Principles of Computer Communication
Project 1: Data Transmission Simulation

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Contents

1 Introduction

This project simulates the process of data transmission between two computers (Computer A and Computer B) using encoding, decoding, modulation, and demodulation techniques. The implementation covers four fundamental transmission modes:

1. **Digital-to-Digital**: Line coding techniques for transmitting digital data over digital channels
2. **Digital-to-Analog**: Modulation schemes for transmitting digital data over analog channels
3. **Analog-to-Digital**: Source coding for converting analog signals to digital representation
4. **Analog-to-Analog**: Modulation techniques for transmitting analog data over analog channels

The project includes a graphical user interface (GUI) built with Python's Tkinter library, allowing users to select transmission modes and algorithms interactively.

2 Theoretical Background

2.1 Digital-to-Digital Encoding (Line Coding)

Line coding transforms a sequence of bits into a digital signal suitable for transmission over a physical medium. The key objectives are:

- Clock synchronization between sender and receiver
- Error detection capability
- Bandwidth efficiency
- DC component elimination

2.2 Digital-to-Analog Modulation

Digital-to-analog modulation maps digital data onto an analog carrier signal by varying its amplitude, frequency, or phase. This is essential for transmitting digital data over bandpass channels like telephone lines or radio frequencies.

2.3 Analog-to-Digital Conversion

Analog-to-digital conversion involves sampling, quantization, and encoding continuous signals into discrete digital representations. This process is fundamental in digital communication systems.

2.4 Analog-to-Analog Modulation

Analog modulation techniques modulate one or more properties of a high-frequency carrier signal with an information-bearing analog signal.

3 Digital-to-Digital Encoding Methods

3.1 NRZ-L (Non-Return-to-Zero Level)

In NRZ-L encoding, the signal level directly represents the bit value:

- Bit '0' → High voltage level (+1)
- Bit '1' → Low voltage level (-1)

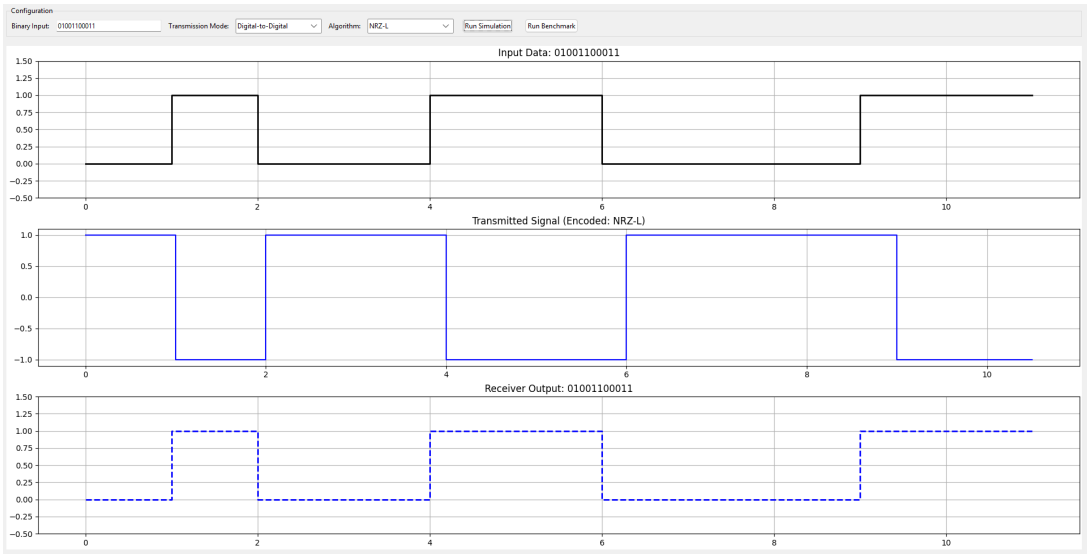

Figure 1: NRZ-L Encoding Example

3.2 NRZI (Non-Return-to-Zero Inverted)

NRZI encodes data based on transitions rather than voltage levels:

- Bit '0' → No transition (maintain current level)
- Bit '1' → Transition at the beginning of the bit interval

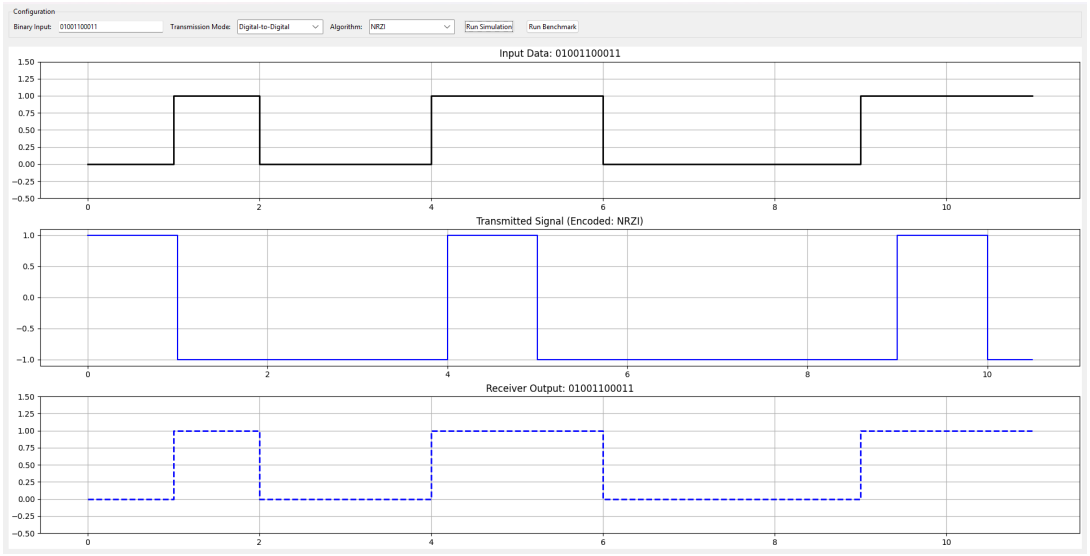

Figure 2: NRZI Encoding Example

3.3 Bipolar-AMI (Alternate Mark Inversion)

Bipolar-AMI uses three voltage levels:

- Bit '0' → Zero voltage
- Bit '1' → Alternating positive (+1) and negative (-1) pulses

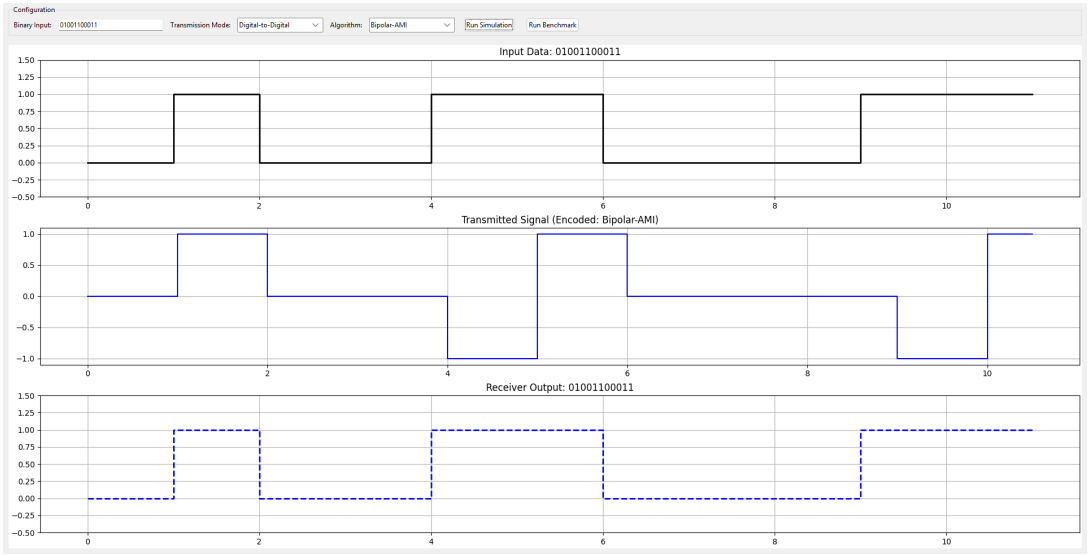

Figure 3: Bipolar-AMI Encoding Example

3.4 Pseudoternary

Pseudoternary is the inverse of Bipolar-AMI:

- Bit '1' → Zero voltage
- Bit '0' → Alternating positive and negative pulses

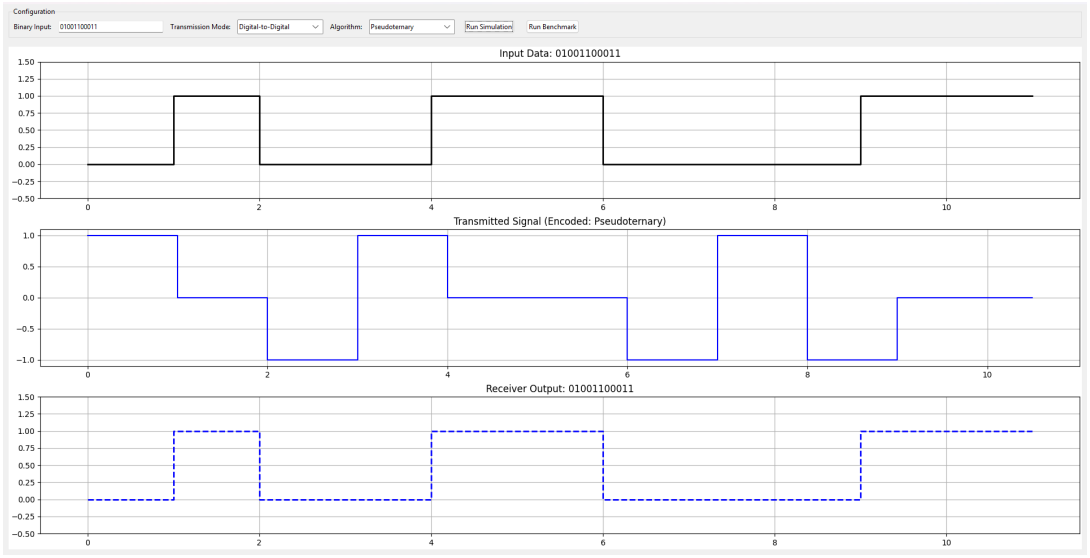

Figure 4: Pseudoternary Encoding Example

3.5 Manchester Encoding

Manchester encoding ensures a transition in the middle of each bit period:

- Bit '0' → High-to-Low transition (falling edge)
- Bit '1' → Low-to-High transition (rising edge)

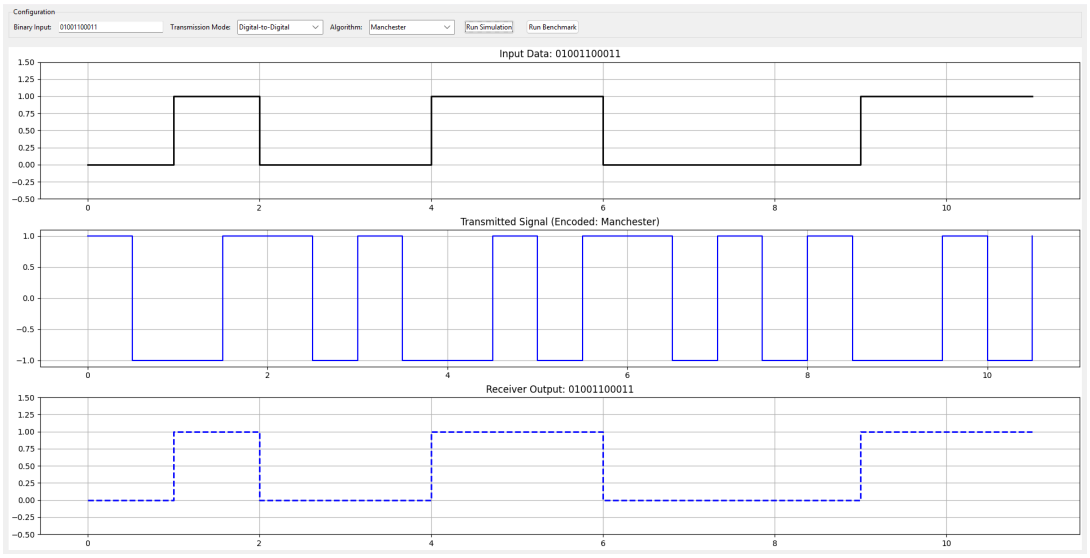

Figure 5: Manchester Encoding Example

3.6 Differential Manchester

Differential Manchester always has a transition in the middle of the bit period, with the bit value determined by the presence or absence of a transition at the beginning:

- Bit '0' → Transition at the start of the interval

- Bit '1' → No transition at the start

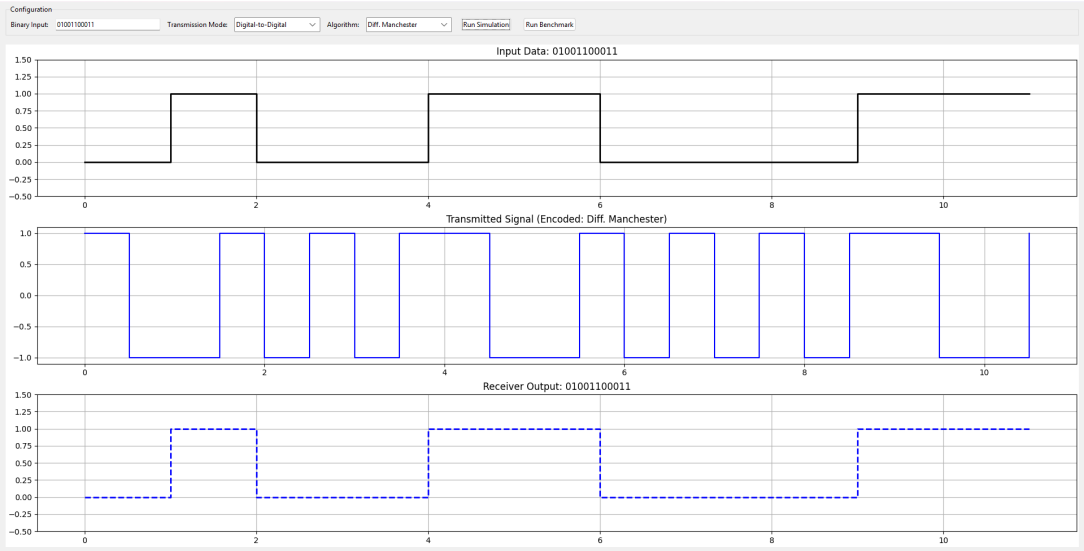

Figure 6: Differential Manchester Encoding Example

4 Digital-to-Analog Modulation Methods

4.1 ASK (Amplitude Shift Keying)

ASK represents digital data by varying the amplitude of the carrier signal.

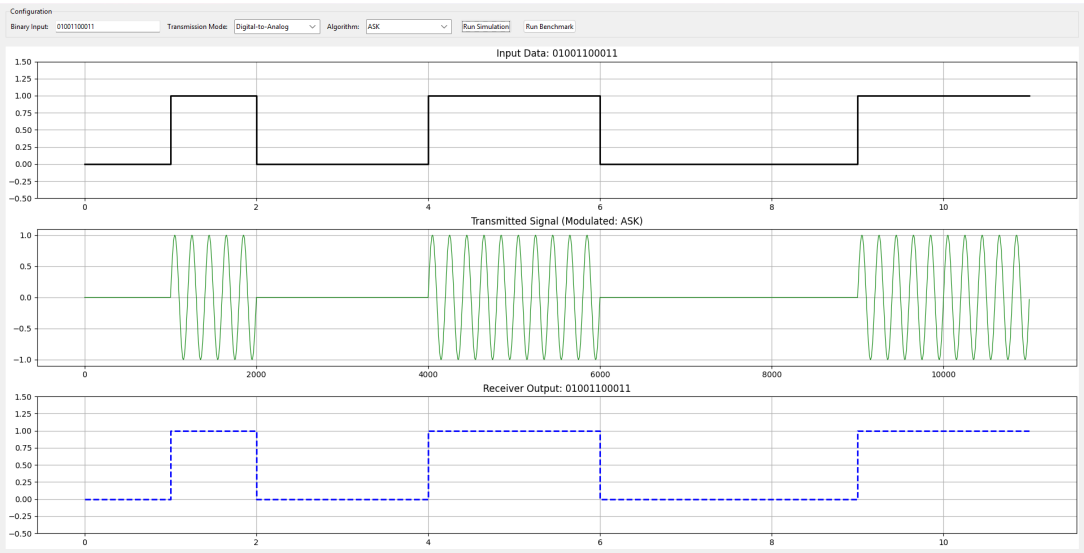

Figure 7: ASK Modulation Example

4.2 PSK/BPSK (Phase Shift Keying)

PSK encodes data by shifting the phase of the carrier.

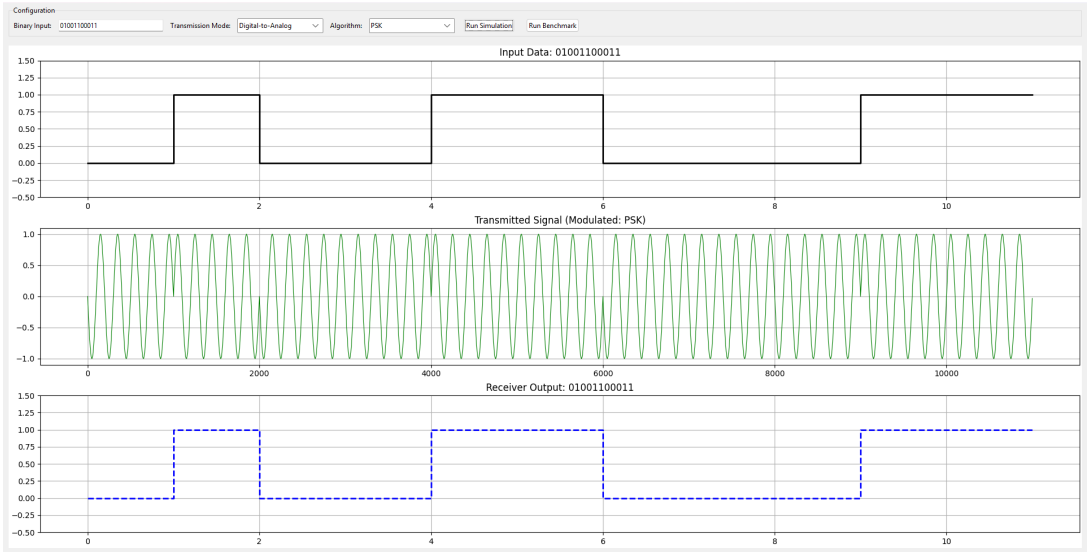

Figure 8: PSK Modulation Example

4.3 BFSK (Binary Frequency Shift Keying)

BFSK uses two different frequencies to represent binary values.

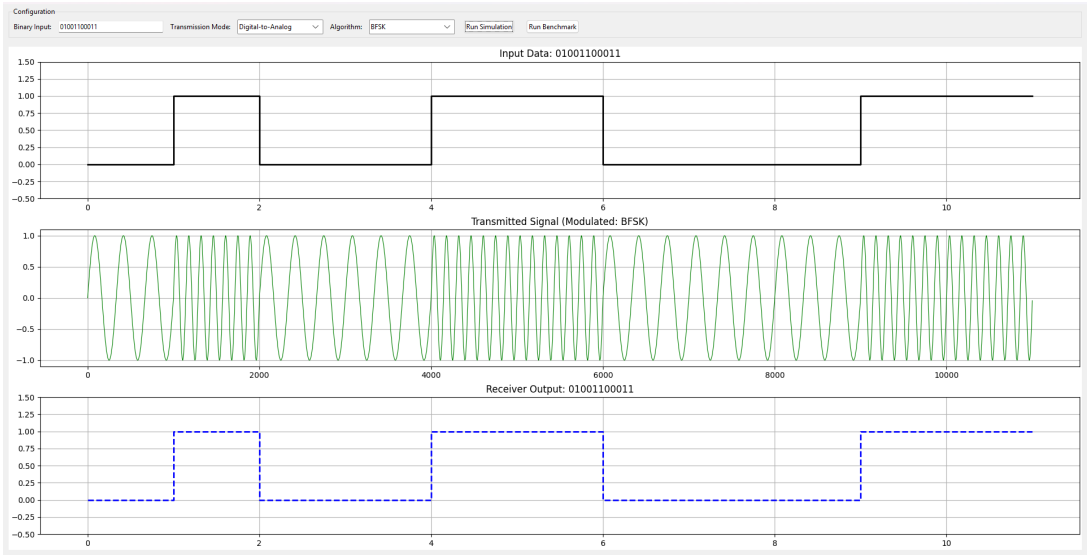

Figure 9: BFSK Modulation Example

5 Analog-to-Digital Encoding Methods

5.1 PCM (Pulse Code Modulation)

PCM converts analog signals to digital through sampling, quantization, and encoding.

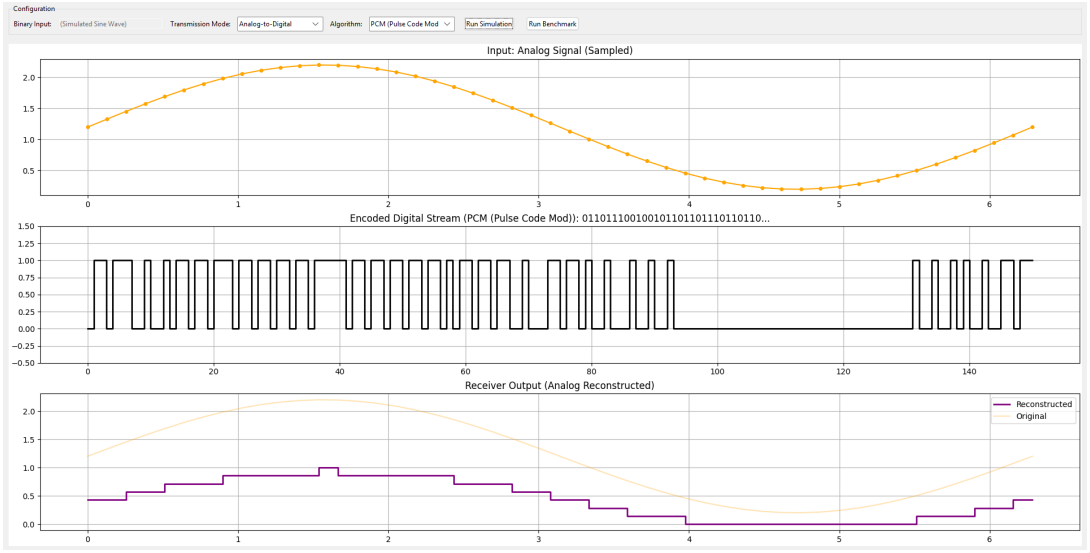

Figure 10: PCM Encoding Example

5.2 Delta Modulation (DM)

Delta Modulation encodes the difference between consecutive samples.

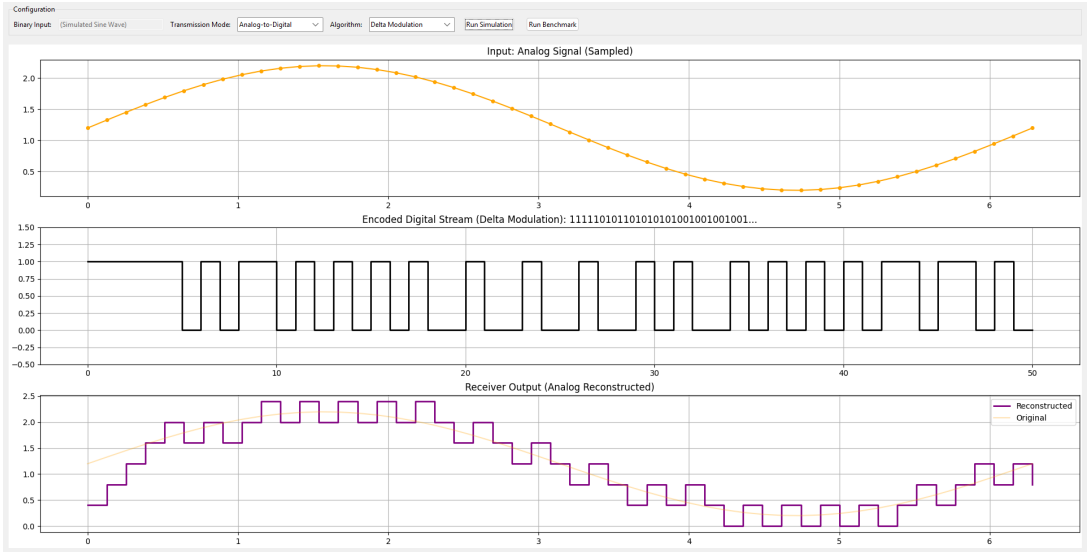

Figure 11: Delta Modulation Example

6 Analog-to-Analog Modulation Methods

6.1 AM (Amplitude Modulation)

In AM, the amplitude of the carrier varies with the message signal.

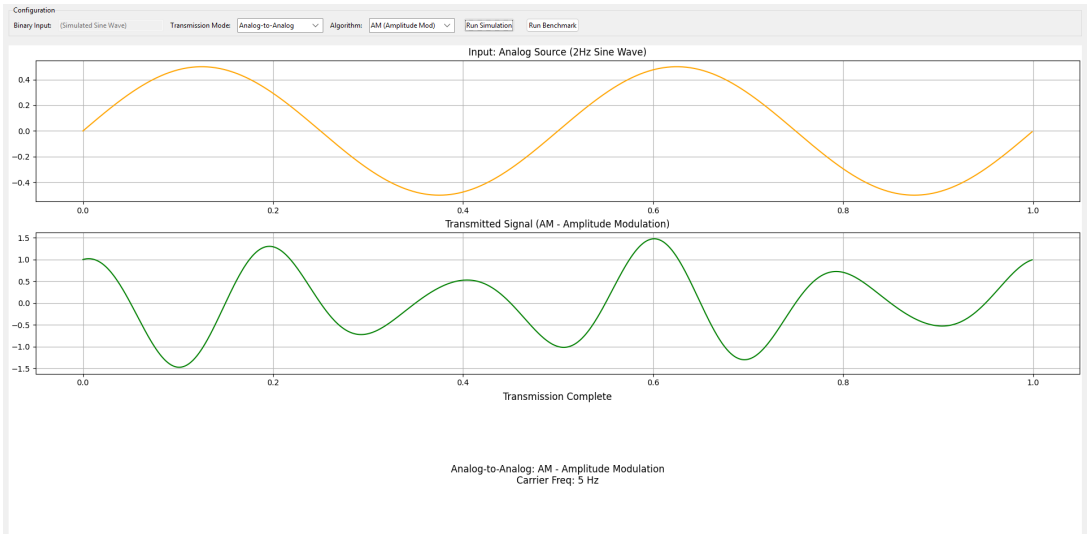

Figure 12: Amplitude Modulation Example

6.2 FM (Frequency Modulation)

In FM, the instantaneous frequency varies with the message signal.

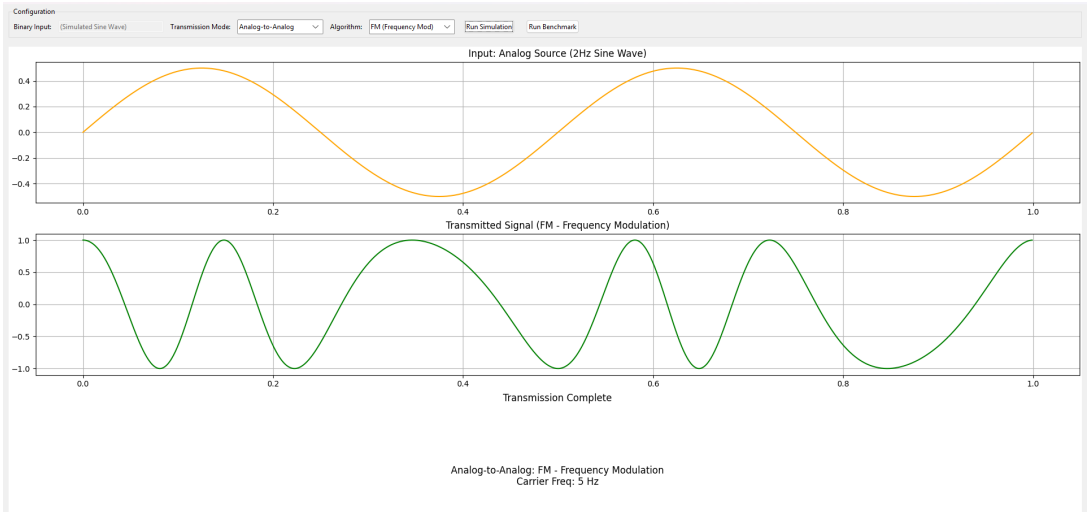

Figure 13: Frequency Modulation Example

6.3 PM (Phase Modulation)

In PM, the phase of the carrier varies directly with the message signal.

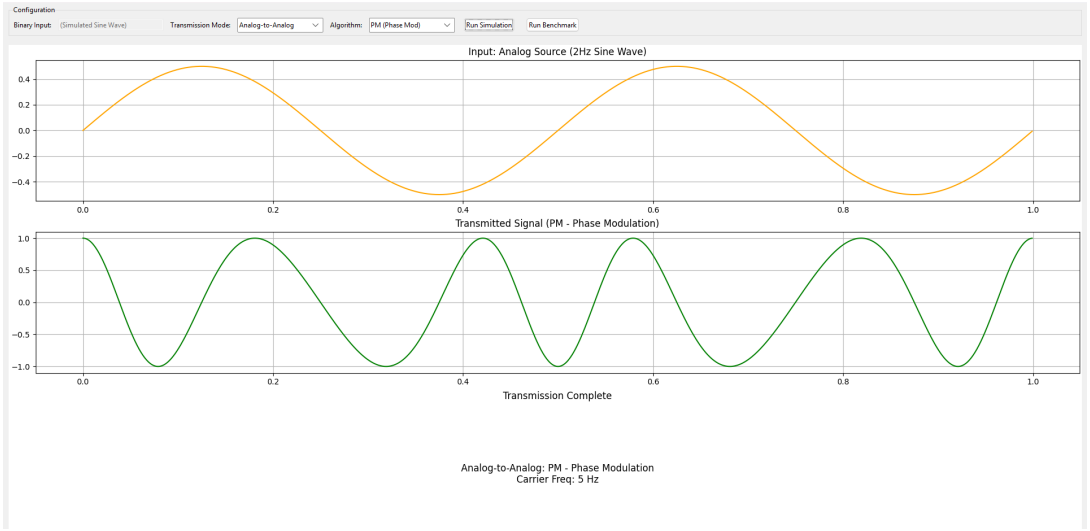

Figure 14: Phase Modulation Example

7 Implementation Details

7.1 Project Structure

The project consists of the following Python modules:

File	Description
`main.py`	GUI application with Tkinter
`encoders.py`	Line coding encoders
`modulators.py`	Digital and analog modulators
`benchmark.py`	Performance comparison script

Table 1: Project File Structure

8 AI-Based Optimization

8.1 Optimization Techniques Applied

1. **NumPy Vectorization:** Replacing loops with array operations.
2. **Pre-allocated Arrays:** Using `np.empty()` for efficiency.
3. **Batch Processing:** Processing multiple samples simultaneously.

8.2 Benchmark Results

Algorithm	**Original (ms)**	**Optimized (ms)**	**Speedup**
NRZ-L Encoder	0.188	0.178	1.05x
ASK Modulator	5.066	1.812	**2.79x**
PSK Modulator	4.611	1.759	**2.62x**
Average	-	-	**1.47x**

Table 2: Performance Comparison: Original vs Optimized

9 Conclusions

This project successfully implemented a complete communication system simulation. The optimization analysis revealed that NumPy vectorization provides substantial benefits for compute-intensive operations like modulation.

References

1. Forouzan, B. A. (2012). *Data Communications and Networking*. McGraw-Hill.
2. Haykin, S. (2001). *Communication Systems*. Wiley.