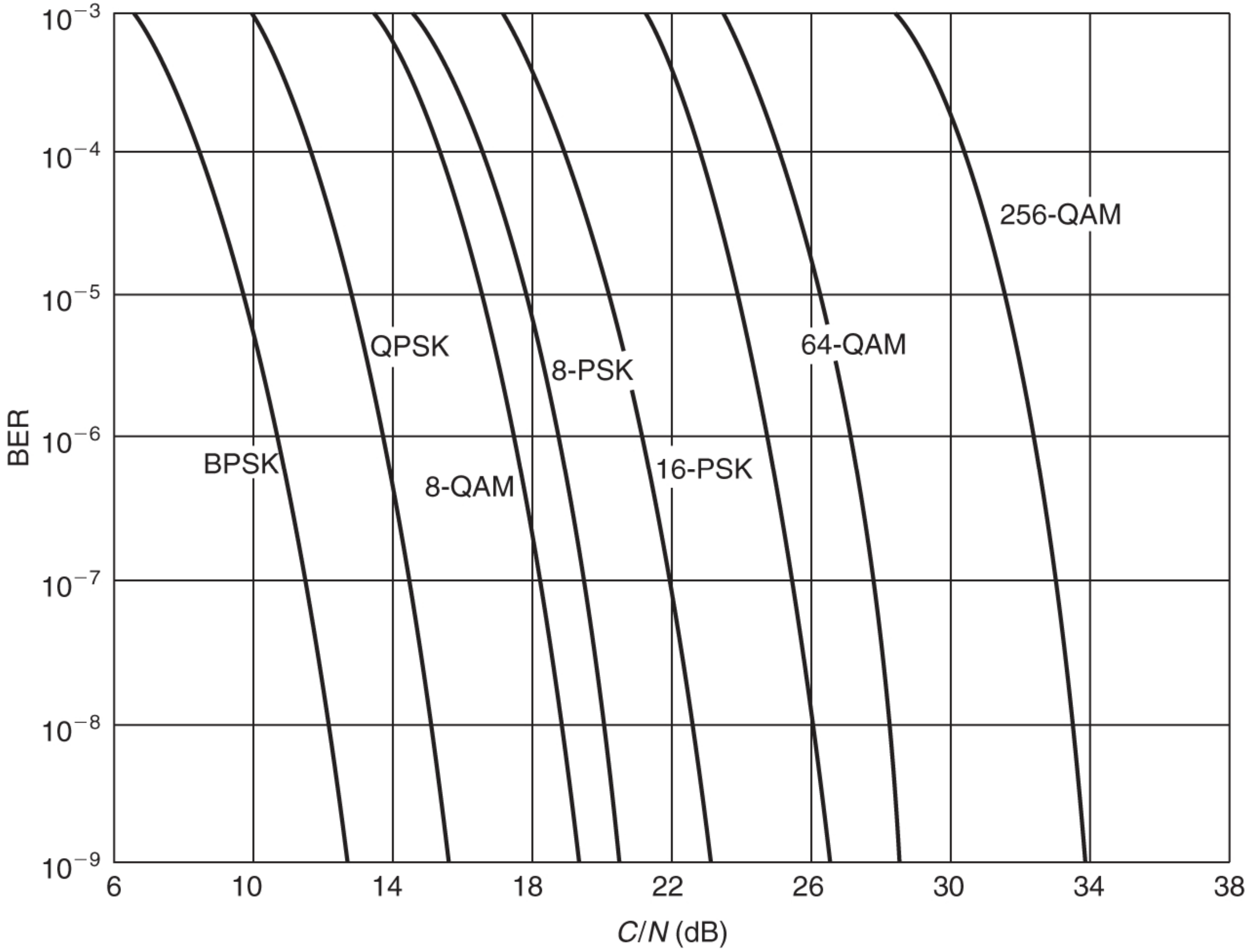
d. 16-QAM

Bit errors

- Another factor that influences spectral efficiency is channel signal-to-noise (S/N) ratio.
- The larger the amount noise present (lower S/N ratio), the greater the number of bit errors.
- The ratio of the number of bit errors to the number of bits transmitted is the bit error rate (BER).
- For example, if 5 bit errors occur every million transmitted bits, the BER is

$$BER = \frac{\text{number of errors}}{\text{number of transmitted bits}} = \frac{5}{1{,}000{,}000} = 5 \times 10^{-6}$$

BER vs. *C*/*N* for digital modulation



BER vs. *C*/*N* for digital modulation

- The bit error rates of various modulation schemes have been calculated versus carrier signal-to-noise ratios.
- The plot shows that the more basic modulation schemes (BPSK, QPSK) have a higher immunity to noise that the more complex constellations.
- This plot does not take signal bandwidth into consideration (noise increases with bandwidth)
- Also, the plot does not take into account the bit rates of the various formats.

Example Problem 2

What is the required carrier signal-to-noise (C/N) ratio required to achieve a BER of 10^{-6} for each of the following modulation schemes?

a. BPSK

b. QPSK

c. 16-PSK

d. 256-QAM

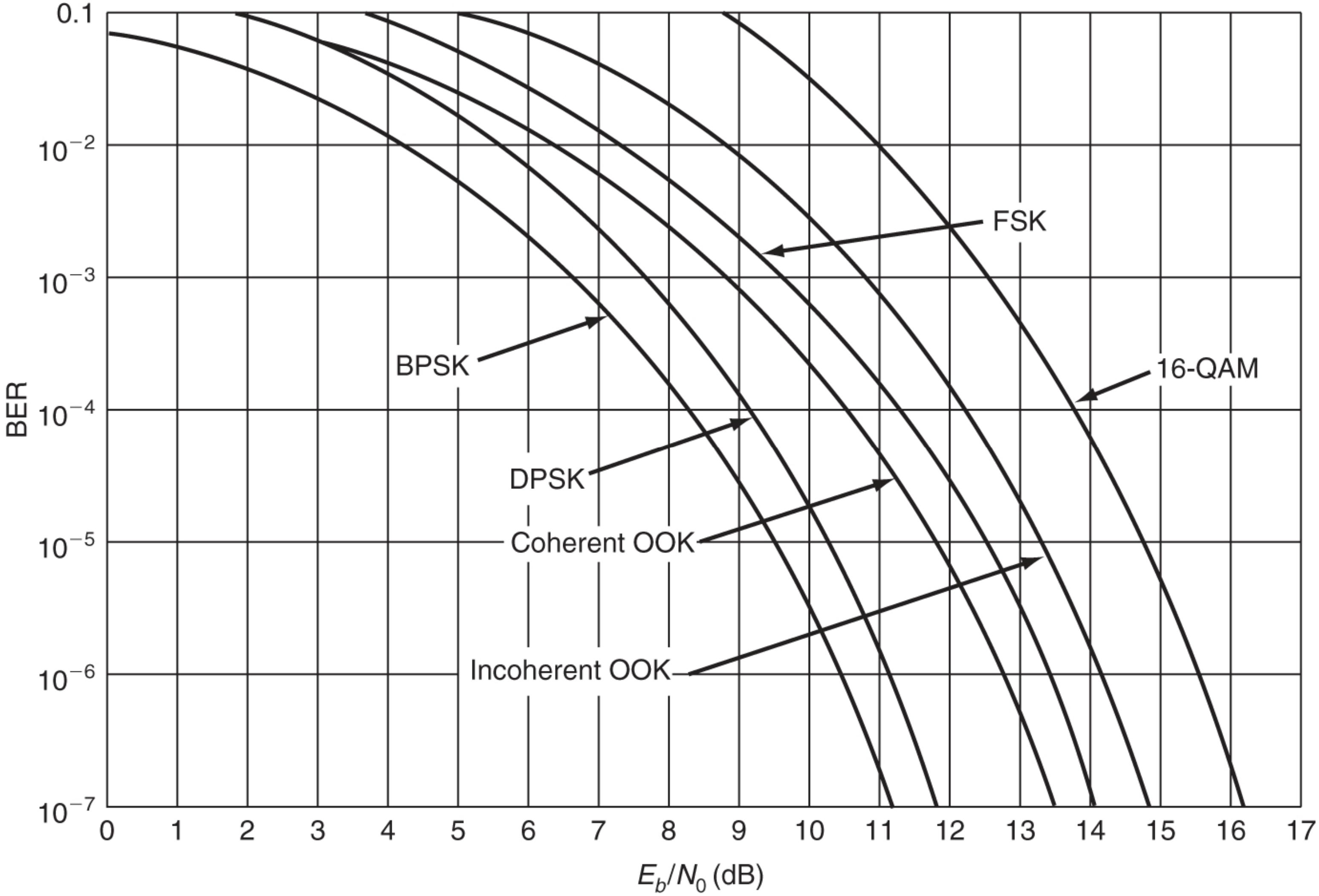
E_b/N_0

- A better measure of signal to noise ratio is to compared the energy per bit (E_b) versus the noise power density (N_0) given by

$$\frac{E_b}{N_0} = \left(\frac{C}{N}\right)\left(\frac{B}{f_b}\right)$$

- E_b/N_0 takes into account the bandwidth requirements and bit rates of the various formats.

BER vs. E_b/N_0 for digital modulation



Example Problem 3

Consider transmitting 10,000,000 bits over a channel with a S/N ratio (expressed in E_b/N_0) of 10 dB. Roughly how many bits errors would you expect to experience for each of the following modulation schemes?

a. BPSK

b. Coherent OOK

c. FSK

d. 16-QAM