Scilab case study project on

ISI Analysis and Mitigation Using Raised Cosine Pulse Shaping papers

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Abstract

This case study focuses on the analysis and mitigation of inter-symbol interference (ISI) in digital communication systems using raised cosine pulse shaping. The primary objective of the study is to examine the impact of ISI on symbol detection and to evaluate the effectiveness of pulse shaping techniques in reducing this interference.

A comparative system design is adopted, where digital data is transmitted both with and without pulse shaping under identical conditions to ensure a fair evaluation. Rectangular pulses are used to represent unshaped transmission, while raised cosine filtering is applied to achieve controlled bandwidth and improved signal characteristics.

The study is implemented using Scilab, utilizing time-domain waveform analysis and eye diagram visualization as key evaluation tools. The results demonstrate a clear improvement in eye opening, reduced waveform distortion, and enhanced signal clarity, indicating effective mitigation of inter-symbol interference and improved reliability in symbol detection.

Keywords: Inter-Symbol Interference (ISI), Pulse Shaping, Raised Cosine Filter, Digital Communication, Eye Diagram, Scilab, Signal Integrity

1. Introduction

In modern digital communication systems, reliable transmission of data over band-limited channels is a fundamental requirement. However, one of the major challenges affecting signal integrity is inter-symbol interference (ISI), which occurs when transmitted symbols overlap in time and interfere with each other. This phenomenon leads to distortion in the received signal and increases the probability of incorrect symbol detection.

To address this issue, pulse shaping techniques are widely employed to control the bandwidth of transmitted signals and minimize interference between adjacent symbols. Among these techniques, raised cosine pulse shaping is commonly used due to its ability to satisfy the Nyquist criterion for zero ISI at sampling instants.

This case study focuses on analyzing the effect of ISI in systems with and without pulse shaping. Using Scilab for simulation, a comparative approach is adopted to demonstrate how raised cosine filtering improves signal quality and enhances overall system performance.

2. Problem Statement

In digital communication systems, transmitted signals often pass through band-limited channels, causing pulse spreading and resulting in inter-symbol interference (ISI). This interference leads to distortion in the received signal and reduces the accuracy of symbol detection, especially at higher data rates. To address this issue, pulse shaping techniques are used to control the signal bandwidth and minimize overlap between adjacent symbols. Raised cosine pulse shaping is particularly effective as it satisfies the Nyquist criterion, enabling ISI-free sampling at ideal instants. The performance can be further improved by tuning parameters such as the roll-off factor and analyzing system behavior under different conditions. In this project, a comparative approach is used to evaluate ISI with and without pulse shaping using Scilab-based simulations and visual analysis tools.

- ISI degrades signal quality and increases detection errors.
- Pulse shaping helps in bandwidth control and ISI reduction.
- Raised cosine filtering improves sampling accuracy.
- Simulation-based comparison is used for evaluation.

3. Basic concepts related to the topic

3.1 Digital Communication and Signal Representation

A digital communication system transmits discrete information in the form of symbols over a communication channel. Each symbol is represented by a pulse waveform in the time domain, and proper transmission requires that these pulses remain distinguishable at the receiver. In practical systems, signals are transmitted over band-limited channels, which restrict the frequency content of the signal.

This limitation affects how pulses behave during transmission and can lead to distortion. Therefore, designing appropriate signal representations is essential to ensure reliable communication.

3.2 Inter-Symbol Interference (ISI)

Inter-symbol interference (ISI) occurs when pulses spread in time and overlap with adjacent symbols, mainly due to bandwidth limitations of the channel. This overlap causes distortion in the received signal, making it difficult to accurately detect the transmitted symbols.

ISI becomes more severe as the data rate increases, since symbols are placed closer together in time. It is one of the major factors limiting the performance of digital communication systems. Reducing ISI is therefore critical to improving system reliability and minimizing errors.

3.3 Pulse Shaping and Raised Cosine Filtering

Pulse shaping is a technique used to modify the transmitted signal waveform to control its bandwidth and reduce ISI. Instead of using simple rectangular pulses, more advanced pulse shapes are designed to minimize interference between symbols.

The raised cosine pulse is one of the most widely used pulse shaping techniques because it satisfies the Nyquist criterion for zero ISI. It introduces a roll-off factor that determines the excess bandwidth of the signal. By adjusting this parameter, a balance can be achieved between bandwidth efficiency and signal smoothness.

3.4 Nyquist Criterion for Zero ISI

The Nyquist criterion provides the condition required to eliminate ISI in a communication system. It states that the pulse shape must have zero amplitude at all symbol intervals except at the intended sampling instant.

This ensures that each symbol can be sampled without interference from neighboring symbols. Raised cosine pulses are specifically designed to meet this criterion, making them highly suitable for practical systems. Compliance with this condition leads to improved signal clarity and accurate symbol detection at the receiver.

3.5 Eye Diagram Analysis

An eye diagram is a graphical tool used to evaluate the quality of a digital signal by overlapping multiple segments of the waveform. It provides a visual representation of the effects of ISI, noise, and distortion. A wide and open eye indicates low interference and good signal integrity, while a narrow or closed eye indicates high ISI and poor performance.

In this study, eye diagrams are used to compare systems with and without pulse shaping. This helps in clearly visualizing the improvement in signal quality achieved through raised cosine filtering.

4. Flowchart

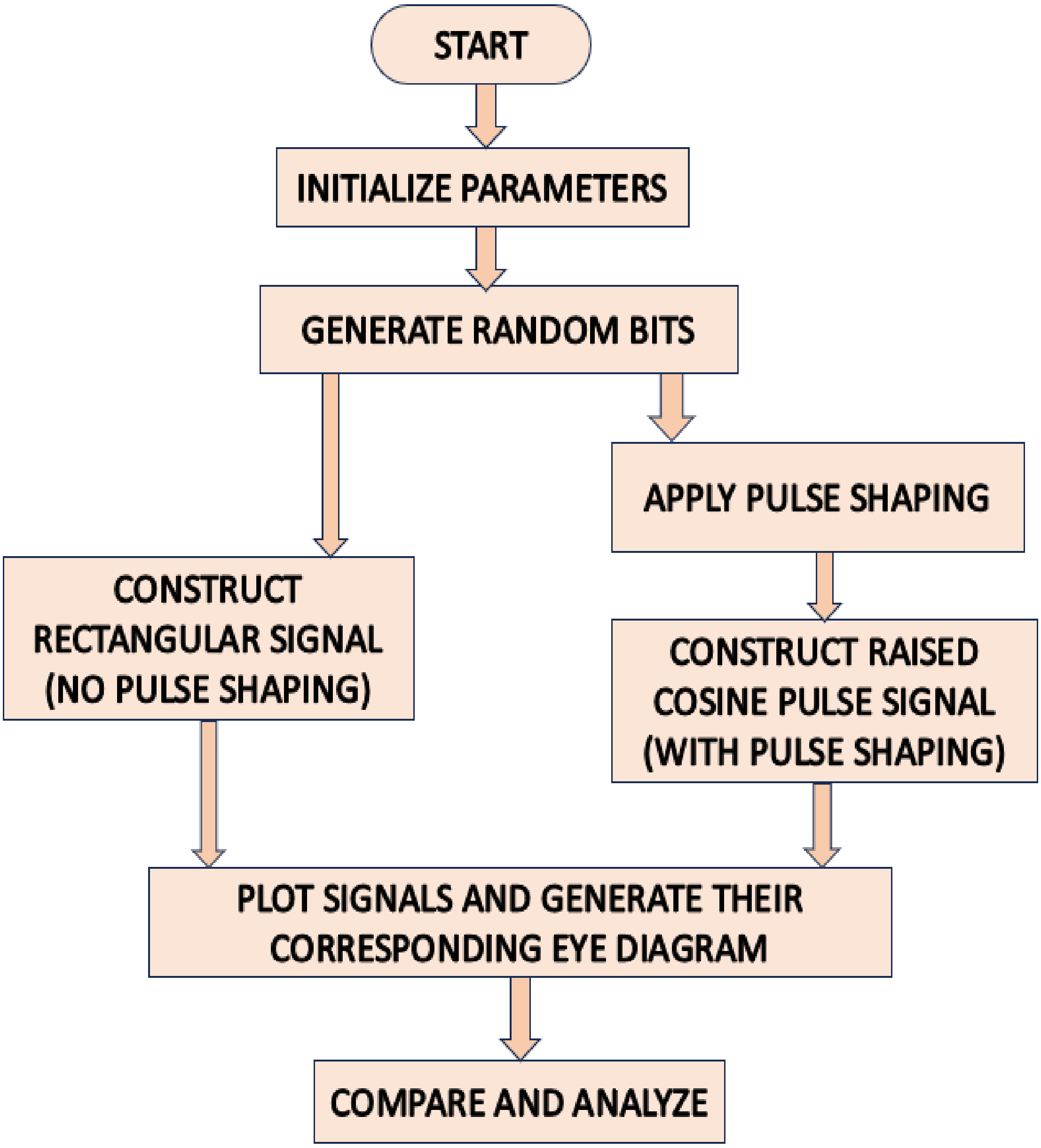


Figure 1: Flowchart

5. Software/Hardware used

Operating System: Windows 11

Toolbox: None

Hardware: Personal Computer with AMD Ryzen 5 Processor, 8GB RAM

Software: Scilab Version: 2024.1.0

6. Procedure of execution

Step 1: Open Scilab on your desktop.
Step 2: Open the provided Scilab script file (.sce) from the editor.
Step 3: Ensure the file is properly loaded and ready for execution.
Step 4: Run the script using the "Execute" button or by pressing **F5**.
Step 5: Upon execution, graphical outputs will be generated, including time-domain waveforms and eye diagrams.
Step 6: Observe the plots to compare the behavior of signals with and without pulse shaping.

7. Results

The simulation results clearly demonstrate the effect of pulse shaping on inter-symbol interference (ISI) in digital communication systems. The comparison is made between signals transmitted using rectangular pulses (without pulse shaping) and raised cosine pulse shaping. Both time-domain waveforms and eye diagrams are used to analyze system performance.

NOTE: The bit sequence generated in the code is random, as it is created using a random number generator that produces values following a normal distribution and then maps them to bipolar levels. Because of this randomness, the exact pattern of bits will be different each time the code is executed. As a result, the generated signals and corresponding eye diagrams will vary slightly from one run to another, although the overall behavior and observed trends (such as the effect of pulse shaping) remain consistent.

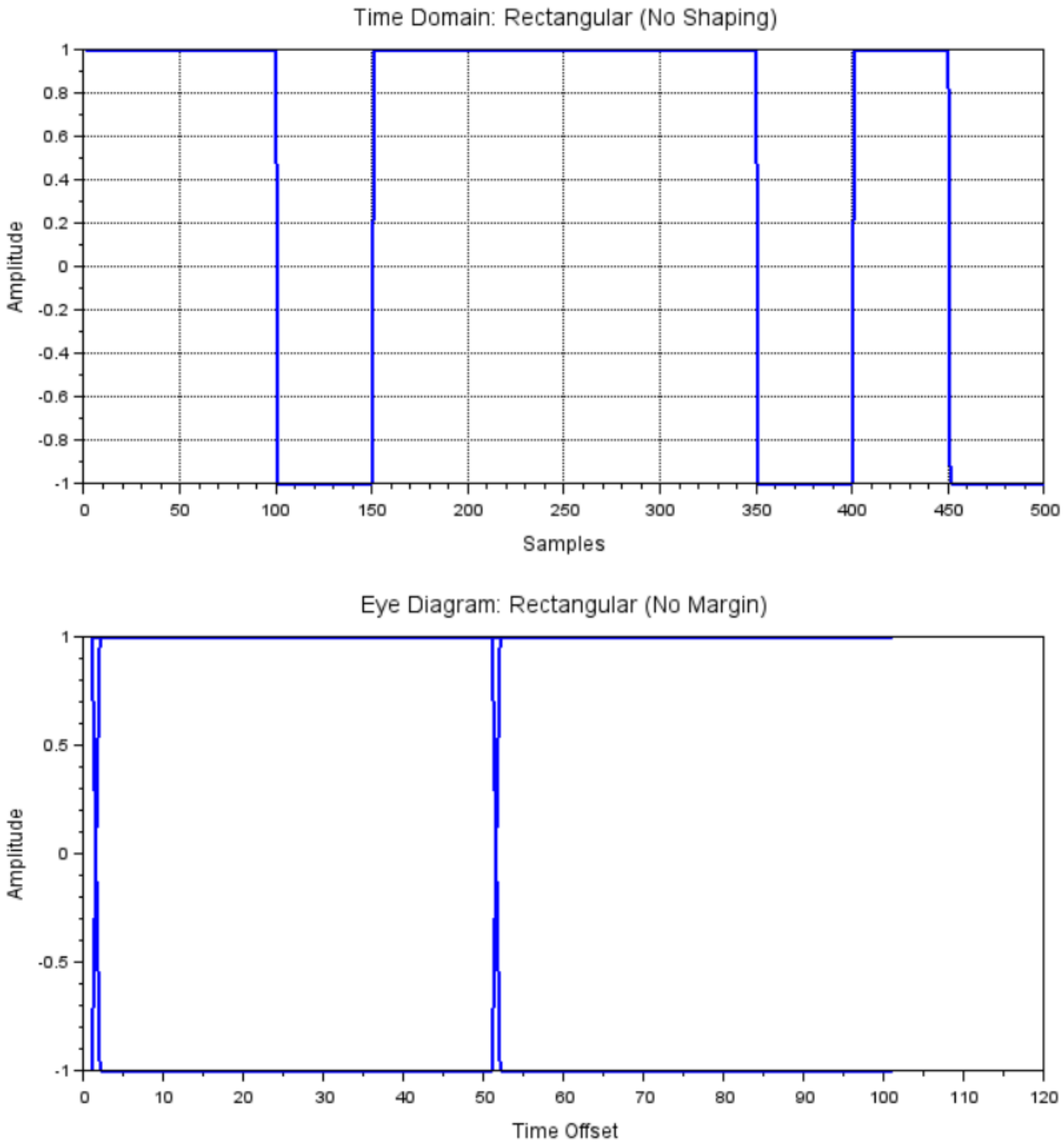
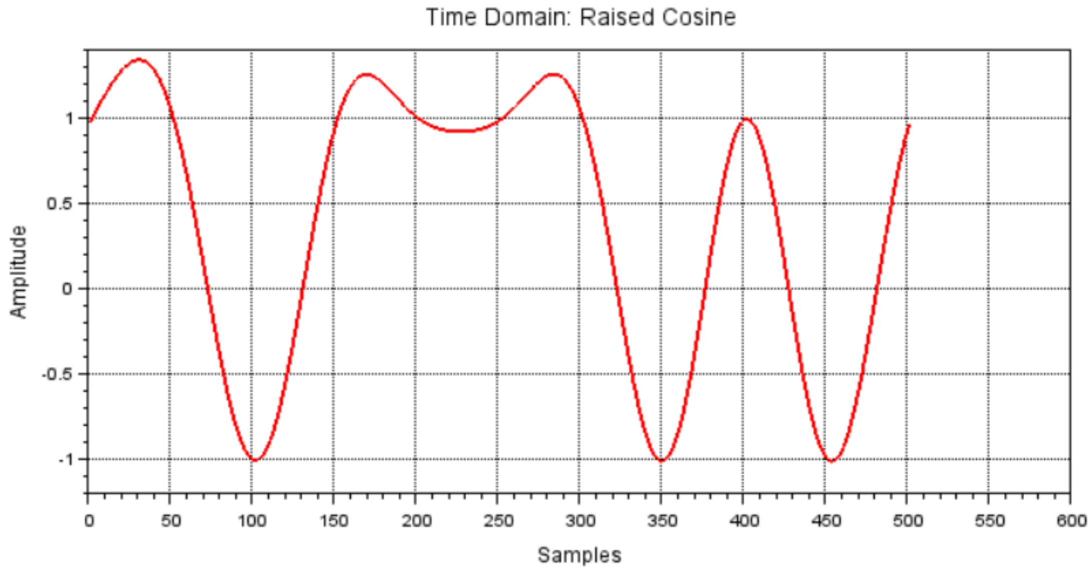


Figure 2: Digital signal and its Eye diagram (without shaping)

In the time-domain representation, the rectangular signal shows abrupt transitions between symbol levels, resulting in sharp edges and a wide frequency spectrum. This leads to significant distortion when passed through a band-limited channel. In contrast, the raised cosine signal exhibits smooth transitions between symbols, indicating controlled bandwidth and reduced spectral leakage. The smoother waveform reduces the chances of symbol overlap and improves signal integrity.



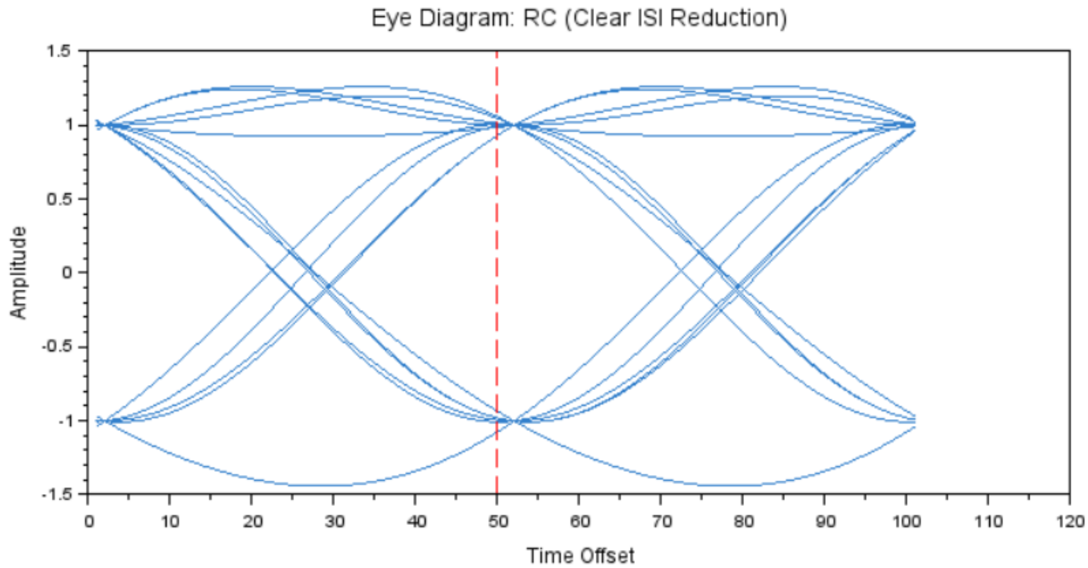


Figure 3: Digital signal and its Eye diagram (with Raised cosine shaping)

The eye diagram analysis provides a more intuitive understanding of ISI. The eye diagram for the rectangular pulse case appears nearly closed, with very little opening at the sampling instant. This indicates high ISI, as multiple symbol trajectories overlap, making it difficult to distinguish between logic levels. On the other hand, the eye diagram for the raised cosine pulse shows a wide and clear opening. This signifies that the symbols are well separated at the sampling instant, resulting in improved detection reliability and reduced error probability.

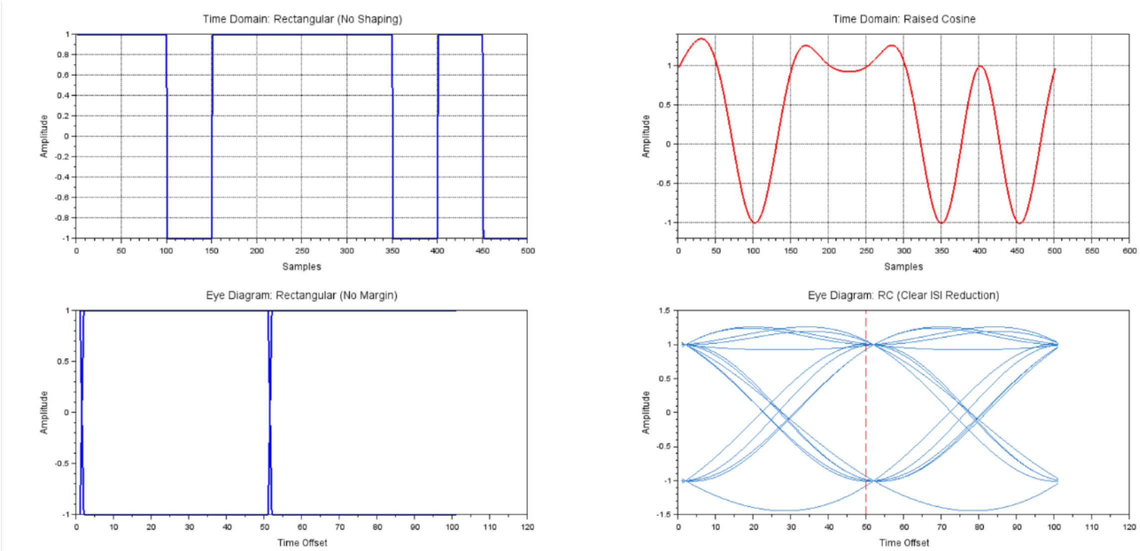


Figure 4: Side by side Comparison of Digital signal and its Eye diagram

Overall, the results confirm that raised cosine pulse shaping effectively reduces ISI by satisfying the Nyquist criterion, leading to better signal clarity and improved communication performance.

8. References

[1] G. Kour, R. Mehra, and M. Singh, "Bit Error Rate Analysis of Square Root Raised Cosine Pulse Shaping Filter," International Journal of Engineering Trends and Technology (IJETT), vol. 28, no. 4, pp. 183–189, Oct. 2015.