Transmission of signals: impairments (noise, signal-to-noise ratio and Bit Error Rate)

Signal impairments

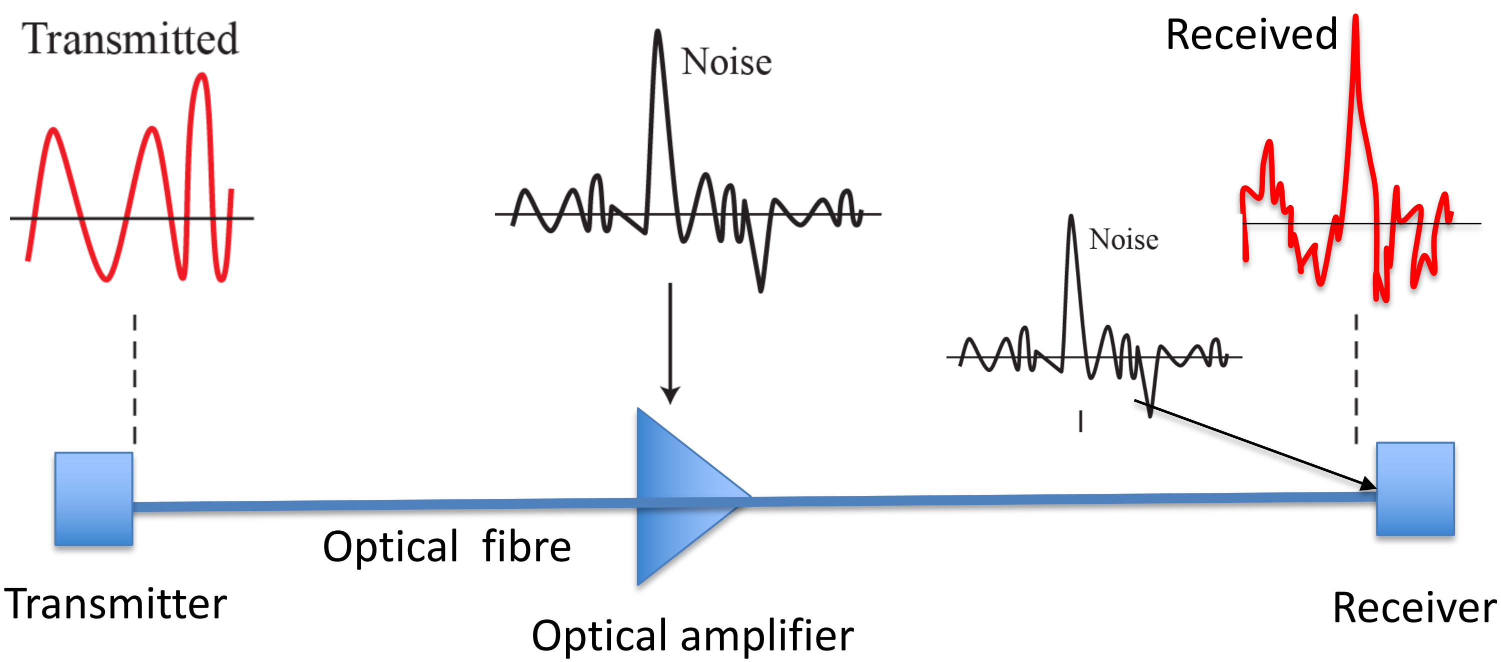
- **Attenuation**: the signal looses power as it propagates
- **Distortion**: the signal changes shape as it propagates
- **Noise**: interference with other man-made or random signals.

Noise

- Noise is any unwanted signal (from another communication source or from a random source) that interferes with our signal.
- Example of noises are:
  - **Thermal noise**: generated by the random thermal motion of electrons inside an electrical conductor
  - **Shot noise**: generated by the random statistical fluctuations of the electric current in an electrical conductor, due to the discrete nature of current (i.e., electrons)
  - **Amplified Spontaneous Emission (ASE) – for amplified optical systems**: due to optical amplifiers, which besides amplifying the signal carrying information also introduce additional noise.

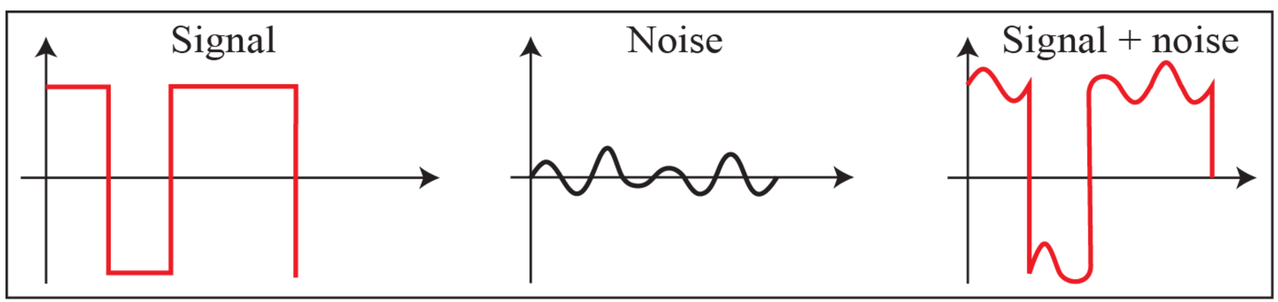
Noise

- Since the noise sums up to the transmitted signal, the received signal is different from the original signal

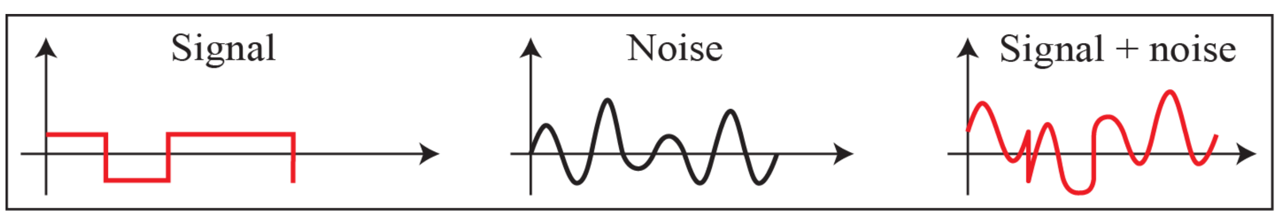


The **Signal-to-noise ratio** (SNR)

- The SNR is the ratio between the power of the signal and the power of the noise.
- The better the SNR the more the received signal is a faithful reproduction of the original one.



a. High SNR



b. Low SNR

Effect of impairments

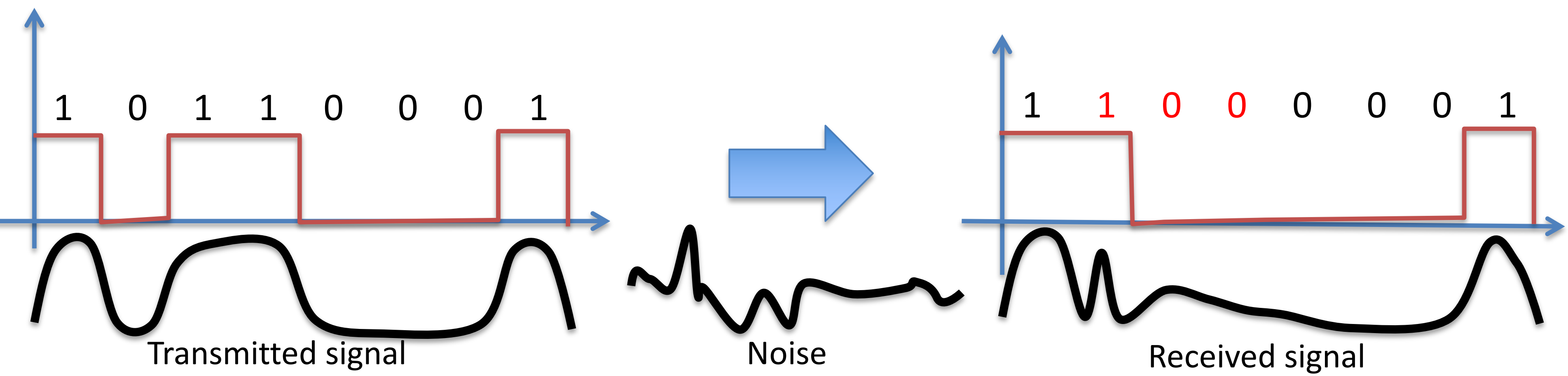
- Why are we worried about power loss, distortion and noise?
- Because these modify the original signal in an unpredictable way, potentially producing errors when receiving the signal.

- **Notice that impairments affect both analogue and digital signals!!**

Signals impairments

- If a signal is analogue, noise and distortion will modify its values, so that at the receiver I get a distorted analogue signal.

- If a signal is digital, noise and distortion will modify its values, so that at the receiver I get the wrong bits



Signals impairments

So, is there a reason why we transmit signals digitally?

1. Well, first of all signal are digital when stored in a computer…
2. But most important, we’ll see that **digital transmission is in principle more resilient to noise!**

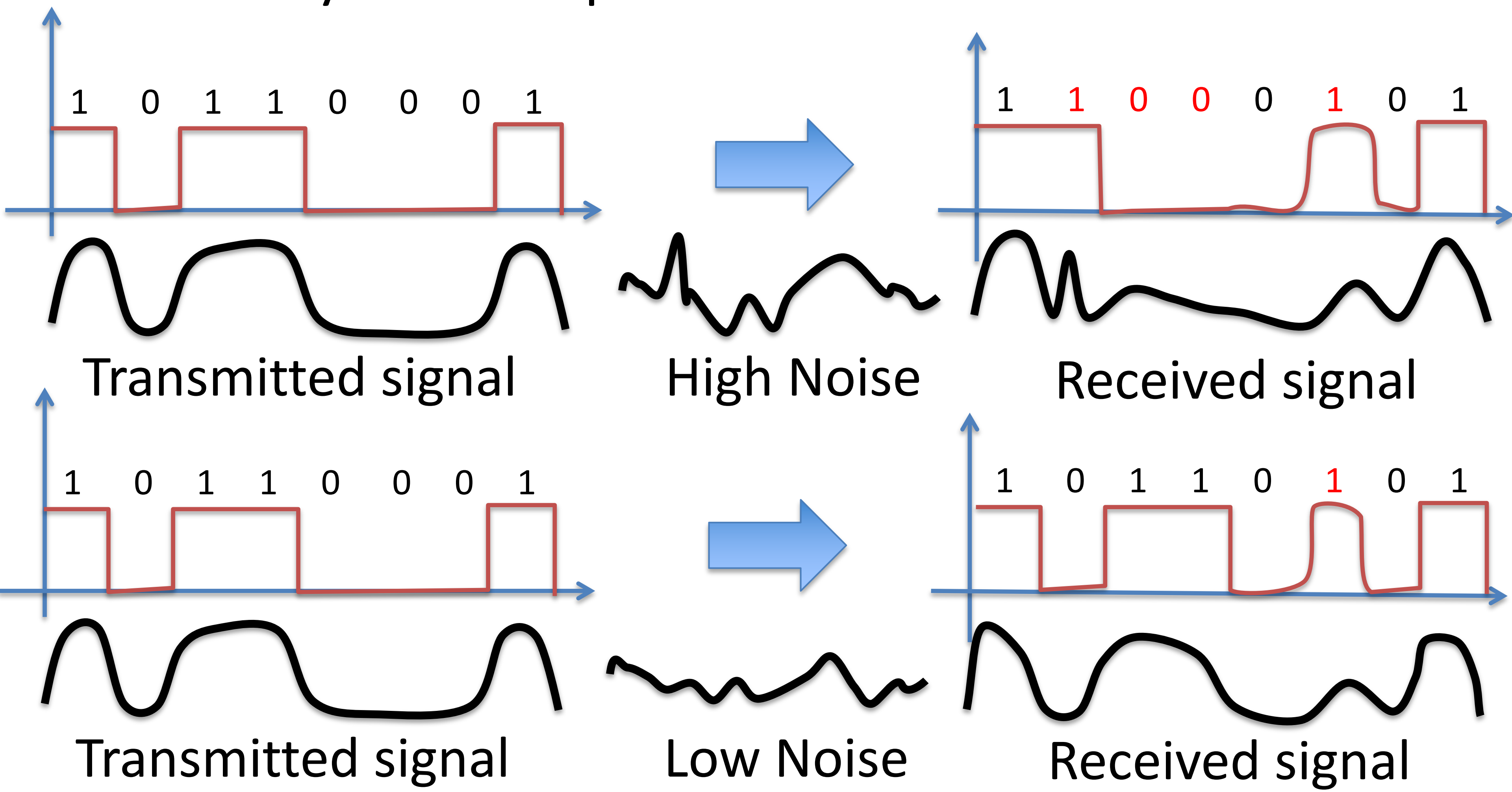
Bit Error Rate

- In digital systems, impairments generate bit errors, thus a typical performance metric for links is the Bit Error Rate (BER)
- It indicates how often can bit errors be expected to occur.
- It is measured as $$\frac{\text{1 bit error}}{\text{Number of bits considered}}$$
- For example if the error is 1 bit every 1,000

$$BER = \frac{1}{1000} = 10^{-3}$$

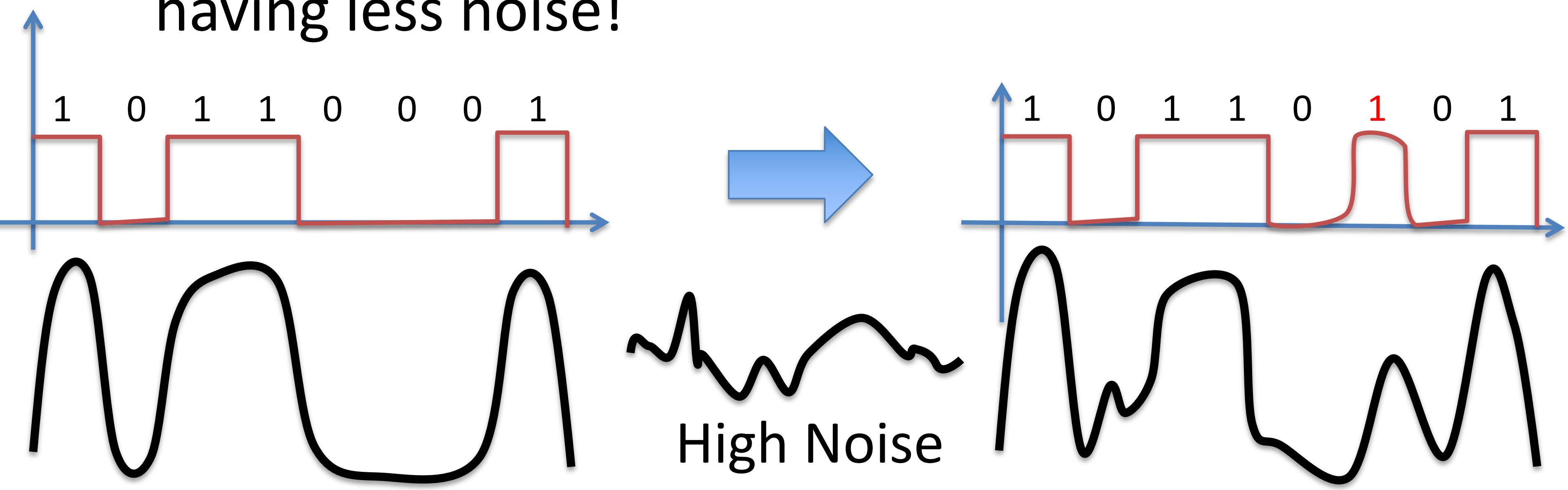
BER vs. SNR

- The lower the SNR, the higher the number of bit errors you can expect in a transmission.



BER vs. SNR

- Alternatively if the signal power is higher, the SNR will be higher.
- Remember $SNR = \dfrac{\text{signal power}}{\text{noise power}}$
- So having more power gives similar results as having less noise!

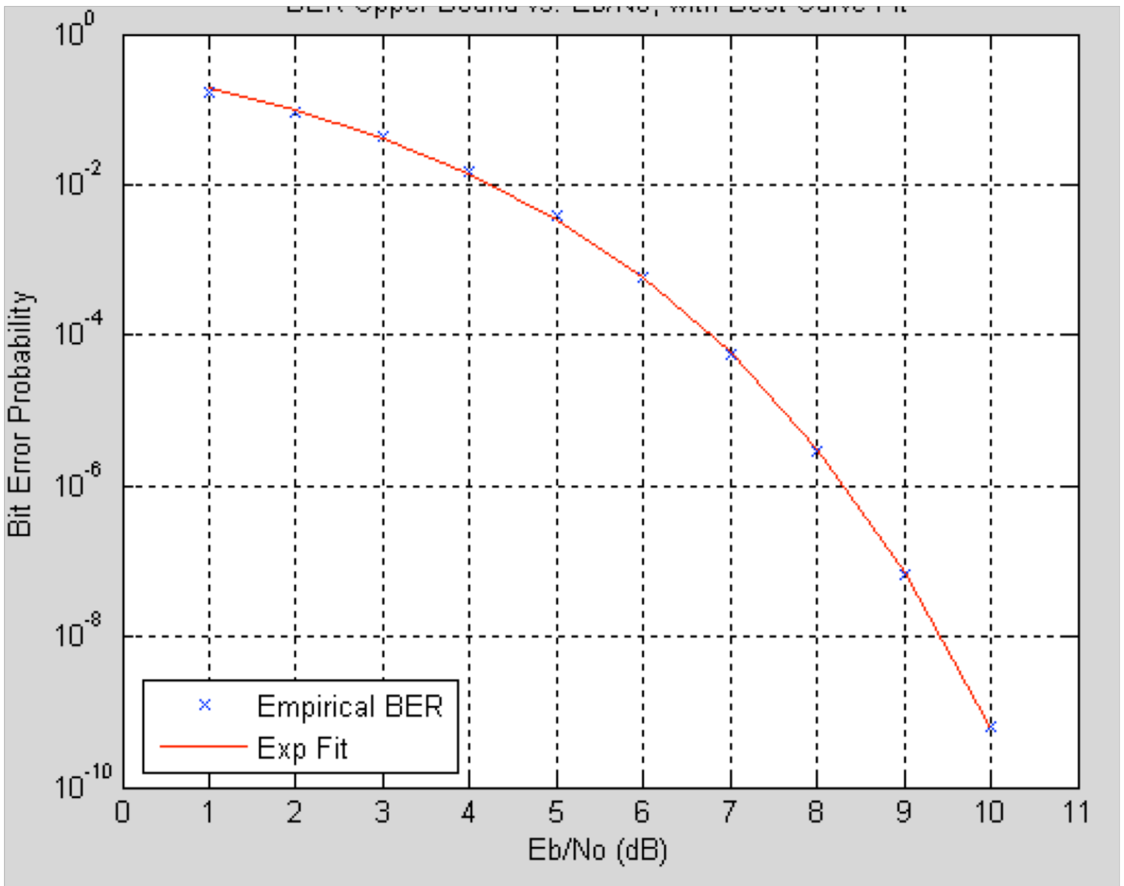


Transmitted signal, high power

Received signal, low BER

BER-SNR curves

- Is there a way for me to know what will the BER be, for a given SNR?



Curves like this are produced to give me exactly this type of information

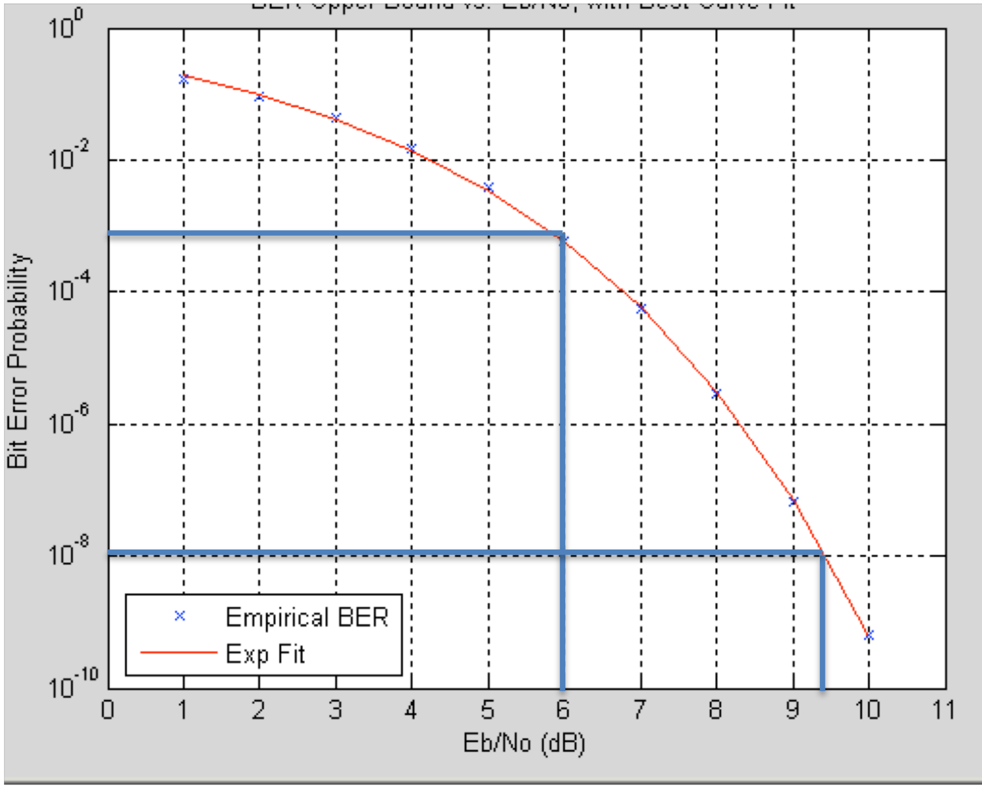
BER-SNR curves

- How to use the curves:
  - What BER I have if SNR=6dB?

    ➔BER≈ 10^{-3}

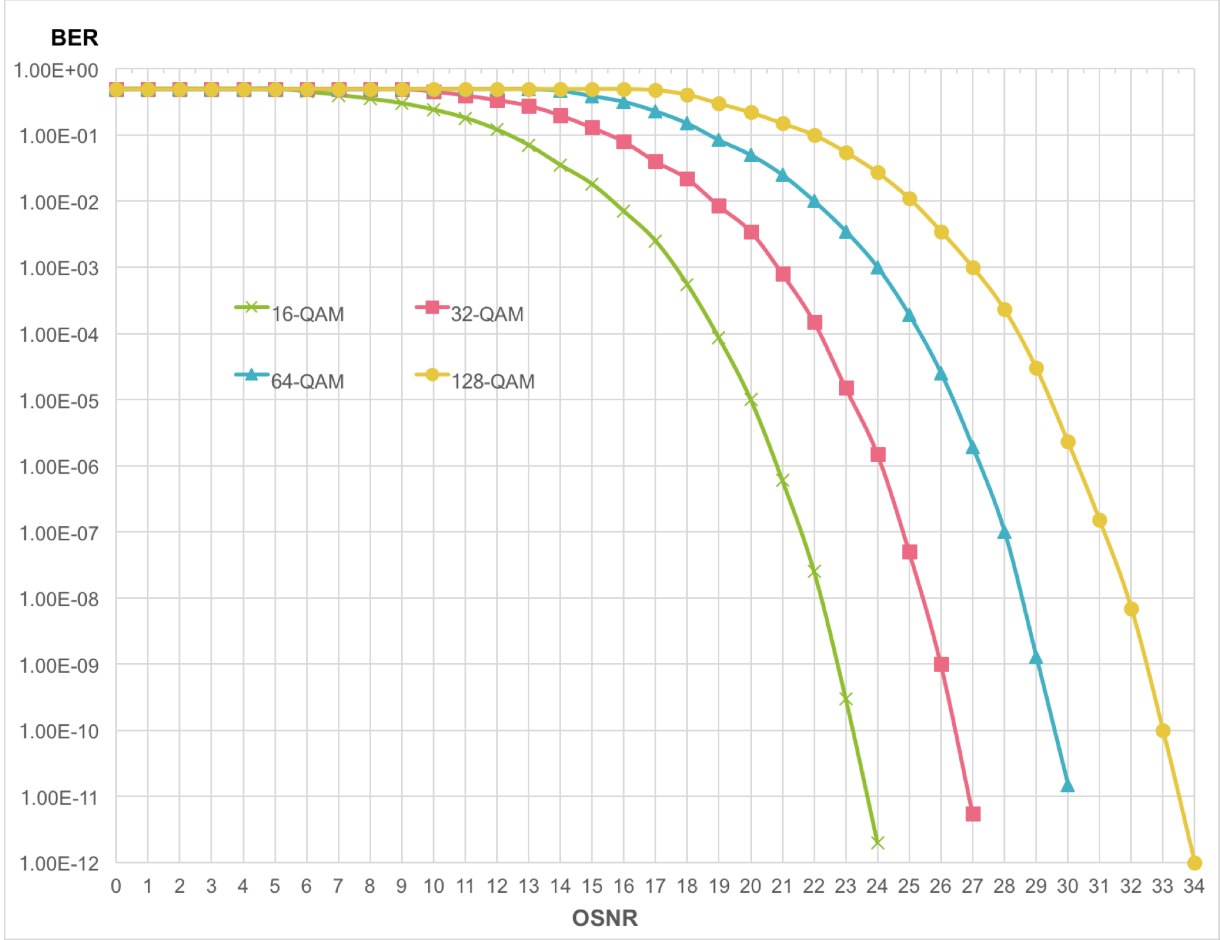
  - What SNR do I require to get a BER of 10^{-8}?

    ➔ SNR= 9.3dB



BER vs. modulations

- So is there just one curve for BER-SNR?
- **NO! Different modulation formats all have different curves!!**



BER vs. multi-level modulations

- In general higher-level modulations are capable of carrying more bits within a given bandwidth…

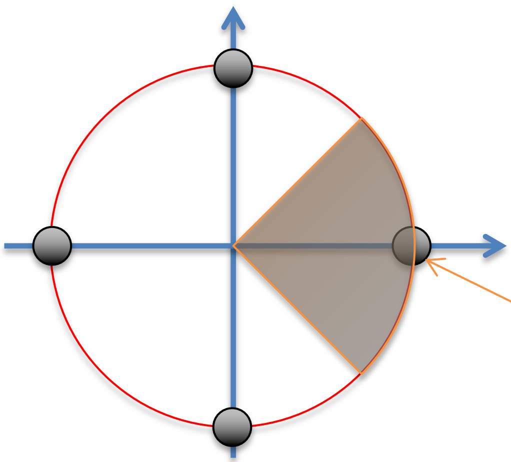
… however they are also more affected by noise!!

Remember, nothing comes from free..!

If you gain in terms of bandwidth occupation you loose in BER performance (or power required,…)

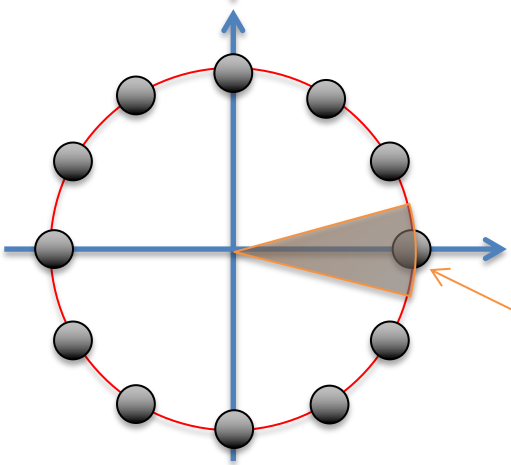
Example I: M-PSK

- Why is 16-PSK more susceptible to noise than 4-PSK?



In 4-PSK, symbols are spaced by 90° ($\pi/2$), so my signal is resilient against phase errors of ±45°($\pi/4$)

Error-free zone for this symbol

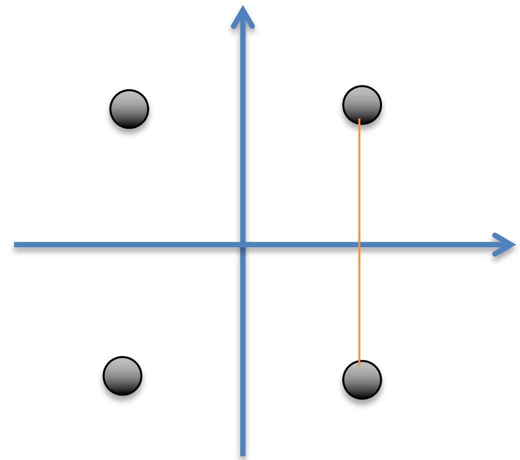


In 16-PSK, symbols are spaced by 30° ($\pi/6$), so my signal is resilient against phase errors of ±15°($\pi/12$)

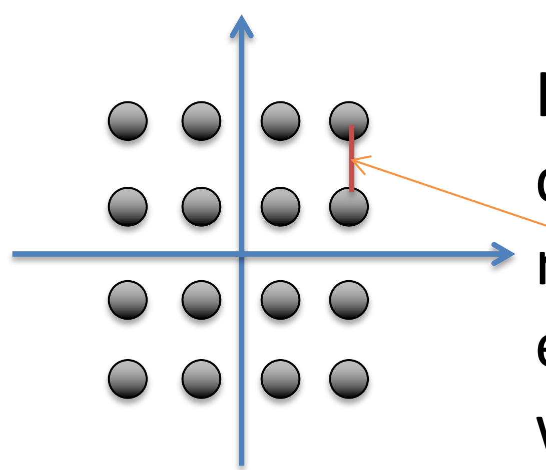
Error-free zone for this symbol

Example II: M-QAM

- 4-QAM



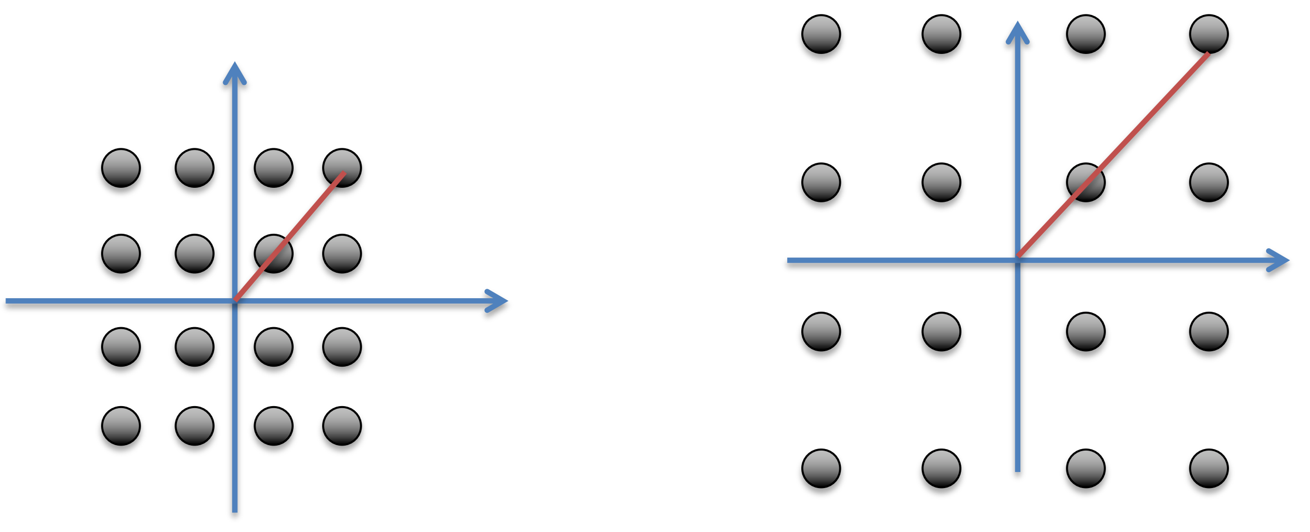
- 16 QAM



If I put more symbols, the distance between them is reduced, and it becomes easier to confuse them when noise is added

Power increase in QAM

- However I can increase the power to keep the distance large…
- Here the average power (i.e. the average distance of symbol from the origin) is higher



BER-SNR summary

- High SNR gives a lower BER.
- $$SNR = \frac{\text{signal power}}{\text{noise power}}$$
- Larger noise (as well as distortion), will decrease SNR, and increase BER
- Transmission loss will decrease the signal power, thus decrease SNR and increase BER

Receiver sensitivity

- When a signal arrives at the receiver, besides the SNR, also the value of the signal power is important.

- The receiver has a certain sensitivity, which means it needs to receive a certain signal power in order to decode it.

- If a receiver has a sensitivity of, for example, -20dBm, this is the minimum input power it requires.