Scilab case study project on

BPSK Communication System with AWGN Channel using Xcos

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Digital communication

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Abstract

This case study presents the design and simulation of a digital communication system using Binary Phase Shift Keying (BPSK) modulation techniques in Xcos. The system models an end-to-end communication chain consisting of random bit generation, digital modulation, transmission through an Additive White Gaussian Noise (AWGN) channel, and coherent demodulation at the receiver. The primary objective is to analyse the performance of digital modulation schemes under noisy channel conditions. Bit Error Rate (BER) is computed for varying Signal-to-Noise Ratio (SNR) values, and the results are used to evaluate the robustness of BPSK technique. The simulation also includes visualization of input and output signals at different stages of the communication system. The obtained results are compared with theoretical expectations to validate the model. This study demonstrates the trade-off between noise immunity and spectral efficiency in digital communication systems and highlights the importance of modulation techniques in reliable data transmission.

1. Introduction

Communication systems play a foundational role in modern technology. It allows us to communicate over huge distances in very small time. With the rapid growth of digital technologies, there has been a significant shift from traditional analog communication to digital communication systems. Digital communication offers improved reliability, better noise immunity, and efficient data transmission compared to analog methods. As the demand for high-speed and accurate communication continues to grow, it is important to understand the fundamental principles and performance of digital communication systems.

2. Problem Statement

Like analog systems, digital communication systems are also susceptible to noise. Since important information is often transmitted through these systems, it is essential for communication to be reliable. One of the fundamental challenges, therefore, is to accurately recover the transmitted data in the presence of noise. To achieve reliable communication, an appropriate modulation technique is required for transmission, along with an effective demodulation process at the receiver. Additionally, filtering techniques are necessary to reduce the effect of noise and improve signal recovery.

The performance of the system can be further enhanced by optimizing filter parameters and using more advanced modulation schemes. To address this problem, a complete communication model is developed in Xcos. The system uses Binary Phase Shift Keying (BPSK) due to its simplicity and robustness against noise. Additive White Gaussian Noise (AWGN) is introduced in the channel to simulate real-world conditions. The received signal is then coherently demodulated and passed through a low-pass filter to reduce noise effects. Finally, the performance of the system is evaluated using Bit Error Rate (BER). The project aims to analyse how variations in noise levels affect BER, and consequently, the reliability of the communication system.

3. Basic concepts related to the topic

3.1 Non-return to zero (NRZ) encoding

- Definition: Non-Return-to-Zero (NRZ) is a binary signal encoding technique where voltage levels remain constant during a bit interval, representing logic '1' (high/positive) or logic '0' (low/negative) without returning to zero voltage in between.
- Mathematical Formulation:

  NRZ signal is given by-

$$m(t) = A\,(2\,b - 1)$$

where:

- A = amplitude of signal
- b = input binary value

3.2 Binary Phase Shift Keying (BPSK)

- Definition: Binary Phase Shift Keying (BPSK) is a robust digital modulation technique that transmits data by shifting the phase of a carrier signal by 180 degrees to represent binary 0s and 1s. It is highly efficient in noisy environments because the two-phase states are maximum distance apart, though it only transmits 1 bit per symbol.
- Mathematical Formulation:

$$s(t) = A\, m(t) \cos(2\pi f c t)$$

where:

- A = carrier amplitude
- m(t) = polar NRZ signal
- fc = carrier frequency

3.3 Additive White Gaussian Noise (AWGN)

- Definition: Additive White Gaussian Noise (AWGN) is a fundamental noise model in communication systems that simulates random processes occurring in nature, such as thermal noise. It is **additive** (adds to the signal), **white** (uniform power across all frequencies), and **Gaussian** (amplitude follows a normal distribution with zero mean).

3.4 Low-Pass Filter

- Definition: A low-pass filter is a signal processing component that allows low-frequency signals to pass through while attenuating or blocking high-frequency components. In communication systems, it is commonly used after demodulation to remove unwanted high-frequency noise and recover the original baseband signal.
- Mathematical Formulation: The formula for first order Butterworth filter is given as follows.

$$H(s) = 1/\tau s + 1$$

where:

- τ = time constant
- s = Laplace variable

3.5 Bit Error Rate (BER)

- Definition: Bit Error Rate (BER) is the ratio of incorrectly received bits (errors) to the total bits transmitted in a digital system, representing reliability, often expressed in exponential notation It measures system quality, where lower BER (fewer errors) indicates higher performance, typically caused by noise, interference, or distortion.
- Mathematical Formulation:

$$\textit{Number of Bit Errors} / \textit{Total Number of Transmitted Bits}$$

3.6 Signal to Noise Ratio (SNR)

- Definition: Signal to Noise Ratio (SNR) is a measure used to compare the level of a desired signal (e.g., audio, image, data) to the level of background noise, expressed as a ratio. A higher SNR indicates clearer, higher-quality data with less interference
- Mathematical Formulation:

$$\textit{Power of Signal} / \textit{Power of Noise}$$

4. *Flowchart*

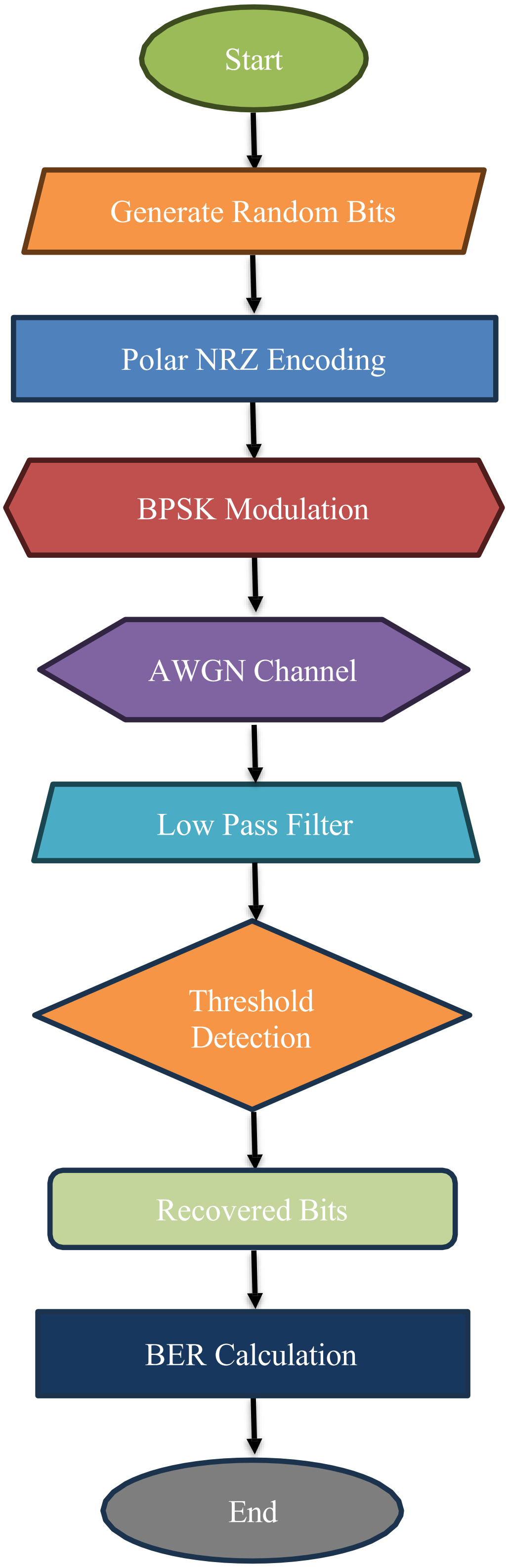

Figure 1: BPSK Digital Communication System Flowchart

5. Software/Hardware used

Operating System: Windows 11

Toolbox: none

Hardware: none

Software: Xcos, Scilab: 2026.0.1

6. Procedure of execution

The following steps are given to run the code:

1. Open BPSK.xcos.
2. Go to Simulation -> Setup. Change the Final Integration time to 5000 and Max integration time interval to 1.
3. Now, click on run.
4. There are five TOWS blocks which extracts original bits in tx_bits variable, nrz signal in nrz variable, the received bits in rec_bits variable, the modulated signal in the modulated variable and the noise signal in the noise variable.
5. To plot all these signals, open plot.sce and execute the code.
6. To plot the BER graph, open BER.sce and execute the code.
7. You will see the graph of theoretical BER vs Simulated BER and the other graphs.

7. Result

The following diagrams have been obtained as a result.

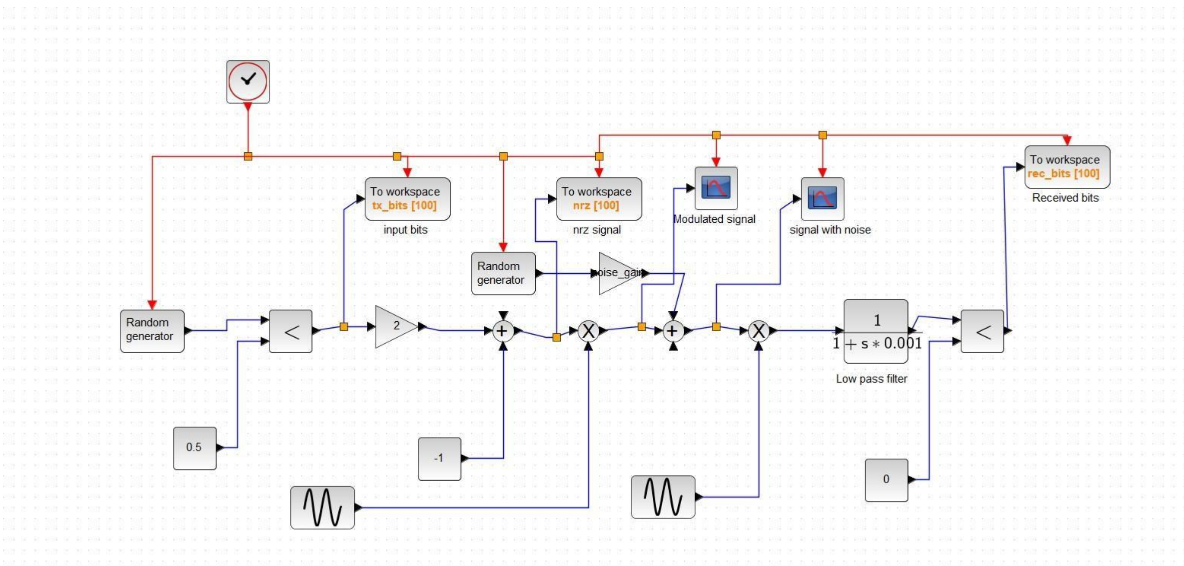

Figure 2: Xcos model for Digital Communication System

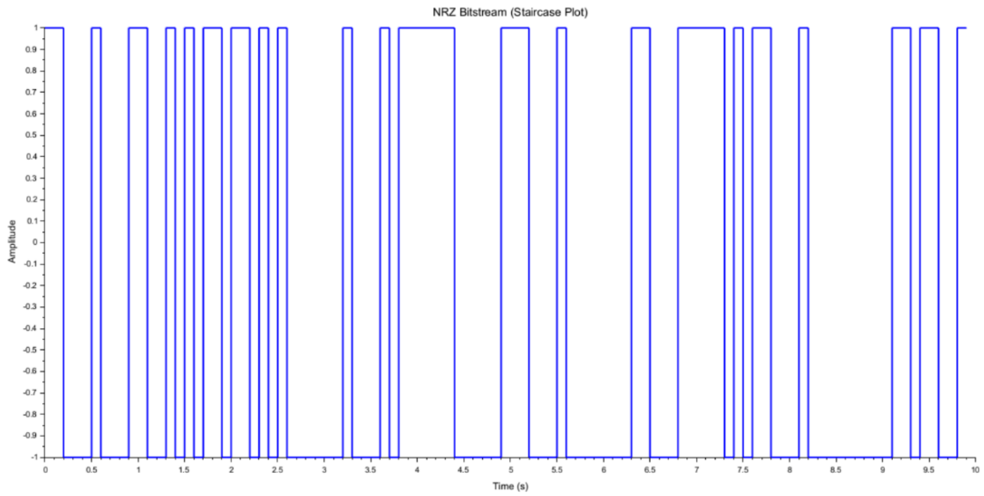

Figure 3: NRZ Signal

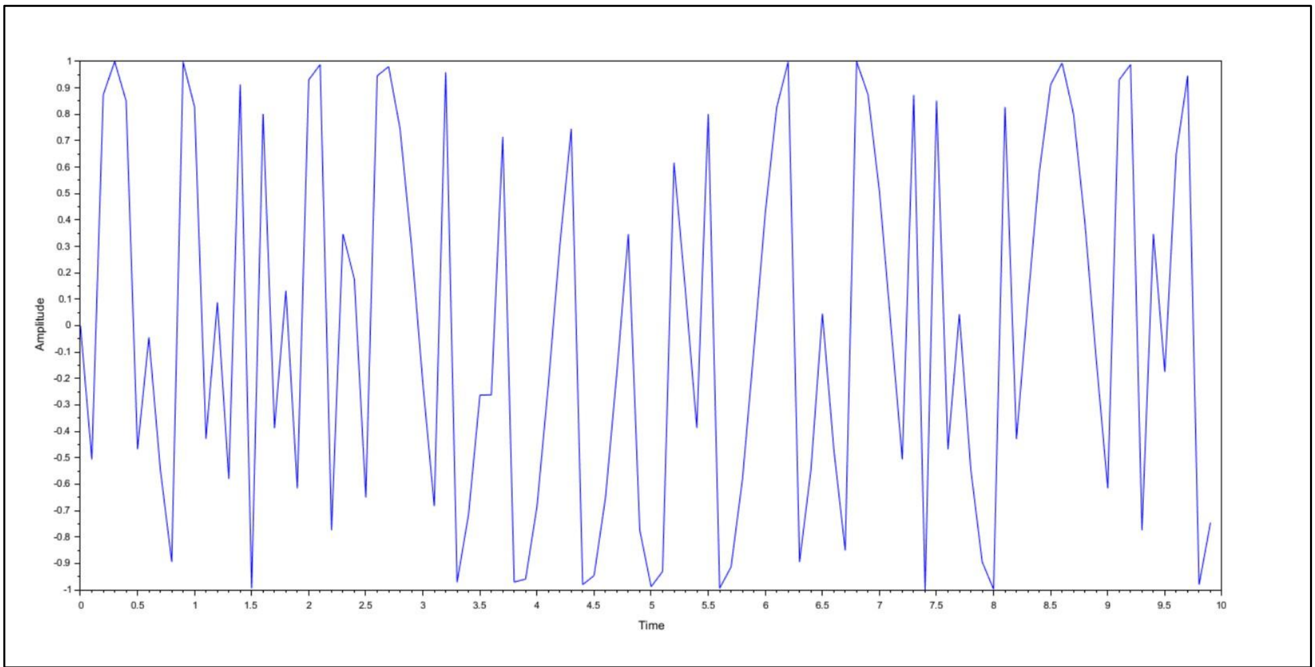

Figure 4: BPSK Modulated Signal

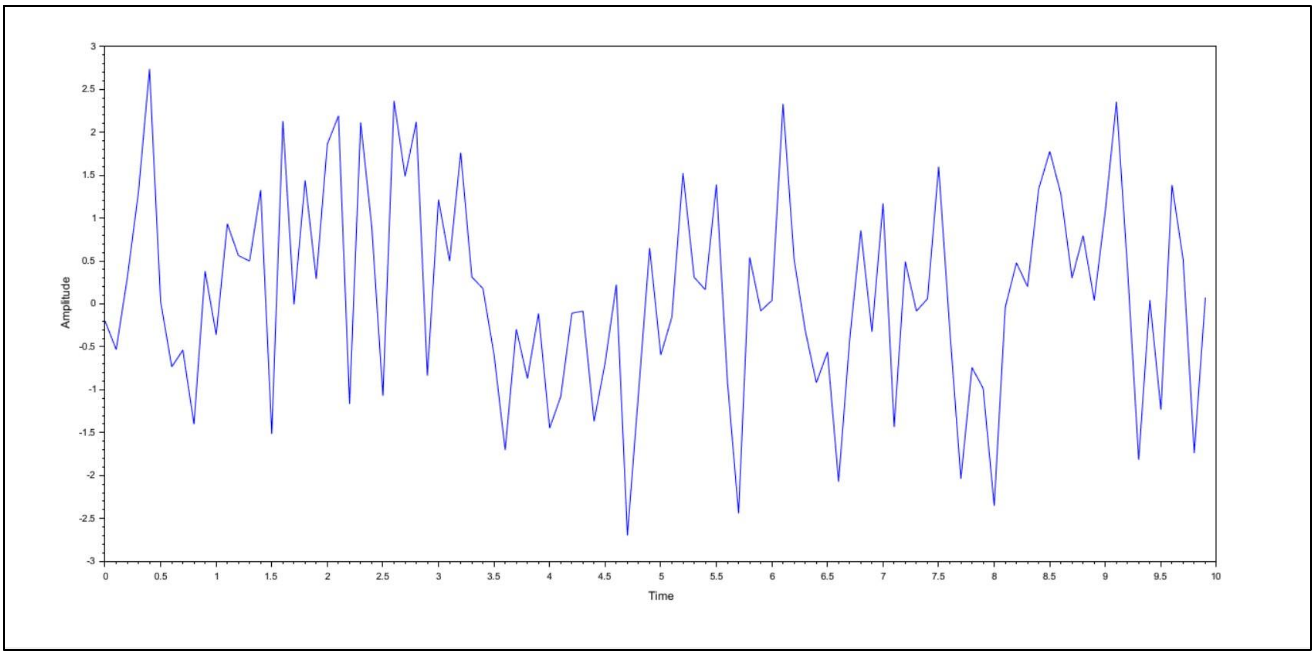

Figure 5: Modulated signal with noise of gain 1

We can see that noise of gain 1 visibly distorts the modulated signal, which is why coherent detector is necessary for recovery

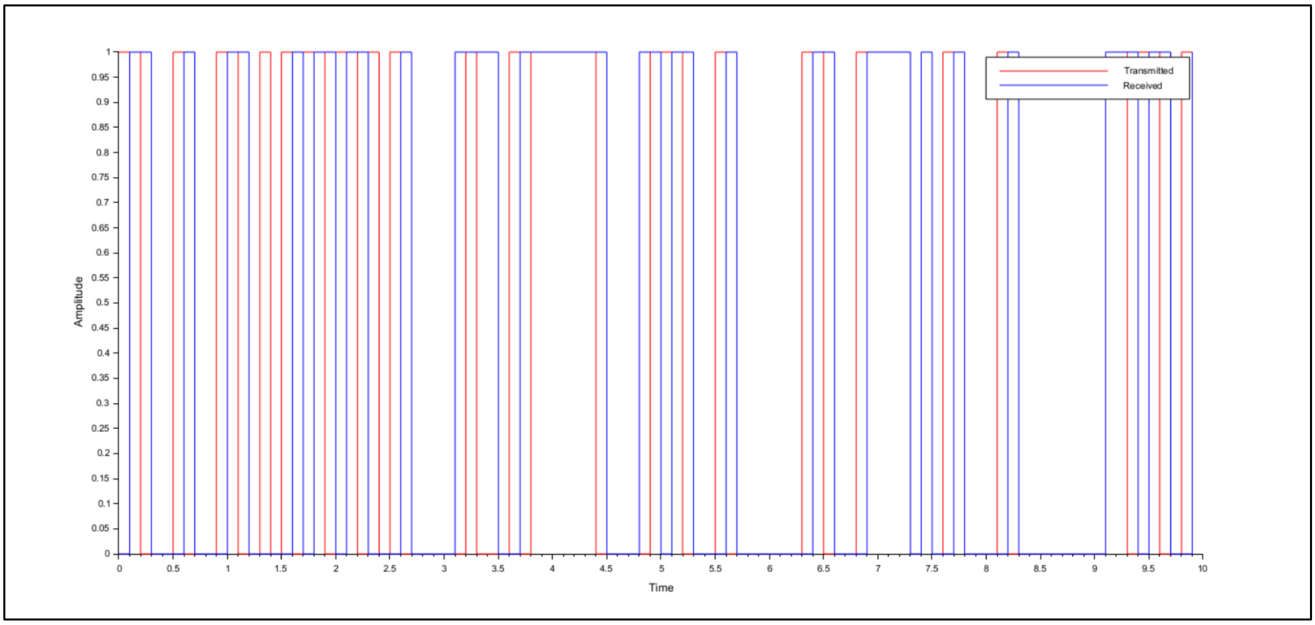

Figure 6: Transmitted bits and received bits.

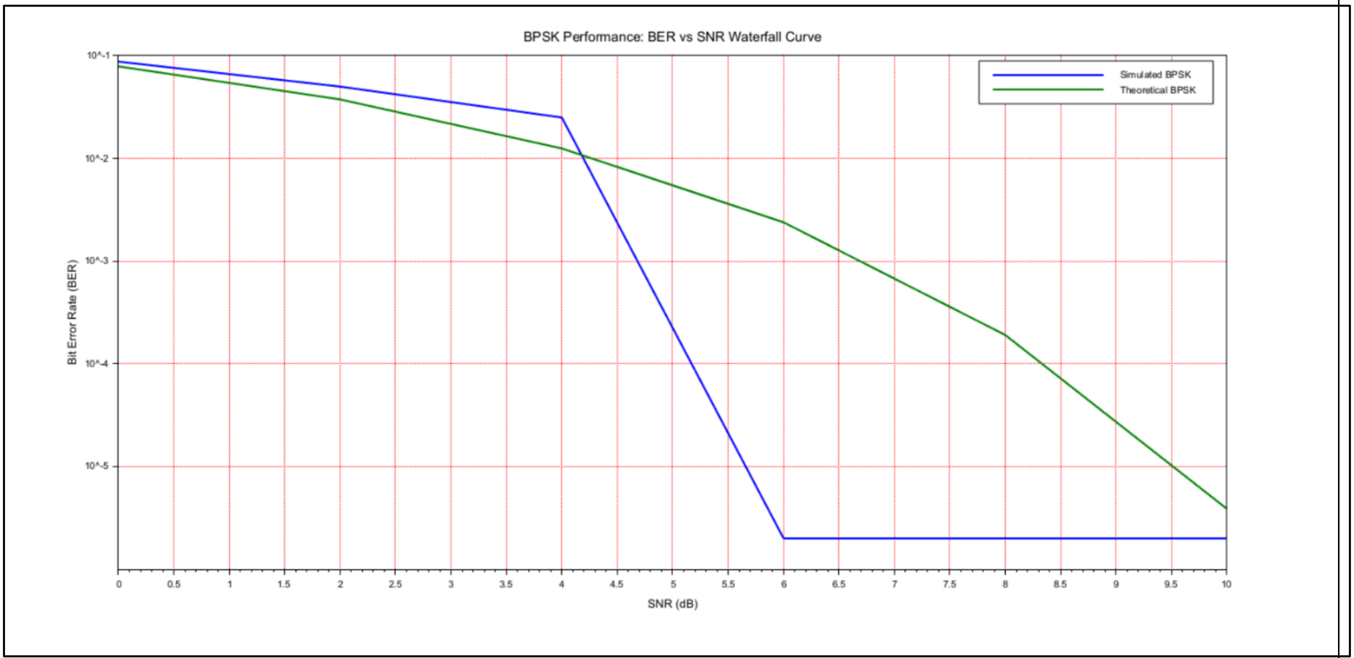

Figure 7: BER vs SNR

The cliff at high SNR represents the limit of our Monte Carlo simulation's statistical depth; we would need a significantly longer integration time to capture the rare bit-flip events at 10 dB.

At higher SNR, the probability of an error is extremely low. Due to this, the simulated BER becomes flat after 6db because the BER was calculated within 5000-bit window.

8. References

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[2] Umar H. Rizvi, Gerard J. M. Janssen and Jos H. Weber Wireless and Mobile Communications Group, Faculty of EEMCS, Delft University of Technology, BER Analysis of BPSK and QPSK Constellations in the Presence of ADC Quantization Noise. https://www.researchgate.net/publication/224380351_BER_analysis_of_BPSK_and_QPSK_constellations_in_the_presence_of_ADC_quantization_noise

[3] M. K. Simon and M.-S. Alouini, Digital Communications over Fading Channels: A Unified Approach to Performance Analysis. NY, USA: John Wiley & Sons, 2000.