# Binary Phase shift Keying (BPSK)

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# Introduction to Monte-Carlo Simulations

- Simulation technique
  - probabilistic system's nature is approximated by random number generator
- Basic idea
  - Generate several (pseudo-) random realizations
    - The number of realizations depend on desired accuracy of output
  - Compute output for each realization
  - Obtain an average value of output (eg. error probability)
- Some Applications
  - Communication systems
  - Queuing systems
  - Statistical physics
  - Signal processing

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# Problem: Numerical Computation of Error Probability

- Model: a basic communication system comprises of
  - Transmitter
    - transmits BPSK symbols $+\sqrt{E_b}, -\sqrt{E_b}$
    - bit '1' $\rightarrow +\sqrt{E_b}$ & bit '0' $\rightarrow -\sqrt{E_b}$, where $E_b$ is the bit energy
    - symbols are equally likely

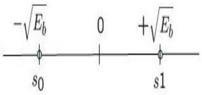


Figure: BPSK constellation.

  - AWGN channel adds randomness to the communication system
  - Transmitted symbols are independent of noise
  - Receiver model: Coherent & maximum likelihood (ML) detection receiver
- Derive optimum decision rule and symbol (or bit) error probability (SEP/BEP) (in class)

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# Algorithm to Estimate SEP

- Choose range of SNR values in dB
- M = 2 (binary PSK)
- Initial count = 0, number of realizations = $10^5$
- For each SNR & for each realization
  - Generate transmit symbols which are equiprobable
  - Generate Gaussian noise
  - Add random noise to the transmitted symbol
  - Perform symbol-by-symbol maximum likelihood (ML) detection and compare detected symbol to the transmitted
  - Declare an error if transmitted symbol is not equal to decoded symbol
- Count the number of errors and divide them by the number of realizations

# Usefulness of Simulations & Some Remarks

- MC simulations are used to validate theoretical/analytical formulae derived
- Close matching of simulation results with analytical results shows correctness of the analysis
- If some approximations are used in analysis, simulation results will not match with theoretical results
- Researcher often do simulations first. Later they validate simulation results using mathematical or experimental analysis
- MATLAB is widely used programming language for MC simulations
  - since it has strong built-in library functions
  - easy to learn and use
- Drawback of MATLAB is its speed
- Avoiding loops and using vector notations can improve speed

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# Important Instructions

- Try to complete all tasks within 2 hours. After 2 hrs, evaluation starts.
- For each subtask, create mfiles (eg. $CT\_HT$.m) and save them with suitable name.
- Prepare a word document naming your name and ID. In it, save all results including plots.
- In all plots, put x-label, y-label, legend, font 'Arial'(Size = 10), and, Width '2'.

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# Useful Commands

- Understand following library functions/commands
  - qfunc
  - erfc
  - rand
  - floor
  - randn
  - abs
  - min
  - semilogy

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# SNR per Bit

- Let $P_s$ denote transmitted signal power and let $T_b$ denote bit duration
- For ideal BPSK, $T_b = \frac{1}{B}$, where $B$ is bandwidth
- Bit energy $E_b = P_s T_b$
- If noise power ($N_0 B$) normalized to unity, $SNR$ per bit = $P_s$ (how ?)

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    - Normalized *SNR* per bit = $\frac{P_s}{\mathbf{E}[n_0^2]B} = \frac{P_s}{N_0 B} = P_s$

# Code Fragments

- Generation of BPSK symbols $\alpha$
  - m = floor(M*rand);
  - $\alpha = exp(-i2\pi \frac{m}{M});$
- generation of Gaussian noise of unit variance
  - $n_0 = (randn + randn * 1i)/sqrt(2);$
- Received signal $y_0 = \sqrt{E_b}\alpha + n_0;$

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# Task: SEP Computation & Plot

- Question: Write a program to numerically compute SEP and plot the following
  1. SEP as a function of SNR using formula derived in class
  2. SEP as a function of SNR using MC simulations
     - Show analytical and simulation curves in single plot. In the plot, provide x-label, y-label, title, and legend.

# Question

- Suppose that the noise power is $-27$ dBm. What is the average probability of error at $P_s = 9$ dB? (Hint: Determine from the SEP plot.)

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